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Digital Technology and Infrastructure Productivity

Infrastructure Victoria

Final, July 2024

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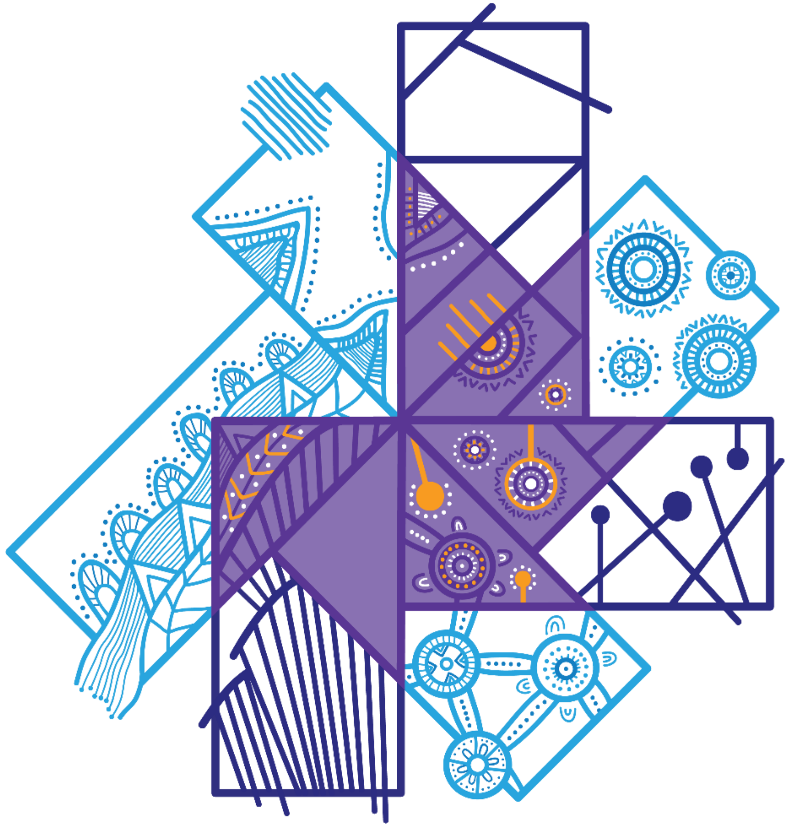
Contents



'Shift to shape an even better world' by Gilimbaa artist Tarni O'Shea

Arup acknowledges the Traditional Custodians of the land on which our offices are located and pay our respects to Elders past, present, and emerging. We recognise and celebrate their continuing connection to the land and waters, and their cultures, traditions, and protocols.

Executive summary

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Executive Summary – Digital Technology and Infrastructure Productivity

Adoption of digital technology in the infrastructure sector is a potential solution to our most pressing challenges. It can allow us to do more with less to meet the pressures of our growing population, reduce greenhouse gas emissions and better adapt our infrastructure to the impacts of climate change.

Research question and background

Infrastructure Victoria is the state's independent infrastructure advisory body. It takes a long-term, practical and evidence-based view of infrastructure planning to shape government action and better inform community discussion.

As part of updating Victoria's 30-year infrastructure strategy, Infrastructure Victoria is considering a range of questions posed by some of the state's complex, long-term challenges – in particular, how can Victoria's infrastructure be more productive, helping us do more with less?

This study looks to the impact of digital technology on infrastructure to answer this question, specifically asking:

Which digital technologies, that have not yet been adopted at scale in Victoria's infrastructure sectors, will most boost productivity by 2030?

To answer this question Arup undertook an analysis to identify 25 digital technologies which could be widely adopted by 2030 and deliver productivity gains to Victoria, and to quantify the potential economic benefits of the five most promising.

Arup undertook a 3-stage approach to achieve this. It drew on a broad range of specialist skills and experiences across infrastructure, foresight, technology, economics and strategy.

The findings aim to promote a productive and tangible discussion about the potential benefits that technology could bring to Victoria's infrastructure and productivity challenges and where efforts could be focused.

1. Scan

A horizon scan drew on research and specialist observations to identify 25 emerging and viable technologies.

These were organised according to broad technology fields, and sorted into three key categories of technological adoption and economic impact:

1. *Near-future technologies* – those with a high potential for wide adoption by 2030 and high likely economic impact.
2. *Future technologies* – those technologies anticipated to have high impact beyond the 2030 time horizon.
3. *Enabling technologies* – those which are critical to be in place to support the impact of other technologies.

The technologies identified by the horizon scan, organised by its technology field and their assessed impact and adoption are shown in Figure 1.

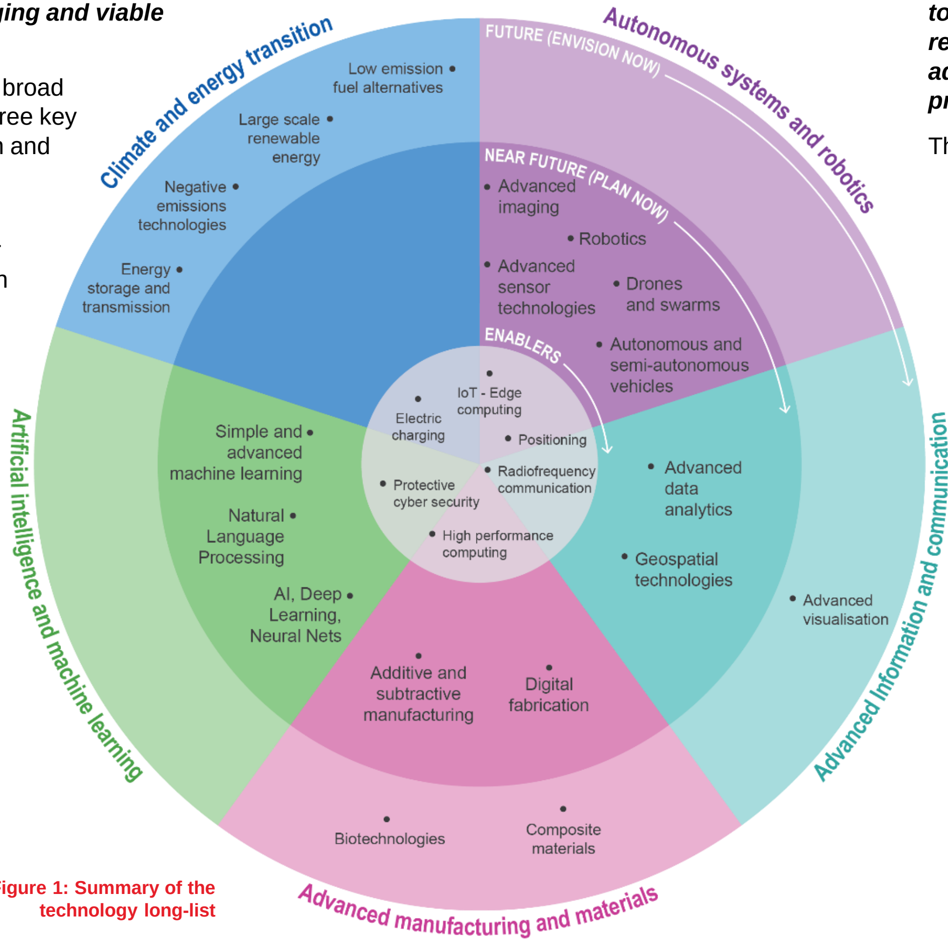

Figure 1: Summary of the technology long-list

2. Assess and prioritise

Technologies were assessed according for the ability to have a high productivity impact, contribute to a resilient future, and their probability of being broadly adopted by 2030. This filter identified five most promising technologies.

The five prioritised technologies are:

Machine Learning and Artificial Intelligence
Machine learning and artificial intelligence includes deep learning and natural language processing, allowing computers to analyse and learn from data without human intervention to generate actions, model future states and test scenarios.

Robotics
Advanced robotics integrates sophisticated programming, powerful hardware and smart sensor technology like ultrasonic, touch and light sensors to perform intricate physical tasks autonomously.

Advanced imaging
A range of imaging techniques that use sophisticated equipment and algorithms to capture images of greater resolution, and which penetrate through surfaces.

Advanced data analytics
Advanced algorithms and coding that integrate and model multi-dimensional data to develop replica and real-time models and advanced scenario testing and optimisation.

Geospatial Technologies
Combinations of positioning, satellite imagery and locational data to map information and perform advanced spatial analysis, monitoring and prediction.

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Executive Summary – Digital Technology and Infrastructure Productivity

There are significant benefits to the Victorian economy from increased adoption of technology. The Victorian government can directly achieve significant cost savings on government infrastructure projects as a first step.

3. Quantify and evaluate

Economic analysis was used to quantify potential benefits. To achieve this, the short-listed technologies were applied to a specific 'use case' to demonstrate their real life potential and possible broader applications.

In order to quantify the benefits 'use cases' were defined for each technology. These are specific applications of the technology to an industry and a task which demonstrate how the technology could be realised and the potential economic impact.

Relative cost 'scores' were also developed to contextualise the findings in the potential scale of costs anticipated for adoption. Costs indicate the kinds of costs anticipated to be incurred in adoption, such as for workforce retraining, technology development, and capital investment.

The findings are shown in Table 1 below.

Key findings

Some of the key conclusions from the analysis include:

- Robotics have the greatest potential impact but also the greatest estimated investment required.
- Geospatial technologies represents the most attainable near-term opportunity in terms of level of technology development and estimated scale of investment, but also offers lower measured benefits.
- Majority of technologies have significant potential to scale beyond specific application as described in each 'use case' – for example, the use of artificial intelligence for school construction is a relatively confined use case, however if proven and expanded across the entire infrastructure portfolio is estimated to deliver $9.3 billion of economic impact by 2055 (refer to slide 23).
- This is also true of the scaling potential of technologies beyond the public sector. For example, while building information modelling was applied specifically to Victorian public housing construction, benefits to the broader residential development sector could amount to $45.9 billion by 2055 (refer to slide 35).
- The technologies that have been assessed as having the greatest productivity potential directly address two of the biggest productivity challenges facing Victorian infrastructure: the growing cost of infrastructure in a financially constrained environment; and the intertwined impacts of climate change and low productivity.
- The short-listed technologies represent near-future opportunities. However, the broader list of future technologies should not be discounted in their importance. In particular, climate and energy transition technologies will be critical to addressing what is likely to be the largest driver of cost and change over the coming decades.
- Analysis of the technologies and their key barriers and enabling requirements reveal common actions required to support their successful adoption and impact:
  - **Industry readiness –** building industry understanding of applications, benefits and how to procure.
  - **Skills and workforce transformation –** developing the required specialist workforce and accreditations and understanding and planning for workforce displacement or transition.
  - **Informed procurement –** leveraging government's purchasing power with a consistent approach driven by experienced practitioners reduce risk, and drive consistency in outputs.
  - **Technology development –** technologies are highly interdependent, and all development should be supported to ensure impact is not impeded by the slowest mover.
  - **Governance and regulation frameworks –** frameworks are required to support the development and adoption of technologies to support safe testing and developing early-stage technologies, and to coordinate privacy, legal and data and technology standards for the scaling, sharing and interoperation of technologies.

Table 1: Summary of key economic findings ($2024, undiscounted)

Short-listed Technologies	Use Cases	Estimated impact ($2024)		Relative cost and key investment
		Per annum	By 2055	
1. Machine learning (ML) and artificial intelligence (AI)	1. AI/ML/deep learning to support school and kindergarten construction	$20.6 million	$516.1 million	*Moderate* – primarily for incremental development, software licensing and workforce upskilling
2. Robotics	2. Robotics for inspections and maintenance in the water sector	$140.2 million	$3.5 billion	*High* – large investments in development, capital, specialist workforce development
3. Advanced Imaging	3. Ground penetrating radar and advanced image processing to reduce utility strikes	$44.4 million	$1.1 billion	*Moderate* – primarily for incremental development, capital and specialist workforce development.
4. Advanced data analytics	4. Building information modelling facilitating drawingless construction of public housing	$76.5 million	$1.9 billion	*Low* – primarily relating to workforce upskilling and training
5. Geospatial technologies	5. AI-enhanced geospatial hazard management for bushfires and floods	$45.9 million	$1.1 billion	*Low* – primarily relating to workforce upskilling and training

1. Introduction

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1. Introduction

Understanding how digitally enabled infrastructure can drive economic activity and productivity.

1.1. Project background

Infrastructure Victoria is the state's independent infrastructure advisory body. It takes a long-term, practical and evidence-based view of infrastructure planning to shape government action and better inform community discussion.

Infrastructure Victoria has three main functions:

- Preparing a 30-year infrastructure strategy for Victoria, to be reviewed and updated every 3 to 5 years.
- Advising the Victorian Government on specific infrastructure matters.
- Publishing research on infrastructure-related issues.

As part of updating Victoria's 30-year infrastructure strategy, Infrastructure Victoria is considering a range of question posed by some of the state's complex, long-term challenges. Questions include:

1. How can social equity be improved by access to infrastructure?
2. How can Victoria's infrastructure be more productive, helping us do more with less?
3. How can Victoria's infrastructure help mitigate the impacts of climate change, and be adapted to withstand more frequent and extreme weather events?
4. How can infrastructure respond to change and disruption, in population and technology?

This report aims to understand how change and disruption presented by digital technologies can help uplift state productivity, reduce delivery time and environmental costs, and lengthen asset lifecycles – in the words of the review, how do we use technology to 'do more with less'.

In 2023, Australia faced its lowest productivity growth in 60 years.[1] As a nation, Australia has now entered a per-capita recession. Victoria is not immune to these headwinds and will face significant financial constraints going forward requiring new, productivity driving innovations in infrastructure. Over the next 30 years population growth will drive new infrastructure requirements, while competing with critical maintenance and adaptation needs of existing infrastructure and everyday operational needs.

Becoming more sophisticated in how we use digital technologies, and getting ready for future technology, is an opportunity to rethink infrastructure productivity, growth and resilience. Embracing new digital technologies can ensure infrastructure investments better meet today's needs while getting 'future-fit', from managing congestion to extending asset life and growing climate change resilience.

Research shows the biggest productivity gains in Australia will come down to wider adoption of established technologies and practices.[2] While we must stay abreast of emerging technologies and new opportunities it is equally important that we do simple things well. This means getting the most out of existing digital technologies to improve how infrastructure is planned, managed and operated.

1.2. Research question and context

A proactive vision for digital technology backed by a clear roadmap is needed. Infrastructure Victoria is seeking to kickstart this conversation to help government and the community identify priorities, understand trade-offs, and transition to a more digitally enabled future by identifying priority technologies for widespread adoption.

Arup was engaged by Infrastructure Victoria to identify the emerging trends and technologies which can address some of our most pressing challenges and demonstrate the economic benefits of these by answering the question:

Which digital technologies that have not yet been adopted at scale in Victoria's infrastructure sectors will most boost productivity by 2030?

This report quantitatively evaluates the potential infrastructure productivity, and related wider economic, gains for the state of Victoria from technologies that have potential for widespread deployment by 2030.

It considers barriers to adoption and potential disbenefits and harms, as well as opportunities to advance equity, wellbeing and resilience in the service of Victoria's communities, economies and environments.

The outcome of this analysis will aid in Infrastructure Victoria making recommendations to the Victorian government on how to best use digital technology, and where investment, governance and coordination, and hardware and software development is most needed.

1.3. Scope and limitations

The study aims to:

- Identify 25 digital technologies which have potential to deliver productivity gains in Victorian infrastructure.
- Prioritise five technologies which demonstrate the greatest productivity potential.
- Undertake an economic analysis to quantify the benefits of these five technologies and enable their comparison and evaluation.

The following key parameters have guided this study:

- Digital technologies must demonstrate market maturity for widespread deployment by 2030.
- The analysis focusses on technologies that have not been adopted, or adopted at scale, across Victorian infrastructure lifecycles. Digital technologies that may have been available for some time, but which have not found widespread adoption or full utilisation in Victorian infrastructure have been included.
- The analysis measures estimated economic impact as a per annum impact and cumulative impact between 2030 and 2055, reflecting the time horizon of the updated 30-Year infrastructure strategy. These are presented in real terms in 2024 dollars and have not been discounted.
- The analysis has provided high level costing information but does not seek to conduct a cost-benefit analysis of each.

1. Productivity Commission, 2023
2. Australian Government, 2023c

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1. Introduction

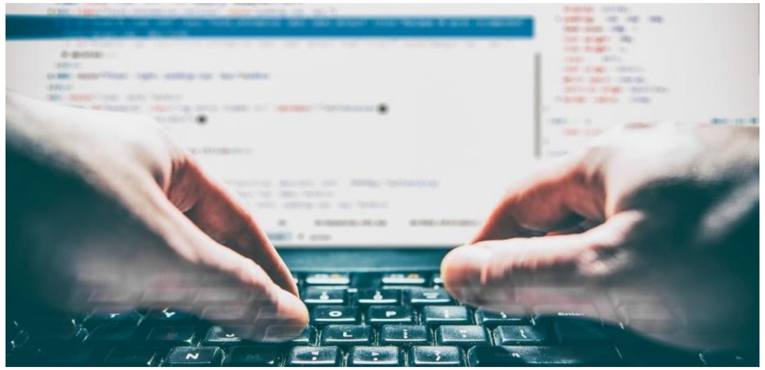
Macro challenges across digital technology, infrastructure and the economy are driving change.

Technology

Digitisation of the built environment

Our built environment is generating data in increasing volumes, complexity and frequency. As data-generating technologies like sensors and satellites develop so must our ability to make sense of and leverage this, as well as our ability to do so securely and ethically.

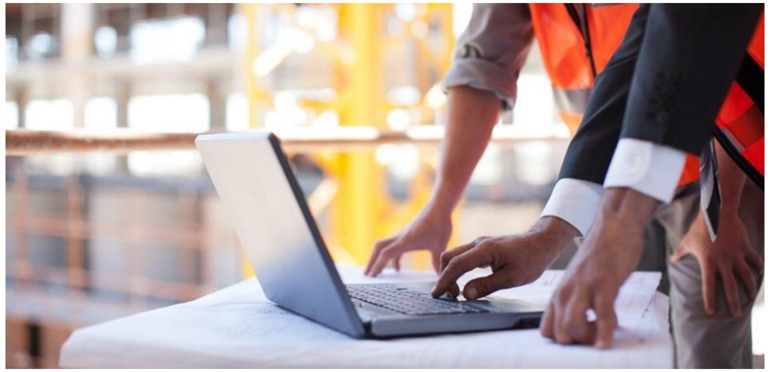
Transforming capability and workforce



New technologies will fundamentally transform how we design, build and operate infrastructure. These will completely change how we undertake routine tasks and require a regeneration of the workforce with specialist skills.

Productivity

Increasing financial constraints



Victoria's productivity growth has remained persistently low while debt has increased. Technology provides opportunity to reverse this trend through targeted planning, smarter design, more efficient construction, optimised operations, predictive maintenance, and extended asset lives.

The cost of climate

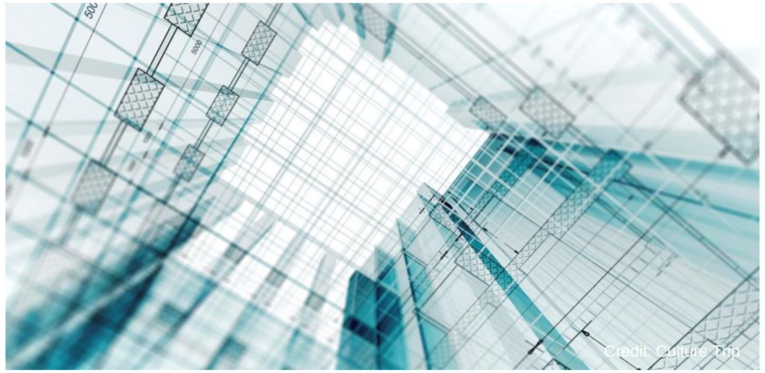
Climate change is the biggest and most urgent generational challenge faced by our economy and our infrastructure. We must minimise and dramatically reduce the carbon content of new and existing infrastructure, while increasing our resilience to climate stresses and disasters.

Infrastructure

The growing infrastructure task

Victoria is already the nation’s fastest growing population and will be the most populous in the future. Maintaining our quality of living will require a substantial effort to ensure our current and future infrastructures are efficient and resilient.

Convergence and complexity



Infrastructure is not what it used to be. The infrastructure we build in the future must operate in tighter environments, be connected and programmable, multifunctional and integrated, decarbonised and adaptable – future infrastructure demands a new level of sophistication.

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1. Introduction
The approach used a cross-disciplinary team to identify, prioritise and assess potential technologies.

1.4. Methodology overview

This section summarises the approach for identifying, prioritising and assessing digital technologies with the potential to drive productivity improvements in Victorian infrastructure.

The approach included a mix of foresight techniques and recognised infrastructure and economic evaluation and quantification methodologies to provide a robust and repeatable approach which can be added to or evolved over time. The process tested these techniques by drawing on Arup's on the ground experience in infrastructure delivery and technology application. A detailed methodology is provided in **Appendix A**.

1.4.1. Approach

This process was delivered using a cross-disciplinary approach that leveraged a core delivery team with specialist techniques and industry experience, including:

- **Foresight** – providing methods of identifying and assessing emerging technologies and their potential for impact and uptake.
- **Technology** – validating the technical viability of emerging technologies and the key technical risks and requirements to support their development.
- **Infrastructure** – grounding findings in real challenges and needs faced by the infrastructure sector and to define high impact applications of technology.
- **Strategy** – ensuring technologies and applications identified in international contexts were couched in the strategic context of the Victoria's economic, policy and infrastructure landscape.
- **Economics** – adapting best practice techniques in cost benefit assessment to develop a fit-for-purpose quantitative approach for the study.

1.4.2. Process summary

The process included three steps.

1. **Scan** – A horizon scan to identify emerging technology and infrastructure trends and drivers of change. The data for the horizon scan was then categorised using a technology taxonomy to ensure consistency and completeness of this scan. This was used **to produce the initial list of 25 potential technologies.**

   A high-level assessment of technological and commercial readiness and scale of impact was applied to identify the highest potential technologies.

2. **Assess and prioritise** – Technologies were assessed through a multi-criteria assessment which reflected the study purpose and broader Infrastructure Victoria objectives. The assessment was informed by research, workshops and interviews with a range of subject matter experts. **This step produced a short-list of five technologies** assessed to have the greatest potential to deliver productivity benefits to Victorian infrastructure.

3. **Quantify and evaluate** – Specific applications of each technology were defined to quantify the potential benefits they could have if applied to an infrastructure sector **to demonstrate and evaluate the productivity impact of each short-listed technology**. A high-level review of potential costs and benchmarking was also applied.

   The analysis was used to identify the more feasible and highest impact technologies and the key actions to support adoption and impact.

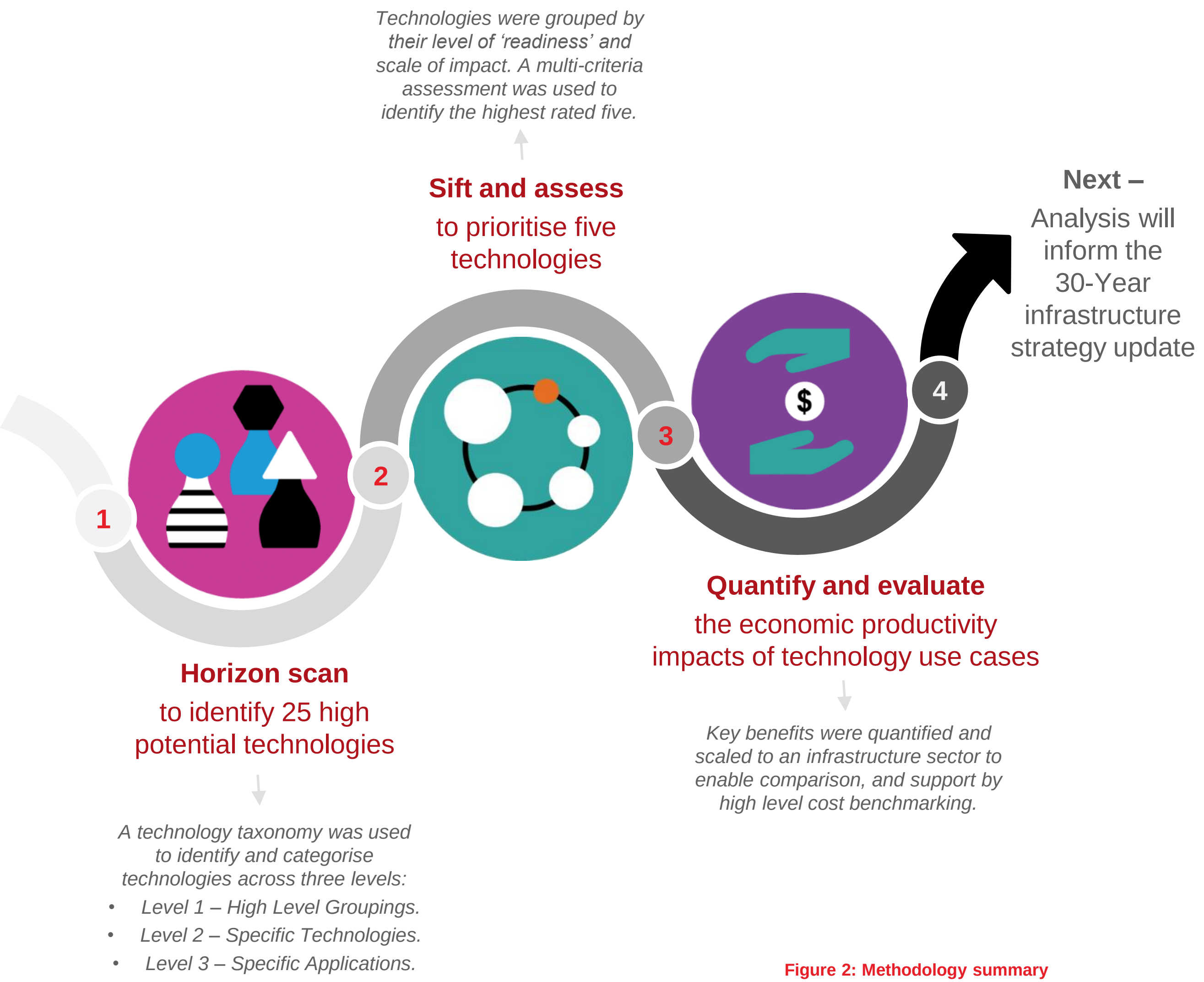

Figure 2: Methodology summary

2. Long-list of technologies

2.1. Near-future technologies

Near-future technologies are those that are likely to be widely adopted by 2030 and have high impact so we must act now so they can be fully realised.

Twelve of the 25 technologies were assessed as near-future, having a high potential productivity impact and high likelihood of adoption by 2030 (as measured by their technological readiness level (TRL) and commercial readiness level (CRL)).

This section summarises each of these technologies, described at **Level 2** in the technology taxonomy, and nested as per its **Level 1** designation.

Autonomous systems performed strongly in this field, being well developed or anticipated to rapidly grow and having tangible and significant impacts.

Most artificial intelligence (AI) and machine learning technologies were also identified due to their rapid development, level of existing use and uptake, and likely widespread impact.

Climate and energy transition technologies are not well represented in the ‘near-future’ technologies. While these will significantly transform our economy and infrastructure they were not assessed to be widely adopted by 2030, primarily due to the scale of regulatory and economic barriers and the level of investments required.

Autonomous systems and robotics

Robotics

Robotics uses machines to perform tasks either through pre-programmed instructions or in partnership with people. Typically limited to highly specific tasks, robotics are increasingly common in infrastructure delivery and operations. For example, construction robotics are deployed for site grading, drilling, waste sorting and handling materials while soft robotics find applications in healthcare and navigating complex structural environments.

Key strengths and weaknesses

+ Enhances safety by replacing and protecting humans in hazardous tasks and by operating remotely in dangerous or hard-to-reach locations.
+ Automates tasks, guaranteeing precision and efficiency in construction and maintenance, resulting in cost savings, time efficiency, and adaptability.
- Deployment of robots may face resistance from workers due to entrenched cultural and operational practices and concerns about job losses.
- High capital costs and uncertain return on investment could serve as a barrier to entry for robotics.[1.]
- Incorporating robotics into current infrastructure systems and workflows entails complex integration and customisation, with challenges around legislation and potential cyber threats.[2.]

Advanced imaging

Advanced imaging uses a range of techniques that surpass traditional methods of imaging, such as photography and basic radiography, to enhance resolution, detail and penetration of images. Emerging technologies include thermal cameras, 4D scanning, digital radiography and ground penetrating radar (GPR) combined with high powered analytical tools, and have diverse uses across engineering and construction, medical imaging, astrology, biology and physics.

Key strengths and weaknesses

+ Improves productivity and service quality at health institutions and could reduce costs, while also potentially positively impacting overall healthcare costs and population health.[3]
+ Detects defects and inconsistencies for quality control, while also tracking progress and verifying completed work to minimise errors and delays.
- Interpreting large volumes of data, custom solutions, and integration with existing Victorian workflows is required to realise gains.

Drones and Swarms

Drones are becoming commonplace in some jurisdictions for infrastructure applications like site surveys, safety inspection and monitoring, and cargo delivery in remote or inaccessible areas. Drone swarms operate in a collective unit ranging from a few to thousands. Increasingly enabled by AI, sensor and drones advancements can perform tasks like real-time bushfire information collection with minimal risk to human safety.

Key strengths and weaknesses

+ Enhances inspection and monitoring by quickly covering large areas, reducing labour costs and carbon emissions of tasks, and enabling preventive maintenance to lower expenses.
+ Improves safety by accessing hazardous and hard-to-reach areas, reducing the need for human workers.
+ Swarms of drones enhance scalability for large projects by working together to cover extensive areas more efficiently than single drones.[4]
- Security and potential hacking are a significant risk.
- Regulatory barriers, liability issues and flight paths pose challenges, particularly in uncontrolled sites.[5.]
- Deployment may be challenged by established cultural and operational practices and high initial costs.

1. Davila Delgado et al., 2019
2. Licardo et al., 2024
3. Brady, Allen, Chong, et al., 2024
4. Tahir, Boling, Haghbayan et al., 2019
5. Norton Rose Fulbright, 2016

2. Long-list of technologies
Near-future technologies

Autonomous systems and robotics

Advanced sensor technologies

Sensors convert inputs like heat, pressure, motion and light from physical environments into digital data. Categorised into placeable, wearable, and implantable devices, advanced sensor technology is used to monitor infrastructure use, wear and repair. Ubiquitous sensor networks speed up real-time processing, wearables monitor environments and worker health, and nanoscale sensors detect air pollution and environmental contaminants.

Key strengths and weaknesses

+ Promotes real-time worker safety, issuing alerts for hazards and ensuring compliance with safety protocols, while also contributing to health through pollution and contaminant monitoring.
+ Sensor data informs resource allocation and enables continuous improvement in infrastructure operations, optimising efficiency and effectiveness.
- Widespread adoption demands further development, substantial initial investment and specialised technical expertise that is lacking, complicating infrastructure management.[1]

Autonomous and semi-autonomous vehicles

Road, rail and sea transport sectors are exploring automation for more convenient mobility. Semi-autonomous cars are already widely available in 'self-aware' consumer vehicles. Vehicles with limited human oversight are increasingly used in controlled environments like construction sites, ports and agriculture. In-vehicle driver monitoring is also on the rise, detecting risks like drowsy drivers but also raising privacy issues.

Key strengths and weaknesses

+ Reduces human error and accidents, enhancing safety and providing more predictable and controlled behaviour.
+ Increases efficiency by working continuously, optimising routes, cutting labour costs, and driving fuel-efficiency, enhancing overall productivity, and reducing costs.
+ Provides precise execution, continuous data collection, and increased safety by reducing human risk in hazardous environments.[2]
- Requires substantial initial investments, ongoing maintenance, regulatory and legal change.[3]
- Rollout of autonomous vehicles poses a risk of job displacement, but new job opportunities can emerge with different skill requirements.

Advanced manufacturing and materials

Additive and subtractive manufacturing

Additive manufacturing uses techniques like 3D and 4D printing to create objects layer by layer. Subtractive manufacturing precisely controls the removal of materials. Both use digital models and offer more efficient prototyping, production speed, efficient assembly and repair. Already widely used in aerospace, automotive, healthcare, and consumer goods, this method is increasingly adopted for mass customised prefabricated construction and infrastructure.

Key strengths and weaknesses

+ Accelerates construction timelines and reduces material waste and energy consumption.
+ Operates in remote or challenging environments where traditional construction methods are not feasible.
+ Creates complex geometries, while reducing reliance on imports, promoting local manufacturing and economic self-sufficiency.[4]
- Material selection and structural integrity are vital in 3D printing construction and must be integrated into construction standards and practice.[5]
- Currently there is slow industry adoption of available technologies within the infrastructure sector.[6]

Digital Fabrication

Digital fabrication uses a combination of technologies like computer-aided design and modelling, and additive manufacturing, to create component parts through a digital workflow. Precise, complex shapes can be produced with minimal material waste. Both customisation and scalability are simplified with the ability to fabricate one-off or mass customised products at low-cost, on or near a site.

Key strengths and weaknesses

+ Faster, more sustainable and cost-efficient construction through reduced minimal waste, labour costs and construction delays.
+ Guarantees higher quality and consistency in the finished product, along with the capacity for innovative design solutions and customised options.
- Modular construction faces slow adoption and public skepticism in Australia despite its benefits, currently representing just 3% of the construction sector.[7]
- High-cost barriers to modular / prefabricated construction in small and medium companies
- Australia's building regulations cater to traditional methods, hindering prefab and modular construction, with 68% of industry professionals calling for changes to planning, codes, and standards to enable prefab and modular construction.[8]

1. Clark C,, 2023
2. Othman K., 2022
3. Pattinson, JA., Chen, H. & Basu, S, 2020
4. Kantaros, Antreas, Ganetsos et al., 2023
5. Dobrzyńska, E., Kondej, D., Kowalska, J., & Szewczyńska, M, 2021
6. Building for Humanity, 2022
7. Kim K., Connolly T., Ryschka S., et al., 2023
8. Gad, E., Kumar S., Pham L., et al., 2022

2. Long-list of technologies
Near-future technologies

Artificial intelligence and machine learning

Simple and Advanced Machine Learning

Machine learning (ML) uses data to make predictions and recommendations about specific problems or explicit objectives. ML comes in several types, including supervised, semi-supervised, unsupervised, and reinforcement learning. Use cases include predictive maintenance, optimising planning and construction programs, layout, and whole lifecycle carbon assessment, as well as traffic flow optimisation for urban transportation efficiency.

Key strengths and weaknesses

+ Improves predictive maintenance by anticipating equipment failures and maintenance needs, reducing downtime and improving operational efficiency.
+ Reinforcement learning optimises operations by continuously learning and enhancing strategies for traffic management and energy distribution.
+ Automates routine tasks like data entry, monitoring, and anomaly detection, allowing human workers to focus on more complex activities.
- Supervised learning needs extensive high quality labelled data, which can be challenging and costly to acquire.
- Implementing and maintaining ML is hindered by a skill gap and the complexity of developing and tuning models.[1.]

Artificial Intelligence, Deep Learning and Neural Nets

Deep learning (DL) is a branch of Machine Learning inspired by the structure of the brain. DL is capable of sorting unstructured data to identify complex patterns or generate new content (generative artificial intelligence (AI)). If adequate guardrails are in place, DL can improve infrastructure demand forecasting, generate and assess design and construction options, streamline procurement processes and monitoring. AI can enhance DL models by optimising decision-making, further improving effectiveness.

Key strengths and weaknesses

+ With rapid prototyping and iteration of infrastructure designs, generative AI offers the potential for novel design solutions that can offer more efficient resource utilization.
+ DL models possess the ability to adjust to evolving environmental conditions and demands, thereby guaranteeing the resilience and durability of infrastructure.[2]
- Immature market and skills base, for example, 44% of Australian businesses are not expanding or upgrading basic AI adoption.[3]
- Uses enormous amounts of data and, consequently, enormous amounts of water and energy.

Natural Language Processing

Natural Language Processing (NLP) allows machines to comprehend and mimic human language using techniques like Large Language Models (LLMs) trained on deep learning algorithms. Automated assistants and copilots aid with task management and decision support, while voice and speech recognition integrated into devices or vehicle assistants enhances human-machine interaction like language translation, and customer service.

Key strengths and weaknesses

+ Extracts valuable insights from unstructured text data like reports, emails, and online content, supporting decision-making.
+ Automates responses to common queries and requests, enhancing communication efficiency among stakeholders.
+ Analyses legal documents for compliance and monitors policy changes, aiding stakeholders in staying informed and meeting regulatory requirements.
- Ethical concerns around privacy, potential bias and ‘black box’ systems lacking transparency.[4]
- The lack of context or completeness in unstructured text data can impact the accuracy and reliability.

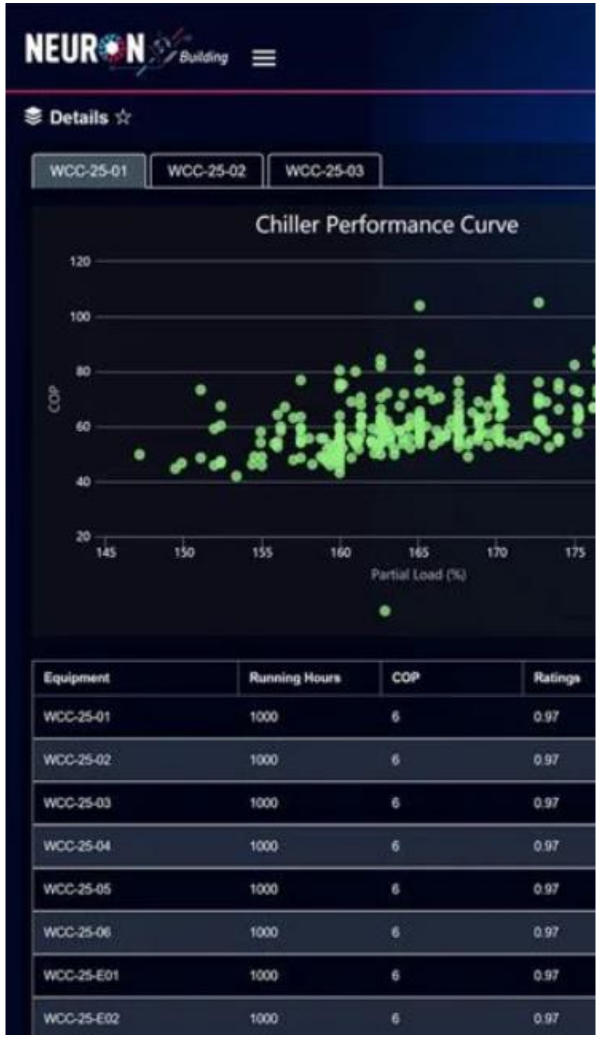

Figure 3: Neuron Digital uses continuous machine learning and AI to autonomously predict energy demand and match cooling loads (Arup, 2024a)

1. TC Global, 2024
2. Argyroudis S., Mitoulis S., Chatzi E., et al., 2022
3. CSIRO, 2023
4. Caliskan A, 2021

2. Long-list of technologies
Near-future technologies

Advanced information and communication

Advanced data analytics	Geospatial technologies
Advanced data analytics uncovers patterns in complex and multi-dimensional datasets to model and predict future states. Large volumes of data are collected, processed, and analysed, often with the aid of Machine learning and artificial intelligence. Buildings and infrastructure are becoming increasingly automated for better experience, efficiency and management through advanced analytics centralising and making sense of constant data flows.	Geospatial technologies provide tools for navigation and situational awareness by combining positioning, satellite imagery, and locational data using spatial analytics and artificial intelligence it is possible to rapidly visualise, model and predict utilisation, management and behaviour patterns across the natural and built environments. Data analysis then generates insights for design and space planning, from route optimisation and site selection to improved emergency response and adaptation development.
Key strengths and weaknesses + Critical to developing insights from volumes of data generated by other technologies. + Lowers engineering, construction and project management costs and speeds up compliance and approvals. + Reduces equipment downtime, operational and maintenance costs, and energy consumption. - Meaningful gains depend on industry-wide adoption and upskilling – uptake of existing versions of this technology are low, particularly for mid-size and smaller contracts.	**Key strengths and weaknesses** + Facilitates accurate geographic and environmental data analysis for improved infrastructure planning and site selection, allowing real-time project monitoring to promptly identify and address issues (e.g. emergency responses).[1] + Supports data-driven decisions by providing a robust spatial information database, assisting informed decision-making and scenario analysis to understand potential outcomes within a geographical space at every project stage. - Failure to coordinate interoperable systems across organisations leads to fragmentation and duplication. - Requires specialised skills, training and accreditation which are currently not widely available.[2]

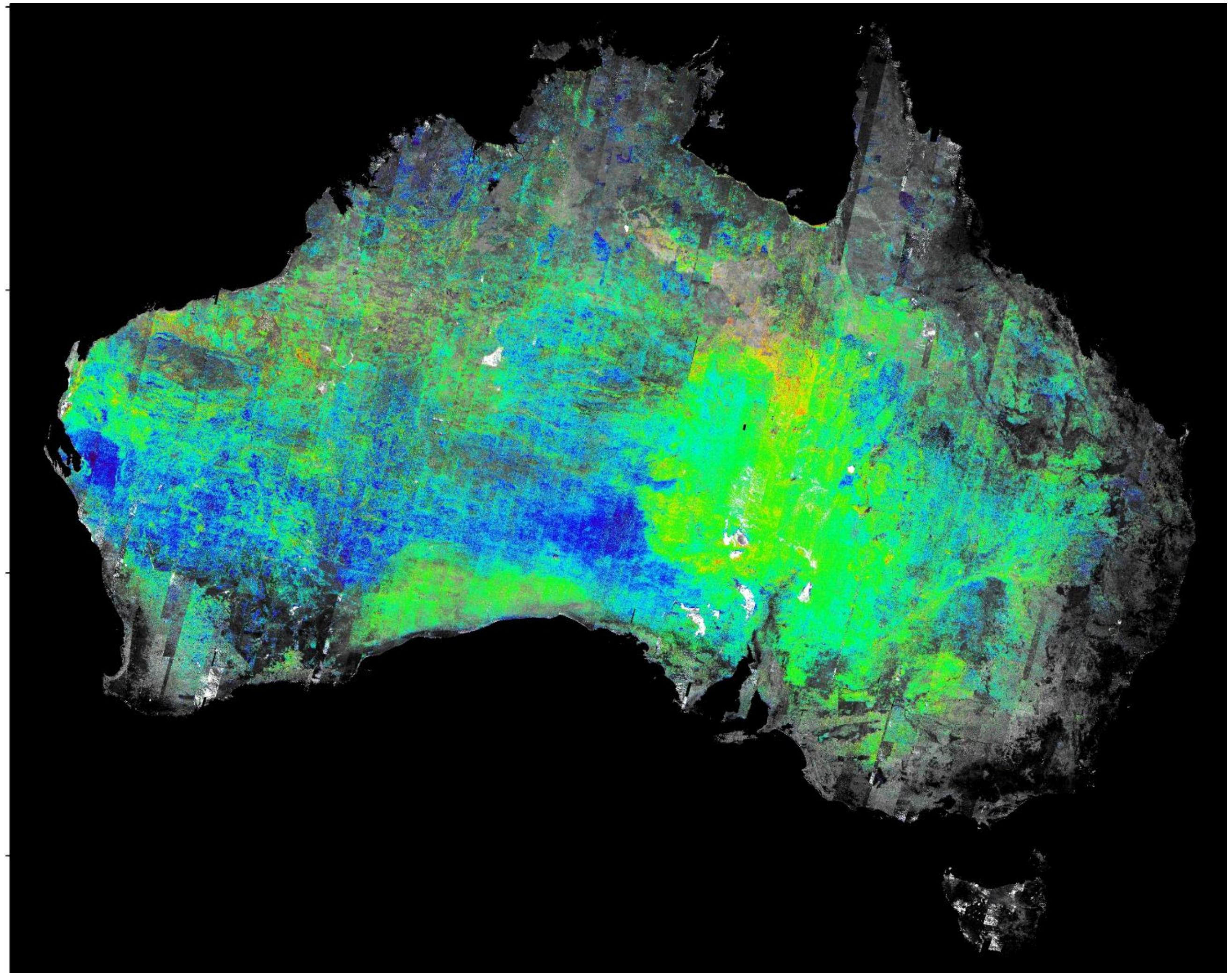

Figure 4: CSIRO's recent purchase of a share in a new satellite (NovaSAR-1) has advanced sovereign capabilities in earth observation, such as the world first mineral composition maps shown here (CSIRO, 2024b)

1. Innovation News Network, 2023
2. Geospatial Council of Australia, 2024a

2.2. Future technologies

Future technologies are those that are unlikely to be broadly adopted until after 2030, but which will have high impact and that we must start to plan for now.

Seven of the 25 technologies were assessed as being high potential but likely to be adopted after 2030. Victoria should continue to progress the development of these technologies as they will be critical to Victoria's future. However, they do not meet the technical or commercial readiness criteria for this assessment.

In particular, climate and energy transition technologies feature strongly in this group. These technologies will be transformative across the entire economy and infrastructure sector and critical to meeting our future energy and environmental commitments. The scale of the task requires sustained and widespread investment which will occur over a long-time period.

These technologies also include next stage storage, generation and distribution technologies such as nano-based energy-efficiency and advanced thermal energy storage which are still in development but will significantly increase the efficiency of energy generation and distribution, reducing cost and emissions.

Advanced manufacturing and materials

Composite materials

Composite materials are engineered from two or more different physical or chemical properties. Composites like recycled steel, Cross-Laminated Timber, nanotech aerogels and 'self-healing' concrete can offer equal or better performance when it comes to strength-to-weight ratios, durability, and circularity. Generative artificial intelligence is set to accelerate new material production by rapidly identifying and testing stable materials.

Key strengths and weaknesses

- \+ Improves sustainability and promotes Circular Economy approaches, consistently outperforming steel, cast iron and concrete in terms of CO2 emissions.[1]
- \+ Reduces installation and lifecycle costs.
- \+ Enhances durability and strength, with many composite materials demonstrating corrosion-resistance and having a long service life of 150 years or more.[1]
- \- Requires large investment to be viable by 2030 with many applications still in testing.[2]

Biotechnologies

Biotechnology harnesses biological systems to create novel products and processes. In infrastructure, biomimetic manufacturing replicates natural designs for resilient buildings, efficient transportation systems, and sustainable energy production. Biotechnology plays a crucial role in wastewater treatment, employing biological processes to detoxify water and generate energy, while also offering potential for public health monitoring.

Key strengths and weaknesses

- \+ Prolongs asset lifecycles and reduce energy consumption for all building applications.[3]
- \+ Improves overall effectiveness of infrastructure for combating infectious diseases.[4]
- \+ Microorganisms in biotechnology can recover metals from waste like e-waste, slags, tailings, and acid mine drainage.[5]
- \- Tests, standards and protocols are required to ensure new materials are safe and stable in use.
- \- Replicating the complex structures and functions of living organisms poses challenges, limiting biomimetic technology performance and reliability.[6.]

Advanced information and communication

Advanced visualisation

Advanced visualisation augments the physical world with immersive or semi-immersive experiences. Augmented Reality overlays computer-generated content onto the real environment for visualising infrastructure projects, streamlining collaboration and precise positioning. Virtual Reality creates fully immersive environments for tasks such as creating 3D models, training simulations, or therapeutic use in healthcare.

Key strengths and weaknesses

- \+ Integrates real-time data, instruction prompts, and weather alerts into construction operations to establish a comprehensive view of complex working environments.[7]
- \+ Offers high quality training and collaboration chances, creating a secure environment for practicing procedures and safety protocols.[8]
- \- Early-stage uptake is limited to sectors like health and education, with the proposed advantages generally not yet well received in the construction industry.[9]

1. Czapla A., Mahesh G., and Jakub D., 2021
2. Czapla A., Mahesh G., and Jakub D., 2021
3. Webb M, 2022
4. Khan A., Ostaku J., Aras E., et al., 2022
5. CSIRO, 2024a
6. Kantaros A., Ganetsos T., & Petrescu F. I. T, 2024
7. Rodriguez, 2022
8. Kaliaraju V., 2023
9. Wang Y., Oraee M., Vaz-Serra P, et al., 2021t

2. Long-list of technologies
Future technologies

Climate and energy transition

Low-emission fuel alternatives

Alternative fuels offer low-emission mobility solutions. Biogas and biomethane, derived from organic matter breakdown, utilise feedstocks to power the energy sector. Hydrogen shows promise in transportation, particularly for city buses, commercial fleets, and specific rail networks. Synthetic fuels sourced from materials like waste oil, fats, and non-food crops offer renewable options for commercial aviation.

Key strengths and weaknesses

+ These fuels lower greenhouse gas emissions and pollutants, improve air quality, promote recycling, reduce landfill use, and biomethane alone can offset 29% of global natural gas consumption.[1]
+ Bolsters national and regional energy security by reducing dependence on imports and supporting local production.[2]
- Amidst evolving demand, low-emission fuels face hurdles in efficiency, storage, distribution, infrastructure adaptation, technological advancement, and regulatory uncertainty.[3]

Energy storage and transmission

Advanced energy storage and transmission improves grid energy consumption while offering backup, peak load management, and integration solutions for renewable energy. Technology to support sector ‘coupling’ (integrating energy demand sectors) is also being deployed. Long Duration Energy Storage, Advanced Thermal Energy Storage, and microgrids which operate connected or independently from the main grid are also being explored.

Key strengths and weaknesses

+ Advanced energy storage systems ensure grid stability and renewable integration through load shifting and fast response capabilities, ensuring reliable energy supply.
+ Facilitates renewable integration, reducing emissions and improving power generation and transmission efficiency, achieving up to 57% emissions reductions with minimal renewable curtailment.[4]
+ Establishes backup power during grid outages, enhancing Australia’s energy security, and supports islanded operations in remote areas.[5]
- Involves significant upfront costs and economic uncertainties, alongside technical challenges in scaling up capacity and developing mature technologies for 2030.

Negative emissions technologies

Negative emissions technologies capture and store greenhouse gases from the atmosphere. This will be required to not just reduce, but reverse Victoria’s emissions impact. Direct Air Capture retrieves CO2 from the atmosphere for storage or industrial use, while Carbon Capture, Utilisation, and Storage focuses on emissions from power plants and industrial facilities. Membrane separation offers a promising approach with potential for over 90% carbon capture from coal flue gas.

Key strengths and weaknesses

+ Extracts carbon from the atmosphere, which will be an essential part of the technological mix to address climate change. Direct Air Capture is 100 to 400 times more efficient than forests at carbon dioxide sequestration.[6]
+ Offsets the impacts of emissions producing technologies with no viable fuel alternative.
- Existing carbon capture technologies have faced challenges with cost effectiveness and high energy demand which limits efficacy.[7]
- Current skepticism of technologies may inhibit investment in the near-term.

Large-scale renewable energy

Achieving 100% clean energy means investment in large-scale projects like solar, wind, hydro, and tidal. Existing renewable energy technology is well developed but will require sustained investment to meet this target. Next generation technologies are also being developed that increase the efficiency of space use and energy generation and lower cost, such as floating wind turbines, perovskite-based solar panels, and nano-based energy technologies for self-powered infrastructure.

Key strengths and weaknesses

+ Diminishes reliance on fossil fuels, lower emissions, and bolster energy security, thereby promoting environmental sustainability and reducing ecological harm.
+ New technologies will optimise energy production through generation efficiency and reducing distribution requirements.
- Scale of emissions reduction requires sustained and widespread investment to transform critical infrastructure,
- Nano-based energy technologies are in early stages of development.

1. Marconi P., Rosa L., 2023.
2. IRENA, 2022.
3. International Energy Agency, 2024.
4. Arbabzadeh M., Sioshansi R., Johnson J.X. et al., 2019.
5. ARENA, 2019.
6. Energy Transition Institute, 2024.
7. Dziejarski B., Krzyżyńska R., Andersson K., 2023.

2. Long-list of technologies
Enabling technologies

2.3. Enabling technologies

Enabling technologies are those that are critical for the broad adoption and impact of other technologies but have a low productivity impact as standalone technologies compared to others.

But these technologies will be fundamental to the broad take up and adoption of the near-future and future technologies.

These were predominantly from the technology field of advanced information and communication, as being required to support the fast, accurate and secure capture and transmission of data. For example, cyber security is a risk for almost all technologies investigated and will be a key enabling technology to ensuring the safety and security of data, assets and operations.

Similarly, effective radiofrequency communication technologies are essential to supporting the transfer and processing of data which is how many of the high potential technologies will have impact.

Autonomous systems and robotics

IoT – Edge Computing

Edge computing decentralises computation by processing and storing data on sensor devices close to the input source. Advanced imaging analytics often uses edge computing. For example, images and data collected for pedestrian and traffic counts is calculated on the camera 'at the edge' with data sent back to a central repository. Although less broadly capable than cloud computing, edge computing improves processing speeds and enhances data security in sensitive contexts.

Key strengths and weaknesses

+ Increases response times by processing data closer to the source, reducing latency, optimising bandwidth usage, and alleviating future network congestion.[1]
+ Guarantees reliability, privacy, security, and scalability via uninterrupted operation, processing data locally, and employing distributed architecture.
+ Optimises bandwidth usage and enhances reliability by processing data closer to the source and operating locally to ensure continuity.
- Distributed edge infrastructure presents challenges in complexity, interoperability, limited resources, and data consistency.
- Distributed nature poses security risks due to an increased attack surface and data exposure.[2.]

Climate and energy transition

Electric charging

Charging technology needs to accelerate to meet rising demand for electric vehicles and electrified equipment like construction machinery and heating. Fast charging stations, wireless capabilities through inductive and resonant inductive coupling, and smart grid integration are critical to offer the convenience, efficiency, and accessibility needed to make the switch.

Key strengths and weaknesses

+ Electric charging offers energy-efficiency and cost-effectiveness due to regenerative braking, cheaper electricity, and reduced maintenance needs, offering potential long-term savings.
+ Underpins the sustainability of other technologies.
+ Reducing reliance on imported fossil fuels enhances energy security and independence while supporting renewable integration, driving innovation in batteries, and charging systems, and enabling efficient smart grid management through charging methods such as vehicle-to-grid.[3]
- Scale of the distributed technology required is a significant financial and logistical challenge.[4]
- Technology development required to increase charging speed for batteries.[5]

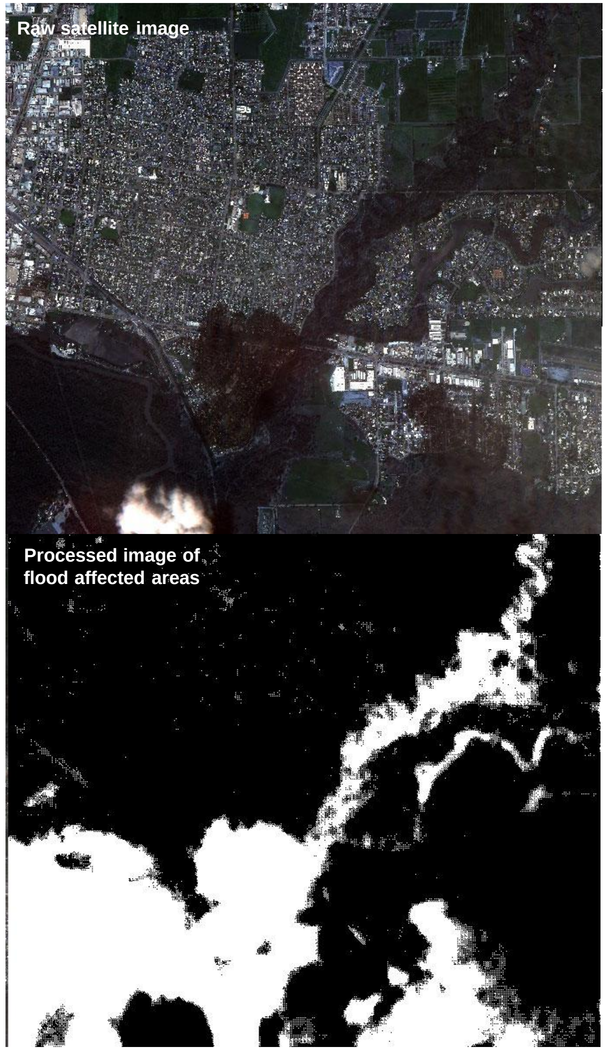

Figure 5: Spiral Blue is a powerful edge computer equipped with artificial intelligence to immediately process raw images to increase speed of analysis and transfer of data (Australian Space Agency, 2024)

1. IBM, 2024
2. Archon, 2023
3. Essential Energy, 2024
4. Mohammed A., Saif O., Abo-Adma M. et al., 2024
5. Drive, 2024

2. Long-list of technologies
Enabling technologies

Advanced information and communication

High-performance computing

High-Performance Computing aggregates computing power to achieve far higher performance than traditional desktop computers or workstations can achieve alone. This enables large calculations to be undertaken much more quickly, delivering cost and time efficiency while opening the door to more powerful simulations and reducing the need for physical testing.

Key strengths and weaknesses

+ Supports functionality of other technologies, such as for simulation and modelling.
+ Reduces time required for data analysis, decision-making, and project delivery, increasing productivity and saving costs long-term.
- Requires increasingly dense computing needs, with hyperscalers currently averaging 36kW per rack, expected to grow to 50kW by 2027, and artificial intelligence clusters projected to reach requirements of 80-100kW per rack, posing sustainability challenges.[1]
- High cost due to high-density infrastructure requirements.[2]

Protective cyber security

Cyberattacks and data breaches are on the rise. In 2022-2023 publicly reported attacked rose by 23% across Australia. Cyber security and advanced threat protection is vital to safeguard physical and digital infrastructure by combating malevolent attacks. It finds applications in enforcing data governance, endpoint protection, and network security, as well as in algorithmic early detection systems.

Key strengths and weaknesses

+ Quantum-resistant algorithms provide protection from future quantum threats.[3]
+ Enables detection and response to cyber threats in real-time, preventing breaches before they cause damage.[4]
+ Protects essential infrastructure, including power grids, water supply, and hospitals, from attack.
- Ongoing maintenance requirements and expenses associated with updates and the monitoring of cyber security systems.
- A heavy reliance on technological solutions, without considering human factors and organisational processes, can foster a misleading sense of security.[5.]

Radiofrequency communications

Radio frequency communications exchange information between devices over airwaves, serving as the backbone for communication systems like radio broadcasting, television, mobile phones, and wireless networking. The introduction of 5G is speeding up information exchange, reducing latency, and increasing device connectivity. Now is the time to prepare the ground for a planned 6G rollout in 2030.

Key strengths and weaknesses

+ Critical cross-cutting enabler for practices like telehealth and remote education that safeguard productivity and equity for remote and regional locations.
+ Improves extent and immediacy of coverage and reduced congestion, suitable for large-scale infrastructure like power grids, transport networks, and remote monitoring systems.[6]
+ 6G could assist with the move to renewable energy and smart grids to optimise energy distribution.[6]
- There are risks of signal interference from other electronic devices, weather conditions and physical obstructions.
- Environmental considerations include land use, aesthetics, and increased energy use.

Positioning

Precise positioning pinpoints objects or people with high levels of accuracy by bringing together tools and techniques like indoor positioning systems, Real-Time Location Systems, ultra-wideband, LiDAR, and augmented reality mapping. Precise positioning combats traditional ‘blind spots’ in settings like urban canyons and low GPS visibility locations and sets the foundation for robotics to confidently and precisely navigate and complete tasks.

Key strengths and weaknesses

+ High accuracy in design, construction, and monitoring, including in complex environments, with reduced errors and rework, saving material, labour and time, and improving safety.
+ Enables quality control and automated measurement of construction progress and finished structures, ensuring they meet standards and efficient resource management.
- Introduces size and power demand and vulnerability to system outages or interference, which can impact the reliability and accuracy of critical infrastructure.[7]
- High initial costs that include significant investment in specialised equipment, tools, software, and personnel training, which can be a barrier for smaller firms.[8]

1. JLL, 2024
2. Nelson, M, 2022
3. Laing T., Charles T., 2024
4. Lord N., 2023
5. International Society of Automation, 2024
6. Rajkotia P., 2022
7. Du Y., Wang J., Rizos C. et al., 2021
8. U-Blox, 2018

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3. Short-list of technologies and economic analysis

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3. Short-list of technologies

3.1. Introduction and overview

Five near-future **Level 2** technologies were prioritised from the long-list on the basis of greatest potential and likelihood of driving productivity benefits in Victorian infrastructure within the parameters of the study.

Figure 6 summarises the five **Level 2** technologies that were prioritised and the cascade to **Level 3** – the level at which more tangible use cases could be developed, described and economically assessed.

The use cases allowed specific benefits to be identified, measured and right-sized to the Victorian infrastructure sector. They were developed on the basis that they were commercially feasible, technically viable and high impact demonstrations of how the short-listed technologies could be applied. The economic analysis provides a demonstration of the potential impact that an application of the prioritised **Level 2** technologies might have.

This section provides an expanded discussion of each of the prioritised technologies, including:

- *Level 2 Technology discussion* –describing the technology, it's potential uses and key benefits.
- *Level 3 Use Case analysis* – an economic analysis of a specific use case of the technology in the Victorian context, quantifying potential economic benefits and broader findings.
- *Barriers and enablers discussion* – including discussion of the current state of adoption in Victoria, key barriers, and potential enabling actions.

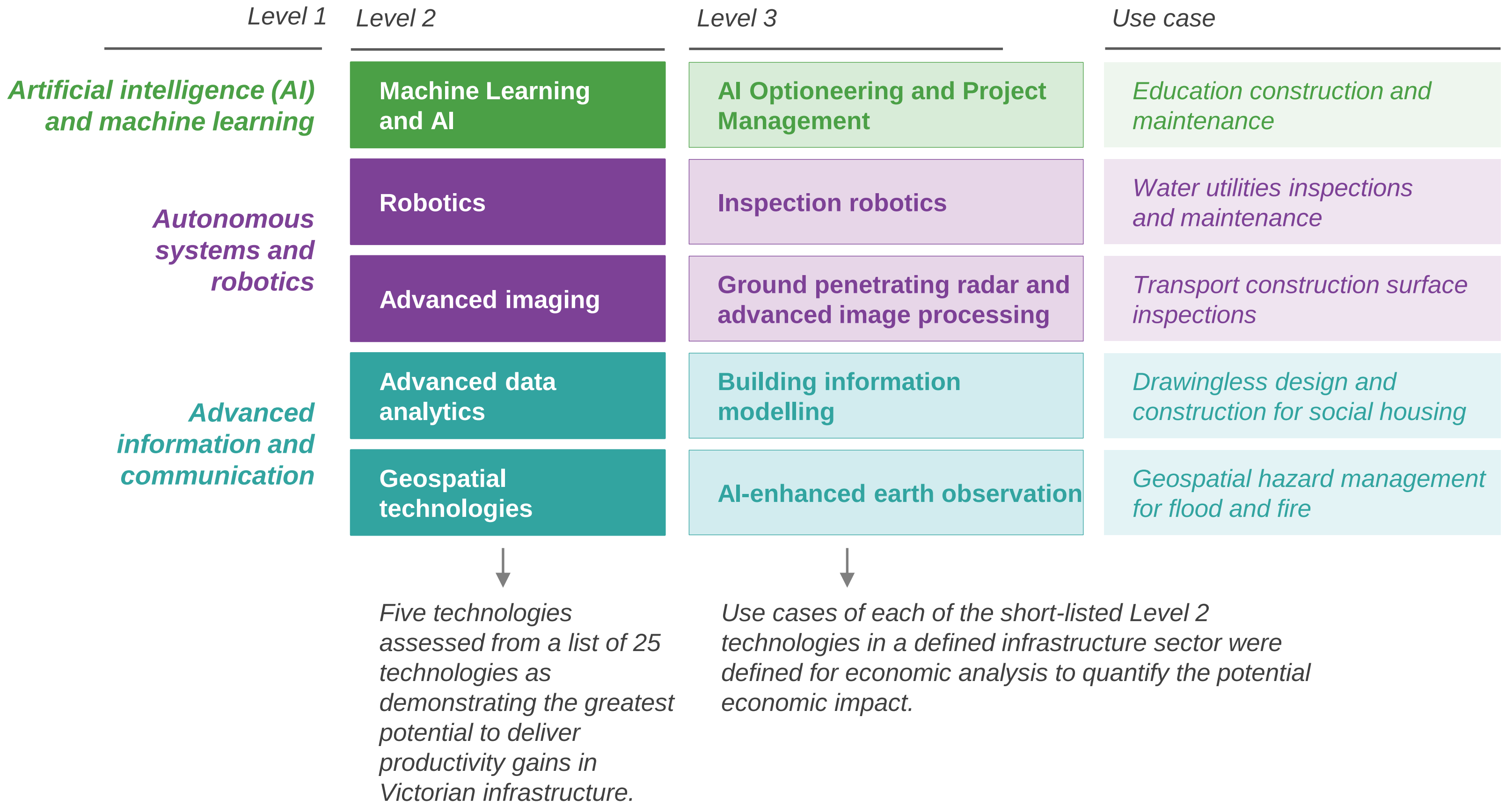

Figure 6: Summary of short-listed technologies and use cases of each that progressed to economic assessment

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3. Short-list of technologies

Machine learning and artificial intelligence

3.2. Machine learning and artificial intelligence

Machine learning and Artificial Intelligence (ML and AI) were considered as a cluster. They allow computers to learn from data without human programming to provide computer-assisted or computer-led integrated analysis, decision-making, and prediction. It provides the 'brain' that helps derive meaning from and use large and complex data.

AI can be applied across the project lifecycle from generating and assessing design and project management options, automating decision-making such as in procurement, and managing assets. This allows projects to be delivered faster, cheaper and with lower risk.

The technology may include **deep learning (DL)** which uses **artificial neural networks** modelled after the brain for advanced capability, and **natural language processing (NLP)** which enables better comprehension and use of human language.

3.2.1. Key benefits and applications

The value of the global AI infrastructure market is rapidly growing and projected to reach $309.4 billion by 2031.[1]

It has the potential for widespread applications across all infrastructure sectors and all phases of an asset's life cycle for data analysis.

It consistently ranked as high impact and high certainty by stakeholders consulted and scored highly across all of the assessment criteria.

Ways in which these technologies can be applied with existing and future advancements include:

- Streamlining and replacing administrative and repetitive tasks including with the support of copilots, automated assistants and voice recognition.
- Automated procurement decision-making.
- Design and project management optioneering (generative option development and iteration) and assessment.
- Predictive maintenance and risk management.
- Optimised and automated asset management and operations, including for buildings, transport and emergency services.

Applying the technology in these ways will reduce the cost of projects through reduced labour costs, increased design and delivery efficiency, and reduced risk and associated contingency costs. Benefits will also be realised in more efficient asset operation and extended asset lives, through optimised and automated asset management, improved design leading to better performance, and more efficient and comprehensive maintenance.

Examples have shown applications like these to:

- Increase accuracy in building modelling by 98% allowing for enhanced design.[2]
- Reduce equipment downtime by 45%[3] in the water sector through failure detection and extend asset lives by 20%.[4]

Delivering projects more efficiently and increasing the use and life of infrastructure will be key to meeting some of the broader productivity challenges facing the state. This suite of technologies will play an important role to help us reduce how much we build and how it's built, reducing the environmental impact of infrastructure. This will be especially relevant in the context of an aging population and constraints on budget capacity.

While having significant benefits in standalone applications, machine learning and artificial intelligence will also dramatically enhance the impact of many other technologies – such as when combined with image processing in health, or with edge computing in sensors to enhance the effectiveness and responsiveness of robotics. All data-generating technologies will need to be supported by AI in order to making meaning and derive value from this data.

This technology is similar to advanced data analytics (see section 4.5) but offers distinct and nearer-term opportunities.

1. Allied Market Research, 2023
2. Cerè G., Rezgui Y., Zhao W., et al., 2022
3. InfoTech
4. Cloudlflight, 2023

3. Short-list of technologies

Machine learning and artificial intelligence

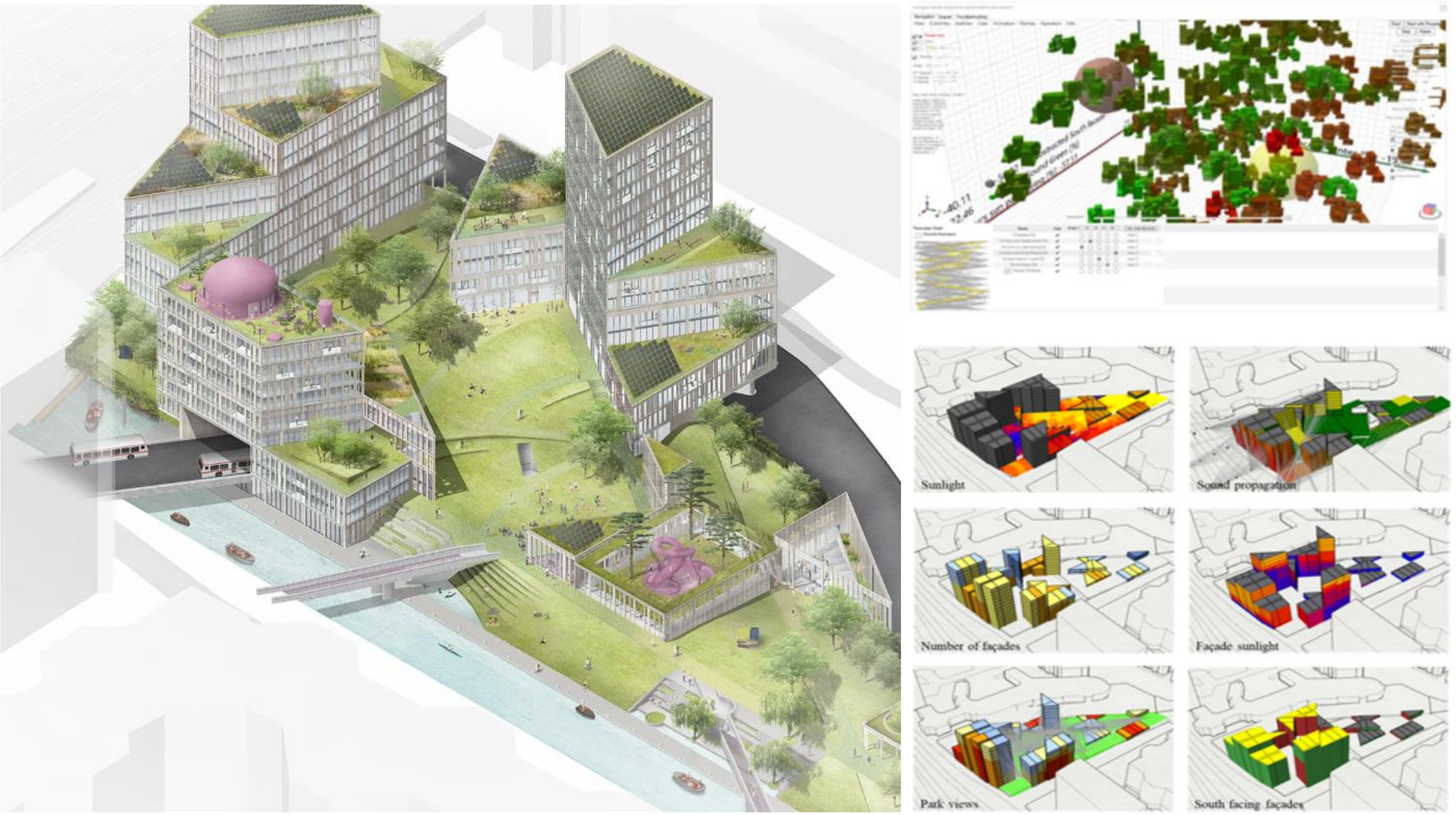

Figure 7: Parametric design applied to Smakkelaarspark redevelopment used to optimise design for noise, sun exposure and energy generation (Arup, 2024b).

SUCCESS STORY

Generative design to optimise Smakkelaarspark for sunlight exposure and energy, Arup Netherlands

A parametric design tool (InForm, Arup) was used to optimise the design of the redevelopment of a city-block in Utrecht, Netherlands. Parametric design uses algorithms to generate multiple variations of a design based on key parameters and performance metrics entered by the designer. This allowed new ideas to be generated and evaluated.

The Smakkelaarspark project generated hundreds of designs to optimise defined outcomes relating to noise, daylight to the building and open space, views, and energy generation from building mounted solar.

This allowed the site layout, massing and apartment configuration to be varied, the performance of variations to be calculated and assessed, and an optimal design selected.

Artificial intelligence can be combined with this to automatically assess and learn from design variations, iterate designs and select a single recommended solution.

Key impacts

- Targeted definition of key metrics and parameters for the design.
- Rapid and large-scale generation of design options and performance measures.
- Used to generate more design options than possible by typical design processes and optimise design for performance outputs.

3. Short-list of technologies

Machine learning and artificial intelligence

3.2.2. Economic analysis and results

Machine Learning (ML) and artificial intelligence (AI) to support ***Government education capital construction delivery and project management.***

The economic analysis quantified how the use of ML and AI in managing projects can reduce cost overruns and project risks on Government education capital projects.

These technologies can be used to allow designers and project managers to rapidly assess different design scenarios and manage on-site project challenges dynamically. This cost efficient "what if" analysis can be used to iterate different designs and ways to build, to pressure test existing schedules, and explore design and scheduling alternatives.

Education capital design and delivery demonstrates a high potential sector for applying this technology due to its high degree of standardised and regulated decision-making and large pipeline of projects across all of Victoria.

When combined with imaging and sensor technologies, real-time information can be integrated, and options developed and evaluated using ML or deep learning (DL) technologies to make faster and better design and construction decisions.

Key measured benefits of the technology are described below, with the quantified economic impacts shown in Table 3.

- Specific data was not available to assess the average cost overrun of education capital projects. As a proxy, the average cost overrun on major Governments projects is estimated at 10.7%.[1]
- ML and AI adoption across project design and delivery is expected to reduce cost overruns by 23%.[2] Considering these two points, adopting ML/DL across projects is **expected to reduce the average cost overrun on projects by approximately 2.5%.**
- To meet the needs of Victorian students, **$27.4 billion of school and kindergarten capital is expected to be delivered by 2055.** The Victorian Government sector comprises 65% of this total ($2022-23). Additionally, Government is expected to spend another $254.3 million each year on maintenance and upgrades at schools ($2022-23). Cost overruns are estimated at 2.5% of the combined capital and operating spend.
- By reducing actual cost overruns, adoption of ML and AI across education capital can also reduce the contingency held to deal with cost overruns, valued to the social discount rate of 7%.

The analysis also demonstrated the potential for broader impact of the technology across all education capital, and all government infrastructure:

- The analysis focused on direct benefits that can be delivered on the Victorian Government education capital program. By expanding this technology to include the non-Government sector, ML and AI adoption could **deliver $790.0 million in benefits by 2055.**
- ML and AI have the potential to transform the design and delivery of Government infrastructure. By extrapolating across the whole Victorian Government infrastructure investment spectrum, using **ML and AI to increase cost efficiency on Government infrastructure could deliver $374.6 million per year or $9.4 billion by 2055.3.**

Key assumptions informing the analysis include:

- ML and DL are adopted across the whole pipeline of education capital projects and are able to realise these benefits.
- Capital and operational expenditure estimates are derived from Scenario 1 (Compact City) of the CIE's *Economic, social, and environmental impacts of alternative urban development scenarios for Victoria*, which informed Infrastructure Victoria's *Choosing Victoria's Future* study in 2023.
- Only Victorian Government kindergartens, primary schools and secondary schools are considered (65% of total education expenditure).
- No real terms construction escalation was included based on ABS data – this is a conservative estimate.[4.]

Scale of application	Benefit	Estimated impact ($2024)	
		Per annum	**By 2055**
Applied to all Government education capital projects portfolio	Avoided cost overruns	$19.3 million	$482.3 million
	Reduced project risk	$1.4 million	$33.8 million
	Total	**$20.6 million**	**$516.1 million**
Scaled to all education capital	**Total**	**$31.6 million**	**$790.0 million**
Scaled to whole Government Infrastructure Sector	**Total**	**$374.6 million**	**$9,365.7 million**

Table 3: Summary of quantified benefits of ML, DL and AI for design and project management ($2024, undiscounted)

1. Grattan Institute, 2020. Based on projects between $350m and $1b recognising the programmatic nature of education capital.
2. Project Management Institute, 2019.
3. Victorian Government, 2024. 2015 – 2024 government infrastructure investment estimated based on the 10-year average expenditure from 2015-16.
4. Australian Bureau of Statistics, 2024. 2014-2024 real terms construction inflation was estimated at 0.13 per cent per year between 2014 and 2024 based on a comparison of Consumer Price Index and Producer Price Index data.

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3. Short-list of technologies

Machine learning and artificial intelligence

3.2.3. Current state of adoption and key barriers

The exploration of the literature and the use case show that there are initial releases of the technology and a good baseline of skills in simple forms of the technology. As more data becomes available and is harnessed for training and testing, opportunities and impact will grow.

The Productivity Commission's *Productivity Inquiry* and Victorian Government *State of the Victorian Labour Market* indicated that from Australia's comparably low technology adoption base, most productivity gains will be made by widespread adoption of established or even dated technologies and practices - in other words, doing simple things well and at scale. Both reports note Artificial intelligence (AI) as being one of these technologies and the need to move quickly.

Prominent and sophisticated uses of the technology in Victoria have included a BreastScreen Victoria research grant for AI assessed mammograms, project management applications within the Office of Projects Victoria, and Melbourne Water's use of deep learning for tree detection and vegetation counting.

However, adoption beyond advanced users and large organisations is limited. Broader adoption and the abundance of more advanced skills are lagging behind international peers. Despite Australia's high international ranking, it scores just 34.2 out of 100 for talent in Tortoise's 2023 AI study, which suggests that the country is experiencing a shortage in AI skills needed to facilitate implementation.[1]

Key risks and barriers to broad adoption and impact include:

- Given the existing rate of development it is anticipated that the costs of adoption will be moderate and associated with workforce retraining and ongoing software development and licensing.

  For example, a licence to use generative AI software Copilot under a business plan is currently $538.80 per user, per year. This is a new application which may require additional add-ons to consider task scheduling and prediction but gives an indication of potential costs.[2]
- The technology faces a range of risks general to many data-based technologies including relating to cyber security, IP theft, leakage of value from data, fraud, privacy, quality assurance, supplier interactions, and supplier-delivered capabilities – each with corresponding social, legal and financial implications.
- Many of the applications of this technology depend on a suite of enabling technologies including radiofrequency technology, positioning, protective cyber security, sensors including edge computing, and high-performance computing. It will also demand high levels of energy and water and so require clean and renewable sources to be sustainable.
- AI has the potential to drive job displacement without adequate transition strategies. Further work must be undertaken to understand the employment risks of this technology, to identify transition plans, training and skills requirements and transferability.
- The technology will be challenged by consistency of adoption as it scales. This includes the technology that is used and the format of data inputs and outputs that will be critical to supporting widespread use and interoperability.
- A recent survey reveals that only one-third of Australians believe that adequate guardrails are in place to ensure the safe design, development, and deployment of AI.[3.]

Key enabling actions

Successfully adopting this technology, realising its benefits and mitigating key risks will require a mix of regulatory and technological supports.

- Widescale adoption will depend on effective governance and regulation, but which enables innovation and investment. Rules and regulations must be updated to encourage the responsible use of AI, data analytics and digital tools in infrastructure development and maintenance.
- Protocols and training must be developed to facilitate cross-organisational use of technologies to avoid fragmented or incomplete practices and data which will inhibit scale.
- Standards and regulations are needed to underpin security and responsible use.
- Informed government procurement can be used to drive technology development, standardisation and upskilling.

1. Brown P., 2023
2. Microsoft, 2024
3. Gillespie N., Lockey S., Curtis C., et al., 2023

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3. Short-list of technologies
Robotics

3.3. Robotics

Advanced robotics integrates sophisticated programming, powerful hardware and smart sensor technology (such as ultrasonic, touch and light sensors). Robots and soft robotics will be autonomous, able to be operated remotely, and involve intricate and multi-segmented units capable of dealing with complex movements and environments.

They are currently being used to undertake repetitive and low value tasks, but more advanced applications can use robotics for tasks that are fully-autonomous and more intricate. This could include operating in remote, high-risk or hard-to-reach locations such as underwater maintenance or performing high-precision and less intrusive medical procedures.

Robotics will be enabled by Artificial Intelligence (AI), sensors and advanced imaging which allow them to understand and respond to varied environments.

3.3.1. Key benefits and applications

Automation is predicted to deliver Australia a $2.2 trillion dividend over the next 15 years if businesses, including those in the infrastructure industry, accelerate their uptake of new technologies.[1] While costs are currently high, rapid cost decreases are anticipated to drive the AI robotics market to grow at a cumulative average growth rate (CAGR) of 12.6% to 2030.[2]

Robotics demonstrate significant potential for a wide range of productivity gains from the factory to the hospital floor, although construction and maintenance tasks offer the most immediate and substantial returns for the Victorian infrastructure sector

Robotics was ranked highly by most stakeholders for both certainty and impact, and it scored highly in most criteria with only moderate benefits relating to resource efficiency.

Ways in which robotics can be applied with existing and future advancements of the technology include:

- Use in construction to reduce delivery cost, increase speed, and increase worker safety.
- Inspect and maintain assets more frequently and in hard-to-reach or remote locations.
- Health care applications such as assisting or delivering medical procedures.

Applying the technology in these ways can reduce projects costs and increase quality through reduced error, increased precisions and reduced labour costs. Applications in asset monitoring and maintenance can enable more frequent and expansive upkeep of assets, increasing performance and extending assets lives. And using robotics in these instances can increase worker safety and reduce costs with the associated risks and downtime.

Research found that among all sectors a 1% increase in robot density correlated with an increase in productivity of 0.8 % - this productivity improvement was as high as 5% when in the early stages of adoption of robotics.[3]

Robotics can also aid in responding to the larger and more long-term productivity challenges facing Victoria.

Cost and time savings and extensions of asset lives of infrastructure will help Victoria meet the growing demand for infrastructure.

Driving productivity through this technology aligns with a focus in the Australian Government's *Intergenerational Report* and *Working Future White Paper* and The Productivity Commission's *Productivity Inquiry* to rapidly evolve Australia's manufacturing sector with a focus on high-skill, high value-add areas. Both this need and the potential productivity impact are particularly acute in context of recent emphasis on re-establishing national economic independence and sovereign capabilities.

Robotics can also help Victoria to meet skills shortages being faced in many areas where it can be applied including in engineering, trade, health and education.

This technology can deliver significant benefits for health and construction when combined with other technologies including composite materials, digital fabrication, additive and subtractive manufacturing, and biotech.

1. Butler L., 2018
2. Allied Market Research, 2023
3. Select USA, 2020

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3. Short-list of technologies

Robotics

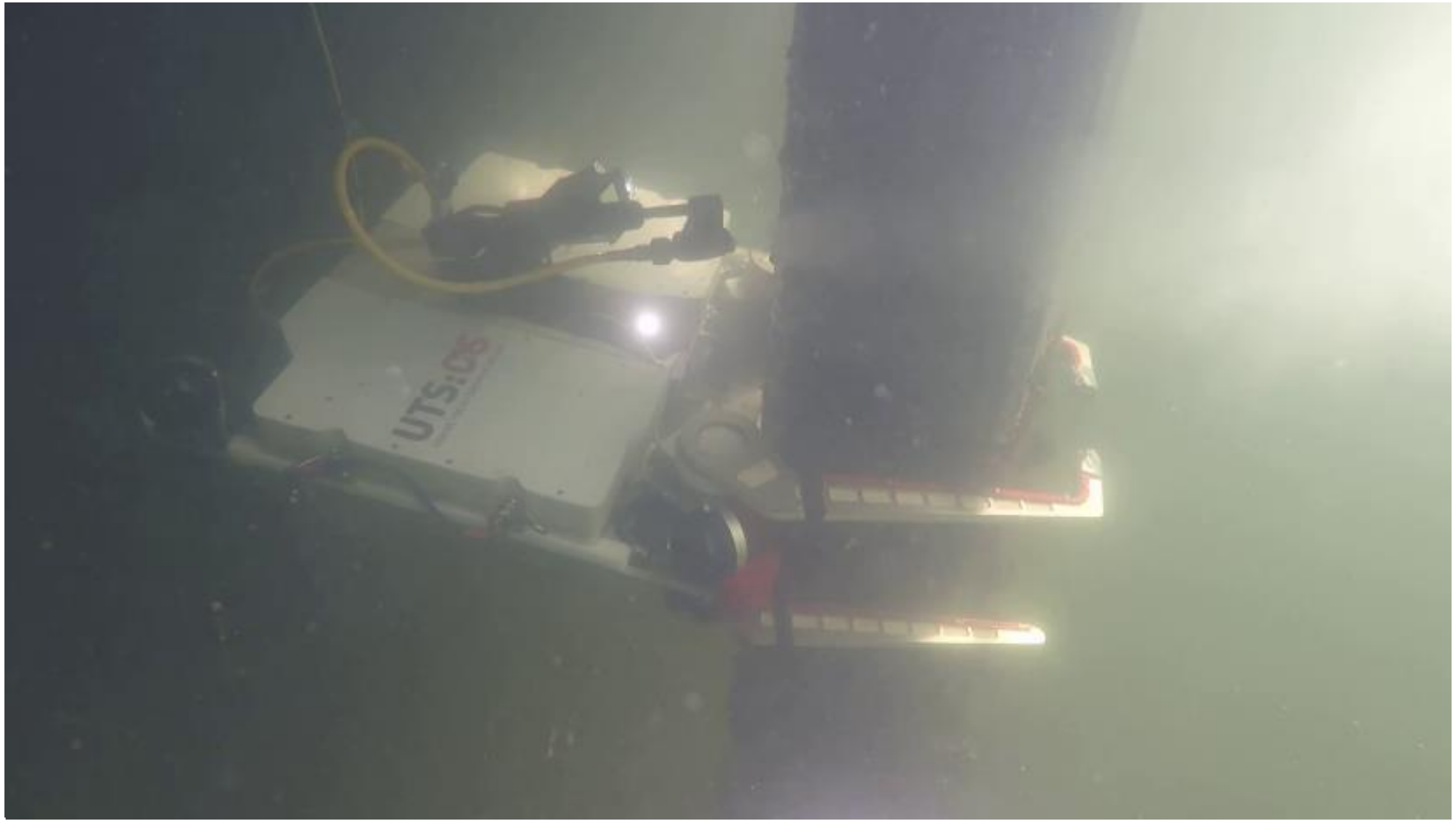

Figure 8: Underwater robots developed in Sydney for cleaning and inspection of underwater objects (UTS, 2021)

SUCCESS STORY

SPIR: Underwater robots for infrastructure inspection and maintenance, Sydney

The submersible pile inspection robot (or SPIR) was developed by researchers in Sydney to assist in inspecting and cleaning underwater infrastructure. SPIRs have claw arms that allow them to grasp a pile, conduct surface cleaning using high-pressure water jets, and use cameras and sensors with advanced algorithms to allow the robot to work autonomously and collect high-definition images of the cleaned pile. It then produces a 3D map of the structure to support the condition assessment undertaken by an operating team.

Inspections are currently done by divers who are costly, face a range of safety risks and can require infrastructure to be shut down during sampled inspection. The cost savings of maintenance using the SPIRs has allowed more piles to be inspected and cleaned more frequently. This enables greater monitoring of the overall condition of infrastructure and extension of the asset's life.

Key impacts

- More frequent and expansive maintenance, enhancing infrastructure safety and longevity.
- Greater degree of data capture, allowing improved monitoring and assessment.
- Exponential productivity impact, as one operator can manage several SPIRs at once.
- Potential to be scaled for use for over 50,000 bridges and at 70 ports across Australia.

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3. Short-list of technologies

Robotics

3.3.2. Economic analysis and results

*Robotics for **inspections and maintenance** in **water utilities**.*

The economic analysis quantifies how inspection robotics (like those highlighted in the case study above) could be used for inspections and maintenance of pipelines within the water sector. Specifically, the analysis measured how:

1. Proactive maintenance enabled by robotics can reduce the overall cost of asset renewal.
2. Increased remote inspection and maintenance can eliminate blockages.
3. Improved asset health can reduce non-revenue water leakage from the network.

Water utilities provide a high potential demonstration of the technology due to it's expansive and often underground infrastructure which limits the extent of maintenance. In addition, non-revenue water resulting from leakage can range between 8-15% of total water supply with immediate revenue impact, and longer-term ramifications for capital efficiency and climate resilience. In addition, downtime as a result of failure has extremely high social and economic costs.

Key measured impacts of the technology are described below, with the quantified economic impacts shown in Table 4.

- Average annual renewals expenditure was assumed to be $612 million, based on capital expenditure approved by the Essential Services Commission.[1.]
- Based on evidence from Sydney Water, the estimated **reduction in maintenance expenditure from robotic monitoring is 20%.**[2] While overheads and other fixed operating costs are not expected to be materially impacted by non-revenue water leakage, this water still needs to be pumped and treated ($0.06/kL of water).[3] The cost of this is borne by utilities, and a portion is likely passed on to consumers.
- Additionally, robotic inspection and maintenance is expected to reduce the incidence of blockages. This represents **an avoided cost for utilities of $1,333 per blockage.**[4.]
- It is estimated that **over 7,400 blockages each year could be avoided** based on data provided by the ESC.[5.]
- Non-revenue water from leakage is estimated at 10% of total water supplied, which equates to 58.7GL per year.[6.]

In addition, broader economic impacts that robotics may have, which have not been measured include:

- Robotics allows a shift to more frequent, expansive and preventative inspection, which can improve asset performance and extend asset life.
- Robotics can undertake tasks in unsafe environments, increasing safety for humans, reducing downtime costs associated with incidents, and reducing overall labour costs associated with high-risk activities.
- This kind of technology could be adopted in a variety of sectors and infrastructure, including utilities, bridges, jetties, roads and buildings. An estimate of how similar maintenance cost savings may translate to the electricity distribution infrastructure has been also quantified for illustration purposes.[7.]

Key assumptions informing the analysis include:

- All water utilities networks across Victoria adopt robotic monitoring and inspection for maintenance.
- We have conservatively used data from Sydney Water that estimated that proactive maintenance using remote sensors reduced maintenance costs by a higher 50%.[4] Adopting the benchmark provided by SA Water would result in maintenance cost savings of $314.7 million per year or $7.9 billion by 2055.
- The analysis assumes all non-revenue water leakage and blockages are avoided through improved asset maintenance.

Scale of application	Benefit	Estimated impact ($2024)	
		Per annum	By 2055
Applied to water utilities inspection and maintenance	Maintenance cost savings	$125.9 million	$3,147.6 million
	Avoided cost of blockages	$10.8 million	$269.9 million
	Avoided pumping and treatment cost of non-revenue water	$3.5 million	$85.9 million
	Total	**$140.2 million**	**$3,504.8 million**
Applied to electricity transmission infrastructure	**Total**	**$5.4 million**	**$133.9 million**

Table 4: Summary of quantified benefits of robotics for inspection and maintenance ($2024, undiscounted)

1. Essential Services Commission, 2023b.
2. UTS TechLab, 2021
3. Essential Services Commission, 2023b.
4. Australian Water Association, 2022
5. Essential Services Commission, 2023a.
6. Water Services Association of Australia, 2019
7. Always Powering Ahead, 2022

3. Short-list of technologies

Robotics

3.3.3. Current state of adoption and key barriers

The exploration of the literature and the use case show the initial stages of robotics have been successfully deployed at scale in manufacturing via semi-automated production lines and is increasingly seen in logistics for picking and packing. There are also a range of applications of robotics in construction emerging.

More advanced robotics are beginning to be seen in Victoria which integrate more intricate mechanics and sensors, and increased computing power, artificial intelligence (AI) and other technology for more sophisticated and autonomous uses. Examples include the use of AI-powered robots for waste sorting and a Victorian Government partnership for hands-free voice-operated medical procedures using advanced 3D imaging.

Key risks and barriers to broad adoption and impact include:

- The costs to adopt robotics are expected to be high due to the high level of software and hardware development to occur and significant investment in equipment required.[1]

  For example, Sydney water have been part of a large innovation program with University Technology of Sydney for many years with the support of a $16 million-dollar, five-year international research grant.[2] As part of this program, Sydney Water have worked with Pipe Management Australia to commercialise a robot called the RACER™. According to the website: RACER™ can safely inspect 14km of a sewer network in a single 3-4 hour session.
- High capital costs of robotics remains one of the primary barriers to entry. These are compounded by a lack of understanding of the benefits of the technology and how it can be sourced and applied.
- This pace of growth may be inhibited by regulatory or commercial frameworks which do not allow rapid technological development and opportunities for commercial deployment. Social distrust and disbenefits must also be managed to avoid resistance to change.
- The spread of robotics will likely have a significant and direct impact on job displacement which must be understood and planned for. A study found that an increase in industrial robot density of 1% was correlated with a 2.7% decrease in working hours of employees.[3] Beyond economic impacts this kind of workforce disruption can generate social and workplace resistance to change.
- The technology will create demand for new skilled jobs and a requirement for training to deliver these which must be rapidly developed in time to accommodate the anticipated pace in growth.
- The technology is challenged by common risks relating to cyber security, IP theft, leakage of value from data, fraud and privacy. The physicality of robotics and interaction with the people and the built environment also represents a unique version of these threats which may take the form of digital or physical cyber attacks and safety concerns.
- The advancement of robotics is dependent on the simultaneous development and integration of other technologies including advanced imaging, advanced data analysis, advanced visualisation, radiofrequency technology, edge, high-performance computing, electric charging, protective cyber security, sensors and AI. These technologies will enable the increasing intricacy of movements, ability to sense environments, and computing power to assess and respond.
- Technology must be able to be developed in a way that manages safety and security of infrastructure and people. Failure to manage flaws may generate social distrust and legal and commercial risk which inhibits uptake.

Key enabling actions

Given the pace of anticipated growth, technological and non-technological readiness will be key to successful adoption and uptake.

- Building workforce and industry readiness including by promoting the benefits and uses of the technology, supporting the skilling of new specialists, and understanding and responding to risks of job displacement.
- Robotics are highly dependent on the supported development of other enabling technologies including sensors, robotic components, and AI.
- Technological safeguards should be put in place to ensure the technology develops safely and efficiently. Controlled testing environments and interventions must be considered to ensure that autonomous systems that show instances of inaccuracy of malfunction can be managed safely.

1. EY, 2023
2. UTS, 2014
3. Select USA, 2020

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3. Short-list of technologies

Advanced imaging

3.4. Advanced imaging

Advanced imaging allows images to be captured which are of greater resolution and detail and which can penetrate through surfaces.

It uses diverse techniques and technology including **thermal cameras, 3D and 4D scanning** and **ground-penetrating radar,** which surpass traditional methods like photography and basic radiography. It can be employed across engineering, medical imaging, astronomy, biology and physics to improve diagnostic precision and decision-making.

The technology may include the use of **advanced visualisation** and **artificial intelligence**, combined with other data sources and complex algorithms, to enable images to be processed, interpreted and used.

3.4.1. Key benefits and applications

Advanced imaging has the potential to deliver productivity gains across all infrastructure sectors and tasks.

Advanced imaging was ranked highly by most stakeholders for both certainty and impact, and it scored highly in most criteria but with only moderate benefits relating to resource efficiency.

Combined with traditional and emerging data sources and advanced data analytics, it can be used to dramatically increase the precision and timeliness of understanding the environment and making decisions.

Ways in which advanced imaging can be applied with existing and future advancements of the technology include:

- Analysing patterns of land use change.
- Transport monitoring and optimisation.
- Site monitoring for project management.
- Non-intrusive investigation of underground utilities and ground conditions reduce risk and increase precision of underground construction.
- Management of natural hazards such as for bushfire detection and coastal hazards.
- Medical applications for non-intrusive diagnostics.
- Public health and safety monitoring.

The benefits of increased penetration and precision of imaging will lead to increased accuracy, reduced costs for construction projects and medical diagnosis and procedures, improve the ability to maintain and operate assets and extend asset lives and utilisation. The ability to detect hazards in construction or in the natural environment will also reduce damage and downtime associated with these incidents.

Reduced cost and improved performance of infrastructure will also help to meet the growing demand for infrastructure from the population more efficiently. Technology applications in healthcare will directly improve the ability to deliver high quality and low-cost healthcare to our ageing population.

The productivity benefits of advanced imaging will be greatest when combined with other technologies. This includes technologies that benefit from increased sensing such as robotics, and those which enable meaningful analysis of new and complex data including advanced data analytics and advanced visualisation.

3. Short-list of technologies

Advanced imaging

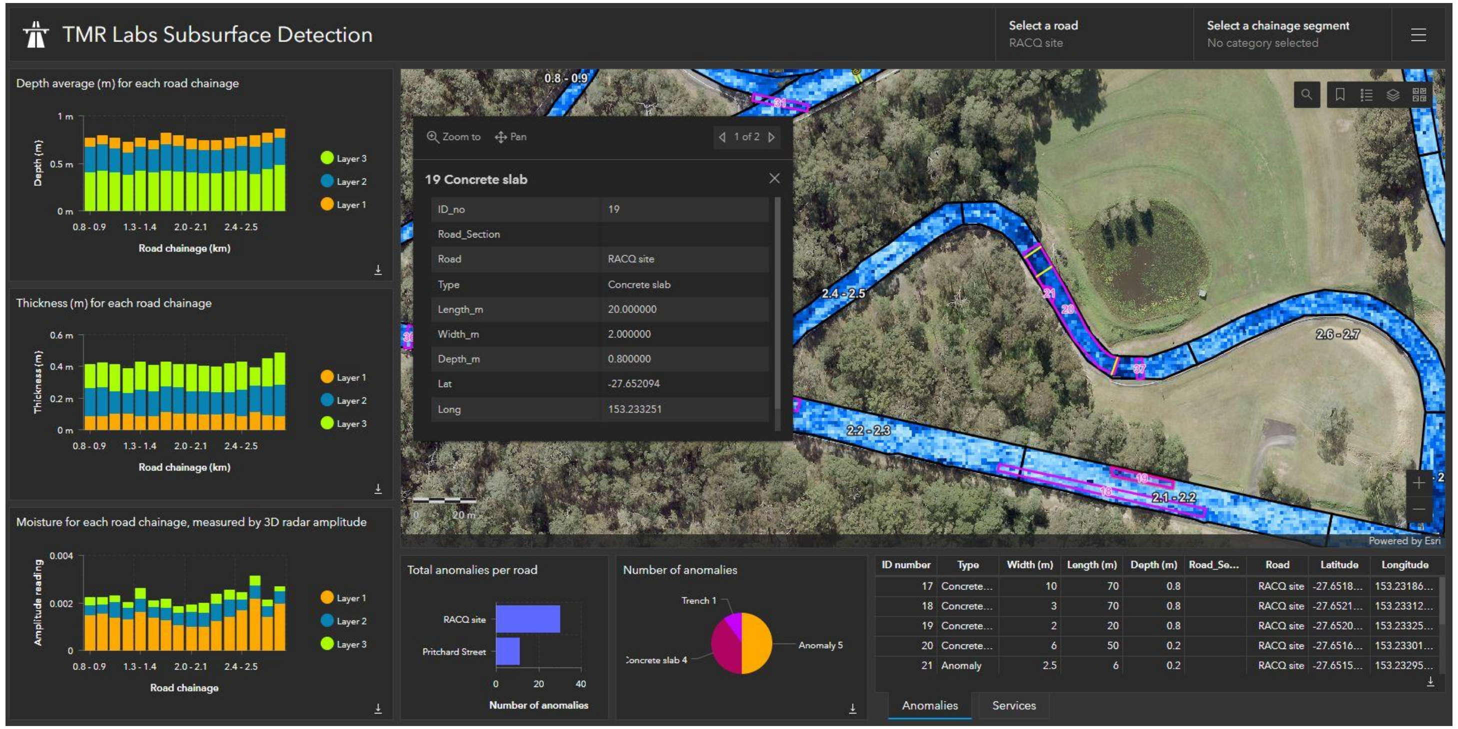

Figure 9: Overview dashboard of GPR scanning and advanced image processing of subsurface road (above) and vehicle-towed 3D GPR unit (right) (Veris, 2024)

SUCCESS STORY

3D Ground penetrating radar to provide detailed subsurface scanning, Veris Australia

In 2022, Veris was one of the first companies in Australia to use 3D ground penetrating radar (GPR) and advanced image processing. Such multi array technology (most GPR are single or dual) allows it to collect data from multiple depths at the same time. This capability and multi array equipment is only one of a small but growing number 3D GPR units in commercial use in Australia.

The vehicle-towed unit captures high accuracy and high-resolution subsurface data quickly and safely with depths down to 3-4 metres. The hardware is maximised when combined with spatial analytics and artificial intelligence computer vision to detect pipes, rebar, pavement thickness, moisture, voids and utilities without penetration.

3D GPR and image processing can be used to survey construction projects rapidly and with a high degree of accuracy, and to detect potential signs of defect or maintenance needs earlier.

Currently the technology is being used to undertake subsurface investigations to support the provision of additional high-voltage network cables to Central Place Sydney, identifying underground infrastructure, minimising service interruptions and project risk.

Key impacts

- Produces high-resolution, high-detail 3D subsurface imaging to detect subsurface features and early signs of defects.
- Limits risk and costs associated with utility strikes.
- Mounted to vehicles, this technology can provide expansive, rapid and non-intrusive methods for subsurface surveying.

3. Short-list of technologies

Advanced imaging

3.4.2. Economic analysis and results

***Ground Penetrating Radar (GPR)** and advanced image processing of **subsurface conditions** to reduce utility strikes.*

The economic analysis quantifies how GPR (enabled through artificial intelligence and advanced image processing) can be used to map subsurface utilities rapidly and at scale. It specifically measures how:

1. Precise information about subsurface infrastructure can avoid the direct repair costs associated utility clashes.
2. Increased use of non-intrusive ground inspection can deliver cost savings on road infrastructure projects.

GPR is a non-intrusive method of surveying the sub-surface to investigate underground utilities and objectives such as concrete, asphalt, metals, pipes, cables or masonry and potentially contaminated soils. They are rapidly decreasing in size and compact units can now be towed behind cars and even smaller units mounted underneath vehicles.

Compared to traditional methods, the non-destructive nature of GPR offers several advantages such as its ability to make repeated measurements, save on labour, and provide more extensive spatial coverage (in terms of both vertical and horizontal spatial variability) with geo-referenced data. This is enhanced by advanced imaging to improve resolution, accuracy and reliability of data.

Undetected objects are one of the key drivers of cost and schedule overruns in construction effecting all infrastructure sectors. GPR presents major cross-cutting benefits for reduced costs, reduced delivery time and reduced risk and related contingency.

Key measured impacts of the technology are described below, with the quantified economic impacts shown in Table 5.

- For comparability, the direct cost of damage to utilities was estimated to be $6,807 per clash on average, based on international research, converted to present value Australian Dollars.[1]
- The number of incidents was approximated at 6,097 each year in Victoria, leading to a total direct cost of $61.1 million. Exact incident data from Victoria was not readily available. However, BYDA was able to provide an incomplete, conservative estimate of the number of incidents for 2023 based on reports from utility providers.[2]
- The avoided cost of ground condition inspections was estimated at 0.5% of capital cost for road transport project, based on Arup's internal project data
- Total avoided cost of ground condition inspections was scaled based on an annual capital spend of $9.7 billion on transport infrastructure.[3]

In addition to the benefits measured, the technology has the potential to deliver broader economic impacts relating to time- and health-related benefits associated with utility clashes avoided, which are a significant cost. This includes (but is not limited to) transport network delays, construction delays and injuries and fatalities. An estimate suggests that consideration of these broader impacts increases the overall cost avoided by 407%.[4]

Key assumptions informing the analysis include:

- All clashes are avoided resulting from improved sub-surface information.
- There is no change in the rate of clashes. It is not clear how the frequency of clashes is expected to change, noting that:
  - As more subsurface infrastructure is developed, this increases the potential for clashes.
  - The location of newer infrastructure may be better understood than existing infrastructure.

Scale of application	Benefit	Estimated impact ($2024)	
		Per annum	By 2055
Applied to subsurface infrastructure detection	Avoided cost of utilities clashes	$41.5 million	$1,037.6 million
	Reduced project risk	$2.9 million	$72.6 million
	Total benefits	**$44.4 million**	**$1,110.2 million**
Applied to ground condition inspections	Avoided cost of ground condition inspections	$5.2 million	$130.1 million
	Total benefits	**$5.2 million**	**$130.1 million**
Scaled to direct and indirect impacts of subsurface infrastructure clashes	**Total benefits**	**$180.7 million**	**$4,517.2 million**

Table 5: Summary of quantified benefits of GPR and advanced image processing ($2024, undiscounted)

1. Common Ground Alliance, 2020
2. BYDA, 2023
3. Scenario 1, The CIE, 2023
4. Geoscope Locating, 2023. Analysis from Common Ground Alliance, 2019, estimates that broader impacts can be up to 29 times larger than the direct costs. A conservative estimate was taken for this analysis.

3. Short-list of technologies

Advanced imaging

3.4.3. Current state of adoption and key barriers

The exploration of the literature and the use case show advanced imaging is currently being used on projects within Victoria but is limited. Current local applications include video analytics for traffic management and flow optimisation, vehicle mounted radar devices to locate underground services for construction and infrastructure planning, design and tracking, and use in natural hazard management.[1, 2]

Human behaviour and data availability are large contributors to utility strikes, making accurate and timely data even more critical in reducing these incidents. It underlines the need for education of work crews on the value of using GPR and sharing data for others to use to improve the quality of baseline subsurface information that is available.

Multi array equipment and software used for ground scanning for Victorian road projects (see page 30) is just one of a small number of units in Australia. Establishing the technology and the capability for this required a substantial investment in the equipment and the expertise to use it and interpret the data. Key risks and barriers to broad adoption and impact include:

- The technology is relatively new and in the early stages of development. Development costs as well as investment in equipment will be required. As such, costs remain high and the equipment highly technical.

  For example, the cost of operating a leading 3D GPR unit with image processing is estimated to be approximately $6,000 per day, to survey approximately 10 kilometers of road. A mix of human interpretation, analysis software and algorithms will be required by operators.[3]
- Due to the current level of development:
  - The technology and specialists required to operate and use it are not widely available within the Australian market.
  - It is not easily integrated into broader project processes.
  - The existence and benefits of the technology are not well understood.
- The potential of the technology is limited by the depth of imaging penetration to only a few metres underground. Advances that enable greater depth and more nuanced understanding of ground conditions will unlock substantial benefits.
- Widespread use of the technology depends on supporting technologies which can interpret, visualise and analyse imaging outcomes, and which improve the timeliness of images. These include radiofrequency technologies; protective cyber security; positioning; sensors; advanced data analytics, integrated data visualisation; machine learning and artificial intelligence; robotics; and geospatial technologies.

Key enabling actions

Given the pace of anticipated growth, technological and non-technological readiness will be key to successful adoption and uptake.

- Building industry awareness of the technology and expanded availability of specialist equipment and skills will support the current available benefits to be realised.
- This includes supporting a new workforce skilled in operating imaging equipment, as well as integrating it in practice.
- Broader advancements of the technology will also be required to maximse its benefits. Improved timeliness of data collection, enhanced precision of imaging, increased depth to which it can penetrate and the ability to better integrate with data analytics technologies will make the technology more appealing for broader application in the infrastructure sector.

1. University of Melbourne, 2019
2. Veris, 2024
3. Confidential source

3. Short-list of technologies
Advanced data analytics

3.5. Advanced data analytics

Advanced data analytics use rules and processes to discover hidden patterns and trends in data across **multiple dimensions** (in 2D, 3D, and over time). This can be used to **develop replica and real-time models, advanced scenario testing and to optimise future states**.

Advanced data analytics will become **increasingly essential as the complexity, diversity and volume of data grows**, and beyond the capacity of existing tools of analysis and decision-making.

The technology often combines with machine learning and generative artificial intelligence, leveraging computer science and data for a range of multi-dimensional data driven applications.

3.5.1. Key benefits and applications

Advanced data analytics are a well developed technology with strong existing industry understanding and application. However, there are significant near-term benefits which can be realised through more effective utilisation of this technology. In addition, it will be a critical technology to realise the productivity benefits on offer through the increased digitisation of Victoria's infrastructure, and gains will grow over time.

Advanced data analytics was ranked highly by all stakeholders for both certainty and impact and performs strongly across all assessment criteria.

Ways in which advanced data analytics can be applied with existing and future advancements of the technology include:

- Building information modelling (BIM) to inform project planning, design and delivery.
- Building management systems (BMS, an evolution of BIM) which provides real-time data on the state of the modelled asset to inform operation.
- Digital twins which provides a digital replica of an asset or network to monitor and operate or simulate and test scenarios and options.
- Digital consenting to evaluate complex decisions in planning, construction and health.
- Data hubs for efficiently and securely storing, managing and transferring large volumes of data.

The effective modelling and use of more complex sources of data enabled by advanced data analytics can deliver a wide range of benefits for infrastructure.

This includes:

- Enhancing planning, design and construction decision-making to reduce materials and labour costs and reduce delivery time.
- Increasing the design quality of assets and their performance.
- Optimising operations and maintenance and increasing asset life.

Studies have shown applying advanced data analytics in these various ways can:

- Increase labour productivity by 75% - 250% for modelled areas of specialty contracting.[1]
- Reduce unbudgeted construction changes associated with conflict detection by 40%.[2]
- Reduce equipment downtime by 20 – 50% through improved management.[3]
- Reduce maintenance by 25% due to predictive maintenance abilities.[4]
- Reduced energy consumption by 30% through lighting optimisation and heating, ventilation and air conditioning.[4]

The increased efficiency and effectiveness that the technology allows data to be used will help to meet the growing demand for infrastructure more efficiently. This will be achieved by reducing costs, allowing for more targeted asset delivery, and increasing the utilisation and life of assets.

Advanced data analytics has cross-cutting potential to enhance the impact of a range of other technologies. This includes technologies that generate or use complex data requiring processing, such as geospatial technologies, positioning, robotics, and advanced sensor technologies.

In addition, early development and use of advanced data analytics technologies, such as BIM, will be critical inputs and 'stepping-stones' for the development of future iterations including advanced BMS and digital twins.

1. Poirier E., Staub-French S., Forgues D., 2015
2. BRANZ
3. Anadea, 2023
4. InfoTech

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3. Short-list of technologies

Advanced data analytics

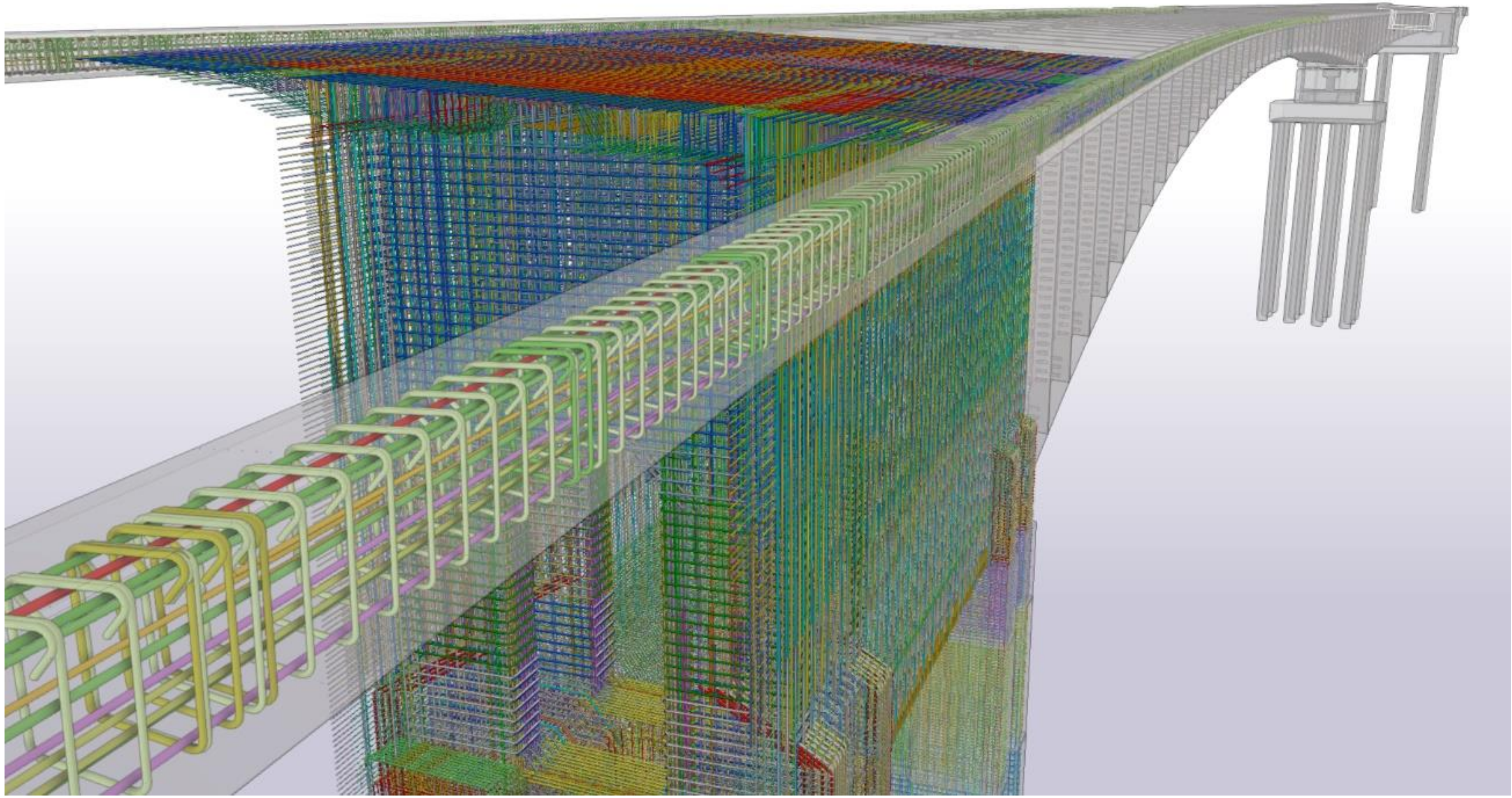

Figure 10: Randselva bridge in Norway used advanced data analytics to design and construct the bridge entirely without drawings (Sweco, 2021)

SUCCESS STORY

Drawingless design and construction of bridges using building information modelling, Norway

Building information modelling (BIM) uses parametric design rules to create 3D digital models that layer in more information than is possible through the standard 2D drafting process. While Australia is yet to adopted it fully, Norway is at the forefront of a model-based approach. The Randselva Bridge is the world's longest bridge designed and built without drawings, and highlights the vast potential BIM offers to integrate information and streamline construction workflows.

The detailed design of all foundations, four pier piles, and one abutment were all undertaken through a single BIM model, which represents more than 60% of the structure and contains over 200,000 rebars and 250 post-tensioning cables. This allows reinforcements and adjustments to be carried out directly through the model, eliminating the need for manual drafting and allowing more efficient constructability testing. 95% of files on the project were shared through the cloud-based BIM model, allowing five teams across five countries to collaborate easily and effectively.

Key impacts

- Efficient file sharing and workflow makes remote and cross discipline collaboration easier.
- Data and geometries are produced once and shared.
- Reduced time and errors in design, as BIM allows greater quality assurance and expedited revisions.

3. Short-list of technologies

Advanced data analytics

3.5.2. Economic analysis and results

Full utilisation of ***building information modelling (BIM)*** *to deliver drawingless construction of* ***public housing.***

The economic analysis quantifies how BIM could be used to deliver drawingless construction of public housing, and in particular how this can reduce project cost overruns and associated risk.

BIM in architecture, engineering and construction projects generates and manages data relating to physical and functional characteristics of a structure. This enables rapid design iterations, scenario testing, integrated decision-making and real-time assessment of assets for construction, management, and environmental solutions.

BIM technologies are proven to deliver major savings through reduced delivery time, cost and material savings, and improved asset quality.

Despite its widespread availability, BIM is not utilised to its full potential. For example, where BIM models are procured and built but not used or used only for visualisation purposes, or where models are duplicated by manual drawings.

BIM demonstrates a near-term, highly actionable opportunity with minimal barriers which would deliver immediate and growing benefits and costs avoided.

Key measured impacts of the technology are described below, with the quantified economic impacts shown in Table 6.

- The average cost of developing a single dwelling is estimated at $408,717 by CIE (2022-23 dollars).[1] The Victorian Government has committed to upgrading at least 2,000 public housing homes per year to respond to demand.[2] Considering escalation, this equates to **an estimated capital spend of $1.0 billion each year on public housing.**
- It is estimated that full adoption of **BIM can save 6.92% of project costs on residential housing**.[3] These savings are considered a reduction on cost overruns for this analysis and amounts to **$76.5 million saved per annum** including contingency.
- Beyond the use case, CIE estimated **annual investment in road infrastructure of $5.2 billion** is required each year until 2056.[4]
- Specific experience on roads projects from Norway has found that adoption of drawingless construction of roads **can reduce average cost overruns from 19% (drawing-only), to 9% (drawings + BIM) or 5% (drawingless).**

In addition to this specific use case, the analysis considered broader opportunities to scale the application of BIM across the private sector.

- Across the broader residential sector. Victoria will need to deliver 1.8 million new homes from 2021 to 2056, or approximately 51,000 each year. Adopting drawingless construction could have a significant productivity impact for the residential construction sector, **reducing the delivery costs of homes by $1.8 billion each year.**
- In addition, cost savings delivered through drawingless construction can be realised (to different degrees) across all major infrastructure works. There is a broader opportunity for Government to drive significant productivity improvements across the construction sector by fully embracing BIM and drawingless construction.

Scale of application	Benefit	Estimated impact ($2024)	
		Per annum	By 2055
Applied to public housing construction	Reduced cost overruns	$71.5 million	$1,786.6 million
	Reduced project risk	$5.0 million	$125.1 million
	Total benefits	**$76.5 million**	**$1,911.7 million**
Scaled to all residential development	**Total benefits**	**$1,837.7 million**	**$45,941.2 million**
Applied to road construction	Reduced cost overruns	$501.8 million	$12,544.0 million
	Reduced project risk	$35.1 million	$878.1 million
	Total benefits	**$536.9 million**	**$13,422.1 million**

Table 6: Summary of quantified benefits of BIM ($2024, undiscounted)

Key assumptions informing the analysis include:

- The cost of a public housing dwelling is assumed to cost the same as other residential dwellings.
- There is no production of hard copy drawings during the construction process to realise these savings.
- All relevant construction and building regulations enable the goals for drawingless construction.
- Drawingless construction is adopted for new capital projects. Cost savings are realised on average across the whole package of works.
- It is estimated that Victoria currently only partially adopts BIM, and the average cost overrun is estimated as the mid-point between drawing-only and drawing + BIM (equating to an average overrun of 14%).

1. Thorsen, T, 2022
2. Average cost of all dwelling types, The CIE, 2023
3. Lu, W., et al., 2014
4. Scenario 1 of The CIE, 2023

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3. Short-list of technologies

Advanced data analytics

3.5.3. Current state of adoption and key barriers

The exploration of the literature and the use case show there is widespread adoption of the early stages of advanced data analytics across a range of sectors in Victoria. Digital consenting in planning approvals has been tested in Victoria on the small lot housing code saving an estimated four weeks in approval times. Victoria is one of several states developing a digital twin platform and one of two which has a Digital Twin Strategy and BIM is used in various forms across design and construction.

However, many of these applications lag international standards. Despite being widely available for some time, the Australian construction industry continues to miss out on the productivity benefits of adopting BIM which lags international rates, estimated at $7.6 billion in savings lost over a decade.[1]

Digital consenting remains in pilot stage and only for standardised assessments but has broader demonstrated potential in more complex planning evaluations and other sectors such as health which has not been realised.

The current Victorian digital twin primarily provides a data visualisation function, does not yet have scenario modelling and operational monitoring and management capabilities and eventually should be fully integrated across the various infrastructure operators and owners.

Key risks and barriers to broad adoption and impact include:

- A key barrier to adoption has been the high cost, data requirements and labour intensity required to implement and maintain advanced data analytics and models, leading to a hesitancy to commit to these technologies.
- The cost of BIM hosting is generally charged based the number of users and the level of functionality (including the ability to view vs ability to edit and download or the level of security). Autodesk Construction Cloud is one of the more high-end products. Autodesk Collaborate its $1,040 per end users.[2] While this is relatively affordable, effectively using it requires specialists and full time staff or teams dedicated to maintaining the model and processing data.
- As part of this partial adoption, the necessary reskilling of workers and development of specialists required to build, operate and use these analytical tools has also lagged.
- Stakeholders advised that current adoption and capabilities were limited to large organisations, and needed to expand beyond this to fully realise benefits and ensure smaller firms and engineers are not left behind.
- Uptake has also been hindered in consistency in data frameworks and interfaces to support interoperability between organisations and across the lifecycle of projects. This also inhibits broad adoption across industry.
- High water and energy use is associated data warehousing and processing.
- The technology faces a range of similar risks to many data-based technologies, relating to safe and ethical data collection, and storage and management of data. Increased digitisation of and operational activities also presents cyber infrastructure security risks. Each of these risks carries corresponding social, legal and financial implications.

Key enabling actions

Given the existing availability of the technology, uptake should primarily be enabled through the promotion of benefits, skilling of workforce, and reduction of cost associated with implementation.

- Skills and training should focus both on broadening expertise beyond a few key players, but also on deepening industry understanding and developing specialists who can deliver advanced data analytics to their full potential.
- International examples have also demonstrated improved uptake and reduced costs by mandating advanced data analytics in procurement processes. While this exists to an extent in Victoria, both a digital and paper copy of drawings are required, so there is limited incentive to fully utilise the digital environment.
- Scaling advanced data analytics over the longer term will also depend on the interoperability of platforms and readiness of data as it becomes available. Regulatory, legal and data protocols and frameworks must be developed to guide consistency across the industry to fully realise the scale of a digitised infrastructure sector.
- The development of other technologies will also enhance the benefits from the computing power afforded by advanced data analytics. This is especially true of those technologies that generate, transmit, analyse and store data - radiofrequency technology; positioning; protective cyber security; sensors; and edge and high-power computing.

1. JWPM Consulting, 2017
2. Autodesk, 2024

3. Short-list of technologies

Geospatial technologies

3.6. Geospatial technologies

Geospatial information and technology is a combination of **positioning**, **satellite imagery** and **locational data** used to map and integrate geospatial and non-geospatial data into analytical tools.

Rapid advancements and access to **earth observation** technology and availability of sovereign **satellite infrastructure**, integrated with **advanced data analytics,** are increasing the precision, timeliness and processing power of geospatial technologies.

These will deliver step changes in the power of geospatial analysis and decision-making, such as in monitoring and forecasting harmful events, understanding exposure to natural hazards, and managing traffic and logistics flows and routes.

3.6.1. Key benefits and potential applications

Geospatial information provides a foundation for most infrastructure projects as every project is spatially located. There are large time and cost savings associated with increasing the specificity, availability and integration of knowing this locational data.

Geospatial technologies were ranked highly by all stakeholders for both certainty and impact and performs strongly across all assessment criteria.

Geospatial technologies are rapidly developing in the field of earth observation. This group includes geospatial information systems (GIS), positioning technology and satellite imagery will evolve to incorporate 3D (GeoBIM), 4D and GeoAI. Each of these components allows for faster and more accessible spatial analysis. They also make better use of geostationary satellites and ground stations to enhance global navigation satellite systems.

Ways in which these technologies can be applied with existing and future advancements include:

- Land use management and development optimisation.
- Resource management in urban and regional contexts.
- Natural hazard prediction, management and response.
- Construction site monitoring and safety through the use of digital shields.
- Transport infrastructure management and operation including for logistics, traffic optimisation and route optimisation.

Applying the technology in these ways can be used to reduce project costs through precision design, planning and construction, risk management and mitigation, resource use optimisation, and operational management and optimisation.

As the quality and volume of geospatial data increases and the processing tools associated with it develop the uses of geospatial technologies and benefits will expand.

Continuing the development of geospatial technologies and information will be critical to managing Victoria's vulnerability to climate hazards and protecting infrastructure and communities, in addition to optimising the delivery and operation of infrastructure and scarce resources. This capability particularly benefits sectors with critical, always-on infrastructure, such as energy, water and transportation.

Geospatial technologies will be a critical technology to develop to fully realise the benefits of emerging spatial data sources. Technologies that geospatial technologies will leverage include advanced data analytics, voice to speech recognition, positioning; all autonomous technologies, radiofrequency technology, positioning, image processing, digital fabrication, robotics, sensor, and machine learning and artificial intelligence.

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3. Short-list of technologies

Geospatial technologies

Figure 11: Earth observation used to monitor land rehabilitation and manage environmental risk (Ozius Spatial, 2016)

SUCCESS STORY

Supernova observation technology is adapted into a system for rapid fire detection

Fireball, an Australian Space intelligence company based in Queensland, has reoriented technology developed to look at supernova explosions to focus on early smoke signals. This artificial intelligence-powered geospatial intelligence platform identifies and maps wildfires with unmatched speed and accuracy, facilitating an emergency response when they are still small and easy to extinguish. It fuses real-time satellite imagery with camera sensors on the ground for near immediate threat identification, as pixels showing heat are used to confirm instances of smoke detected.

The Fireball system was deployed to monitor approximately 50 million hectares across the state of California and detected over 850 fires in the 2020 season. It was able to detect 65% of these in less than a minute and 95% within 10 minutes, enabling responders to limit danger and damages caused by controlling fires more quickly. This represents vast improvements compared to traditional fire detection systems, which can take over 30 minutes to report a threat, with every 10-minute delay estimated to put an additional 1,500m^2 of land at risk of burning.

Key impacts

- Dramatic increase in the speed of fire detection and associated improvements in emergency response times.
- Potential for application at scale to limit the threat and impact of fires on critical infrastructure.

3. Short-list of technologies

Geospatial technologies

3.6.2. Economic analysis and results

*Artificial intelligence (AI) and earth observation for enhanced **geospatial hazard management** of bushfires and floods.*

The economic analysis quantifies how AI enabled predictive analytics and Earth Observation can be integrated into geospatial technologies to enhance the detection of flood and fire risk and optimise responses. Specifically, it measures:

1. How the use of Earth Observation could help emergency services respond to bushfires faster (through earlier detection), reducing the likelihood of economic losses.
2. How proactive hazard management following flooding could reduce the damage to roads.

Applying this technology for natural hazard management can reduce the cost of damaged infrastructure and associated downtime costs through more precise and real-time tracking of natural disasters. Additional data can be overlaid to analyse and inform risk responses, such as modelling population and traffic locations and flows, critical infrastructure risk factors, or behaviour and intervention impacts. Predictive capabilities can also be used to anticipate risk and inform more adaptable and resilient infrastructure planning.

Environmental management of infrastructures networks and productivity challenge as the severity and frequency of climate events increases. Technologies that respond to this will have significant direct benefits as well as large benefits for community resilience.

Key measured impacts of the technology are described below, with the quantified economic impacts shown in Table 7.

- Geospatial technologies can support the detection of natural disaster within 9 minutes of ignition[1].
- Early detection reduces the likelihood (and likely damage) of fires, which has a direct economic benefit. Improved detection is expected to reduce the direct economic impact to the (non-insured) built environment of severe bushfires by 4.92% each year.[2]
- In addition, using geospatial technologies to manage hazards can also reduce the damage caused by floods to roads by 23%.[3]
- The quantified benefits only considers the tangible impacts of bushfire – which account for 35% of the total impact.[4] However, these applications of the technology can also mitigate impacts relating to insured losses and intangible losses (like human lives lost or travel delays from infrastructure downtime) which will have significant impacts on the Victorian economy.

The quantified benefits reflect two specific applications of the technology; however, there are broader opportunities that can be realised in future disaster management strategies.[5] These could include:

- Improving response times to other extreme weather and flooding.
- Increasing preparedness for extreme weather for vulnerable areas (for example, through proactive controlled burning).
- Increasing response rates to emergencies by enabling response vehicles to reroute and be prioritised through signalised transport systems.
- Facilitating recovery processes by locating citizens and prioritising areas most affected by damage.

Key assumptions informing the analysis include:

- The cost of bushfires has been estimated using an annual cost of $390 million (2017 dollars), escalated by 3.6% annually.[6] This reflects the growing severity of these disaster as the climate changes.
- Annual damage to road infrastructure after flooding is estimated using a total cost of $165 million[7] and an average exceedance probability of flooding of 20%.[3]
- The overall impact of floods is considered conservative and is based on announce flood response costs from 2022. As the severity and frequency of flooding increases with climate change, the impact on roads is also expected to increase.
- We have represented the cost of bushfires and flooding as an annual cost, but natural disasters are characterised by larger, but less frequent, impacts.

Scale of application	Benefit	Estimated impact ($2024)	
		Per annum	By 2055
Applied to natural disaster management	Reduced likelihood of bushfire	$37.6 million	$939.1 million
	Avoided cost of repairs after flood damage	$8.4 million	$209.1 million
	Total benefits	**$45.9 million**	**$1,148.2 million**
Scaled to direct, indirect and intangible natural disaster costs	**Total benefits**	**$106.0 million**	**$3,238.5 million**

Table 7: Summary of quantified benefits of geospatial hazard management for fire and flood ($2024, undiscounted)

1. Muon Space, 2024. Detection times are expected to be between 9 minutes (for bushfire-prone areas) and 20 minutes (globally). An average of 12 minutes is used for this analysis
2. Australian National University Centre for Social Research Methods, 2020
3. Arup, 2023
4. Deloitte Access Economics, 2017
5. Geospatial Council of Australia, 2024b
6. Deloitte Access Economics, 2017
7. Australian Broadcasting Corporation, 2022

3. Short-list of technologies

Geospatial technologies

3.6.3. Current state of adoption and key barriers

The exploration of the literature and the use case show there is broad and sophisticated usage of geospatial technologies across Victoria. However, significant advances will likely deliver a step-change in capability of these tools and where and how they are used, requiring upskilling and preparation to ensure the benefits are fully realised.

Victoria, along with several other states, has a geospatial strategy and framework in place. Geospatial data is used for a range of applications in Victoria, and which is widely available, for example Vicmap contains a wide number of spatial datasets, and spatial technologies such as LiDAR are being applied for a variety of uses across Victoria such as capturing elevation data of Victoria's alpine regions.

While this provides a strong foundation, geospatial information and technologies are developing rapidly and there is a risk that the opportunities associated with this are missed if the supporting structures and industry are not ready.

Key risks and barriers to broad adoption and impact include:

- While there are high initial development costs associated with this technology, such as the launch of satellites, once established the data generated can be quickly and cheaply used. For example, The Australian National University Institute of Space and its partners received $1.3 million in 2023 to contribute to the development of OzFuel, a space-based sensor platform that will assist in bushfire prevention, detection, mitigation and resilience.[1] However the ongoing cost will be primarily associated with the availability of a sufficiently skilled workforce. This is largely already available but requires continual training to keep up with recently available developments.
- A key risk is the readiness of a skilled workforce to utilise these emerging capabilities. A Curtin University study noted that while GIS was recognised as a legitimate field of specialism the industry lacked standards of qualifications and that current accreditations may not be appropriate for the quality of work expected of GIS professionals.[2]
- Similar to other rapidly evolving frameworks, there is an immediate need to develop sufficient governance frameworks and training and skills accreditations to support and facilitate opportunities as they emerge.
- Full utilisation of these technologies is dependent on the wide availability and interoperability of geospatial data including satellite images and sensor data for input into technologies.
- Facilitating this requires appropriate guardrails to manage security and privacy concerns relating to data and governance frameworks and standards to coordinate data complexity and interpretation across organisations and platforms.
- In addition, geospatial technologies will benefit from the development of enabling technologies including Artificial intelligence; radiofrequency technology; positioning, protective cyber security; sensors and edge computing; and integration with advanced data analytics, high performance computing, and advanced imaging. These technologies will underpin the effective and secure operation of the technology as well as provide increasingly high quality and volume data for these technologies to leverage.

Key enabling actions

Technology development is underway and will be facilitated through the rapid advancement of Earth Observation technologies and new available and access to sovereign satellite capabilities. As such enablers are largely non-technical:

- Governance frameworks and industry standards and protocols are needed to ensure data and technology can be scaled across the industry and readily accessible.
- Upskilling of specialists is needed to ensure it keeps pace with emerging technologies and integration of other technologies.
- Development of supporting technologies that communicate analysis outputs to the people who need it in a form that they understand – such as routing information for emergency services and SMS communication for communities.

1. ACT Government, 2023
2. Standards Australia, 2023

4. Conclusions and next steps

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4. Conclusions and next steps

4.1.1. Key economic conclusions

The economic analysis, summarised in Table 9, establishes a baseline for quantitatively comparing and discussing technologies which have high potential to drive productivity gains in Victorian infrastructure and be broadly adopted by 2030.

A summary of the findings of the quantitative analysis of the five short-listed technologies and their assessed used cases demonstrates:

- Robotics have the greatest near-term and long-term impact, but equally incur the highest estimated upfront investment to develop and deploy at scale.
- Geospatial technologies represents the most attainable near-term opportunity in terms of level of technology development and estimated scale of investment required to adopt, but also offers lower measured benefits.
- Majority of technologies have significant potential to scale beyond the use case application – for example the use of machine learning and artificial intelligence for schools construction. Within the analysis this is a relatively confined use case, but in reality, this application could expand across the entire infrastructure portfolio estimated to deliver $9.3 billion of economic impact by 2055.
- This is also true of the scaling potential of technologies beyond the public sector. For example, while building information modelling was applied specifically to Victorian public housing construction, benefits to the broader residential development sector could amount to $45.9 billion by 2055.
- The technologies that have been assessed as having the greatest productivity potential directly address two of the key productivity challenges facing Victorian infrastructure identified at the beginning of this study – the growing cost of infrastructure in a financially constrained environment; and the intertwined impacts of climate hazards and productivity. The highest performing technologies were those that addressed these through:
  - Increased effectiveness of planning, design and delivery of infrastructure to reduce costs.
  - Higher quality assets with enhanced operation and more effective quality, increasing their productive use and extending asset lives.
  - Better managing natural and critical resources, and increasing prediction, response and resilience to increase natural disasters.

Overall, the analysis highlights the significant potential that technology can bring to the Victorian infrastructure landscape, in direct productivity impact and in addressing some of our most pressing economic, environmental and social challenges.

Short-listed Technologies	Use Cases	Estimated impact ($2024)		Relative cost and key investment
		Per annum	By 2055	
1. Machine learning (ML) and artificial intelligence (AI)	1. AI/ML/deep learning to support school and kindergarten construction	$20.6 million	$516.1 million	*Moderate* – primarily for incremental development, software licensing and workforce upskilling
2. Robotics	2. Robotics for inspections and maintenance in the water sector	$140.2 million	$3.5 billion	*High* – large investments in development, capital, specialist workforce development
3. Advanced Imaging	3. Ground penetrating radar and advanced image processing to reduce utility strikes	$44.4 million	$1.1 billion	*Moderate* – primarily for incremental development, capital and specialist workforce development.
4. Advanced data analytics	4. Building information modelling facilitating drawingless construction of public housing	$76.5 million	$1.9 billion	*Low* – primarily relating to workforce upskilling and training
5. Geospatial technologies	5. AI-enhanced geospatial hazard management for bushfires and floods	$45.9 million	$1.1 billion	*Low* – primarily relating to workforce upskilling and training

Table 8: Summary of key economic findings ($2024, undiscounted)

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4. Conclusions and next steps

4.1.2. Common enablers of adoption

The analysis of the prioritised five technologies, their current state of adoption and key barriers revealed many of the technologies as having shared challenges and which can be addressed by a suite of common enabling actions. Key enabling actions include:

- **Industry readiness** – the application of technologies are inhibited by a lack of industry awareness and insufficient access to specialised equipment. Industry development is needed to promote a better understanding of the benefits and how they can be procured.
- **Skills and workforce transformation –** technologies require specialist expertise but also have the potential to displace current workforces. Strategies are needed to understand the workforce implications of the technologies, including how an existing workforce might be impacted and can be supported or will work with new technologies, and what new skills and accreditations are required to operate and maintain the technology.
- **Informed procurement** – high costs and first-mover risks is preventing adoption of existing technologies, in lieu of business-as-usual. Leveraging government's purchasing power with a consistent approach driven by experienced practitioners will help to reduce risk, and drive consistency in outputs.
- **Technology development** – there are large interdependencies between technologies in order for their benefits to be fully realised. These include technologies that provide data inputs, as well as analytical and computing power to assess impacts and those that support visualisation and interpretation of outputs. In this way, failure to effectively prepare for the adoption of one technology can result in lost gains associated with other interdependent technologies.
- **Governance and regulation frameworks** - Similarly supportive environments for technology development and commercialisation must be in place to facilitate the evolution and adoption of technologies. This includes providing controlled environments and opportunities for testing and developing early-stage technologies, but also governance frameworks which coordinate privacy, legal and data and technology standards for the scaling, sharing and interoperation of technologies.

These enabling actions, revised to reflect the maturity of each technology and their particular needs, provide the foundations for planning for their successful uptake and impact.

4.1.3. Other findings

In addition, the long-list of technology opportunities in the Victorian context revealed a number of common themes which should inform future thinking for how we capture these:

- A key project parameter was that technologies need to be deployed by 2030. However, the broader list of technologies, in particular the 'future' technologies should not be discounted in their importance. In particular, climate and energy transition technologies will be critical to addressing what is likely to be the largest driver of cost and change over the coming decades.
- Most of the prioritised technologies relate to those which are platforms or tools for the use of the increasing complexity, volume and diversity of data that will become available and as our built environment becomes increasingly digitised. Ensuring technologies which enable the effective use of this data will be critical to realising these benefits and which will grow over time.
- Some of the high priority technologies identified are anticipated to develop rapidly. Common barriers will take time to address and so must be actioned soon to ensure Australia's infrastructure and technology landscapes are ready to fully benefit from technology developments.
- Maintaining cyber security and secure use of systems and data will also be important as infrastructure becomes more digitalised.

While the findings of this study relate to applications of technology to Victorian infrastructure, the scaled benefits demonstrate a major opportunity to drive impact across all aspects of the economy.

The tasks and challenges faced by the Victorian infrastructure sector are shared with the broader private sector. Leadership and innovation by government can provide the catalyst to broad industry adoption that would be a material boost to economic productivity. Beyond this, technological adoption and transformation across both private and public sectors is necessary if we are to meet some of our greatest social, environmental and economic challenges.

Appendices

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Appendix A – Methodology
Step 1 – Technology Scan

Technology taxonomy

A **'technology taxonomy'** was developed at the beginning of the study to frame the technology horizon scan and categorise the potential technologies that were investigated.

The taxonomy provided a framework for consistently organising and describing the technology. The taxonomy was adapted for this project from the Australian Government's approach outlined in the *List of Critical Technologies in the National Interest* (2023), which categorises and describes technology fields crucial to Australia's economic prosperity, national security, and social cohesion.

The taxonomy grouped technologies into 'families' with shared characteristics, and then explored three levels of definition further detail. This allowed technologies to be consistently defined in comparable terms and was used to ensure all fields of emerging technology were considered by the study.

Building and refining the long-list

Once the taxonomy was developed, the team undertook a horizon scan of literature and research to identify potential technologies. **Horizon scanning** is a research and foresight tool that identifies emerging global and local forces of change and assess their potential impact.

Primary and secondary sources reviewed included:

- Peer reviewed journal papers from Australia and abroad, and a scan of established Australian university research groups testing technologies at scale such as Australian Research Council and Cooperative Research Centre projects.
- Grey literature from Australian governments, agencies and advisory bodies including Infrastructure Victoria reports, government reports from Victoria, New South Wales and South Australia, and Commonwealth policies and white papers focusing on infrastructure and productivity.
- Grey literature from abroad, with a specific focus on technology strategies.
- Existing Arup horizon scanning materials, research and industry-specific thought leadership.
- Discussions with local and global subject matter experts.

Technologies were then allocated across each level of the technology taxonomy, considering existing and potential applications to infrastructure, key benefits and risks, the commercial and technological readiness of the technology, and interdependencies with other technology types. This resulted in a long-list of 25 potential technology applications.

Challenge Workshop

A **'Challenge' workshop** was held to interrogate the list of technologies and further 'sift' the long-list for high potential applications. The workshop brought together a group of specialists across infrastructure, technology and economics who were asked to assess the productivity impact and likelihood of adoption of each technology and discuss challenges, trade-offs and opportunities. The workshop was supplemented with further conversations with specialists and research to confirm key assumptions.

The technology long-list was refined based on the outputs of the workshop. Key findings and changes included:

- Several technologies were added, subtracted or refined on the list following feedback.
- Several technologies were combined on the basis that their impact would likely be realised and more impactful in consolidation – for example machine learning, deep learning and natural language processing were combined.
- Technologies were organised according to specialist assessment of impact and uncertainty. Specifically, they were organised as enabling (being necessary to enabling the productivity impacts of other technologies); future (being high impact but with insufficient technological or commercial readiness); and those that were deemed near-future (to have high potential and likelihood of adoption by 2030).

Detail of workshop attendees and key findings are provided in **Appendix C.**

Following this sifting process, a final list of high potential, near-future technologies (12) were taken forward to the next stage, a multi-criteria analysis (described on the following page).

Taxonomy	Definition and how the taxonomy level is applied in this study
Level 1 – Technology field	Describes the five key groupings of technologies at the highest level: • Advanced information and communication. • Advanced manufacturing and materials. • Artificial intelligence and machine learning. • Autonomous systems and robotics. • Climate and energy transition.
Level 2 – Technology cluster	Describes specific technology subcategories at a high level of specificity to inform practical next steps for further investigation. At the same time, these are broad enough to understand material productivity impacts across the Victorian infrastructure landscape. Level 2 technologies were defined as the appropriate level of detail for long-listing and short-listing technologies.
Level 3 - Technology application	This is the next level of application specificity and describes the next level of technology specificity in terms applications of that technology and used in a particular sector and task. Level 3 was defined as the necessary level of detail to undertake economic analysis, providing real life applications from which to derive assumption, enhancing the precision of the analysis.

Technology taxonomy level definitions and application in this study

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Appendix A – Methodology
Step 2 – Assess and prioritise

Short-listing

A **Multi-Criteria Assessment (MCA)** framework developed to further filter the 12 high potential **Level 2** technologies and identify the five highest performing.

MCA analysis provided a systematic way to compare the *relative* merits of technologies against agreed objectives and criteria. The MCA was designed and applied in line with the Infrastructure Australia *Guide to MCA,* allowing the technologies to be qualitatively assessed in structured and objective way.

The MCA framework is shown here and was designed to include two stages:

- Stage 1 – strategic assessment of **Level 2** technologies to filter from 12 to the 5 highest potential technologies.
- Stage 2 – translate the 5 high potential technologies into implementable 'use cases' to demonstrate how the technology could be applied in Victorian infrastructure.

Stage 1 - Objectives 1 and 2 of the MCA framework were derived from Infrastructure Victoria's objectives for the updated 30-Year infrastructure strategy and the project objectives. These objectives were applied first and used to assess the 12 near-future **Level 2** technologies.

These objectives relate to economic productivity and risk and so criteria for these were drawn from the key benefits identified for measurement within the economic methodology, aligning the MCA with the later economic analysis. These criteria were weighted to reflect the relative priorities of each.

The application of the **Level 2** component of the MCA identified 5 prioritised technologies.

Defining use cases

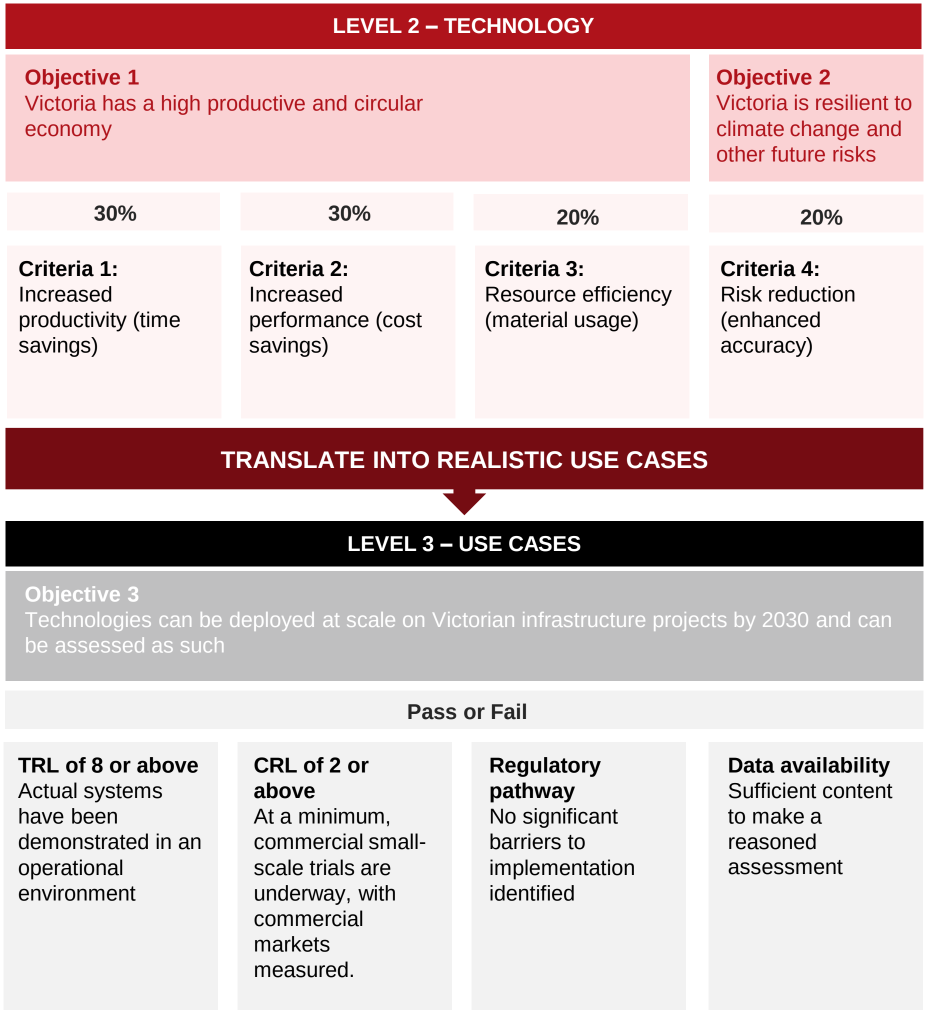
Stage 2 - Having identified the 5 highest potential **Level 2** technologies, the team undertook additional research at the **Level 3** level (technological application) to identify potential use cases that could tangibly demonstrate the productivity impacts.

These were defined as specific applications of the short-listed technology, infrastructure industries to apply them too, and tasks that would be affected.

Objective 3 of the MCA was developed to test deployment readiness. These included:

- Minimum thresholds for commercial readiness and technology readiness levels assessed at the use case level.
- The absence of significant and insurmountable regulatory barriers.
- Sufficient data availability to enable robust analysis.
- Potential to deliver high, measurable economic benefits and which responded to strategic productivity challenges or needs.
- Demonstrated a diversity of industries and problems which could benefit from application of technologies.

The final use cases provided a representative and strategic application of the technologies which would demonstrate the potential productivity impact to be achieved and had sufficient available data to provide a robust measurement of this.



MCA Framework

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Appendix A – Methodology

Step 3 – Quantify and evaluate

The 5 short-listed use cases were then brought forward for more detailed economic analysis, to allow benefits to be quantified and evaluated. It did not aim to give a detailed economic analysis of costs and benefits.

The economic evaluation includes 4 steps, each discussed in detail below.

Benefits framework and benchmarking

A framework of potential benefits was developed to allow consistent and comparable analysis across the use cases.

This benefits framework (including how they are quantified and monetised) is shown in the table on the following page.

The framework was derived from the *BIM Level 2 benefits measurement methodology paper* published in 2018 and which was prepared to align with the UK Green Book (2022) methodology for cost-benefit analysis.

The adapted framework identifies benefits that can be consistently measured across the use cases and be the primary basis for measuring impact and comparing across technologies. These benefits were identified by researching live examples (reference cases) of the use cases currently being deployed. These reference cases were also used to derive benchmark variables for the benefits that could be adapted for the use case analysis.

Other potential benefits specific to each use case were also identified and quantified where they exist and are included for completeness. However, these were excluded from the core productivity analysis as they were not consistent across all use cases or subject to data limitations.

The benefits framework forms the basis for the economic analysis and provided an approach so that each use case could be compared consistently.

Impact quantification and monetisation

Each benefit was benchmarked for the use case was then quantified to match the scale of application defined in the use case and monetised to determine the financial value of the impact.

The table on the page over shows how each benefit was quantified and monetised (however the exact methodology for each varies according to the specifics of the use case).

Where possible, assumptions were derived from Australian and Victorian cost-benefit standards and practice. Detailed assumptions for each use case analysis is provide **Appendix B**.

Scale impacts by sector

The analysis scaled the measured impacts from the above step to the size of the Victorian infrastructure sector. This provided an economic measurement that reflected the potential total impact of a use case if it were fully adopted across the defined infrastructure sector – a measurement represent the total potential impact of a use case.

By developing impacts derived from reference cases and scaling the measured impacts across sectors this method enables real-world scenarios and industry-specific nuances to be considered while providing an insight into the potential total scale and impact offered by these technologies.

Key benefits are presented as the per annum economic impact, in present value terms (that is, undiscounted) of the cumulative economic impact to 2055 – reflecting the time-frame of the updated 30-year infrastructure strategy.

Measuring cost

To support the interpretation of results, a high level cost assessment was undertaken to provide a reference point for potential extent of costs that might be required to adopt and scale each of the short-listed technologies.

This assessment is not an estimate of actual costs.

For each technology, a series of criteria were identified that described the scale of costs that could be incurred. These included:

- The existing level of adoption.
- The requirements for new plant of equipment.
- The magnitude-of-order scale of new plant or equipment.
- Whether costs were expected to be recurring.
- The level of workforce training anticipated.

Based on the assessment of each of these criteria a score out of 5 was determined which described the relative extent of costs which may be incurred by each technology.

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Appendix A – Methodology

Step 2 – Quantify and evaluate

Economic benefits framework

	No.	Benefit category	Nature of benefit	Quantifying the impacts	Monetising the impacts	Data required
Key benefits	1	**Time savings**	Use of a digital technology has the potential to result in time savings throughout the lifecycle of a project, in both asset delivery and service delivery. E.g.: reduction in site visit costs due to virtual review.	Reduction in labour cost	Application of labour cost to determine total benefit. *Value of time savings ($) = estimated reduction in labour hours x average daily wage ($)*	Time savings from the digital technology reference cases for reduction in labour. Daily wages and overheads for industry application.
				Reduction in time-related costs	Value of broader time savings. *Value of time savings ($) = estimated reduction in activity hours x activity cost ($)*	Specific data about the cost of an activity will vary based on the technology application.
	2	**Material savings**	Use of a digital technology has the potential to result in material savings in every stage of the lifecycle (build, construct, operation etc) measured by the reduction in volume of materials required. This has both cost and environmental benefit.	Reduction in amount/volume of materials	Value of material savings. *Sum of estimated reduction in waste materials x cost of materials ($/material)*	Reference case where the technology selected has resulted in materials savings in build stage. Cost of material for project type (e.g.: concrete blocks).
				Environmental benefit	Using embodied carbon values as a proxy for total environmental impact.	Volume and type of material. Embodied carbon of that material.
	3	**Cost savings**	Potential of a digital technology to reduce cost savings across the asset lifecycle from improvements in detection of faults, facilities management, maintenance, and fewer changes.	A change in the number of instances of a particular event	Apply the average cost of an instance to the number of instances for cost savings. *Reduction in number of instances of an event (#) x change in average cost (time and materials) of an instance ($)*	This may be cost savings in labour, material, or time savings due to optimisation of a process. Can be cost savings from fewer changes, better clash detection, asset maintenance, refurbishment, asset disposal.
Additional benefits	4	**Health and Safety improvement**	Use of a digital technology can significantly enhance safety and reduce fatalities across the entire lifecycle of an asset. From improved staff training and briefing to simulation activities, technology plays a crucial role in safeguarding workers during construction and demolition processes.	A change in the number of fatal and non-fatal injuries, illness attributable to the technology implementation	Apply the cost to society per accident or incident of work-related illness. *Reduction in # of accidents due to the chosen technology's application x Cost to society per accident ($)*	Reference cases of two similar projects to analyse number of accidents on sites (e.g.: project A without the use of technology and project B with the use of technology). The number of fatal and non-fatal accidents per project.
	5	**Reduced project risk**	Digital technologies have the potential to enhance the accuracy of project or asset information, providing better visibility into associated costs, delivery timelines, and risks. By improving certainty and reducing risks, these technologies can mitigate the variability of costs, ultimately enabling a reduction in the contingency needed to guard against cost overruns in both capital and operating expenditures.	Reduction in the amount of contingency	Apply the opportunity cost (the discount rate of time preference in the case of government construction clients) to the change in the value of the contingency. *Reduction in contingency held per annum ($) x social discount rate (% per annum currently)*	Project contingency detail for the relevant stage (capital/operating) for two similar projects with and without the chosen technology. A social discount rate of 7% will be used (consistent with current DTF guidelines).
	6	**Improved asset utilisation**	Potential of a digital technology to improve the availability of an asset once it has been constructed to be used more productively over its lifetime such as faster maintenance and refurbishment through use of an asset information model or reduced asset downtime.	Reduction in the downtime of assets	Depending on the asset type, estimate how much more productive an asset would be if downtime was reduced because of the utilisation of the technology. *Value of improved asset utilisation ($) = Reduction in asset downtime (hours or days) x value of the service the asset provided ($ / hour or day)*	Change in asset's downtime or improvement in asset's productivity due to the chosen technology. Value of the service the asset provides/rental costs of alternative premises.

Economic benefits framework

Appendix B – Detailed assumptions for economic analysis

Overarching assumptions and exclusions

The proposed methodology is based on the following key assumptions:

- Digital technologies must have market maturity to achieve widespread deployment by 2030. This parameter means technologies have been excluded where there is not hard evidence of the ability to scale for widespread adoption in the next six years.
- Analysis evaluates digital technologies that have not been adopted, or adopted at scale, across Victorian infrastructure lifecycles. This includes digital technologies that may have been available for some time but which have not found consistent purchase, or have not been consistently optimised, in Victorian infrastructure sectors.
- The economic analysis measures the difference between a future with and without the short-listed digital technologies, such that the measured outputs will be incremental in nature rather than sizing a whole economy. This includes assumed time-based parameters for when technologies will be adopted and their rate of uptake under a base case and test case scenario. Analysis quantifies how infrastructure can be built and operated more efficiently and effectively but will not forecast future economic growth in Victoria or particular sectors.
- The analysis measures estimated economic impact as a per annum impact and the cumulative impact between 2030 and 2055, reflecting the time horizon of the updated 30-Year infrastructure strategy. Economic impacts are presented in real terms in 2024 dollars and have not been discounted.
- More efficient delivery of infrastructure may result in a lower level of borrowing required (and therefore lower interest costs to government) or an increase in the provision of other services/infrastructure. Within the scope of the analysis, assessing whether there may be a broader impact on Government finances is not feasible. The analysis assumes that infrastructure spending would remain constant regardless of changes in cost that may occur because of innovation and will not make assumptions about how these savings may be used.
- Implementation of new technologies is only possible if there is a workforce that supports its use. The analysis assumes that relevant education and training is provided to enable the technologies identified to be rolled out across the workforce and economy. The final Report will identify general and specific risks and requirements for successful technology adoption where possible.
- Without completing a detailed analysis across all workforce activities and sectors, simplifying assumptions are required to assess the broader impact of each technology and will be agreed with Infrastructure Victoria as part of the analysis. The analysis assumes that technologies can be reasonably scaled across sectors, noting that the actual implementation of technologies may not be uniform.
- The benefits of new technologies will need to be compared against the cost of their implementation. The analysis will not seek to quantify the cost of implementing the short-listed technologies or conducting a cost-benefit analysis for each technology. However, where the data enables a comparison of each technologies relative cost of implementation, we will provide this through a qualitative scale (e.g. low, medium, high, or similar).
- The analysis relies on publicly available data sources including (but not limited to):
  - Research about the cost and delivery schedule of previous infrastructure projects.
  - Australian Bureau of Statistics data for daily average wage rates.
  - Unit rates for the average cost of specific materials.
  - Embodied carbon energy and carbon coefficients for specific materials.
  - Sectoral information about the size or level of activity of industries (to scale results).

Detailed assumptions underlying the economic analysis are provided over the following pages.

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Appendix B – Detailed assumptions for economic analysis

General modelling assumptions

General modelling assumptions

Parameters	Input	Unit	Key sources
Appraisal period	25	Years	Aligned with expected implementation date for new technologies (2030) and Infrastructure Victoria's 30-Year infrastructure strategy end date (2055).
Discount rate	7	%	Department of Treasury and Finance technical guidelines on economic evaluation
Capex of road infrastructure (total until 2056)	181.0	$ billion 2023	2021 to 2056. Scenario 1 of The CIE, Economic, social, and environmental impacts of alternative urban development scenarios for Victoria prepared for Infrastructure Victoria, 2023
Capex of road infrastructure (annualised)	5.2	$ billion 2023	*Calculation [*Capex of road infrastructure (total until 2056) */ 35]*

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Appendix B – Detailed assumptions for economic analysis

Use case assumptions

Technology 1: Machine Learning and artificial intelligence for Government education capital construction

Parameters	Input	Unit	Key sources
Benefit 1: Avoided cost overruns			
Total education capex funding from government sector	17.9	$ billion 2023	2021 to 2056. Scenario 1 of The CIE, 2023
Annualised education capex funding from government sector	0.5	$ billion 2023	Calculation [Total education capex funding from government sector / 35]
Total operating cost (Government sector)	8.9	$ billion 2023	2021 to 2056. Scenario 1 of The CIE, 2023
Annual operating cost (Government sector)	0.3	$ billion 2023	Calculation [Total operating cost (Government sector) / 35]
Expected annual expenditure - government sector	0.8	$ billion 2023	Calculation [Annualised education capex funding from government sector + Annualised education capex funding from government sector]
% of mega projects experience cost overrun (likelihood of occurrence)	41	%	Based on projects between $350m and $1b recognising the programmatic nature of education capital. Grattan Institute, 2020
Average cost overrun	26	% more than initial cost	Based on all Government projects between $350m and $1b and adopted recognising the programmatic nature of education capital which is usually packaged in larger bundles of work. Grattan Institute, 2020 No specific education capital program cost overrun data was available.
Average cost overrun of program	10.7	%	Calculation [% of mega projects experience cost overrun (likelihood of occurrence) x Average cost overrun]
Expected average cost overruns per year	0.08	$ billion 2021	Calculation [Expected annual expenditure - government sector x Average cost overrun of program]
Reduced likelihood of cost overruns	23	%	Project Management Institute, 2019
Reduction in cost overruns	18.8	$ million 2023	Calculation [Expected average cost overruns per year x Reduced likelihood of cost overruns x billion factor]
Reduction in cost overruns	19.3	$ million 2024	Escalated
Benefit 2: Reduced project risk			
Reduction in contingency held	1.4	$ million 2024	Calculation [Reduction in cost overruns x Discount rate]

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Appendix B – Detailed assumptions for economic analysis

Use case assumptions

Technology 2: Robotics for inspections and maintenance in water utilities

Parameters	Input	Unit	Key sources
Benefit 1: Maintenance cost savings			
Total capex - all utilities (2023-2028)	6,715.7	$ million 2023	Sum of available water corporations price review 2023 ESC decision which includes Lower Murray Water (Urban and Rural), GWM, Central Highlands Water, Greater Western Water, Barwon Water, Coliban Water, Goulburn Valley Water, East Gippsland Water, South Gippsland Water, Gippsland Water, Yarra Valley Water, South East Water, Westernport Water, Southern Rural Water And Wannon Water. Essential Services Commission, 2023b
Average renewals as proportion of capex	45.6	%	Yarra Valley Water figures are used as an example where the average is calculated based on Net capital expenditure – renewals / total capex from the years 2023-24 to 2032-33. Essential Services Commission, 2023b
Total renewals capex - all utilities (2023-2028)	3,061.9	$ million 2023	Calculation [Total capex - all utilities (2023-2028) x Average renewals as proportion of capex]
Average annual renewals capex - all utilities	612.4	$ million 2023	Calculation [Total renewals capex - all utilities (2023-2028) / 5]
Reduction in annual maintenance cost through robot adoption	20	%	UTS Techlab, 2021
Reduction in annual maintenance cost through robot adoption	122.9	$ million 2023	Calculation [Average annual renewals capex - all utilities x Reduction in annual maintenance cost through robot adoption]
Reduction in annual maintenance cost through robot adoption	125.9	$ million 2024	Escalated
Benefit 2: Avoided cost of blockages			
No. of sewer blockages reported per 100km [average]	18.5	Blockages per 100km	Statewide. Page 39, ESC, 2023a
Total length of wastewater pipes	40,166	km	Calculation [Sum of all wastewater pipelines km in Victoria Lower Murray water, GWM, Central highlands water, Greater western water, Barwon water, Coliban water, Goulburn valley water, North East Water, East Gippsland water, South Gippsland water, Gippsland water, Yarra valley Water, South East Water, Westernport Water]. Sourced from annual reports for various water corporations.
Estimated number of blockages per year	7,431	Blockages per year	Calculation [No. of sewer blockages reported per 100km [average] x (Total length of wastewater pipes / 100)]

Parameters	Input	Unit	Key sources
Cost savings recorded for blockages	400,000	$ 2022	Australian Water Association, 2022
Total number of blockages detected	300	No.	Australian Water Association, 2022
Cost savings per blockage	1,333.3	$ 2022	Calculation [Cost savings recorded for blockages / Total number of blockages detected]
Cost of blockages avoided	9.9	$ million 2022	Calculation [Estimated number of blockages per year x Cost savings per blockage]
Cost of blockages avoided	10.8	$ million 2024	Escalated
Benefit 3: Avoided pumping and treatment cost of non-revenue water			
Pumping and treatment cost per litre	0.06	$ / Kl 2023	Calculated based on input costs for electricity and chemicals per megalitre included in Yarra Valley Water's 2023 Price Determination submission. This is considered conservative compared to benchmarks from other jurisdictions. Essential Services Commission, 2023b
Total volume of water supplied (average 2017-18 to 2021-22)	587,240	ML/annum	Page 239, table G.5, Scenario 1 of The CIE, 2023
Average leakage rate across Australia	10	% of supplied water	Water Services Association of Australia, 2019
Total avoided pumping and treatment cost of non-revenue	3.4	$ million 2023	Calculation [Pumping and treatment cost per litre x Total volume of water supplied (average 2017-18 to 2021-22) x Average leakage rate across Australia x 1000]
Total avoided pumping and treatment cost of non-revenue	3.5	$ million 2024	Escalated

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Appendix B – Detailed assumptions for economic analysis

Use case assumptions

Technology 3: Advanced Imaging applied to subsurface infrastructure

Parameters	Input	Unit	Key sources
Benefit 1: Avoided cost of utility clashes			
Estimated incidents 2023	6,097	incidents	BYDA, 2023. Data is incomplete with not all utility providers information available.
Average direct cost per incident	4,003	$USD 2019	Common Ground Alliance, 2020
Average direct cost per incident	5,756.75	$AUD 2019	Calculation [conversion using 0.70 average exchange rate https://www.ofx.com/en-au/forex-news/historical-exchange-rates/yearly-average-rates/]
Average direct cost per incident	6,807.03	$ AUD 2024	Escalated
Estimated direct cost of incidents (2023, Victoria)	44,407,642	$ 2024	Calculation [Average direct cost per incident x Estimated incidents 2023]
Benefit 2: Reduced project risk			
Estimated annual reduction in contingency held on projects site inspections	2,905,173	$ 2024	Calculation [Estimated direct cost of incidents (2023, Victoria) x Discount rate]

Technology 3: Advanced Imaging applied to ground condition inspections

Parameters	Input	Unit	Key sources
Estimated saving on physical site investigations as proportion of capital value	0.5	%	Estimated using Arup's internal project data for road transport projects.
Estimated annual saving on physical site investigations	2,787,557	$ 2024	Escalated, Calculation [Capex of road infrastructure (annualised) x Estimated saving on physical site investigations as proportion of capital value x factor of billion]
Capex of transport infrastructure	338.0	$ billion 2023	2021 to 2056. Scenario 1 of The CIE, 2023
Ratio of road to all capex	0.54	Ratio	Calculation [Capex of road infrastructure (total until 2056) / Capex of transport infrastructure]
Estimated annual saving on physical site investigations (all transport)	5.2	$ million 2024	Calculation [Estimated annual saving on physical site investigations / Ratio of road to all capex]

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Appendix B – Detailed assumptions for economic analysis

Use case assumptions

Technology 4: Advanced data analytics [Social housing sector]

Parameters	Input	Unit	Key sources
Benefit 1: Cost savings – reduced cost overruns			
House construction cost	392,155	$ 2021	The CIE, 2023
Townhouse construction cost	370,497	$ 2021	The CIE, 2023
Apartment construction cost	463,499	$ 2021	The CIE, 2023
Average construction cost per residence	516,359	$ 2024	Calculation [Average of the above and escalated to 2024 cost using a factor of 1.26]]
Upgrading of public housing per year	2,000	Houses per year	Page 31, Victorian Government, 2023
Cost savings in project construction costs (using BIM)	6.92	%	Lu, W., et al., 2014. The study found that using BIM at the design stage increased the cost (by 45.93 percent), but at the building stage decreased the square meter for by 8.61%, leading to an overall saving of 6.92%.
Annual cost saving from drawingless construction	71,464,039	$ 2024	Calculation [Average construction cost per residence x Upgrading of public housing per year x Cost savings in project construction costs (using BIM)]
Benefit 2: Reduced project risk			
Reduction in contingency held from cost overruns	5,002,483	$ 2024	Calculation [Annual cost saving from drawingless construction x Discount rate]

Technology 4: Advanced data analytics [Road sector]

Parameters	Input	Unit	Key sources
Benefit 1: Cost savings – reduced cost overruns			
Cost overrun without BIM	19	%	Based on project data supplied by the Norwegian Road Administration. Thorsen, T, 2022.
Cost overrun with BIM and paper drawings	9	%	Based on project data supplied by the Norwegian Road Administration. Thorsen, T, 2022.
Cost overrun with only BIM (drawingless construction)	5	%	Based on project data supplied by the Norwegian Road Administration. Thorsen, T, 2022.
Average cost overrun based on level of design	14	%	Calculation [Average of cost overrun without BIM and cost overrun with BIM and paper drawings]
Reduction in cost overrun based on drawingless construction	9	%	Calculation [Average cost overrun based on level of design - Cost overrun with only BIM (drawingless construction)]
Expected annual cost overruns for road projects	501.8	$ million 2024	Escalated. Calculation [Capex of road infrastructure (annualised) x Reduction in cost overrun based on drawingless construction]
Benefit 2: Reduced project risk			
Reduction in contingency held from cost overruns	35.1	$ million 2024	Calculation [Expected annual cost overruns for road projects x Discount rate]

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Appendix B – Detailed assumptions for economic analysis

Use case assumptions

Technology 5: Geospatial technologies for natural hazard management

Parameters	Input	Unit	Key sources
Benefit 1: Reduced likelihood of bushfire			
Modelled reduction in detection time	30	minutes	Australian National University Centre for Social Research and Methods, 2020
Estimated average detection times with EOM	12	minutes	Muon Space, 2024. Detection times are expected to be between 9 minutes (for bushfire-prone areas) and 20 minutes (globally). An average of 12 minutes is used for this analysis.
Estimated reduction in likelihood of severe fires related to EOM	60	%	Calculation [Estimated reduction in detection times related to EOM / Reduction in detection time]
Cost under base case detection times	1,911,119,488	$	Table 5, Australian National University Centre for Social Research and Methods, 2020
Cost with 30-minute reduced detection times	1,754,565,504	$	Table 5, Australian National University Centre for Social Research and Methods, 2020
Reduction in cost of bushfire	8.2	%	Calculation [30-minute reduced detection times / Base case detection times]-1
Average annual growth of economic cost for Victoria	3.6	%	Table B.3, page 107, Deloitte Access Economics, 2017
Total cost of bushfire in Victoria	1.1	$ Billion 2017	Chart 2.2, Page 20, Deloitte Access Economics, 2017
Total insured and tangible cost of bushfire	0.6	$ Billion 2017	Table B.3, page 107, Deloitte Access Economics, 2017
Proportion of insured and tangible costs relative to total costs	53.9	%	Calculation [Total insured and tangible cost of bushfire / Total cost of bushfire in Victoria]
Total insured cost of bushfire	0.2	$ Billion 2017	Table B.3, page 107, Deloitte Access Economics, 2017
Proportion of insured costs relative to total costs	18.5	%	Calculation [Total insured cost of bushfire / Total cost of bushfire in Victoria]
Proportion of tangible costs relative to total costs	35.5	%	Calculation [Proportion of insured and tangible costs relative to total costs - Proportion of insured costs relative to total costs]
Total tangible cost of bushfire in Victoria	0.4	$ Billion 2017	Calculation [Total cost of bushfire in Victoria x Proportion of tangible costs relative to total costs]

Parameters	Input	Unit	Key sources
Estimated reduction in cost due to EOM	4.9	%	Calculation [Estimated reduction in likelihood of severe fires related to EOM x Reduction in cost of bushfire]
Estimated reduction in annual costs associated with bushfire	(0.02)	$ Billion 2017	Calculation [Total tangible cost of bushfire in Victoria x Estimated reduction in cost due to EOM]
Estimated savings in annual costs associated with bushfires	19.168,677	$ 2017	Calculation [Estimated reduction in annual costs associated with bushfire x billion factor]
Estimated saving in annual costs associated with bushfire	23,792,016	$ 2024	Escalated
Estimated saving in annual costs associated with bushfire	37.6	$ 2024	Calculation. Annualised over 25 year appraisal period using Average annual growth of economic cost for Victoria
Benefit 2: Avoided cost of repairs after flood damage			
Base case cost 2022	577,679	$ 2022	Table 5-6, Page 44, Arup, 2023
Cost after hazard management 2022	443,069	$ 2022	Table 5-6, Page 44, Arup, 2023
Savings 2022	23.3	%	Calculation [Cost after hazard management 2022 / Base case cost 2022]-1
Base case cost 2070	927,439	$ 2022	Table 5-6, Page 44, Arup, 2023
Cost after hazard management 2070	712,118	$ 2022	Table 5-6, Page 44, Arup, 2023
Savings 2070	23.2	%	Calculation [Cost after hazard management 2070 / Base case cost 2070]-1
Average of the savings from hazard management (2022 & 2070)	23.2	%	Calculation [average]
Cost of responding to flood events	165.0	$ million 2022	Australian Broadcasting Corporation, 2022
Modelled average exceedance probability	20	%	Page 36, Arup, 2023
Expected average annual cost savings from GIS hazard management across Victorian roads	8.4	$ million 2024	Escalated. Calculation [Average of the savings from hazard management (2022 & 2070) X Cost of responding to flood events X Modelled average exceedance probability]

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Appendix B – Detailed assumptions for economic analysis

Indicative cost analysis

Relative Costings

Approach to relative costings

This analysis has not sought to quantify the cost of implementing and operating the five short-listed technologies that have been assessed.

However, to support the analysis and the discussion of future benefits, a qualitative assessment of the relative cost of each technology has been undertaken.

The relative cost of each technology has been ranked based on an assessment against 5 criteria – where a higher score refers to a higher relative likely cost of wide technology adoption.

Criteria were designed to reflect the following principles:

- Technologies that are already adopted but currently underutilised represent the cheapest solutions.
- Technologies that require investment in physical capital are the most expensive solutions.
- One-off investments will be cheaper than recurring expenses.
- Preparing a workforce to adopt technologies has a cost which needs to be recognised.

Technologies were assessed at **Level 2** – Technology Cluster to compensate for the different relative scale of the specific **Level 3** use cases.

Criteria for assessment

The cost of each technology was assessed based on the following criteria:

1. Is the technology already adopted, but underutilised? (Yes = 0, No = 1)
2. Does adoption require investment in new plant or equipment? (Yes = 1, No = 0)
3. Is capital investment expected to be significant? (Yes = 1, No = 0)
4. Are adoption costs expected to be recurring or one-off? (Recurring = 1, One-Off = 0)
5. Will it require major workforce retraining to enable adoption? (Yes = 1, No = 0)

Short-listed Technologies	Criteria					Total Score
	1 Already adopted?	2 New plant and equipment?	3 Significant capital investment?	4 One-off or recurring adoption costs?	5 Workforce retraining or adoption?	
1. Machine learning and artificial intelligence	0	0	0	1	1	**2 = Moderate**
2. Robotics	1	1	1	0	0	**3 = High**
3. Advanced Imaging	0	1	0	1	0	**2 = Moderate**
4. Advanced data analytics	0	0	0	0	1	**1 = Low**
5. Geospatial technologies	0	0	0	0	1	**1 = Low**

Summary of estimated relative costs of short-listed technologies

Appendix C – Summary of workshop attendees and findings

Summary of findings

The following appendix summarises attendees and key findings and commentary captured at a ‘Challenge’ workshop held on 8 March 2024. The Challenge Workshop gathered a range of subject matter experts in infrastructure and digital technology to interrogate a work-in-progress list of technologies identified which could impact the productivity of Victorian Infrastructure. Participants were asked to place technologies on a matrix of level of productivity impact and level of certainty of uptake. The notes below reflect this activity and the associated discussions.

Workshop attendees

Workshop attendees represented a range of backgrounds and skills including policy and strategy, economics, digital technology, telecommunications, transport, water, building information modelling, structural engineering, and resilience and adaptation planning.

The attendees were from the following organisations and government departments:

- Infrastructure Victoria.
- Department of Jobs, Skills, Industry and Regions.
- Major Transport Infrastructure Authority.
- Department of Treasury and Finance.
- Department of Government Services.
- Digital Twin Victoria.
- Arup.

Summary of key findings and commentary

Technologies identified as high impact and high certainty:

- Advanced information and communications technologies, with all groups supporting:
  - Advanced data analytics – requires simple tools and workforce upskilling but there is recognition of industry resistance to uptake (e.g. building information modelling and other digital tools).
  - Geospatial technologies.
  - High-performance computing.
  - High uncertainty for cyber security impact was mostly related to it being deemed as an enabler across the entire scope of technologies considered rather than driving productivity impacts itself.

Technologies identified as high impact but varying views on level of certainty:

- Artificial intelligence (AI) and machine learning.
  - Technologies were highly clustered, highlighting interdependency between simple machine learning, deep learning and neural nets, and natural language processing which all offer great potential in terms of prediction capabilities.
  - For each of these technologies, they are in parts already implemented but there needs to be a greater emphasis on doing more with the existing technologies. Benefits will be realised through optimisation of, rather than a revolution in productivity. In this context, barriers exist but there is a baseline of skills already (creates opportunities to accelerate the impact).

Technologies with varied views around impact and certainty:

- Advanced manufacturing and materials – digital fabrication discussions identified barriers relating to reliance on digitised data, insufficient quality of products, prohibitive costs, and need to meet industry standards / safety requirements. Composite materials also had no clear consensus view.
- Autonomous systems and robotics – agreed this was already adopted to some extent (e.g., using drones to undertake surveys in construction) but widescale adoption and impact relies on appropriate security protocols, quality of digitised data, and sufficient workforce capacity.
- Climate and energy transition – general consensus on these technologies' role as an enabling technology (electric charging) and futureproofing for other technologies, with benefits primarily relating to avoided costs and disruption to productivity.

Dual importance of enhanced productivity and loss prevention

- There were strong views that futureproofing existing infrastructure is as important as developing new infrastructure to avoid costs or disruptions. Enabling technologies that achieve this are vital.

Factors affecting how benefits will be realised

- Game changers vs. accumulation of incremental shifts – participants agreed that the type of technology has strong implications for the type of impact, how it will be measured and realised over time.
- Walk before you can run – some technologies are foundational pieces which we are currently missing. Incremental layering of technology adoption is needed to unlock other opportunities / greater potential (e.g. enabling climate and energy transition technologies like electric charging or advanced information and communication technologies like digital data and protective cyber security - which is non-negotiable).
- Benefits will be realised not by the technology, but also by its usability – outcomes can be enhanced by providing applications and services that are easy for people to use, are tailored to workforce capabilities (especially making sure smaller firms are included) and by identifying areas that require more specific and or significant training – for example, robotics, small scale digital prefabrication vs. large infrastructure which involves a longer timeline and a significant shift in workforce capability.
- Need to mitigate non-technological hurdles to adoption – not just skills but broader reluctance to technology uptake across the infrastructure industry. People won’t make a change if they can’t easily use or implement technology or see the benefits to them.

Interdependencies of technologies

- There were many links and clusters identified between various artificial intelligence and machine learning technologies and advanced information and communication technologies.
- Technologies need to be further segmented to use cases to understand their individual productivity potential i.e., the variation in benefits or appeal of implementation is different contexts or conditions.
- This especially relates to AI and for understanding the role of various technologies as an enabler or as a direct influence on productivity. It is cross-sectoral technology that would underpin almost every other tech innovation listed like 4G, 5G, etc.
- Due to interdependencies, the impact of some technologies may be exponentially increased when combining technologies together.

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