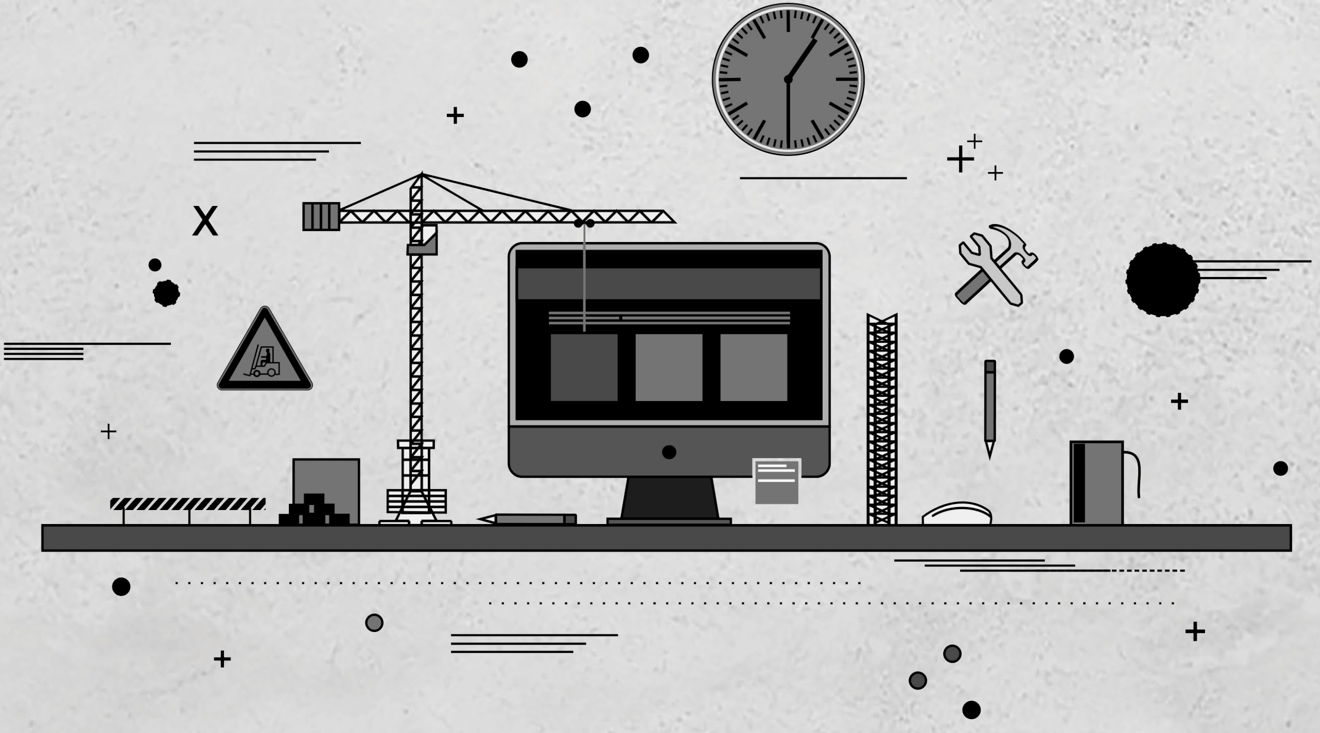
PROJECT #38: DIGITAL BUILD – TRANSLATING THEORY INTO PRACTICE

FOREWORD TO FINAL REPORTS



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ABBREVIATIONS

CDE	Common Data Environment
ECI	early contractor involvement
IP	intellectual property
KPI	key performance indicator
OCi	offsite category index
OPV	Office of Projects Victoria
SCCi	supply chain capacity index
VDAS	Victorian Digital Asset Strategy

EXECUTIVE SUMMARY

Translating theory into practice

Project #38 is a cross-sector collaboration that aims to address the gap between theory and practice to facilitate greater uptake of digitally integrated building and offsite construction in Victoria.

There is a strong willingness by both government and industry to enhance the capacity, frequency, and effectiveness of off-site and digitally enabled construction in Victoria. While the potential of advanced construction to drive cost, quality, and performance improvements has long been recognised, a disconnect exists between the body of research positing the benefits of industrialised building with the realities of commercial innovation. Despite cyclical waves of government investment and industry initiatives in advanced building, uptake has not been widespread in the construction sector when compared with productivity gains in other industries.

A lack of Victoria-specific data prevents accurate determination of the costs and benefits involved in the transition from traditional to advanced construction processes. In turn, the information-gap limits the realisation of effective long-term implementation strategies. This year-long study has looked to collate relevant data from government and industry about the costs and benefits of off-site and digital construction in Victoria to develop practical frameworks for transitioning. Three sub-projects explored the viability of change.

#38.1 Offsite + Modular Construction Hubs: explored opportunities for industry to collaborate to create off-site and modular construction hubs in Victoria.

#38.2 Benefits of Digital Build: aimed to create pathways for Victoria's digital transition by developing a systematic understanding of the benefits of integrated project data management.

#38.3 Project Applicability Decision-making Framework: aimed to develop a decision-making framework that provides early information to project teams about the suitability and methods of offsite manufacturing.

Building 4.0 CRC's *Project #38: Translating theory into practice* demonstrates that in order to create the conditions for the Victorian building sector to advance, first a better understanding of the contemporary state of play of the state's industry is required to:
1) gain access and/or synthesise meaningful data; 2) establish benchmarks for a sustainable transition; and 3) develop multi-criteria decision frameworks to support holistic industry change.

Facilitating industry-wide change is integral for the viability and longevity of digitally enabled, offsite construction. Scale, cooperation, and culture present opportunities for transition. The scale of the Victorian construction market and interdependencies within the value chain means no single actor, government or industry, can affect—and sustain—the necessary shifts alone. Cooperation is needed between government, industry, research and education to facilitate innovation and mitigate the short-term barriers emerging from an already constrained construction sector. Ancillary armatures (legal, infrastructural and workforce development) are also required for ongoing growth and advancement. Further the culture of construction, as a project-oriented industry has constrained its ability to realise long-term innovation.

The efficacy of innovation is reliant on a number of concurrent inputs by different actors across the building value-chain. The wide-ranging needs and capacities of stakeholders means that the costs, benefits and timeframes of transition are not of equal measure but are nevertheless reliant on reciprocal changes across the industry ecosystem.

Pressure points for translating theory and practice

Adoption barriers

- Industry decisions based on cost and time.
- Difficult to estimate – insufficient precedents; uncertain project roadmap; different modes of offsite construction for a project.
- Lack of leadership support is a major barrier to change reluctance of staff to change, lack of time and budget.
- Without demonstrated incentives, mandating changes may be necessary.
- Economic cycles, combined with construction's project-basis present challenges for long-term innovation investment.

Supply chains

- Relevance and integrity: rarely collected, not updated
- Constructability of different offsite products.
- Poor data collection and maintenance of sustainability indicators and end of life supply chains.

Data, definitions, skilling

- Multiple and concurrent sources of construction information – IP, data accountability, retrieval, accessibility, interoperability, reliability and reuse.
- Literacy: Lack of awareness of the Victorian Digital Asset Strategy (VDAS). Inconsistent understanding of digital and Industry 4.0
- Training and recruitment: high demand for digital expertise; uncertainty about required technical skills and capabilities.

Benchmarking and transitioning

- Project and location-specific issues challenging to generalise with few benchmarks available.
- Low levels of functionality with existing technology to replicate ISO 19650 information management tasks.

Recommendations

Build on this year-long study for longer-term investigations:

- Focus on building projects currently being implemented.
  Early access to projects and stakeholders needed to benchmark benefits of digital build and connected data including time/cost of entire design & build
- Develop a framework for a real-time data repository, build on existing clustering + collaborations.
- Education and training
  existing and future workforce development
- Short term projects to implement the VDAS involving Government and industry, and results shared as widely as possible

Prioritise sustainable development

- Staging for longevity of off-site construction e.g. resolving zoning issues, workforce + housing challenges to ensure balanced growth.
- End of supply chain
- Offers broader benefits and incentives

Policy coherence

- Across different sectors (e.g., housing, transportation, and environmental regulations) to create a supportive and consistent policy environment for infrastructure development.
- Offsite construction product category scale: regulation, code compliance, quality assurance and safety.
- IP issues and data sharing: data sharing agreements; data security to promote transparent data exchange while safeguarding competitive advantage.

Parallel investments

- Transportation networks, utilities: efficient material production and transportation
- Digital connectivity to enable communication among stakeholders.

PROJECT OVERVIEW

Government imperatives
Victoria-specific evidence that
demonstrates the benefits of
advanced construction.

Industry imperatives
Create an environment that enables
the successful realisation and
longevity of construction innovations.

Industry experience suggests that advancements in digital infrastructure have often occurred by accident or in response to immediate needs and risks. Similarly, efforts to take construction activity offsite are often implemented on a project-by-project basis in response to immediate needs. When prospective innovations encounter the demands of live commercially focused project delivery (e.g., time and cost certainty), prototypical solutions tend to be compromised and/or project execution reverts to traditional processes with known outcomes. Early-adopters of offsite and digitally enabled building processes have found the shift challenging to sustain, let alone capitalise on over time. This not only presents a lost opportunity for the innovations pursued but has also resulted in a limited number of initiatives that can be used to demonstrate the long-term benefits of advanced construction. This points to the dual need to generate context-specific evidence that can:

1. Demonstrate the benefits of advanced construction at government level.

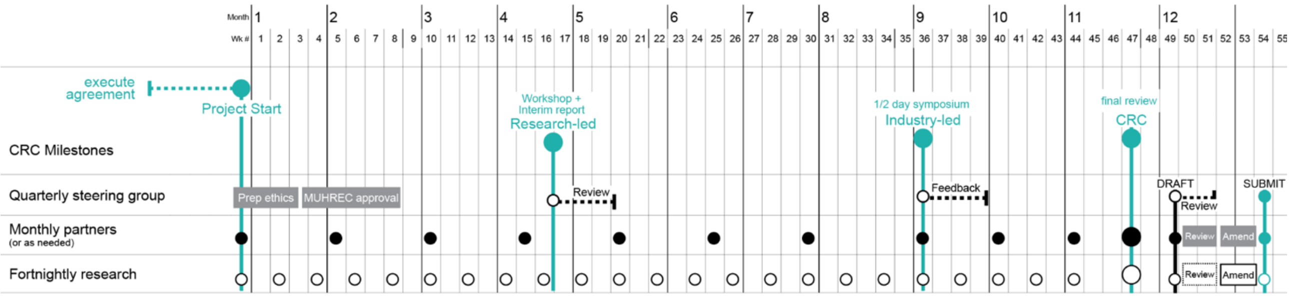
   The understanding and communication of enhanced construction information management within government could e improved. This could contribute to an advanced construction industry in Victoria.

2. Create an environment that supports industry imperatives, enabling the successful realisation and longevity of construction innovations.

   For example, the transition from traditional to advanced construction methods requires concordant shifts in the legislative, procurement and certification processes employed during project planning, design and execution. Victoria-specific evidence is required to identify relevant stakeholders impacting on key phases of project success, determine appropriate armatures to accommodate the uncertainties of delivering innovations and support public consultation around the tensions emerging from the transition from traditional to advanced construction.

Project structure and governance

Project #38 was steered by a coordinating group of academics and representatives from the former Office of Projects Victoria. The three sub-projects were led by an academic expert in the relevant field from Monash University and University of Melbourne, collaborating with nominated OPV and industry partners through monthly research meetings (see project reports for contributors). Project teams came together for facilitated knowledge-exchanges at three key milestones (below).

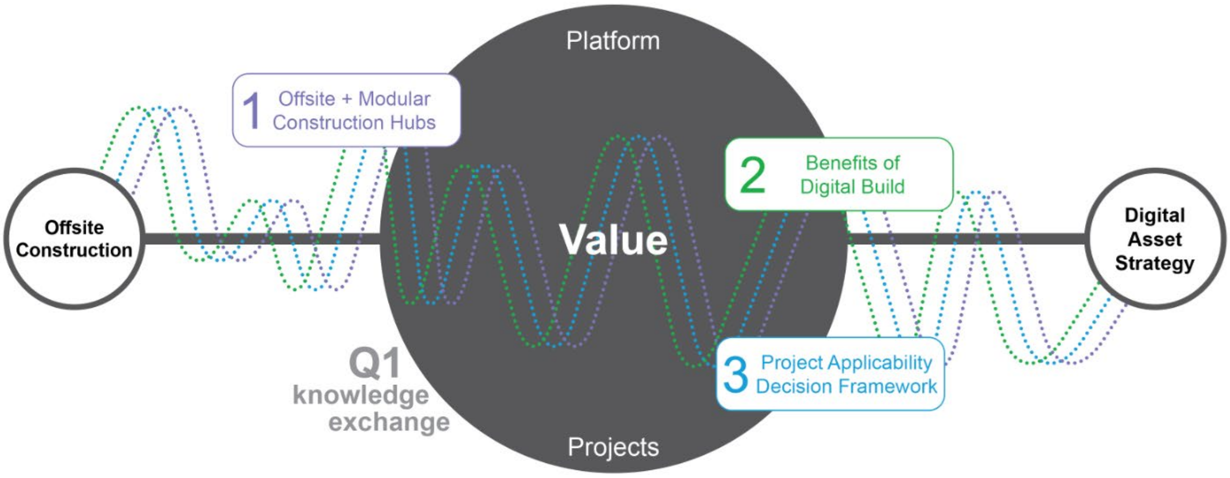


Q1 Research-led Knowledge Exchange: Projects to Platforms

The implementation of construction innovation whether in terms of offsite production or digital build requires a long-term perspective. The traditional project-oriented nature of the building industry, together with macro-economic cycles mean that innovation investment, prototyping and testing, and widespread uptake to drive change in construction can be hard for commercial actors to sustain.

Platform-based construction is a central concept of the Building 4.0 CRC. It has potential to drive product and process improvement in an environment that is separated from traditional one-off project execution. In terms of construction activity, this means the consideration of buildings as products with components tested and built in controlled factory-based environments. Design, manufacture, and assembly is informed by data, feedback, and the reuse of knowledge and experience from implementation in project cycles. Similarly, in the digital realm, built environment platforms are emerging from the technology sector where these platforms facilitate digital data exchanges. These platforms manage, analyse, and extract value from data across the building value chain, separate to the traditional digital tools necessary for project-implementation.

Project #38: Translating theory into practice has taken this conceptual shift from traditional construction to a platform-based future into its methodological framing to connect the sub-projects at a high-level and drive the research in support of the Victorian Government's offsite construction and Digital Asset strategies when viewed together in a common platform future.



Q2 Industry-led Knowledge Exchange

Strategies for change:

- Exploring the potential of contractual requirements and government mandates to drive change.
- Addressing concerns related to IP issues when sharing models.
- Emphasising the importance of capturing and measuring the benefits to make a case for offsite construction.
- Advocating for early contractor involvement (ECI) as a worthwhile approach.
- Minimising the gap between design drawings and as-built drawings by transferring skills upstream.
- Recognising that the strategy of pushing risk downstream has diluted knowledge and skills from upstream.

Additional considerations:

- Defining what constitutes onsite and offsite construction and identifying different offsite-built products.
- Assessing whether the use of pre-existing offsite-built components qualifies as offsite construction.
- Evaluating the sustainability aspects of prefab concrete versus in-situ concrete, including factors such as sourcing, quality, logistics, temporary works, craning requirements, and factory emissions.
- Development of a repository for case examples with baseline metrics
- Identification of qualitative and quantitative data to support the decision framework
- Development of reliable metrics that compare onsite and offsite/modular production

Q4 Final CRC Milestone Review

In July 2023, research findings and steps towards project finalisation were presented at a Building 4.0 CRC Final Milestone review. Project-specific outcomes were presented as the teams prepared draft reports. At the milestone the integration of the scope of Project #38's three sub-projects was discussed. Looking to the alignment of the sub-projects points towards valuable areas of future investigation:

- **Platform for Industry Access**: Policymakers should explore the development of a platform that provides the construction industry with access to comprehensive and authoritative datasets for products, materials, and other relevant information. This platform can facilitate data sharing and support the implementation of the Common Data Environment.
- **Real-Time Data and Algorithmic Reasoning**: promote the use of real-time data and algorithmic reasoning to enhance digital transformation in the construction industry. This can improve decision-making, project planning, and efficiency throughout the construction lifecycle.
- **Collaborative Design Process**: encourage early contractor involvement in the design process to facilitate collaboration among contractors, architects, engineers, and manufacturers. This collaborative approach will reduce clashes between different systems and components and lead to more efficient construction processes.
- **IP Issues and Data Sharing**: address Intellectual Property (IP) concerns to encourage data sharing and collaboration among stakeholders. Establishing frameworks for data sharing agreements and ensuring data security will promote transparent data exchange while safeguarding competitive advantage.
- **Adoption of VDAS**: prioritise the understanding and promote the adoption of the Victorian Digital Asset Strategy (VDAS) in the building and construction industry. This can be achieved through targeted marketing, workshops, and training programs to familiarise stakeholders with the benefits and best practices of the VDAS.

PROJECT OUTCOMES

The three reports are enclosed as prepared by sub-project leads, tailored to the differing aims, methods and deliverables for the respective areas of investigation under Project #38.

These year-long studies have successfully explored and outlined the key challenges and opportunities that would be valuable to address through future research and implementation pathways for facilitating and achieving a successful long-term commitment to off-site and digitally enabled construction in Victoria. The sub-project outcome summary below outlines the project-specific recommendations that have led to identification of 5 tangible priority projects (see next section).

#38.1 Offsite + Modular Construction Hubs:

Challenges

- **Diverse Workflows and Processes:** The construction industry in different states of Australia follows diverse workflows, processes, and models. This lack of standardisation and coordination between states creates complexities in establishing uniform construction hub practices across the country.
- **Limited Coordination Between Upstream and Downstream Activities**: The lack of coordination between upstream and downstream activities in the construction process poses a challenge. A more integrated and collaborative approach is needed to ensure smooth operations and communication throughout the entire supply chain.
- **Resistance to Technology Adoption:** The fear of technology and resistance to adopting new digital solutions and innovations in construction is identified as a barrier. Overcoming this resistance and promoting a culture of innovation and technological advancement is crucial for the success of offsite construction becoming a more accepted practice.
- **Logistical Challenges:** Establishing construction hubs in regional areas requires addressing logistical challenges, including transportation networks and digital connectivity. Efficient infrastructure connectivity is essential for the movement of materials, equipment, and personnel.
- **Environmental Impact and Sustainability Concerns:** Construction hubs need to address the environmental impact of their operations and construction activities. Minimising carbon emissions, optimising transportation, and promoting sustainable construction practices are important considerations.
- **Labor and Skill Shortages:** The availability of skilled labour is critical for the success of construction hubs. Addressing skill shortages and investing in workforce development and upskilling initiatives are necessary to ensure a competent and capable workforce.
- **Holistic Approach to Regional Growth:** Government prioritisation of regional growth without considering a holistic approach that includes factors such as access to labour, public transport, cost of transport, travel time, etc., can limit the overall effectiveness of construction hubs.
- **Financial and Investment Challenges:** Establishing construction hubs requires significant financial investments. Securing funding and attracting investments from both public and private sectors may be a challenge.
- **Overcoming Existing Practices:** The construction industry may have established traditional practices that need to be adapted and integrated into the new construction hub framework. Overcoming resistance to change and promoting innovative approaches is essential.
- **Interstate and Regional Differences:** Different states and regions in Australia have varying ecosystems and construction practices, leading to contrasting challenges for each hub location. Addressing these regional differences while creating a cohesive approach is necessary.
- **Proximity and Collaboration:** The level of collaboration and proximity requirements vary depending on the stage and type of construction. Identifying the right balance between top-down and bottom-up approaches for collaboration is essential.

Opportunities and Recommendations

Sustainability	• Ensure an adequate and skilled construction workforce in the region to attract firms and support hub development. • Maintain cost-effective labour and housing to attract and retain construction firms and workers.
Market dynamics	• Regional location should offer convenient access to affordable and reliable energy sources to minimise operational expenses. • Evaluate material supply chain for availability and pricing to maintain competitive project budgets. • Prioritise robust internet and communication infrastructure for efficient project management. • Collaborate with key regional industries and firms for joint projects and shared resources. • Align hub services with regional demand in the residential, commercial, or industrial sectors. • Address regional housing gaps or imbalances to create consistent demand. • Proximity to delivery and distribution centres for efficient material and equipment movement.
Resources	• Prioritise locations with existing assets like serviced sites and power infrastructure for quick setup and sustainability. • Proximity to educational and research institutions for skilled workforce and innovation. • Assess presence of a strong trades network for efficient project execution. • Align hub specialisation with local material strengths for cost-effectiveness and sustainability.
Infrastructure	• Choose locations with easy access to rail, airports, and ports to facilitate material and personnel movement. • Proximity to urban centres, transportation nodes, and key entities for better collaboration and logistical efficiency. • Focus on efficient logistics and workflows within the hub for cost reduction and timely completion. • Efficient material flow and project delivery with focus on inventory management and quality control.

#38.2 Benefits of Digital Build

Challenges

- Lack of integration with a Common Data Environment (CDE) leads to data fragmentation and compromises data integrity.
- The Victorian Digital Asset Strategy (VDAS) is overwhelming for many in the industry, presenting challenges for embracing digital transformation.
- Unclear definitions of terms like digital build, CDE, and connected data create confusion and hinder effective communication within the industry.
- The absence of proper examination and selection of case studies for research leads to difficulties in recruiting suitable interview participants.
- Intellectual property concerns prevent the sharing of data and hinder collaboration between stakeholders.
- Reluctance to change and lack of leadership support create barriers to implementing digital transformation in the industry.

Opportunities and Recommendations

Digital Leadership	• Work with training providers to develop certified training programs for construction professionals to enhance their digital skills, leveraging partnerships with educational institutions and industry bodies. • Collaborate with industry stakeholders to formulate digital transformation roadmaps and guidelines, providing a comprehensive pathway for industry transition.
Integrated Data	• Emphasise the use of Common Data Environments (CDEs), establishing best practices for effective data collaboration and management among project teams. • Advocate for standardised data formats and protocols, such as Industry Foundation Classes (IFC) for BIM, to ensure interoperability across diverse software platforms. • Develop data-sharing agreements and protocols to facilitate secure and efficient data exchange throughout the project lifecycle. • Invest in data analytics platforms capable of distilling actionable insights from integrated project data for superior decision-making.
Productivity Enhancement	• Promote lean construction principles, offering training and resources to facilitate streamlined workflows and waste reduction. • Incentivise the investment in digital tools and emerging technologies such as robotics and AI to boost productivity levels. • Endorse collaborative project management platforms to enhance coordination and communication among project stakeholders. • Define industry-standard performance benchmarks and KPIs, encouraging teams to continually assess their performance against these metrics.

#38.3 Project Applicability Decision-making Framework

Challenges

- Current building industry mostly bases decisions on cost and time of completion. Both of which are hard to speculate at early stages of a construction project given unstructured demands and vague project roadmap.
- Decision making framework also faces challenges pertaining to relevance of supply chain data and constructability of different offsite products.
- Finding live datasets for the construction material and product supply chain poses a challenge as such a data is rarely collected and mostly not updated.
- The project attributes such as ‘cost, time reduction, site labour-hour reduction, quality, assembly time, supply chain complexity’ are speculative in nature. A decision-making framework needs to account for the subjectivity of such parameters and its high dependence on the project specific issues which are hard to encapsulate in a passive decision-making framework.
- Data collection and maintenance of sustainability indicators of projects in Victoria lacks behind international best practices such as the UK.
- End of life supply chains in Vic/Australia are inadequate as of now to provide closed loop circular ecosystem of products and materials.

Opportunities and Recommendations

Procurement method selection

- For the construction industry to meet the managerial, technical, and social challenges, both the industry and its participants must welcome “change” and allow innovative procurement methods to grow, which is a client-driven process supported by the rest of the building team.
- The future adoption of early contractor involvement (ECI) relies heavily on the results and outcomes of more completed projects that have implemented ECI schemes. As more projects utilise ECI, the industry will gain a better understanding of its benefits and effectiveness, leading to increased confidence and potential for wider application.
- Further efforts are needed to adapt the decision-making process to the Australian context, by including more data sources such as lessons learned from previous case studies, and questionnaire survey from experts in the industry.

Sustainability and circularity

- The accuracy of the sustainability indicators is underpinned by the accuracy of the emission and embodied energy factors in the relevant databases. For a consistent evaluation across the building sector in Victoria, it is advisable to follow a standardised suite of emission factors approved by the Government.
- Although sustainability evaluation is a relatively new phenomenon in Australia, there is a scope to track building assets via the Australian Bureau of Statistics and create a sustainability scale to benchmark projects based on Australian/statewide standards.
- Circularity is a multi-pronged approach. Industry feedback indicated a strong agreement on the lack of end-of-life supply chain infrastructure in Victoria and Australia. Multiple strategies such as recycling, repurposing, upcycling, downcycling, reusing and remanufacturing require significant capacity building. End-of-life logistics, transport, and processing can significantly impact the methods of project evaluation against circular economic values, and industry should seize the opportunities this presents.

Supply chains

- The supply chain capacity index (SCCi) could be used to quantify a region's capacity to cater to similar kinds of projects quantified in terms of OCi (offsite category index).
- Decision maker could analyse the SCCi vs OCi, for different distances from the construction site, and for required KPIs for the suppliers from the data to find the best suited construction method and the associated materials.
- Analysing trends in SCCi for a given region to assess the regional capacity can be used to fulfil the requirements of a hybrid construction project.

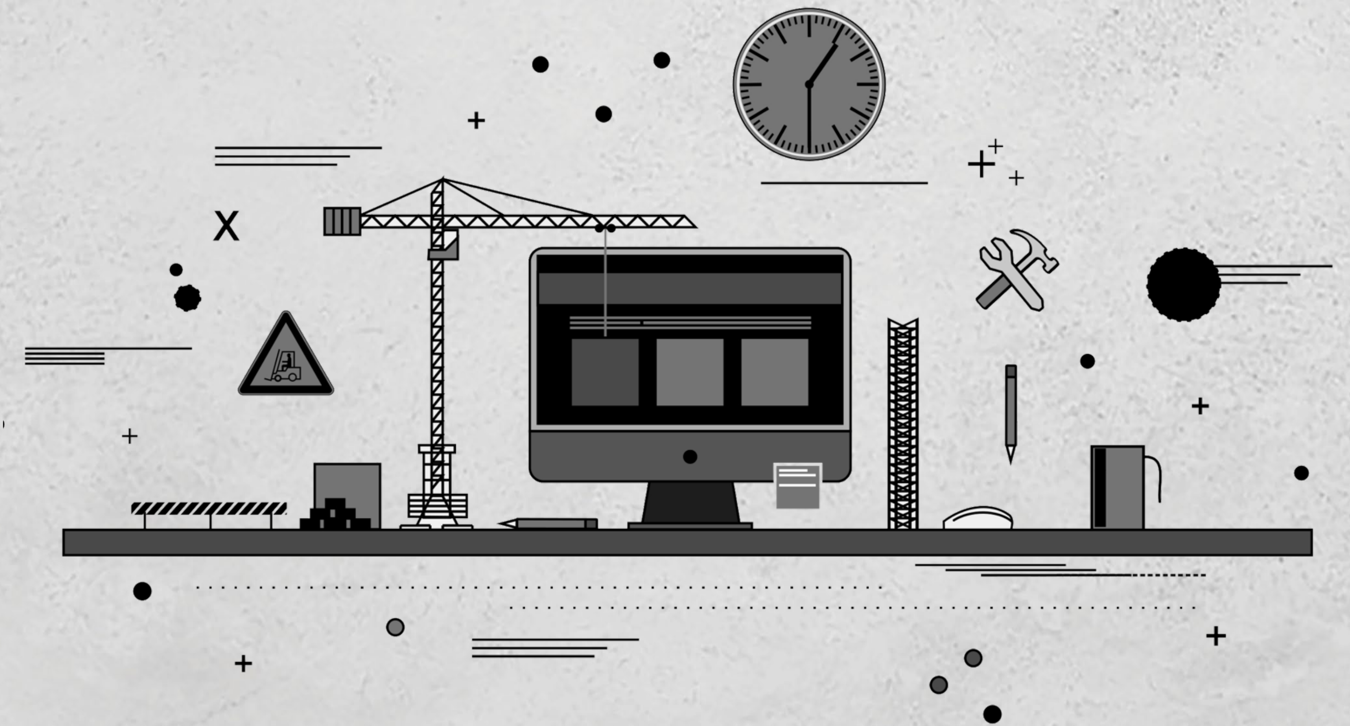
FUTURE RESEARCH PLANS

The outcomes of the year-long study provide a robust scoping for future research. Five strategic focus areas are proposed to support the take up of off-site and digitally enabled construction in Victoria in the short- and long-term:

1. **Comprehensive mapping of the Victorian construction ecosystem**
    - Undertake a detailed Victorian construction industry supply chain mapping with a view to innovation support and development of pathways for increased supply chain coordination. Given the complexity of the construction supply chain, and the low-level of articulation with regards industrialised building and digital-building capabilities, a 'deep-dive' review of the Victorian supply chain is recommended to map its capabilities through workshops and interviews with key actors. This mapping will present the existing capabilities, limitations, and reveal how best the ecosystem can be supported to ensure increased future collaboration, integration, and upskilling.
2. **Finance Data-Collation and Analysis for Informed Decision-Making**
    - Undertake comprehensive finance data-collation and analysis to provide insights into cost-effectiveness, financial efficiency, and opportunities for optimised resource allocation. Utilise construction projects as a source for long-term study of digitisation data capture, aiming to gain insights into the trends, challenges, and benefits of digital build adoption over time. This needs to lead into development of publicly available datasets that facilitate informed decision-making and foster industry-wide collaboration.
3. **Co-Design and Cost-Benefit Analysis of Off-Site Construction Hubs**
    - Assemble key stakeholders to collectively develop an approach for an off-site construction hub. Building on the existing strengths and resources of the selected area, co-design a place-specific hub underpinned by the principles and decision factors outlined by this research. Support the place-specific hub with a digital construction hub to support upskilling and industry ecosystem coordination.
4. **Development and Public Accessibility of the Online Decision-Making Tool**
    - Prioritise the development of an accessible and user-friendly online decision-making tool, which will play a crucial role in facilitating informed decision-making processes.
5. **Streamlined Version of the VDAS**
    - Develop a streamlined version of the Victorian Digital Asset Strategy (VDAS) that is tailored to project constraints and stakeholder capacities. This adaptation will ensure practicality and effective implementation within real-world parameters.

PROJECT #38.1
OFFSITE + MODULAR CONSTRUCTION HUBS

FINAL REPORT



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LIST OF FIGURES

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- Ynomia Pty Ltd (Matthew Lickwar)

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Disclaimer

ABBREVIATIONS

ABS	Australian Bureau of Statistics
AEC	architectural, engineering and construction
AMGC	Advanced Manufacturing Growth Centre
ARTC	Australian Rail Track Corporation
BIM	building information modelling
CAD	computer aided design
CLOS	Cross Laminated Offsite Solutions
DIH	Digital Innovation Hubs
GRP	gross regional product
GSP	gross state product
IB	industrialised building
IoT	Internet of Things
LGA	local government area
NEIC	National Employment Innovation Cluster
OPV	Office of Projects Victoria
RFID	radiofrequency identification
SEC	State Electricity Commission
SEEC	South East Economic Corridor
SME	small and medium enterprise
TAFE	Technical and Further Education
VPA	Victorian Planning Authority

EXECUTIVE SUMMARY

Project #38.1 critically examines how Construction Hubs can emerge in regional Victoria to benefit the state's construction industry, drawing on historical case studies and contextual insights.

Today's construction industry is undergoing fundamental transformation driven by digitalisation and the need for urgent decarbonisation. Contemporary advanced building methods and technologies seek to address the need for increased efficiency, safety, and sustainability. Offsite manufacturing and industrialised construction have emerged as effective strategies to drive this transformation, with well-coordinated systems promoting streamlined supply chains and enhanced stakeholder collaboration. Construction Hubs have been identified as a means of addressing the industry's fragmented nature and fulfilling the potential of offsite construction. Construction Hubs can contribute positively to Victoria's post-industrial transformation of key regions through the consideration of economic, urban, and social inclusion imperatives. Offsite construction has an impact across the building value chain, and historically, fragmented approaches to its implementation have hindered its effective realisation.

Project #38.1 explores historical successes and failures to define the prerequisites for viable Construction Hubs from both physical and digital perspectives that contribute to the evolving Industry 4.0 landscape. This project showed that these perspectives are mutually dependent for an optimal future construction industry and are supported by effective mapping of market capacity and ideation of suitable hub configurations. The integration of government and industry visions and data helps to understand externalities and advanced manufacturing, to define tangible options for Construction Hub implementation. This initiative positions Victoria at the forefront of industry innovation, fostering collaboration, investment, and sustainable growth for the state to take another step on the path to an Industry 4.0 approach to construction.

This research presents a series of recommendations for construction hubs in Victoria. The methods involved a literature review, case studies, an analysis of historical economic patterns in Victoria, and a series of workshops involving industry experts and government representatives. Results of the research include some of the key criteria for success, such as innovation, regional economic development, diversity in approaches to sustainability, and collaborative partnerships between constituent stakeholders within hubs.

Key findings

1. **Construction Hubs constitution:** The study developed a refined definitional framework outlining the drivers and elements associated with different types of Construction Hubs.
2. **Victorian case studies:** Through analysis of 3 regions in Victoria, the report offers insights into their potential as Construction Hub locations.
    - Latrobe Valley emerges as a strong linear network with well-structured with existing manufacturing and construction infrastructure.
    - Benalla could serve as a physical hub due to its established concrete infrastructure.
    - Geelong's proximity to universities, colleges, a skilled workforce, and suitable facilities makes it a compelling candidate for a dual hub.
3. **Evaluation framework:** An evaluation framework is presented guiding placed-based decision-making for Construction Hubs in Victoria, aligning with the following priorities:
    - Innovation: A key aspect of Construction Hubs is the development/testing of new approaches to traditional activities. This driver is currently concerned with identifying opportunities for digitisation, decarbonisation, and developing/validating innovative building production solutions in offsite environments;
    - Regional development: Construction Hubs are influenced by regional economic development, skills migration and scaling of local efforts aimed at the transitioning of industrial centres for offsite manufacturing and production of buildings

  - Digitalisation: A critical driver for contemporary business development and an enabler of decentralisation that is concerned with Industry 4.0 technologies
  - Sustainability: Greater understanding of the environmental impact of construction allows Construction Hubs to contribute to circular building approaches
  - Partnership: Construction Hubs can facilitate a collaborative environment between multiple stakeholders (such as private companies, governmental authorities, SMEs, universities, research centres, and investors).

Key recommendations

Leverage Existing and Potential Strengths

Based on the existing and potential strengths identified in our research, it is recommended to focus efforts and investment on existing strengths. By capitalising on these strengths, the government can maximise the impact of its investments and drive economic growth in the selected locations.

Develop Skilled Workforce

The challenge of skill shortages can be addressed by focusing on workforce development and regionally-focused skills transition programs. This includes collaborating with educational institutions to provide specialised training programs, upskilling the local workforce, and attracting skilled professionals to the region. A well-trained and competent workforce is crucial for the success and growth of the Construction Hub.

Enhance Infrastructure Connectivity

Improving infrastructure connectivity to and within the regional area involves developing and upgrading transportation networks, such as roads, railways, airports, and ports, to facilitate the movement of materials, equipment, and personnel. Ensuring reliable and high-speed digital connectivity is essential for efficient communication and collaboration in the construction industry.

Foster Collaboration and Clustering

Promote collaboration and clustering among industry stakeholders, including construction companies, suppliers, manufacturers, research institutions, and local authorities. By creating an ecosystem that encourages knowledge sharing, resource pooling, and innovation, the Construction Hub can benefit from synergies, increased efficiency, and a supportive business environment. This can be achieved through initiatives such as industrial parks, business networks, and partnerships with educational institutions.

Consider Scalability and Long-Term Planning

Scalability of Construction Hubs is a crucial factor in long-term planning. Assessing the potential for expansion and the ability to increase output in order to meet future demands will ensure that the selected locations have the capacity to grow and become nationally or internationally recognised hubs of innovation and development.

Evaluate Logistics for Increased Production

Logistics should be a key consideration when expanding the output of the Construction Hubs. Evaluate the infrastructure and transportation networks in place to support increased production and consider utilising existing infrastructure to expedite the process. This approach will enable a quicker start to production and reduce potential bottlenecks.

Staged Processes for Sustainable Development

To promote sustainable development and minimise negative impacts, it is recommended to stage certain processes. Local zoning reviews must be prioritised before undertaking significant workforce expansion. By carefully managing the sequence of actions, such as resolving housing market stress, the government can avoid exacerbating existing challenges and create a more sustainable and balanced growth trajectory.

CONSTRUCTION AND SUPPLY CHAIN IN VICTORIA

This report proposes the establishment of Construction Hubs as a targeted solution that helps the industry and government to form a holistic perspective. This section will provide essential context and historic-economic patterns, outlining the magnitude of the obstacles the Victorian construction sector must overcome to pave the way for a sustainable and prosperous future.

The state of Victoria is subject to the built environment challenges that must be addressed in innovative ways, that apply on industry-wide, and state-wide basis. One of the most pressing current needs is the rental and housing affordability crisis (Parliament of Victoria, 2023), which is not set to improve due to expected population growth in the near term (VicGov, 2016). Climate change, decarbonisation, and the need for a swift energy transition, mandates an industry future with improved resilience to climate disruption and the creation of a circular economy for building (Infrastructure Victoria, 2021b). These issues are further exacerbated by the shortage of skilled workers (Victorian Skills Authority, 2022) that imposes extra complexity in dealing with the challenges ahead. Longer-term, broader societal issues also require attention: Victoria's regions need enhanced market access and economic growth, improved connections, and better health, well-being and inclusion services (Infrastructure Victoria, 2021b).

Historic-economic development patterns

Throughout its history, the Victorian economy has undergone structural change in response to changing economic trends, transitioning from wool and gold to manufacturing and services. Industrialisation, technological progress, and urbanisation has significantly shaped the state's economic terrain.

Many countries embraced prefabrication and industrial construction post-World War II due to labour/material shortages and heightened housing demand. Initiatives such as the British Consortium of Local Authorities Special Programme rapidly assembled prefabricated structures for public use, notably to deliver social housing but quality and design suffered. While the focus on modular design drove efficiency, quality issues persisted and social housing delivery by means of prefabricated construction techniques largely came to a halt after the Ronan Point collapse of 1968. The 1980s brought a shift to high-quality, technologically-focused industrialised building methods exemplified by London's Lloyd's Building, however these initiatives were as much about experimentation and innovation as solving the global issues of the preceding decades. A refocus on industrialised building as a means of responding to problematic conditions restarted in the 2000s when increased awareness of environmental sustainability, led to a refocusing on prefabrication as a means of delivering eco-friendly structures that utilised material efficiently.

Victoria's engagement with industrialised building methods and offsite production largely follows this international story. Responding to the global issues of the mid-20th century, prefabricated building techniques and industrialised building approaches sought to ease housing shortages in the state This was exemplified in Australia by Victoria's Housing Commission 'Concrete House Project.' Despite a decline in the 1970s, prefabrication re-emerged domestically in the 2000s, when an increase in multi-unit construction was driven by rapid population growth in the state and changes in the manufacturing priorities in Victoria as the automotive sector closed down. During this period, and since, developers embraced new techniques like precast concrete and modular bathroom pods as a way to drive efficiency.

Victorian construction value chain

Victoria's construction industry contributes significantly to the state's gross state product (GSP), comprising a share of $32.7 billion or 8% of GSP (Infrastructure Victoria, 2021a). Illustrated in Figures 1 and 2, the Victorian Architectural, Engineering, and Construction (AEC) value chain comprises 99,457 businesses in 2021. Major segments include civil construction and building organisations, followed by design and consulting businesses. A key aspect to the industry identity is the large share of small businesses that underpin the building sector. Businesses that exceed 20 employees' number only 1,926, while small enterprises below 20 employees comprise 98% of the total. This base industry character can be perceived as fragile, highlighted by the Australian Federal Government's Senate Economics References Committee review in 2015 with regards to the high proportion of construction industry insolvencies that impact these small businesses (Australian Government, 2017).

A robust building industry for the future is therefore vital for Victoria's economy, yet current pressures on construction businesses are leading to rapid increases in consumer costs, uncertainty and delays (Infrastructure Victoria, 2021a). The construction sector, the fourth-largest workforce in Victoria, employs 309,800 individuals with above-average earnings, though female representation remains limited. Projections indicate a need for 34,000 new construction workers between 2022 and 2025 (Victorian Skills Authority, 2022). Given the prevalence of SMEs in the construction industry, adopting advanced technology poses financial and technical challenges. However, Melbourne's strong research collaborations make it a key player in the field. The VIC government aims to reinforce industry-research ties, facilitate transformative technologies, and bolster high-value product creation. It strives to enhance access to risk capital for advanced manufacturing, promote innovative design and engineering through procurement, and solidify Victoria's global leadership in engineered materials like fibre composites. The government's agenda also includes enhancing export capacities, attracting advanced manufacturing investments, managing energy market exposure, collaborating with the Commonwealth Government, and advocating for competitive national tax and regulatory measures (VicGov, 2017).

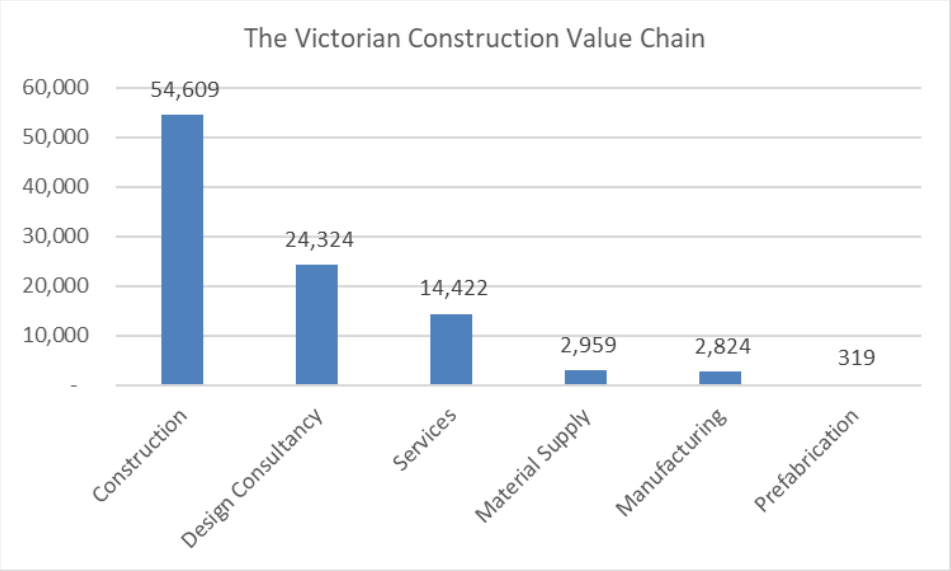


Figure 1. *Quantity of Victorian construction sector businesses per subsector*
Source: Authors using data from ABS (2022b).

Figure 2. *Quantity of Victorian construction businesses, by activity and employment size*
Source: Authors using data from ABS (2022b).

A policy of increasing the percentage of buildings that use industrialised/prefabricated methods offers potential benefits through reduced construction costs. Figure 3 shows the total annual of residential building approvals for the period of 1990 – 2022 (Australian Bureau of Statistics, 2023). These are partially adjusted for inflation as they are based on ABS deflated data, using a change volume measure approach. Based on these historic trends, a predicted future trend for 2023-33 has been plotted (the dotted line in Figure 3). The combined value of all predicted annual values for 2023-33 amounts to $348 billion. Shahzad, Mbachu and Domingo (2015) estimate that the use of prefabrication for residential construction (houses and apartments) could reduce construction costs by 20 %. This estimate suggests that mass-scale adoption of prefabrication technologies and materials could overall reduce the total cost of Victoria's residential construction by up to $70 billion over the next 10 years (20% of $348 billion).

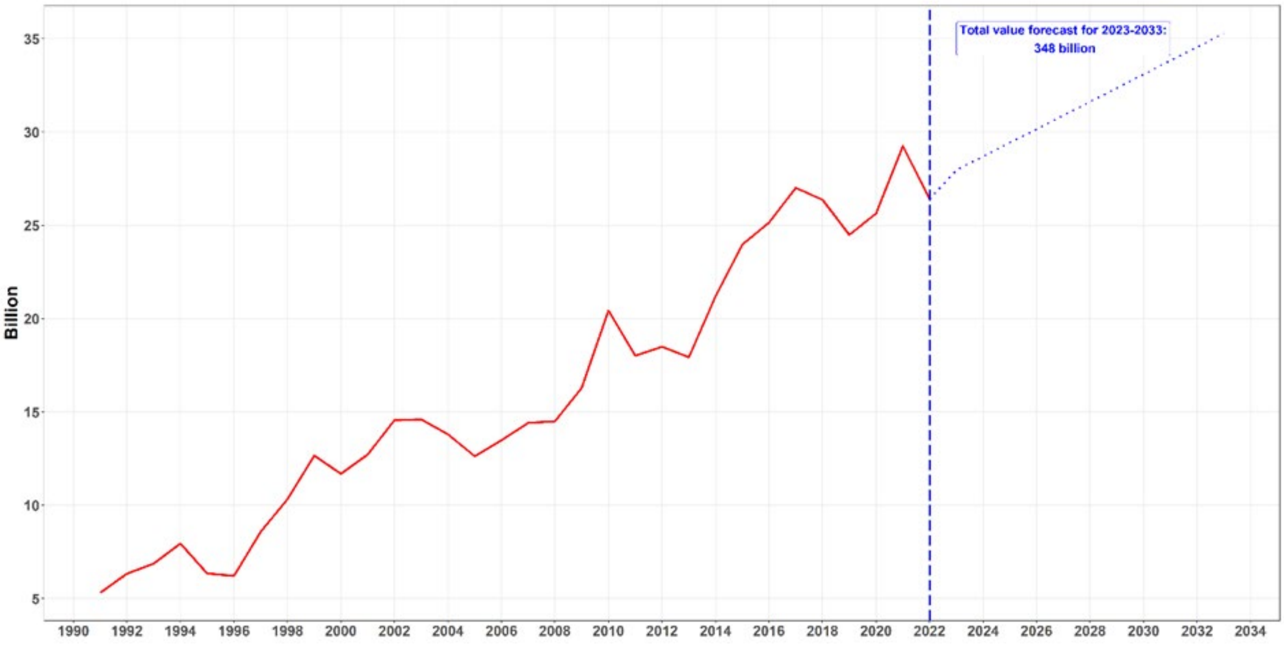


Figure 3. *Projected total value for 2023-2033 for Victoria's residential building construction*

Figure 4 presents the same type of data for the non-residential construction sector, with combined predicted annual values for 2023-33 of $234 billion. An estimated 23% reduction in construction costs of commercial buildings using prefabrication suggests that prefabrication may bring down the total cost of Victoria's non-residential construction by up to $54 billion in the next 10 years (23% of $234 billion).

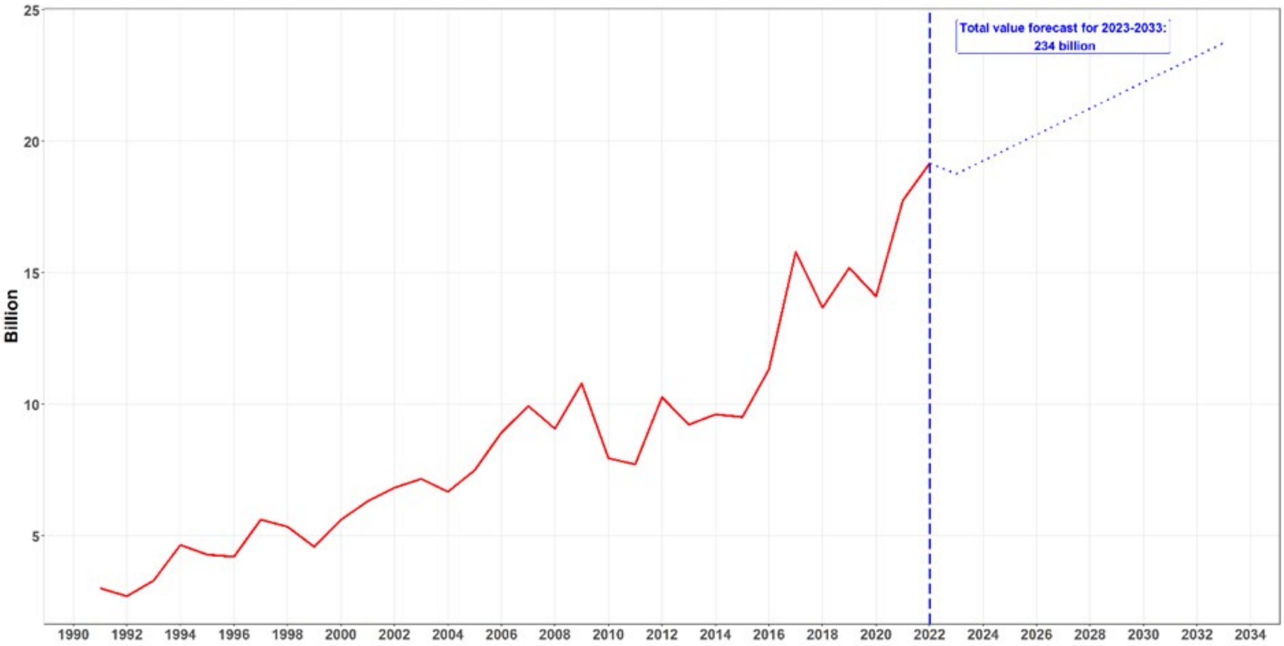


Figure 4. *Estimated total value for 2023-2033 for non-residential building construction*

Challenges of the Victorian construction sector

The building sector is complex, having influence over and being subject to multiple factors. The value chain comprises multiple industry sub-sectors across the building development lifecycle from front-end development feasibility and financing, to mid-phase design and build activities, through to late-phase occupation, asset management, and end-of-life considerations. In Victoria the key challenges for the building sector lie in addressing the housing crisis, responding to a skills gap, improving the industry's environmental impact, and working to raise persistently low productivity.

Housing shortage and affordability

Victoria is at a housing tipping point, revealed by statistics with regards housing needs and cost. The state is expected to require an additional 1.5 million new homes by 2051 (VicGov, 2016). Melbourne is facing a shortage of over 50,000 affordable private rental dwellings for those on the 20% lowest incomes, while 90% of renters in Melbourne with income in the bottom 20% experience housing stress. Social housing infrastructure fulfils the fundamental requirement of providing secure, affordable, and suitable housing for low-income Victorians, a need that the market fails to meet. In the decade leading up to 2018, the number of low-income households experiencing rental stress has increased by almost 60%, totalling over 140,000. Just 11.4% of new rentals in Victoria are affordable for individuals receiving Centrelink benefits (Infrastructure Victoria, 2021b).

Affordable, well-located housing enhances job and service accessibility. Rising house prices means that the overall rate of homeownership has decreased, particularly among low-income Victorians, at the same time the cost of renting has also increased. The COVID-19 pandemic increased pressures on regional housing increasing median rents and reducing vacancy rates as more people relocated away from Melbourne. Average weekly rents in regional areas have now become similar to those in Melbourne, making it difficult for most income-supported households to find affordable and suitable properties (Infrastructure Victoria, 2021b). Figure 5 depicts the acute rise in housing costs for low income households.

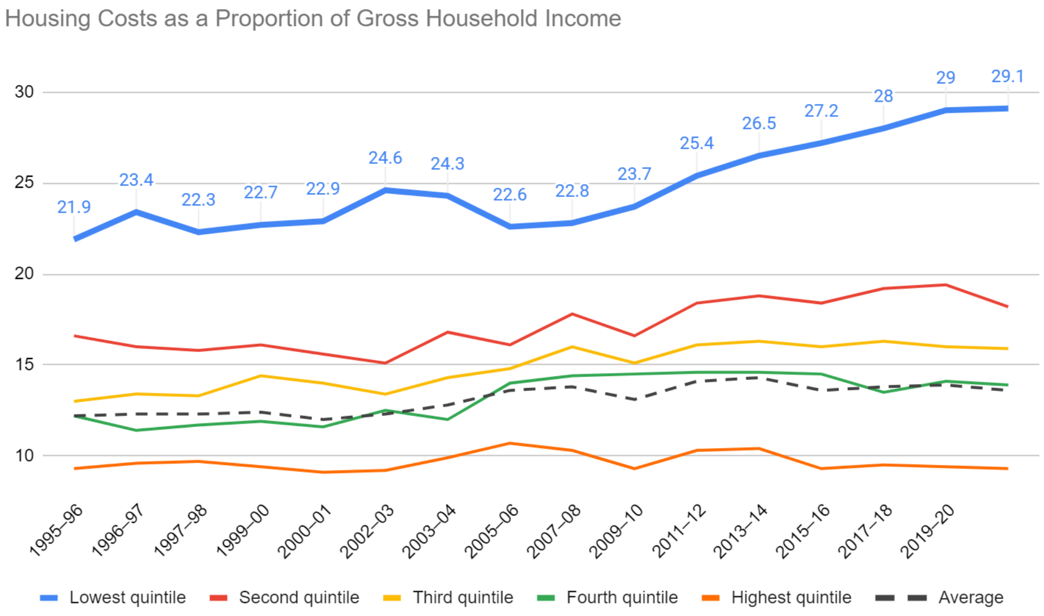


Figure 5. *Housing Costs as a Proportion of Gross Household Income*
Source: Authors using data from ABS (2022a).

The Victorian Government's $5.3 billion *Big Housing Build* program aims to construct over 9,300 new social housing dwellings, yet additional units are required to address housing needs. Achieving a state-wide provision rate of 4.5 social housing properties per 100 households by 2031 would necessitate 3,900 to 4,900 additional properties annually. Homelessness in Victoria has risen by over 40% in the past decade, with around 25,000 people experiencing homelessness on any given night, and the issue is growing in regional areas (Infrastructure Victoria, 2021b). Rural Victoria witnessed a 33.5% surge in building permits between 2019 and 2021, particularly pronounced in Gippsland with a 39.4% increase. Natural disasters have exacerbated supply chain issues, intensifying infrastructure and housing demands and depleting resources (Infrastructure Victoria, 2021a). The Master Builders Association Victoria highlights that planning approval delays and lack of clarity contribute to housing affordability challenges (Master Builders Victoria, 2017).

Jobs and skills shortage

Persistent skills shortages have emerged as a pressing issue within the construction sector, particularly in Victoria. This concern is underscored by the National Skills Commission's identification of 11 construction-related roles on its Skills Priority list, reflecting shortages and future demand. Occupations such as civil and structural engineers, surveyors, electricians, and metal fabricators are among those affected. Projections indicate a workforce growth of 34,100 by 2025, encompassing both employment expansion (19,200) and retiree replacement (14,900). However, this surge in demand is compounded by shortages in various roles, including emerging fields like energy efficiency engineering, solar installation, and digital twin technology, alongside the need for upskilling in software and technological advancements. Collaborative efforts involving government, industry, educational institutions, and more will be pivotal in addressing these challenges and ensuring a robust workforce to sustain Victoria's construction sector (Victorian Skills Authority, 2022). As a cornerstone of Victoria's economy, the construction industry's health is crucial; yet, potential impacts of strain, including cost escalation and delays, necessitate prompt attention (Better Regulation Victoria, 2021). With a workforce of 309,800, the construction sector ranks as the fourth-largest employer in Victoria, albeit with room for enhancing diversity and gender representation (Victorian Skills Authority, 2022).

Environmental impacts

Construction’s emissions as a share of Victoria’s overall emissions has grown from 1.6 to 2.8% from 2010 to 2021 (Figure 6). When considering the emissions of construction activities as well as the operational impact (including commercial and residential buildings), the building industry accounted for 27% of Victorian emissions in 2021.

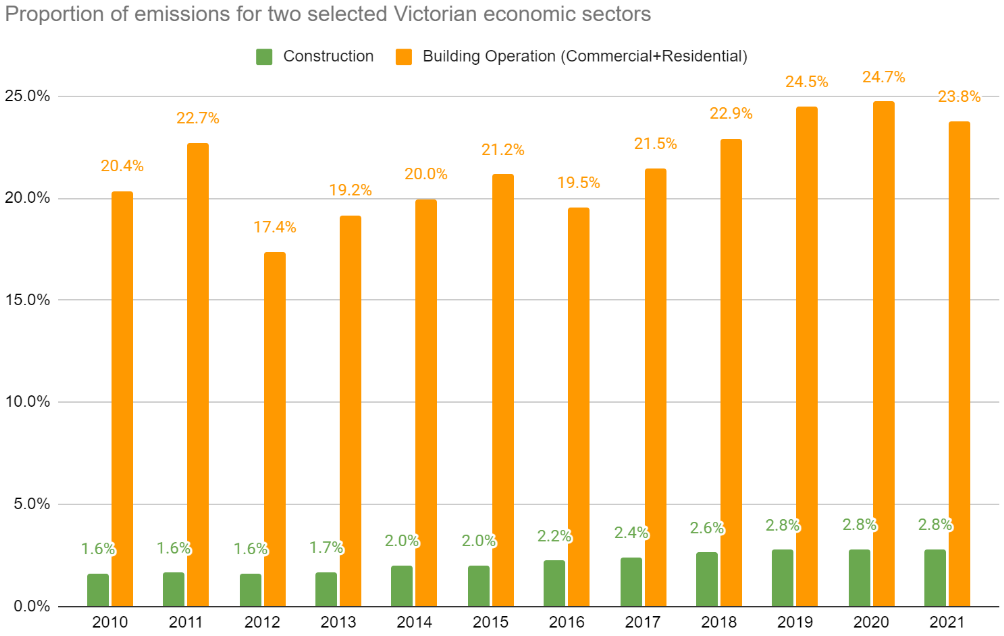


Figure 6. *Relative CO_{2e} emissions for 3 selected Victorian economy sectors*
Source: Authors using data from AusGov (n.d.).

Transport emissions

The majority of Victoria's freight is transported by road, leading to a 35% increase in the freight truck fleet over the past decade. In contrast, rail freight volume has remained relatively stagnant for many years and has even decreased for certain markets. An effective and robust freight rail system offers safer, more reliable, and environmentally friendly transportation compared with road freight. Shifting from trucks to rail can help alleviate road congestion, reduce pollution, and lower maintenance costs, especially in urban areas (Infrastructure Victoria, 2021b).

Biodiversity and forest cover loss.

Recent research challenges the notion of timber harvest being carbon-neutral or eco-friendly, revealing significant emissions from wood harvesting (Peng et al., 2023). Global land-use competition jeopardises climate and biodiversity objectives (Searchinger et al., 2023). Victoria boasts Australia's largest commercial plantation area, 421,000 hectares, with a minor 2% growth in 10 years (Infrastructure Victoria, 2021a). Most of these privately-owned plantation forests supply both export and domestic timber products. While commercial softwood plantations remain steady, hardwood plantation areas doubled between 2000 and 2018 (VicGov, 2018).

Despite elevating formal protection over 17% of its land by 2016, Victoria's native forests endure fragmentation, imperilling biodiversity and ecological services (VicGov, 2018). Wood production-related forestry operations pose a relatively minor threat to flora and fauna compared with factors like grazing and invasive species (Cameron, 2020). Supporting the transition away from native forest harvesting, the Victorian Forestry Plan and Climate Change Strategy encompass a 30-year plan and a $120 million package (Infrastructure Victoria, 2021a). Habitat loss and biodiversity decline stem from land conversion for agriculture and development. Augmenting vegetation on public and private land becomes crucial to temper heat-related challenges and bolster well-being in vulnerable areas (Infrastructure Victoria, 2021b).

Waste from construction and demolition.

Australia's National Waste Policy 2018 proposes moving towards a circular economy in Australia and emphasises waste avoidance, improved resource recovery, and greater utilisation of recycled materials and products. The National Waste Policy Action Plan 2019 establishes national targets to achieve these objectives, such as reducing waste generation per capita by 10% by 2030, achieving an average resource recovery rate of 80% by 2030, and increasing the utilisation of recycled content by government and industry (Office of Energy and Climate Change, 2023).

While Construction and Demolition waste raised its recycling rates from 76% to 81% between 2017 and 2019, there were still an estimated 852,842 tons of masonry materials, 103,622 tons of organic and timber materials, and 416,565 tons of hazardous materials disposed of in landfill in 2019 (Figure 7).

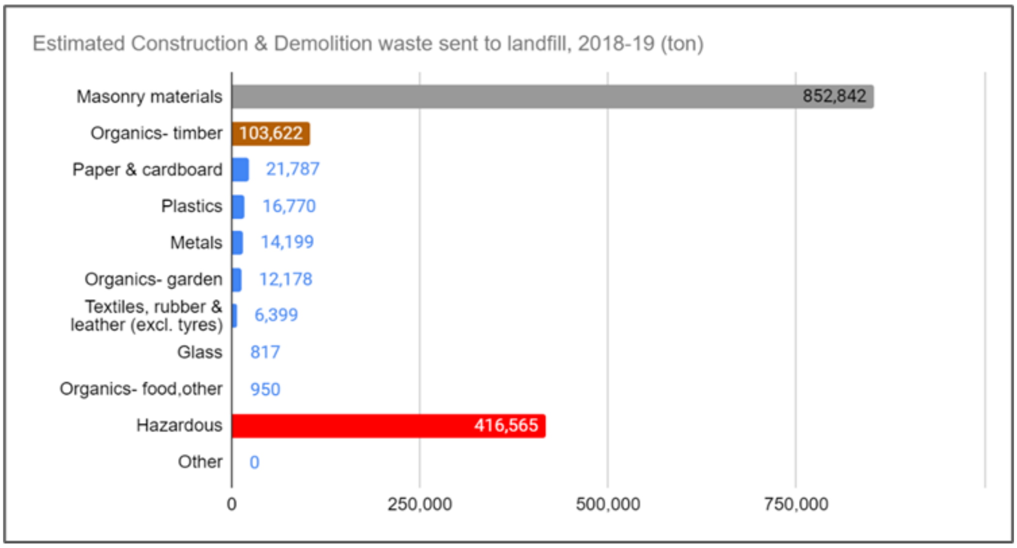


Figure 7. *Estimated construction and demolition waste disposed of in landfill in 2019*
Source: Authors using data from Pickin et al. (2020).

Low productivity

The construction industry in Victoria has faced persistently poor productivity compared with other sectors, both locally and globally (McKinsey, 2017; Deloitte, 2016). The root causes of this issue include weak collaboration within the supply chain, unreliable work planning and delivery, acceptance of high error levels, and risk passing without effective management (Marosszeky, n.d.). Most construction businesses in Victoria are small-scale, leading to limited coordination and innovation in the subcontract structure (Victorian Skills Authority, 2022). Clients' risk shedding has led to a focus on cost certainty rather than productivity improvement and value creation, hindering the implementation of Lean Production principles. The Lean supply chain initiative, emphasising collaboration and reliable commitments, offers potential for continuous improvement in project delivery (Marosszeky, n.d.).

Capabilities and Needs Assessment

The Victorian offsite supply chain represents a critical enabler for addressing the challenges faced by the building industry. The following factors have been identified as the most pressing needs to be addressed for successful establishment of Construction Hubs.

Technological Advancements	The Victorian offsite supply chain has embraced technological innovations, including building information modelling (BIM), computer aided design (CAD), and advanced manufacturing techniques. These technologies streamline design, improve precision, and facilitate seamless communication among stakeholders.
Skilled Workforce	The region benefits from a skilled workforce adept in prefabrication processes and modern construction methods. The presence of skilled labour contributes to the quality and timely production of prefabricated components.

Collaborative Ecosystem	A network of collaboration exists among manufacturers, designers, architects, and contractors. This collaborative ecosystem fosters knowledge exchange, supports innovation, and ensures a holistic approach to prefabricated construction projects.
Supply Chain Integration	Despite technological advancements, there is room for greater integration across supply chain components. Strengthening communication and coordination between raw material suppliers, manufacturers, and construction contractors can further optimise the supply chain.
Material Sourcing	While Victoria benefits from access to quality construction materials, there is potential for diversifying material sources to enhance supply chain resilience and reduce dependence on specific suppliers.
Transportation Efficiency	Improving transportation and logistics practices can minimise transportation-related delays and reduce environmental impacts, contributing to a more sustainable supply chain.

Leveraging Capabilities and Addressing Needs

To fully leverage its capabilities and address the identified needs and challenges, the Victorian offsite supply chain can benefit from targeted interventions. Strengthening workforce development through training initiatives, fostering cross-sector collaboration, and enhancing supply chain transparency can contribute to a more efficient and adaptable supply chain.

As Construction Hubs emerge as a strategic initiative, aligning these hubs with the capabilities of the existing supply chain and addressing its needs will be pivotal. The subsequent sections of this report explore the future trajectory of the prefabricated building industry in Victoria, guided by these assessments and insights, and outline recommendations to support the establishment and success of Construction Hubs.

The building and construction industry will be subject to disruption by industrialised building practice and digitalisation, and globalisation will subject Australian companies to international competition if domestic innovation does not occur rapidly (AMGC, n.d.). The Australian Government announced the creation of a Prefab Innovation Hub in 2019 to support the development of prefabrication in Australia (PrefabAUS, 2023). The hub aims to increase collaboration, enable industry transformation through innovation and technology, and improve the capabilities of the prefab business ecosystem, and is an important early move nationally. Through partnerships, an innovation network will be created by connecting the building and construction supply chain with relevant industry associations, professional bodies, universities and government agencies (AMGC, n.d.).

Industrial clustering

Companies must collaborate and share expertise with partners for enduring business success (Martel and Klibi, 2016). In construction, partnering promotes close collaboration between parties for shared objectives (Oakland and Marosszeky, 2006). The Victorian Government recommends building strong networks of mutually beneficial partnerships in supply chains to enhance productivity and innovation (VicGov, 2017).

Workforce upskilling	The AEC sector in Victoria recognises the need to attract a more diverse workforce, including women, and is committed to providing mentorship and tailored training to foster inclusivity and diversity. To address the evolving demands of advanced manufacturing and circular building practices, collaborative efforts between governments and the industry are essential in

	developing new skills related to technology and cleaner production (Victorian Skills Authority, 2022).
Shared logistics	In Melbourne, manufacturing companies tend to cluster in specific areas, creating opportunities for collaborative logistics and knowledge sharing within these clusters (VicGov, 2017). At the same time, investments in digital connectivity can open new market opportunities for businesses in regional areas of Victoria, contributing significantly to the economy and addressing unique infrastructure needs (Infrastructure Victoria, 2021b). By fostering cooperation and standardisation in the construction sector, the state can improve efficiency and ensure infrastructure decisions align with regional strengths, promoting economic growth and job creation (Infrastructure Victoria, 2020). Collaboration is also necessary to address digital connectivity gaps and enhance access to essential services, empowering businesses and communities across the state (Infrastructure Victoria, 2021b).
Standardisation	Standardisation and cooperation in the construction sector are crucial for efficiency (PrefabAUS, n.d.). Infrastructure decisions must align with regional needs and strengths, promoting economic growth and job creation (Victoria, 2020). Collaboration is necessary to address digital connectivity gaps and enhance access to essential services (Infrastructure Victoria, 2021b).
Hub location	Victoria's regions have diverse needs, and infrastructure must align with local conditions. Regional infrastructure priorities focus on economic strengths and addressing disadvantages (Infrastructure Victoria, 2020). Investments in infrastructure can boost economic development and resilience, supporting job creation and improving quality of life. Regional Victoria contributes significantly to the economy, but extreme events impact the region. Infrastructure investments must capitalise on industry strengths for effective economic growth. Improving transportation networks and digital connectivity is essential to overcome distance barriers (Infrastructure Victoria, 2021b). The focus on social housing investments aims to support vulnerable individuals. Plan Melbourne 2017–2050 integrates land use, infrastructure, and transport planning to address various challenges. The Regional Jobs and Infrastructure Fund drives recovery and growth in rural and regional Victoria (VicGov, 2021).

Advanced Manufacturing

According to the Prefabrication Hub report published by the Advanced Manufacturing Growth Centre (AMGC, n.d.), the AEC industry is ready for significant change and transformation, which means there are big opportunities for Australian companies. However, the global pioneers on implementing advanced prefab manufacturing capabilities will secure international markets. These capabilities encompass automation and digitalisation, robotics, artificial intelligence, augmented and virtual reality, the Internet of Things, and Blockchain.

Industrialised building (IB)	The Victorian Government aims to enhance productivity and sustainability in infrastructure projects by adopting advanced manufacturing and modern construction methods through IB. IB offers significant benefits, including speed, safety, sustainability, and quality. It mitigates skills shortages and allows for quick resource deployment. However, IB represents less than 5% of Australia's AEC industry, with room for growth. To facilitate IB adoption, regulatory recognition, standardisation, and support for design guidelines and training are recommended (Infrastructure Victoria, 2022; AMGC, n.d.; Gad et al., 2022).
Digitalisation	The Victorian Government is driving technology adoption in the construction sector, aiming to bolster advanced manufacturing clusters. Initiatives include supply chain enhancements, funding for new manufacturing technologies, and digital transformation promotion. Programs like Victoria's Digital Future Now and New Energy Jobs Fund improve technology in regional areas, offering broadband services and fostering job opportunities. Embracing Building Information Management, digital technologies, and Design for Manufacture and Assembly (DfMA) is crucial, with outcomes including real-world simulations and new training programs (VicGov, 2017; AMGC, n.d.; PrefabAUS, n.d.).
Innovation	Victoria's premier manufacturers excel in innovative, high-quality products, enhancing global competitiveness. Expanding high-value manufacturing and cultivating design-led culture and engineering expertise are paramount. R&D collaborations between businesses and research communities foster innovation, supported by funding and infrastructure accessibility. The government encourages industry-research initiatives, fosters entrepreneurship, and drives innovation in new energy technologies through programs like C4NET (VicGov, 2017).

Smart Prefab and Industry 4.0

In Victoria, the *Big Housing Build* is a transformative initiative investing $5.3 billion to construct over 12,000 new dwellings for social and affordable housing. The project aims to provide housing for those in need, including Aboriginal Victorians, pensioners, disabled individuals, and family violence victims. The new homes will be energy-efficient, offering tenants lower power bills. The investment is expected to generate $6.7 billion in economic activity and create job opportunities for apprentices and trainees. A quarter of the investment will be in regional areas, ensuring $1.25 billion for 18 local government areas. There will also be significant investments in renewable energy to achieve emissions reduction targets and enhance climate resilience (VicGov, 2021).

Low Carbon, Circular Building strategy

The Victorian Government is actively pursuing a carbon-neutral and circular building strategy, aiming to reduce waste, emissions, and create economic benefits. Key actions include achieving net-zero greenhouse gas emissions by 2050, powering all government operations with 100% renewable electricity by 2025, enhancing natural environments, and implementing the circular economy policy "Recycling Victoria: a new economy." Initiatives like the Recycled Markets Acceleration Package and Recycled First program support strong markets for recycled materials, while investments in infrastructure and research expand these markets over time. The strategy recognises infrastructure's broader role, addressing economic productivity, social equity, and environmental concerns, preparing Victoria for global shocks and disruptions while fostering a resilient and sustainable future. Finding pathways, systems, and supports that enable a circular future for the building industry is a key need for the sector.

DRIVERS AND ELEMENTS OF CONSTRUCTION HUBS

The composition of Construction Hubs is critical, their definition and the intricacies of what drives their effective establishment and function must be clearly understood. Through a comprehensive literature review and market analysis, an understanding of the drivers and definitions of Construction Hubs is presented in order to examine their role in the industry's growth and development. Moreover, the identification of the benefits that Construction Hubs offer is presented alongside potential barriers and challenges that may arise during their implementation. This exploration sets the stage for informed and effective decision-making that will foster the growth and sustainability of the construction sector in regional areas of Victoria.

Definition of Construction Hubs

In the rapidly evolving landscape of modern manufacturing, the concept of Construction Hubs has emerged as a vital catalyst for growth and efficiency. These hubs encompass a wide array of functions, serving as the central "glue" that binds various elements in the value chain. They play a pivotal role in income generation, particularly in the context of the evolving service-oriented manufacturing paradigm. This shift towards service-centric manufacturing emphasises the significance of hubs that facilitate logistics, finance, communication, back-office operations, as well as research and development (R&D), and design and engineering activities. Such integration of key functions empowers manufacturing enterprises to adapt swiftly to emerging challenges and leverage data-driven insights from marketing and distribution activities.

Moreover, the concept of hubs extends beyond the manufacturing sphere, with applications in diverse sectors such as traffic management and smart cities. In various contexts, hubs serve as switching, sorting, connecting, and consolidation facilities, delivering a range of advantages, including lower transportation costs, improved network efficiency, and enhanced service quality. In the domain of smart manufacturing or manufacturing 4.0, the integration of advanced technologies, data analytics, and sustainable practices further underscores the importance of hubs in resource sharing and creating effective manufacturing and logistics networks.

Drivers of Construction Hubs

Multiple drivers underpin the establishment and success of Construction Hubs:

I. **Innovation:** Construction Hubs play a crucial role in fostering new approaches to traditional activities within the construction industry. This driver is focused on identifying opportunities for digitisation, decarbonisation, and the development and validation of innovative building production solutions in offsite environments.

II. **Regional Development:** The influence of regional economic development and skills migration contributes to the scaling of local efforts in transitioning industrial centres for offsite manufacturing and building production. Construction Hubs can act as catalysts for regional growth and prosperity.

III. **Digitalisation:** Contemporary business development heavily relies on digitalisation and the adoption of industry 4.0 technologies. Construction Hubs serve as enablers of decentralisation by leveraging these digital advancements.

IV. **Sustainability:** Growing awareness of the environmental impact of construction activities drives the potential for Construction Hubs to establish circularity building approaches. Through increased efficiency in material usage and processes, Construction Hubs can contribute to more sustainable practices.

V. **Partnership:** Collaboration among stakeholders is a fundamental aspect of an effective Construction Hub. These stakeholders include private companies, governmental authorities, SMEs, universities, research centres, and investors. Construction Hubs must prioritise and facilitate multi-partner collaboration to achieve their objectives.

The integration of these drivers into the planning and implementation of Construction Hubs holds the potential to revolutionise the construction industry. By harnessing innovation, embracing digitalisation, fostering regional development, promoting sustainability, and fostering robust partnerships, Construction Hubs can become transformative forces in modernising the construction sector and driving it towards a more sustainable and efficient future.

Construction Hubs constitution

This section unveils the realm of Construction Hubs, encapsulating their governance models, business structures, activities, and establishment categories (Figure 8).

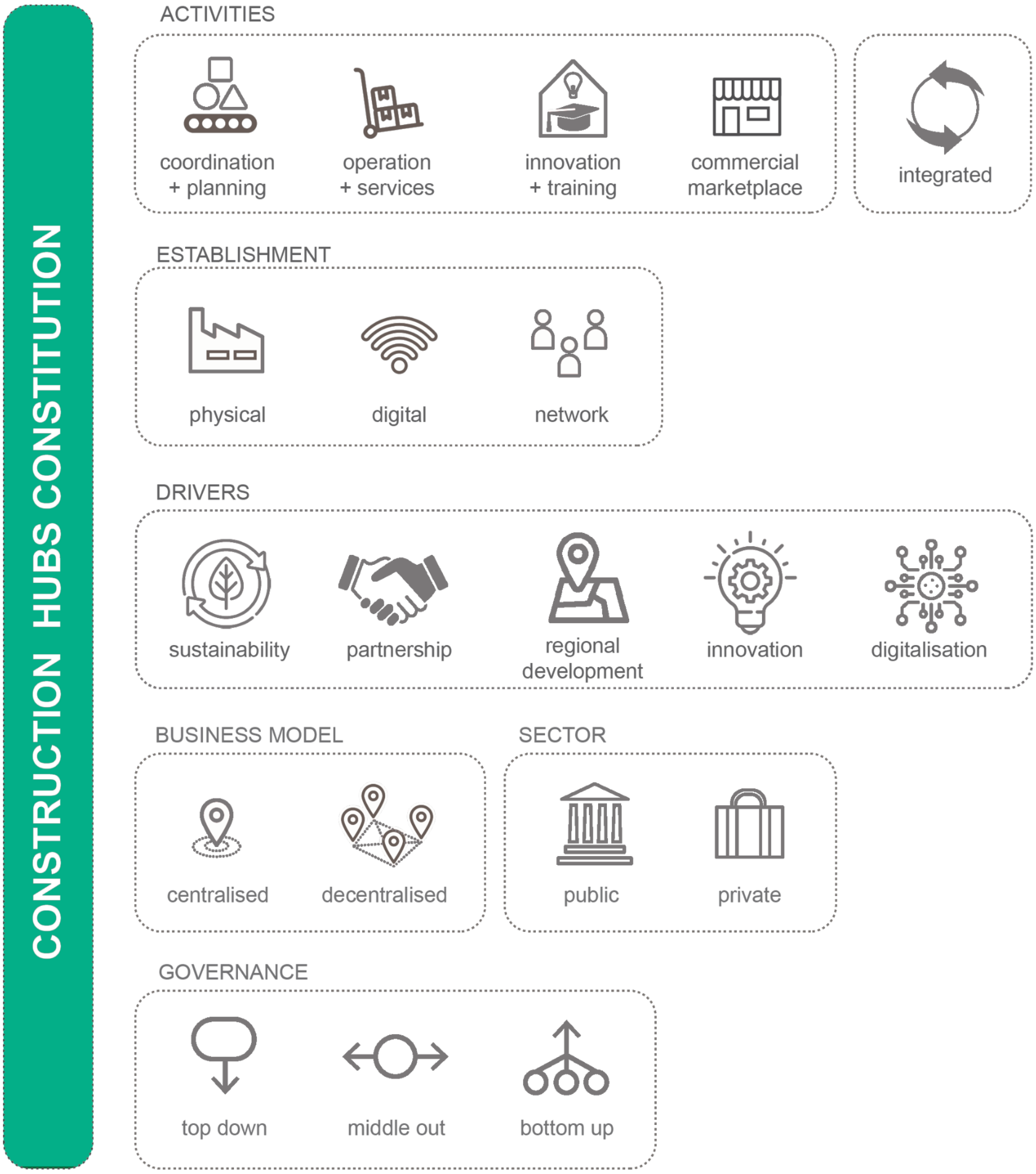


Figure 8. *Constitution of Construction Hubs.*

Activities and functions

Figure 9 shows a summary of Construction Hubs type based on activities and functions, which will be unpacked in the upcoming sections.

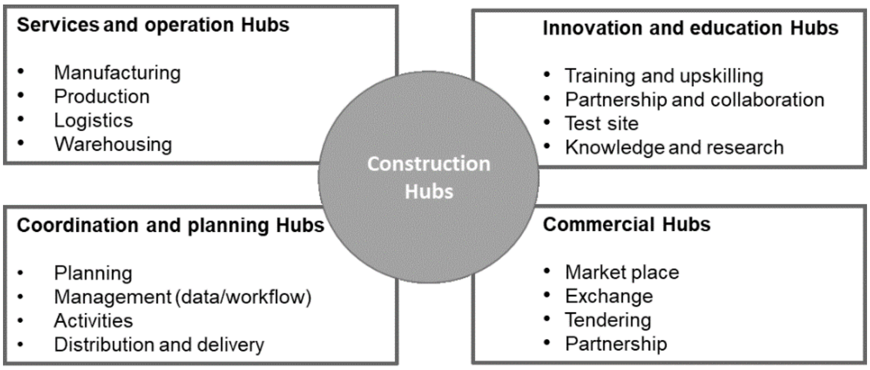


Figure 9. *Summary of Construction Hubs type based on activities and functions*

Innovation and Education Construction Hubs

Most common in Europe (e.g., Digital Innovation Hubs (DIH) program), innovation/education hubs unify regionally-embedded actors (such as universities, research centres, competence centres, private companies, incubators and start-up accelerators, clusters, governmental authorities, SMEs, investors and large organisations) to promote multi-partner collaboration. These hubs enable stakeholders to access the latest knowledge, expertise, and technology for testing and experimenting with innovation relevant to products, processes, or business models.

Partnership and Collaboration

Partnership and collaboration are common in Europe through programs like DIHs (example in Figure 10). Such programs bring together regional actors such as universities, research centres, private companies, incubators, clusters, and governmental authorities. The strength of Innovation and education Construction Hub programs lies in promoting multi-partner collaboration to address the following functions:

- Developing new digital technologies that meet regional/local demand.
- Removing institutional barriers that hinder Industry 4.0 advancements.
- Aligning the interests of local industries.
- Creating awareness of the need for change.
- Offering technological support for the development of new technologies to facilitate the transition.
- Coordinating actors across local industries with a goal of cross-industry fertilisation.
- Creating synergies among actors within the innovation and collaboration platform.
- Legitimising new digital paradigms in their respective regions.

The aim is to create knowledge exchange platforms and collaboration-based networks that can experiment, test, create, recombine, and disseminate new knowledge for the transition into Industry 4.0. This approach emphasises bottom-up collaboration, open innovation, and place-based initiatives.

Test Sites

Test sites enable businesses to access the latest knowledge, expertise, and technology for testing and experimenting with digital innovations relevant to their products, processes, or business models. They act as front office points, boosting digital technologies for companies by offering digital technology testing or pilot project experimentation. They connect local networks of actors, such as chambers of commerce, universities, trade associations, accelerators, incubators, SMEs, startups, research organisations, and investors, while also facilitating access to external factors beyond the region. Test sites involve networks that perform testing, demonstration, and development of applications and solutions for existing regional industries. Leading actors are selected at the regional level to test, experiment, and develop specific digital technologies, providing cost-effective access to specialist experimentation, testbeds, and production facilities.

Knowledge and Research

Innovation and education Construction Hubs play a vital role in creating awareness about the business potential of digital technologies. They engage in activities such as innovation scouting, visioning and strategy development, and working with companies to assess their digital maturity and develop appropriate plans. They also conduct research on the synergies between digital technologies and other key enabling technologies, such as biotech and advanced materials. They signal the necessity for digital technology adoption, legitimise new paradigms, increase awareness, and align the interests of local industries. Innovation activities within Innovation and education Construction Hubs involve identifying opportunities for digitisation and developing and validating innovative solutions.

Upskilling and Training

Innovation and education Construction Hubs have the ability to assess current and future skills needs, providing appropriate training and upskilling programs. They can also help companies assess their competencies, apply solutions, evaluate business implications, and manage resultant changes. Additionally, they offer mentoring support and consulting on finance. They focus on developing a collective understanding of new digital technologies and contribute to business development in the field of Industry 4.0. Innovation and education Construction Hubs possess expertise in various digital technologies, including IoT, robotics and autonomous systems, data mining and big data, simulation and modelling, artificial intelligence and cognitive systems, cyber-physical systems, augmented and virtual reality, sensors, interaction technologies, and cloud computing.

In its mission to drive transformation in the construction sector, this initiative seeks to enhance the adoption of manufacturing and digital approaches, ultimately improving infrastructure delivery, resilience, and performance for the benefit of current and future generations. Supported by the Government and in collaboration with founding partners like the Manufacturing Technology Centre (MTC) and the BRE, it engages with an extensive network of over 600 organizations, including industry bodies, policymakers, practitioners, and academics, as part of the Transforming Construction Challenge. The primary objective is to continue advancing the construction industry, cultivating a market with the capacity and capability required to ensure the sector's future while addressing the increasingly complex needs of infrastructure projects. This holistic program integrates digital and manufacturing advancements and promotes value-based decision-making to enhance sector productivity, economic viability, and long-term resilience.

Figure 10. *Construction innovation hub — UK*

Services and Operation Construction Hubs

As the most conventional form of hub, services/operations hubs are centres for the aggregation of traditional construction activity — often focused on offsite building activity; they are essential to addressing the labour-intensive and product-oriented nature of construction activities. In addition to production and manufacturing, such structures provide the ability to effectively store raw materials, components, work-in-process, and finished goods, operate as distribution and order fulfilment centres, perform localised and value-added warehousing (example in Figure 11).

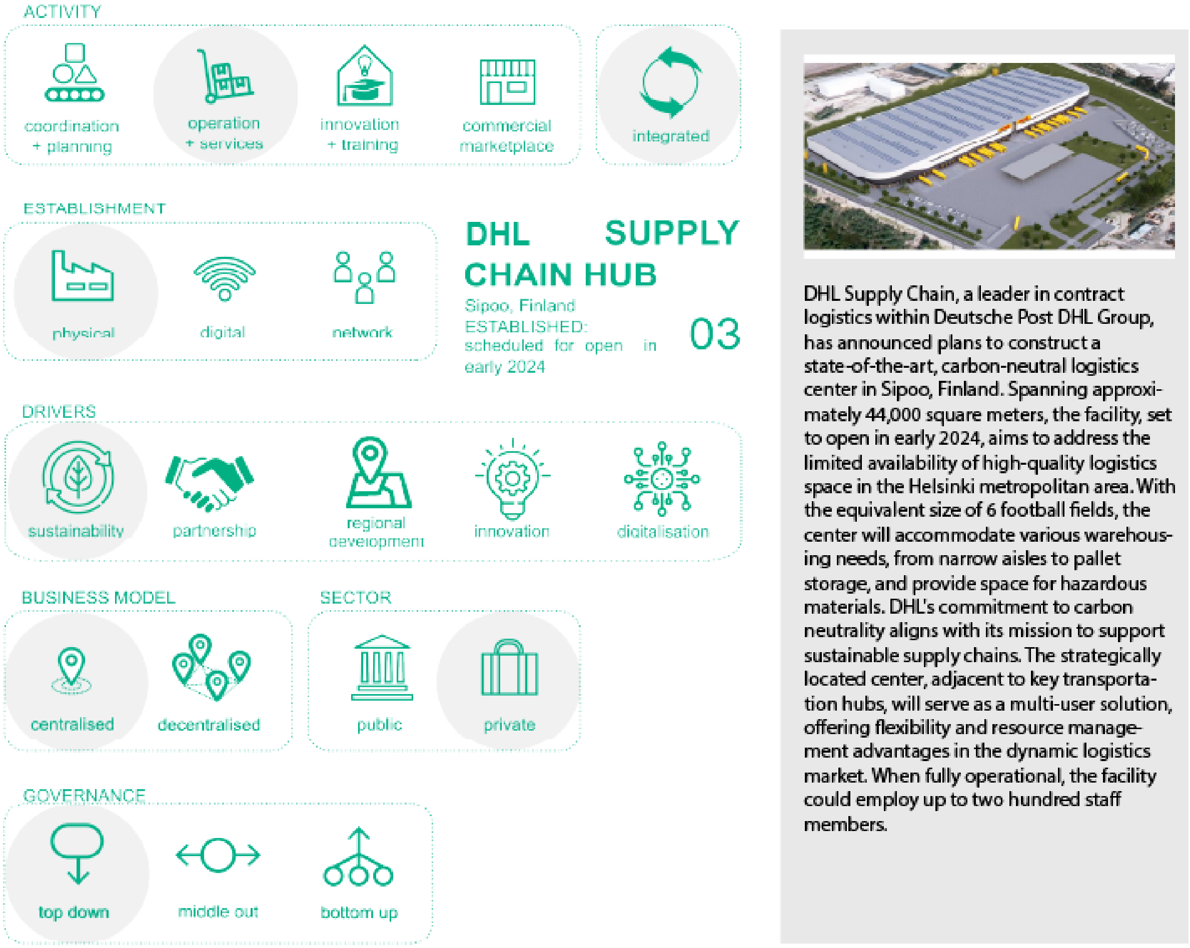
Logistics play a crucial role in the smooth functioning of services and operation hubs. Here are some key considerations when it comes to logistics:

- Identify Loading and Unloading Zones and Warehouses: This knowledge helps streamline the movement of goods and ensures timely deliveries.
- Quantify Time-Cost for Consignment Processing: Measuring the average time it takes to process a consignment is essential for evaluating logistics efficiency. By quantifying this time-cost, companies can identify bottlenecks and implement strategies to optimise the process.
- Assess Customs Posts Capacity: Understanding the capacity of customs posts is crucial for managing international logistics. By gauging their capacity, companies can plan shipments accordingly, minimising delays and avoiding congestion.
- Monitor Shipment Schedule and Vehicle Arrivals: This information allows for better coordination and ensures that goods are transported in a timely manner.
- Utilise Digital Documentation: In the digital age, logistics hubs can benefit from remote uploading of shipping invoices, contracts, product specifications, and other necessary documents. This digital approach ensures efficient and legal transportation of goods, reducing paperwork and streamlining processes.
- Implement Smart Contracts: Smart contracts facilitate transportation agreements between customers (senders or recipients) and logistics companies. By leveraging smart contracts, operations hubs can automate and optimise transportation processes, enhancing efficiency and reducing manual errors.
- Control and Forecast Supply Cycles: Accurate supply cycle control and forecasting are essential for efficient logistics. By leveraging data and analytical tools, operations hubs can proactively manage inventory, optimise resource allocation, and minimise disruptions.
- Streamline Material Flow and Minimise Waiting Times: This can be achieved through strategic planning, optimising routes, and implementing real-time tracking technologies such as QR codes, barcodes, and RFID tags.
- Manage Seasonal Fluctuations: Various businesses experience seasonal fluctuations in demand. Logistics hubs should be prepared to manage these fluctuations efficiently by adjusting inventory levels, transportation capacity, and workforce accordingly.
- Optimise Resource Allocation and Automation: Optimising logistics resource allocation, improving warehouse management, and increasing automation levels are key objectives for operations hubs. By adopting advanced technologies and optimising processes, logistics efficiency can be significantly enhanced.

Warehouses within services and operation hubs serve vital functions. Here are some considerations for warehouse operations:

- Storage and Distribution: Warehouses provide storage for raw materials, components, work-in-process, and finished goods. They also operate as distribution centres, facilitating order fulfilment and timely deliveries.
- Value-Added Warehousing: In addition to storage and distribution, warehouses can offer value-added services such as customisation, labelling, packaging, and quality control. These value-added services enhance the overall customer experience.
- Strategic Data Implementation: Warehouses can leverage strategic data and models to make informed decisions. By implementing data-driven processes, warehouses can optimise inventory management, streamline operations, and improve overall efficiency.
- Smart Warehouse Implementation: Developing a smart 3-dimensional warehouse enables the informatisation process through technologies like RFID and the Internet of Things (IoT). This approach ensures that the right materials reach the right stations or locations at the right time, enhancing operational effectiveness.

- Inventory Management and Control: Effective warehouse design and optimisation require robust inventory management and control. By implementing efficient inventory management systems, warehouses can reduce costs, minimise stockouts, and improve order accuracy.



DHL Supply Chain, a leader in contract logistics within Deutsche Post DHL Group, has announced plans to construct a state-of-the-art, carbon-neutral logistics center in Sipoo, Finland. Spanning approximately 44,000 square meters, the facility, set to open in early 2024, aims to address the limited availability of high-quality logistics space in the Helsinki metropolitan area. With the equivalent size of 6 football fields, the center will accommodate various warehousing needs, from narrow aisles to pallet storage, and provide space for hazardous materials. DHL's commitment to carbon neutrality aligns with its mission to support sustainable supply chains. The strategically located center, adjacent to key transportation hubs, will serve as a multi-user solution, offering flexibility and resource management advantages in the dynamic logistics market. When fully operational, the facility could employ up to two hundred staff members.

***Figure 11.** DHL supply chain hub — Finland*

Coordination and Planning Construction Hubs

The construction industry relies on effective coordination between numerous organisations and stakeholders across the value chain. Coordination hubs play a crucial role in facilitating various structured activities, including planning, data and workflow management, material and product distribution, and delivery. These hubs ensure smooth operations and efficient project execution.

In urban and densely built-up areas, where space is limited, optimising the use of areas for unloading, loading, and manoeuvring becomes essential to avoid bottlenecks. Delivery, storage, and disposal processes must run seamlessly, often operating on a just-in-time basis. Coordination hubs specialise in managing and overseeing all aspects of material and personnel logistics on construction sites. Tasks such as access control, signage, marking, and transportation of material deliveries to their designated locations require careful planning and execution. To ensure efficient operations, innovative planning tools are employed by coordination hubs. For example, Swiss Post utilises advanced planning tools to facilitate orderly processes and skilled coordination in construction site logistics. They prioritise site safety, as well as occupational safety and fire protection measures, to create a secure working environment. By centralising and coordinating various activities, coordination hubs play a vital role in streamlining operations, enhancing productivity, and improving overall project outcomes in the construction industry (example in Figure 12).

The Construction Logistics Hub by Swiss Post is a strategic initiative aimed at improving the efficiency and sustainability of construction projects. These hubs centralize the sorting and assembly of building materials, allowing for just-in-time delivery to construction sites, reducing on-site storage needs, and optimizing traffic routes for construction-related transportation. Many of these hubs, including those operated by Swiss Post, prioritize sustainability by using electric vehicles (e-trucks) for material transport, resulting in reduced environmental impact and noise disruption. The streamlined logistics process helps alleviate space constraints on construction sites, contributing to smoother and more efficient operations.
Key features include:

- Material Sorting and Assembly
- Just-in-Time Delivery
- Traffic Optimization
- Reduced Environmental Impact
- Noise Reduction
- Space Efficiency

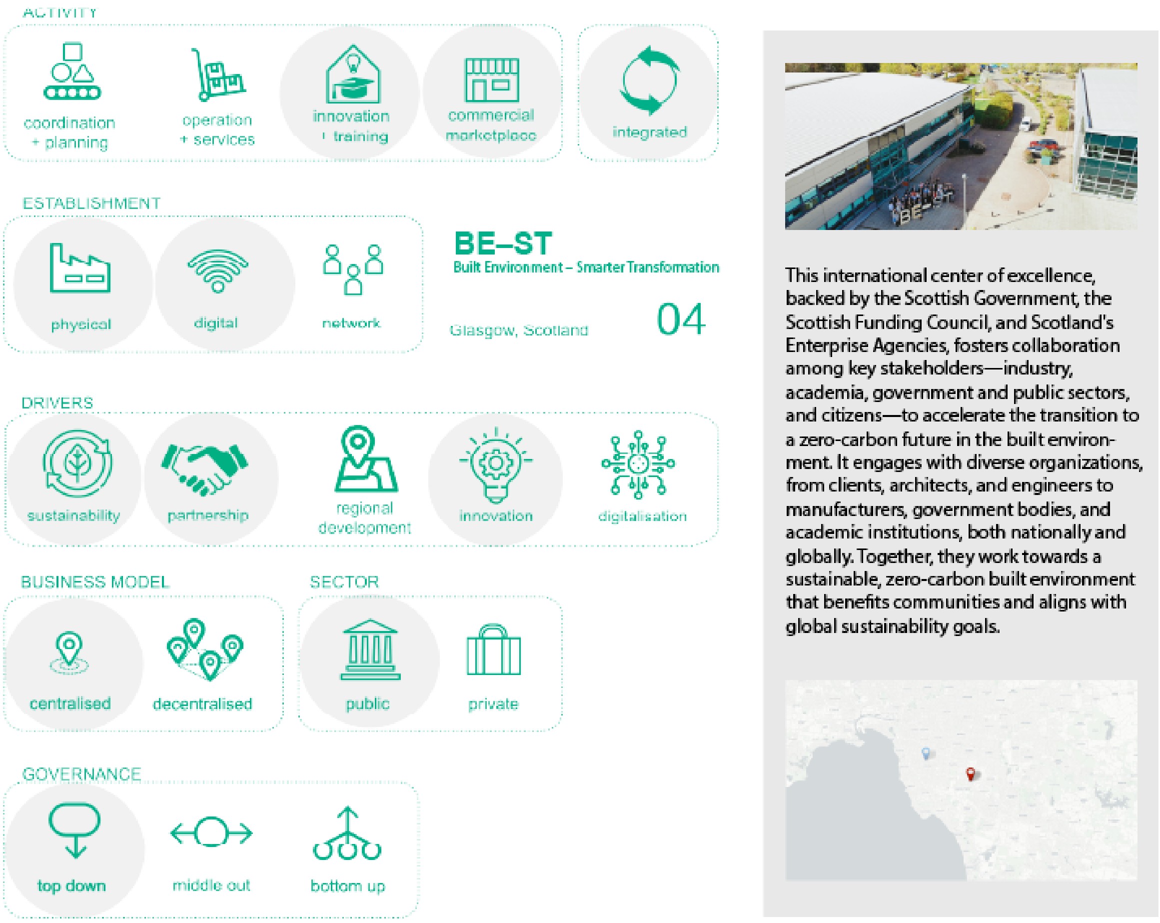
Figure 12. *Construction logistics hub — Switzerland*

Commercial Construction Hubs

Commercial hubs in the construction industry serve as dynamic platforms that foster collaboration and growth for businesses. These hubs provide a conducive environment for businesses to connect, interact, and form partnerships with other companies operating in similar or closely related fields (example in Figure 13).

One of the primary activities within commercial hubs is tendering. They serve as centralised platforms where construction companies can access and participate in tendering processes. These hubs provide a streamlined and transparent system for submitting bids and proposals, allowing businesses to compete fairly for construction projects. By offering a centralised tendering process, commercial hubs simplify and expedite the procurement process, benefiting both contractors and project owners. Another significant aspect of commercial hubs is the promotion of commercial exchanges. These hubs create opportunities for businesses to showcase their products, services, and capabilities to a wider audience. Through digital marketplace platforms, companies can market and advertise their offerings, attracting potential clients and collaborators. This exchange of commercial information and opportunities helps businesses expand their networks, find new customers, and forge strategic partnerships within the construction industry.

Partnership development is another crucial activity facilitated by commercial hubs. These hubs bring together diverse stakeholders, including construction companies, suppliers, contractors, designers, and technology providers. By fostering collaboration and relationship-building, commercial hubs enable businesses to form partnerships that leverage each other's strengths and expertise. These partnerships can range from joint ventures on specific projects to long-term collaborations aimed at innovation and growth in the construction industry.



This international center of excellence, backed by the Scottish Government, the Scottish Funding Council, and Scotland's Enterprise Agencies, fosters collaboration among key stakeholders—industry, academia, government and public sectors, and citizens—to accelerate the transition to a zero-carbon future in the built environment. It engages with diverse organizations, from clients, architects, and engineers to manufacturers, government bodies, and academic institutions, both nationally and globally. Together, they work towards a sustainable, zero-carbon built environment that benefits communities and aligns with global sustainability goals.

Figure 13. *BE-ST hub — Glasgow, UK*

Governance

A Construction Hub can be characterised by different governance models: top-down, middle-out, and bottom-up. These models describe the way the hub is initiated, funded, and the direction of influence within the construction industry ecosystem.

Top-Down	The top-down approach involves a central authority or governing body setting the agenda, priorities, and guidelines for the Construction Hub. They provide the initial funding, infrastructure, and support to establish the hub. The focus is on strategic planning, standardisation, and alignment with broader economic and developmental goals. Smaller businesses and SMEs in the construction industry then uptake and follow the initiatives set by the top-down governance, adhering to the guidelines, regulations, and standards set by the governing body. They may receive support, incentives, and opportunities provided by the government or larger organisations to enhance their capabilities and competitiveness.
Middle-Out	In a middle-out governance model, the Construction Hub is driven by collaboration and partnership between different stakeholders in the industry ecosystem. It involves a mix of larger organisations, industry associations, academic institutions, and government bodies working together to establish and govern the hub. Under a middle-out governance model, the initiative and funding may come from multiple stakeholders, including industry associations, research institutions, or regional development agencies. These stakeholders collaborate to identify common challenges, set goals, and develop strategies to address them collectively. This approach emphasises collaborative decision-making, shared responsibilities, and mutual benefits. It seeks to create an inclusive and

participatory environment where different stakeholders contribute their expertise, resources, and perspectives. The hub's governance structure may involve committees, working groups, or partnerships to ensure collective decision-making and representation.

Bottom-Up In a bottom-up governance model, the Construction Hub is initiated and driven by smaller organisations, local businesses, or grassroots initiatives within the construction industry. It starts with the smaller organisations identifying common challenges, opportunities, or needs and taking the lead in establishing the hub. They may also come together to share resources, knowledge, and best practices, or to address specific local or industry-wide issues. The bottom-up approach values local knowledge, innovation, and community engagement. It encourages active participation, self-organisation, and grassroots leadership. As the hub gains traction and success, larger organisations and government entities may recognise its value and start to follow and support the initiatives driven by the smaller organisations.

Establishment

A Construction Hub can be categorised based on its establishment into 3 types: physical, digital, and hybrid. Each category represents a different approach to facilitating construction-related activities and fostering collaboration within the industry.

Physical A physical Construction Hub refers to a physical location or facility specifically designed and dedicated to supporting construction-related activities. In a physical Construction Hub, companies can rent office spaces, meeting rooms, or co-working spaces to establish a physical presence. This allows for face-to-face interactions, networking opportunities, and a sense of community among industry professionals. Physical hubs often provide additional amenities such as conference facilities, training rooms, and exhibition spaces to support events, workshops, and industry gatherings. These hubs may also include physical infrastructure and resources tailored to the construction sector, such as model rooms, material showcases, and equipment demonstration areas. They serve as a hub for showcasing construction technologies, innovative materials, and building techniques, enabling industry professionals to explore and experience these advancements firsthand.

Digital A digital Construction Hub operates primarily in the online realm, utilising digital platforms, websites, and virtual spaces to connect construction professionals and facilitate collaboration. It leverages technology to create a virtual hub where industry participants can interact, share knowledge, access resources, and engage in digital transactions. Digital hubs may provide online marketplaces where businesses can showcase their products and services, browse available opportunities, and engage in e-commerce activities related to the construction industry. These platforms enable efficient communication and collaboration, allowing professionals from different locations to connect and work together remotely. Digital hubs also serve as repositories of industry-specific information, providing access to databases, research materials, best practices, and educational resources.

Hybrid A hybrid Construction Hub combines elements of both physical and digital hubs, offering a flexible and versatile approach to supporting construction-related activities. It provides a blend of in-person interactions and online connectivity to cater to the diverse needs and preferences of industry professionals. Hybrid hubs may have a physical location where stakeholders can meet, collaborate, and access on-site resources. However, they also leverage digital platforms and technologies to extend their reach and enhance connectivity. This allows for a seamless integration of physical and virtual interactions, enabling participants to connect both offline and online. Hybrid hubs often provide a comprehensive ecosystem that encompasses physical spaces, online platforms, and digital tools. They offer a range of services such as co-working spaces, virtual meeting rooms, online collaboration tools, and access to digital resources.

Business model

A Construction Hub can be understood from the perspective of a centralised or decentralised business model.

Centralised	In a centralised business model, the hub operates as a central point of control and coordination for various construction activities. It acts as a central authority or entity that governs and manages the operations, resources, and decision-making processes within the hub. In this model, key functions such as project management, procurement, resource allocation, and decision-making are consolidated and handled by a central entity. This entity may be a government agency, a large construction firm, or a specialised construction management organisation. The centralised hub has a clear hierarchical structure, with top-down decision-making and centralised control over project execution. This model allows for standardised processes, efficient resource allocation, and consistent project oversight. It also enables economies of scale and centralised expertise in areas such as project planning, risk management, and quality control.
Decentralised	A decentralised hub involves multiple entities or stakeholders working together in a networked fashion, each contributing their expertise, resources, and capabilities to the Construction Hub. In this model, decision-making authority and project responsibilities are distributed among different entities or organisations. These entities can include construction companies, subcontractors, suppliers, and specialised service providers. Collaboration and coordination among these entities are facilitated through shared information, open communication channels, and collaborative platforms. It promotes collaboration, innovation, and flexibility, allowing for local expertise and responsiveness to specific project requirements.

The benefits, barriers and challenges associated with establishing Construction Hubs are summarised in Figure 14.

BENEFITS

Economic Growth and Job Creation: Construction hubs stimulate economic growth in regional areas by attracting construction projects and related businesses. They generate employment opportunities, both directly in construction activities and indirectly in supporting industries such as transportation, logistics, and hospitality. The presence of construction hubs can boost local economies and contribute to the overall prosperity of the region.

Infrastructure Development: Regional construction hubs play a crucial role in developing and upgrading local infrastructure. They attract investments in infrastructure projects, such as roads, bridges, utilities, and public facilities, which contribute to improved connectivity and quality of life in the region. Construction hubs also facilitate coordination and collaboration among stakeholders involved in infrastructure development, ensuring efficient project delivery and the effective utilisation of resources.

Skill Development and Training: Construction hubs often provide training and upskilling programs for the local workforce. This helps develop a skilled labour pool within the region, enhancing employment prospects and career advancement opportunities for residents. By offering training in new technologies and construction methods, hubs contribute to the professional development of workers and increase their competitiveness in the job market.

Enhanced Local Supply Chain: By centralising construction activities, hubs create opportunities for local suppliers and contractors to participate in projects. This strengthens the regional supply chain and encourages the growth of local businesses. Construction hubs can promote local procurement policies, fostering the use of regional resources and supporting the development of a sustainable construction ecosystem.

Knowledge Transfer and Innovation: Construction hubs act as knowledge-sharing platforms, promoting collaboration and innovation within the regional construction industry. They facilitate the exchange of ideas, best practices, and research outcomes among industry professionals, local businesses, academic institutions, and government agencies. This knowledge transfer drives innovation, supports the adoption of advanced construction techniques, and fosters the development of sustainable and resilient infrastructure in the region.

Community Development and Social Impact: Construction hubs often engage with local communities and stakeholders, ensuring that construction activities align with community needs and aspirations. They may contribute to social initiatives, such as affordable housing, community centres, or sustainable development projects, enhancing the overall social impact of construction in the region. Hubs can also serve as catalysts for community revitalization and urban regeneration, transforming underutilised areas into vibrant and sustainable spaces.

CHALLENGES

Overcoming Existing Practices: The construction industry has established traditional practices that need to be adapted and integrated into the new construction hub framework. Overcoming resistance to change and promoting innovative approaches is essential.

Interstate/Regional Differences: Different Australian states have varying ecosystems and construction practices, leading to contrasting challenges for each hub location. Addressing these regional differences while creating a cohesive approach is necessary.

Labour and Skill Shortages: The availability of skilled labour is critical for the success of construction hubs. Addressing skill shortages and investing in workforce development and upskilling initiatives are necessary to ensure a competent and capable workforce.

Holistic Approach to Regional Growth: Government prioritisation of regional growth without considering a holistic approach that includes factors such as access to labour, public transport, cost of transport, travel time, etc., can limit the overall effectiveness of construction hubs.

Proximity and Collaboration: The level of collaboration and proximity requirements vary depending on the stage and type of construction. Identifying the right balance between top-down and bottom-up approaches for collaboration is essential.

Limited Coordination Between Upstream and Downstream Activities: The lack of coordination between upstream and downstream activities in the construction process poses a challenge. A more integrated and collaborative approach is needed to ensure smooth operations and communication throughout the entire supply chain.

Financial Investment and Challenges: Establishing construction hubs requires significant financial investments. Securing funding and attracting investments from both public and private sectors may be a challenge.

Lack of Mandates and Regulations: One of the key challenges identified is the absence of clear mandates and regulations around offset and prefab construction in Australia. Unlike successful examples in places like Singapore, the lack of such mandates hinders the widespread adoption of innovative construction methods and technologies.

Resistance to Technology Adoption: The fear of technology and resistance to adopting new digital solutions and innovations in construction is identified as a barrier. Overcoming this resistance and promoting a culture of innovation and technological advancement is crucial for the success of construction hubs.

Logistical Challenges: Establishing construction hubs in regional areas requires addressing logistical challenges, including transportation networks and digital connectivity. Efficient infrastructure connectivity is essential for the movement of materials, equipment and personnel.

Diverse Workflows and Processes: The construction industry in different states of Australia follows diverse workflows, processes and models. This lack of standardisation and coordination between states creates complexities in establishing uniform construction hu practices across the country.

Environmental Impact and Sustainability Concerns: Construction hubs need to address the environment impact of their operations and construction activities. Minimising carbon emissions, optimising transportation and promoting sustainable construction practices are important considerations.

Figure 14. *Benefits and challenges of establishing construction hubs in regional areas*

EVALUATION FRAMEWORK

In this section, an evaluation framework is presented that is designed to assess the effectiveness and impact of Construction Hubs in the Victorian context. The evaluation framework serves as a vital tool for measuring the success of these hubs in achieving their intended goals and objectives.

By outlining the criteria used to evaluate Construction Hubs, sustainability, infrastructure, resources, and market dynamics were identified as key factors. Each criterion represents a crucial aspect of a Construction Hub's performance and its contribution to the broader construction ecosystem. The evaluation framework serves as a valuable resource for policymakers, industry stakeholders, and investors, providing them with evidence-based insights to support informed decision-making. Evaluating the performance of Construction Hubs can foster continuous improvement and create a robust ecosystem that drives innovation, collaboration, and sustainable growth within the construction industry.

Key criteria of evaluation framework

The evaluation strategy involves assessing regions based on a set of evaluation criteria derived from thorough research and empirical studies. Each criterion is carefully selected to capture the key factors that contribute to the success and suitability of a region for establishing a Construction Hub. In this strategy, the evaluation criteria serve as benchmarks against which the regions are measured. These criteria, as shown in Figure 15, could include factors such as infrastructure availability, labour market conditions, environmental sustainability, market demand, access to resources, and social dynamics.

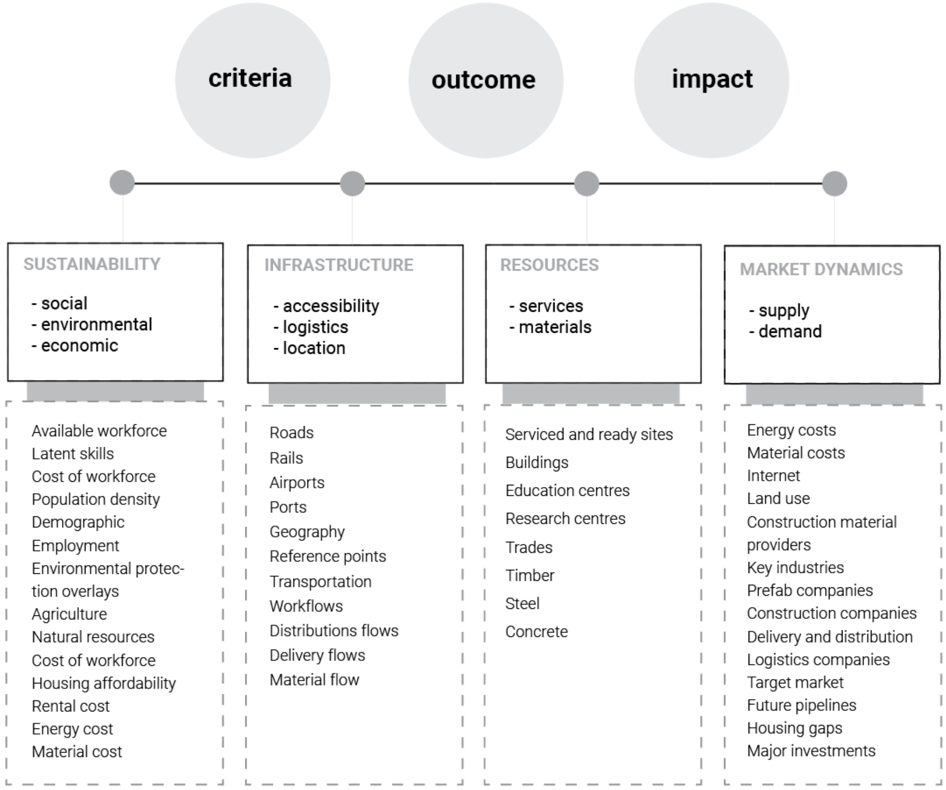


Figure 15. *Evaluation framework for establishing Construction Hubs*

Impact assessment and outcomes

Sustainability factors

Our findings underscore the significance of sustainability as a crucial criterion for evaluating the suitability of a location for establishing a Construction Hub. Sustainability encompasses environmental, social, and economic dimensions, each with its own sub-criteria. By integrating sustainability factors, decision-makers can ensure that it operates in a responsible, balanced, and sustainable manner, benefiting both the present and future generations.

Social Sustainability

- Available workforce: The presence of an adequate and skilled workforce is essential for attract construction companies to establish their operations there
- Latent skills: The presence of latent skills refers to the untapped or underutilised skills within the workforce of a regional area Identifying and leveraging these latent skills can contribute to the establishment of a Construction Hub by utilising the existing talent pool more effectively. It may involve training programs, upskilling initiatives, or workforce development strategies to unlock the full potential of the local workforce.
- Cost of workforce: Higher labour costs may affect the competitiveness of construction projects and the profitability of companies operating within the hub. On the other hand, regions with a more cost-effective labour market can attract construction businesses and stimulate growth.
- Population density (current and projected population): Projected population growth can be a significant factor, as it indicates future demand and the long-term sustainability of the hub. Areas with higher population densities may have increased demand for infrastructure development, housing, and commercial spaces, making them attractive locations for establishing a Construction Hub.
- Demographic (age, gender, income): Understanding the demographic characteristics of a regional area is crucial for tailoring Construction Hub activities to meet specific market needs.
- Employment: Low unemployment rates and a stable job market indicate a healthier economy, which can drive construction activity and provide a reliable labour supply. high unemployment rates may signal challenges in attracting and retaining skilled workers, impacting the growth and sustainability of the hub.

Environmental sustainability

- Environmental protection overlays: It is important to assess potential environmental impacts and develop sustainable practices to minimise negative effects on ecosystems, water resources, air quality, and biodiversity. Compliance with environmental regulations and the ability to implement environmentally-friendly construction practices may be essential for obtaining permits and maintaining community support.
- Agriculture: Agricultural lands may be considered for construction projects, requiring careful land-use planning to balance the needs of both sectors. Conflicts between agriculture and construction may arise due to land availability, water resources, or potential impacts on agricultural productivity. Balancing the interests of both sectors through effective land management strategies and consultation with stakeholders is crucial.
- Natural resources: Construction projects often require access to materials such as sand, gravel, timber, or minerals. Evaluating the availability and sustainability of these resources in the region is essential to ensure a reliable supply for construction activities. Proper resource management and conservation practices should be considered to minimise environmental degradation and maintain long-term resource availability.

Economic sustainability

- Cost of workforce: Higher labour costs may affect the overall project budget and the competitiveness of construction firms operating within the hub. Conversely, a region with a cost-effective labour market can attract construction companies and encourage growth within the hub.
- Housing affordability: If housing costs are high or there is limited affordable housing in the region, it may create challenges in attracting and retaining skilled workers. Adequate housing options and affordability can enhance the appeal of the hub for construction professionals and support long-term sustainability.
- Rental cost: Rental costs can impact both the workforce and construction companies operating within the hub. If rental prices are high, it may place financial burdens on workers and affect their decision to relocate or stay in the region. For construction firms, higher rental costs can increase overhead expenses, impacting their profitability. Therefore, affordable rental options are essential for a thriving Construction Hub.
- Energy cost: Energy costs, including electricity and fuel prices, can influence the feasibility and profitability of construction projects within the hub. Higher energy costs may increase construction expenses, impacting the overall project budget and potential profitability. Access to affordable and reliable energy sources can contribute to the attractiveness of the region for construction companies and support their operations within the hub.
- Material cost: Fluctuations in material costs can affect project budgets and profitability. A region with access to affordable and locally sourced construction materials can offer cost advantages and enhance the competitiveness of the Construction Hub.

Market dynamics factors

Market dynamics, supply and demand, play a pivotal role in establishing a Construction Hub. The demand for construction services determines the need for a Construction Hub in a region. The existing supply of construction services helps assess the feasibility of establishing a hub. By considering these market dynamics, decision-makers can gauge the competitiveness of the region and determine whether a Construction Hub is necessary to address gaps in supply and meet the demand for construction services.

Supply

- Internet: A robust and reliable internet and communication infrastructure is essential for effective project management, collaboration, and information exchange within the Construction Hub. Access to high-speed internet and reliable communication networks ensures seamless connectivity with clients, suppliers, stakeholders and operational efficiency.
- Land use: Adequate availability of suitable land for the Construction Hub's facilities, such as offices, workshops, storage yards, and potential expansion areas, is critical. The regional area should have sufficient land resources and appropriate zoning regulations to accommodate the hub's infrastructure needs.
- Construction material providers: The presence of reliable and diverse construction material providers in the regional area ensures a steady supply of materials for the hub's projects. Having a well-established network of material providers reduces procurement lead times, transportation costs, and potential delays in construction activities.
- Key industries and manufacturers, industries, prefab companies: Collaborations with industries such as manufacturing, energy, and infrastructure can create opportunities for joint projects, shared resources, and mutual growth. Partnerships with key manufacturers can provide access to specialised equipment, materials, or prefabricated components.
- Prefab companies: The availability of prefab companies in the regional area supports the Construction Hub in delivering projects using off-site manufacturing techniques. Collaborations with prefab companies can enhance the hub's capabilities and provide a competitive edge.
- Construction companies: The presence of established construction companies in the regional area can impact the competition within the construction market. It is essential to assess the existing market landscape, identify potential partnerships or competition, and differentiate the Construction Hub's value proposition to attract clients and projects.
- Delivery and distribution centres: Access to delivery and distribution centres within or near the regional area facilitates the efficient movement of construction materials, equipment, and finished products. Proximity to these centres reduces transportation costs and streamlines logistics, ensuring timely project deliveries.
- Logistics companies and pipeline: The availability of logistics companies, including transportation, shipping, and warehousing services, supports the Construction Hub's operations. Efficient logistics networks ensure timely and cost-effective movement of materials, reduce project delays, and enhance overall project execution.

Demand

- Target market: Identifying the hub's target market, such as residential, commercial, industrial, or infrastructure sectors, is essential for aligning the hub's services and capabilities. The regional area's demand for construction projects in the target market affects the hub's activity levels, project pipeline, and revenue potential.
- Hub activity and product: The Construction Hub's ability to provide quality construction services, innovative solutions, and value-added offerings impacts its market demand. Reputation, track record, and expertise in specific construction sectors can influence the hub's competitiveness and attract customers.
- Future pipeline: Assessing the future demand and project pipelines in the regional area is crucial for the Construction Hub's long-term viability. Understanding upcoming infrastructure projects, urban development plans, or major investments helps the hub anticipate market trends and position itself strategically.
- Housing gaps: Identifying housing gaps or demand-supply imbalances in the regional area can present opportunities for the Construction Hub. Addressing affordable housing needs or catering to specific housing segments can generate a steady demand for the hub's services.
- Major investments: Large-scale investments in the regional area, such as infrastructure projects, industrial developments, or urban revitalisation initiatives, can significantly impact the Construction Hub's growth potential. Being aware of these investments and aligning the hub's capabilities with the associated construction requirements can position the hub for success.

Resources factors

The availability and accessibility of resources in a region determine its potential to support a hub. Built assets can provide a foundation for construction activities and serve as a platform for future development. Adequate services are essential for efficient construction operations. The availability of a diverse range of construction materials, including raw materials and supply chains, is crucial for sustaining construction activities in the hub. By ensuring the presence of these resources, decision-makers can create a favourable environment for the growth and success of a Construction Hub.

Services

- Education centres
  - Skilled Workforce: Education centres provide training and education programs that produce a skilled workforce in construction-related fields. This ensures the availability of qualified professionals, such as engineers, architects, project managers, and skilled tradespeople, who can contribute to the Construction Hub's operations.
  - Research and Innovation: Education centres often have research departments that focus on construction-related studies, technology advancements, and innovative practices. Collaborating with these centres can foster research and innovation within the Construction Hub, leading to improved construction techniques, sustainable practices, and increased productivity.
  - Lifelong Learning Opportunities: Education centres offer opportunities for continuing education and professional development in the construction industry. This allows individuals working in the hub to enhance their skills, acquire new knowledge, and stay updated with industry trends and regulations.
- Research centres
  - Technological Advancements: Research centres focus on developing and implementing new technologies, materials, and construction methods. Their findings and innovations can be directly applied within the Construction Hub, leading to improved efficiency, safety, and sustainability.
  - Collaboration and Expertise: Research centres often bring together experts from various disciplines, such as engineering, materials science, and architecture. Collaborating with these centres can provide access to specialised knowledge, consultancy services, and expert advice for the Construction Hub's projects.
  - Industry-University Partnerships: Partnerships between research centres and the Construction Hub can foster knowledge transfer, joint projects, and technology commercialisation. These collaborations can drive innovation, attract investment, and enhance the hub's reputation as a centre of excellence in construction.
- Trades
  - Construction Workforce: Skilled tradespeople, such as carpenters, plumbers, electricians, and masons, form the backbone of the construction industry. The presence of a skilled and diverse trades workforce is essential for the successful execution of construction projects within the hub. The development of educational facilities helps further upskilling within the profession to broaden industry specific skill sets (i.e. roof plumbing, A/C installations, etc.)
  - Local Supply Chain: Trades services, including subcontractors and suppliers, contribute to the local supply chain. Having a reliable network of trades services in the regional area supports the hub's operations by providing specialised services, equipment, and materials promptly.
  - Business Support: Trades services also provide support to construction-related businesses, such as maintenance, repairs, and renovations. Access to these services allows the Construction Hub to efficiently maintain its infrastructure, prolong its lifespan, and address any operational requirements.

Materials

- Timber
  - Local Timber Industry: If the regional area has a significant timber industry, the Construction Hub can benefit from the availability of locally sourced timber. This reduces transportation costs and promotes sustainable practices by utilising renewable and locally harvested materials. Additionally, operational & site-specific infrastructures of timber refineries begin to formulate a variety of timber companies that work with material at different points in the material flow, leading towards a microcosm of industry.
  - Construction Practices: Timber can be a preferred material for certain types of construction, such as wood-framed buildings or timber structures. If the Construction Hub specialises in timber construction or has expertise in working with wood, the availability of timber resources becomes essential.

  - Environmental Considerations: Timber is a renewable and sustainable material when sourced responsibly. The availability of timber in the regional area can support environmentally friendly construction practices and contribute to the hub's sustainability goals.

- Steel
  - Structural Steel Fabrication: Steel is widely used in construction for its strength, durability, and versatility. If the regional area has a steel industry and facilities for structural steel fabrication, the Construction Hub can benefit from a local supply chain for steel components. This reduces lead times, transportation costs, and enables customisation based on project requirements.
  - Infrastructure and Expertise: The availability of steel mills, steel processing plants, and related infrastructure supports the Construction Hub's steel-related activities. It also provides access to skilled labour and expertise in steel fabrication, welding, and other steel-related trades. Presence of small elemental steel fabrication can formulate a pivotal stage in the functionality of manufacturing lines of other products. (timber and concrete access to reosteel, steel cleats, steel pipes etc.)
  - Large-Scale Projects: Steel is often used in large-scale construction projects such as high-rise buildings, bridges, and industrial structures. If the Construction Hub aims to undertake such projects, the availability of steel resources and expertise in the regional area becomes crucial for cost-effective and timely project execution.
- Concrete
  - Concrete Production: Concrete is a fundamental material in construction, used for foundations, walls, floors, and various structural elements. If the regional area has concrete production facilities or a strong cement industry, the Construction Hub can benefit from a local supply chain for concrete. This ensures a steady and reliable supply of concrete materials, reducing transportation costs and delays.
  - Infrastructure Development: Concrete production requires batching plants, aggregates, and related infrastructure. If these facilities are present in the regional area, it supports the Construction Hub by providing easy access to concrete materials and reducing logistical challenges.
  - Local Codes and Practices: Construction codes and practices often dictate the use of specific concrete mixes or specifications. Familiarity with local standards and regulations related to concrete usage enables the Construction Hub to seamlessly comply with local requirements. Understanding of the operational differences between quarry licences and tenements can limit the potential output of supply material.

Infrastructure factors

Infrastructure plays a crucial role in establishing a Construction Hub. A well-connected hub enhances efficiency and reduces transportation costs for materials, equipment, and workforce. Effective logistics ensure smooth operations, timely delivery of materials, and effective coordination among stakeholders. By prioritising robust infrastructures, decision-makers can create a favourable environment that attracts investment, enhances productivity, and facilitates the smooth functioning of a Construction Hub.

Accessibility

- Roads: proper road connectivity is essential for the transportation of construction materials, equipment, and workers to and from the Construction Hub. Well-maintained and efficient road networks can ensure smooth logistics and timely completion of construction projects. Additionally, accessible roads enable easy access to the Construction Hub for suppliers, clients, and other stakeholders, facilitating business operations and promoting economic growth. Connection to arterial roads are pivotal as most domestic suppliers rely on truck distribution through both regional and urban areas. Reliance on road networks disperses small amounts when product outputs exceed weight or size limits allowable on road.
- Rail: The presence of rail infrastructure can enhance the transportation capabilities of a Construction Hub. Rail connections allow for the efficient movement of bulk materials, such as aggregates, steel, and other construction supplies. Rail transport can help reduce transportation costs, alleviate road congestion, and support larger-scale construction projects that require significant material inputs. Proximity to rail lines or the availability of rail spurs within or near the Construction Hub can provide a competitive advantage in terms of logistics and cost efficiency.
- Airports: Airports play a crucial role in supporting the establishment of a Construction Hub, especially for projects that involve international clients, investors, or suppliers. Access to airports enables easy travel and efficient import/export of construction-related goods and services. It facilitates the mobility of skilled professionals, engineers, and project managers who may need to travel frequently. Airports also promote connectivity with other regions, attracting investment and fostering economic development.

- Ports: If the Construction Hub is involved in large-scale projects or requires significant imports and exports of construction materials, having access to ports becomes vital. Ports enable the efficient transportation of materials by sea, which can be cost-effective for bulk shipments. Proximity to ports allows for seamless importation of construction materials and the export of finished products. This accessibility to global supply chains enhances the competitiveness of the Construction Hub and supports its growth.

Location

- Geography
  - Proximity to Natural Resources: If the regional area is rich in natural resources like minerals, timber, or aggregates, locating the Construction Hub close to these resources can reduce transportation costs and increase the hub's competitiveness.
  - Topography and Terrain: The topography and terrain of the area can impact construction activities. Steep slopes or challenging landscapes may require additional engineering and construction efforts. Flat terrains or access to suitable land for construction can be advantageous for setting up the hub's infrastructure.
  - Environmental Considerations: The location's environmental characteristics, such as flood risk, seismic activity, or protected habitats, should be considered. Ensuring compliance with environmental regulations and minimising the potential negative impacts on the environment is essential.
- Reference points (adjacencies, strategic points)
  - Proximity to Urban Centres: Being close to urban centres can provide access to a larger customer base, potential clients, and suppliers. It can also facilitate collaboration with local businesses and enhance the overall competitiveness of the Construction Hub.
  - Transportation Nodes: Being located near major transportation nodes, such as highways, railways, airports, or ports, can improve connectivity and logistics. It enables efficient transportation of materials, equipment, and personnel to and from the Construction Hub.
  - Strategic Industrial Zones: If the Construction Hub is established near existing industrial zones or clusters, it can benefit from synergies and economies of scale. Collaboration, shared resources, and a supportive ecosystem can be advantageous for the growth and development of the Construction Hub.
  - Educational Institutions: Proximity to educational institutions, such as universities or technical colleges, can facilitate the availability of a skilled workforce and promote research and innovation in the construction industry.

Logistics

- Transportation
  - Efficient transportation is crucial for the success of a Construction Hub. It affects the movement of construction materials, equipment, and personnel to and from the hub. Key considerations include:
  - Accessibility: The Construction Hub should be located in an area with good transportation infrastructure, such as roads, railways, airports, or ports. Easy access to these transportation modes ensures smooth logistics and reduces transportation costs.
  - Logistics Network: Establishing a well-connected logistics network enables efficient coordination and movement of materials and equipment. This includes optimising routes, selecting suitable transportation modes, and coordinating deliveries to minimise delays and costs.
  - Just-in-Time Delivery: Adopting just-in-time delivery practices ensures that materials and equipment are delivered to the construction site when needed, reducing the need for on-site storage and minimising inventory costs.
- Workflows
  - Efficient workflows within the Construction Hub can streamline operations and improve productivity. This includes:
  - Planning and Scheduling: Effective planning and scheduling of construction activities optimise resource allocation and minimise downtime. This involves coordinating multiple projects, allocating manpower and equipment efficiently, and ensuring smooth workflow sequences.
  - Collaboration and Communication: Establishing effective communication channels and fostering collaboration between different stakeholders, such as architects, engineers, contractors, and subcontractors, enhances workflow coordination and facilitates timely decision-making.
  - Lean Construction: Implementing lean construction principles, such as eliminating waste, improving process flow, and continuous improvement, optimises workflows and reduces costs.
- Distributions flows

    - The establishment of a Construction Hub involves managing the distribution of materials, equipment, and resources. Considerations include:
    - Supply Chain Management: Efficient supply chain management ensures timely availability of construction materials, equipment, and subcontracted services. This involves selecting reliable suppliers, optimising inventory levels, and coordinating deliveries to meet project timelines.
    - Warehousing and Storage: Proper storage and management of construction materials and equipment in warehouses or storage yards near the hub ensure easy access and reduce transportation delays.
- Delivery flows
    - Seamless delivery of finished construction projects to clients is critical for the Construction Hub's reputation and success. Factors to consider include:
    - Client Coordination: Effective coordination with clients regarding project milestones, inspections, and handovers ensures smooth delivery of completed projects.
    - Quality Control and Assurance: Implementing robust quality control and assurance processes during construction ensures that the final product meets client expectations and minimises rework or delays during delivery.
- Material flow
    - Efficient material flow within the Construction Hub impacts productivity and cost-effectiveness. Considerations include:
    - Inventory Management: Proper inventory management systems help track materials, control stock levels, and avoid shortages or excesses.
    - Material Handling: Implementing appropriate material handling equipment and processes, such as cranes, forklifts, and automated systems, improves efficiency and minimises handling time.

As the report transitions from the evaluation of Construction Hubs to the exploration of Victorian case studies in the subsequent section, it is imperative to carry forward the lessons learned from the evaluation process. The insights gained from successful Construction Hubs globally, coupled with the impact assessment, will serve as a foundation for our examination of the unique configurations and experiences within Victoria.

VICTORIAN CASE STUDIES

This section examines 3 distinct Victorian regions – the Latrobe Valley, Benalla, and Geelong – envisioned as potential contenders for the establishment of Construction Hubs. Scrutinising the distinct attributes, opportunities, and challenges presented by each case will lead to an understanding of the factors that can foster or hinder the successful establishment and operation of Construction Hubs. These case studies serve as prototypes, offering valuable insights and lessons that extend beyond the immediate geographical context. These case studies become a testament to the potency of forward-thinking approaches, collaboration, and targeted investments in shaping the trajectory of construction and regional development. Further, these locations dictate suitable hub form design in response, of which 3 distinct forms are proposed.

Please note that all *figure numbers* associated with the Victorian Case Studies are representative of figures as chronologically found in *CRC38.1 Appendix B* document. For further reference, please see associated document.

Industry and economy

Location 1: Latrobe Valley

The Latrobe Valley is a river valley and an inland district in the Gippsland region, 130 kilometres east of Melbourne. Geographically it is nestled between the Baw Baw Rangers to the north and Strzelecki Ranges to the south. The district is administratively incorporated into Latrobe City local government area (LGA) which covers an area of 1,426 square kilometres and. Legislated in 1994 Latrobe comprises 4 major urban centres: Churchill, Moe/Newborough, Morwell and Traralgon and it is the fourth-largest city in regional Victoria by population.

Latrobe Valley is situated within a geological ecosystem rich in sand, clay, coal, and limestone. The abundant deposits of brown coal have positioned Latrobe as a significant energy distributor throughout Victoria. The region currently hosts 9 active quarries, comprising 3 sandstone quarries, 2 granite quarries, and 4 stone aggregate quarries. These quarries cover an extensive area of more than 470 square kilometres, representing valuable land with extractive potential. Forestry employment throughout Latrobe Valley has remained relatively consistent with small areas of growth throughout Victoria. However, the recent governmental decision to end native logging by 6 years to December 2023, has already implicated the closures of large-scale producers across Victoria with further limitations on potential growth in timber harvesting regions such as Gippsland and Latrobe.

Economy

Originating as an agricultural stronghold, the Latrobe Valley's early prosperity was rooted in farming, dairying, and coal mining that emerged in the late nineteenth century. Private open-cut coal mines played a crucial role, supplying fuel for the Victorian Railways. The State Electricity Commission (SEC), established by the Victorian Government in 1918, later became the sole agency responsible for electricity generation, transmission, distribution, and supply, solidifying its dominance in the region. This led to the creation of significant coal mines and power stations, including Hazelwood, Yallourn W, and Loy Yang power stations during the 1960s to 1980s. At its peak in the 1970s, the SEC employed nearly a fifth of the valley's workforce. However, the landscape shifted following the privatisation and deregulation of the SEC from the mid-1990s onwards. This transition marked the closure of several plants, including the Morwell power station and briquette factory in 2014, and the Hazelwood power station in 2017, alongside the shuttering of all paper mills, signifying a profound economic transformation. Amidst these changes, the Latrobe Valley diversified its economic activities, embracing sectors like healthcare, power generation, retail, agriculture, IT, engineering, and education. Notably, the valley stands as a vital contributor, supplying 85% of Victoria's electricity and hosting a thriving engineering sector that supports power generation and food processing, cementing its role as a multifaceted economic centre.

Location 2: Benalla

Benalla is a rural city located around 200 kilometres north-east of Melbourne. The area is a mostly flat floodplain of the Broken River catchment that adjoins the Great Dividing Range to the north and west. The local settlement was established as a shire in 1869, made a borough in 1949 and a city in 1965. Between 1994 and 2002 Benalla was incorporated into the shire of Delatite before acquiring a current administrative status of a separate rural city. As a rural city it covers an area of 2,353 square kilometres. While the Benalla Local Government Area lacks notable extractive assets, areas southward to Lima South and Yarck supply quarried stone to local businesses. The region hosts 3 granite-based quarries, 2 situated south of the city and one to the north, providing crushed road-metal and concrete aggregates.

Transportation is well-established, with the ARTC Single Gauge Rail freight line connecting Benalla, serving as a crucial link between Melbourne, Sydney, and Brisbane for efficient freight movement. Benalla's landscape features an Old-growth protection area in Mount Samaria State Park to the southwest, while timber harvesting and harvest zones are concentrated in the southeastern Tatong region.

Economy

Benalla's economy has undergone a dynamic transformation over the years, originating as a vital service hub for neighbouring farmers and evolving into a strategic junction on the Melbourne-Sydney railway. The region's agricultural pursuits encompassed a diverse range, spanning from grain production and cattle grazing to wine making and dairying. With the arrival of the main railway line in 1873, further extensions to Yarrawonga and Oaklands followed suit, solidifying Benalla's position as a key interception point for the Hume Highway connecting Melbourne to Sydney, as well as the Midland Highway traversing Victoria's hinterlands. In the post-1945 era, Benalla's economic landscape experienced a marked shift, welcoming secondary and tertiary industries that contributed to its growth. Notably, a clothing factory, initially operating as Latoof and Callil before becoming Perfectfit, provided employment for numerous women from the Benalla Migrant Camp. Schneider Electric entered the scene in 1975, commencing production of electrical transformers that continues to this day. Meanwhile, Thales Australia established an ammunition factory in 1993, producing a range of munitions. One of the standout players in Benalla's economy is LS Precast, owned by Ashley Day, which plays a pivotal role in the production of concrete products for major infrastructure projects, notably the West Gate Tunnel project. This venture has not only generated hundreds of jobs, benefiting residents from Benalla and neighbouring areas such as Euroa, Shepparton, Yarrawonga, and Wangaratta, but has also driven significant demand for housing construction, signalling a robust economic trajectory. The growth of separate houses and medium density dwellings in the area further underscores the burgeoning economic vitality of Benalla. The town's railway station and infrastructure have been instrumental in facilitating these economic activities, although challenges arose as LS Precast's "superloads" necessitated detours through nearby towns, leading to community discontent.

Location 3: Geelong

Geelong is a large port city located in south-western Victoria, about 75 km from the Melbourne CBD. Established in the 1840s at the western end of Port Phillip Bay it is often named as the ‘Gateway City’ because of its proximity to the regional significant centres of Ballarat, Torquay, and Warrnambool. Administratively, it is part of the City of Greater Geelong – a Local Government Area that covers an area of 1,247 square kilometres. The LGA was formed in 1993 from the amalgamation of some rural shires and separate small urban municipalities forming Geelong.

The Geelong region currently hosts 8 operational quarries, comprising 4 basalt quarries, 2 sand quarries, and 2 stone aggregate quarries. These quarries cover an extensive area of over 520 square kilometres, representing valuable land with extractive potential. In terms of transportation infrastructure, the ARTC Single and Broad Gauge Rail freight line connects Geelong to Melbourne and Adelaide, facilitating efficient freight movement between these important economic hubs. It's worth noting that there is no timber harvesting within the Geelong region, with timber harvesting activities concentrated in the northern region of Staughton Vale.

Economy

Geelong's economic evolution is rooted in its historical role as a hub for wool trading and processing, catapulting it into global recognition as a prominent wool centre. The thriving wool mills of the 19th century eventually yielded to changing market dynamics, resulting in their closure by 1980. Leveraging its strategic coastal location, Geelong capitalised on the Port of Geelong, a key player handing over 10 million tonnes of goods annually and facilitating approximately 600 vessel visits. This maritime advantage combined with its status as a pivotal railway junction, notably along the Western standard gauge railway line connecting Melbourne with Adelaide and Perth, underscored the city's strategic importance. The 1920s marked a shift towards manufacturing, with major players like Ford Motor Company, Alcoa, fertiliser plants, Fyansford Cement works, and the Shell refinery driving industrial growth. Nevertheless, shifts in government tariff policies ushered in the decline of heavy industry in the early 21st century. Geelong's subsequent renaissance found its footing in diverse sectors including advanced manufacturing, aerospace, construction, finance, education, and healthcare. In recent times, the Greater Geelong region has demonstrated impressive economic resilience, outperforming peer regions and cities across Australia. With a gross regional product (GRP) estimated at $15.4 billion, the city hosts 120,000 local jobs and is home to 19,600 businesses. Notably, Geelong's labour market boasts remarkable vitality, boasting an unemployment rate at an historic low of 2.5%, significantly below both Victorian and Australian averages. Youth unemployment stands at a modest 6.3%, reflecting a healthy 4.1-point gap compared with the state average. This buoyant labour market is further evidenced by record-high job advertisements, with an impressive 10,550 new jobs posted in the June 2022 quarter.

Evidence-based assessment of the case studies

This section synthesises our evaluation outcomes (see Appendices) into recommendations. These suggestions offer a clear strategic direction, supporting the use of existing infrastructure while promoting innovation and technology integration. Tailored to each region's distinct context, industry composition, and social fabric, the recommendations for Benalla, Latrobe Valley, and Greater Geelong vary significantly to address their unique characteristics.

A visualisation of the evaluation criteria takes the form of a candlestick graph in Figure 16. This graph combines industry workforce data with an assessment of ready-to-operate infrastructure within respective regions and industries. While not grounded in real metrics, this representation offers an indicative tool, providing a basic measure of each region's readiness for industry-based development and its corresponding capital investment requirements. The construction industry in Benalla as seen in Figure 16 presents as the region’s most promising industry market with a well-established workforce in construction and manufacturing, requiring minimal capital investment to develop existing infrastructure to a point of readiness. Multiple construction contractors in Benalla and surrounding regions represent a sprawling presence of construction, however the presence of LS Precast positions itself as the economic keystone of industry within Benalla. Manufacturing positions itself as a significant supportive industry within construction, creating elements through offsite construction by means of independent subassemblies. These subassembly infrastructures are well established with a diversity of warehouse typologies spread throughout Benalla with a variety of material uses.

The positioning of the Glenrowan solar farm, 15 km north east of Benalla establishes a significant contribution to industry adaptation to sustainable energy sources. Similarly, Latrobe’s extensive history of energy production boasts an abundance of existing energy infrastructure recently vacated by large-scale and long-term energy producers, but would require significant capital investment to establish sustainable practices within the region.

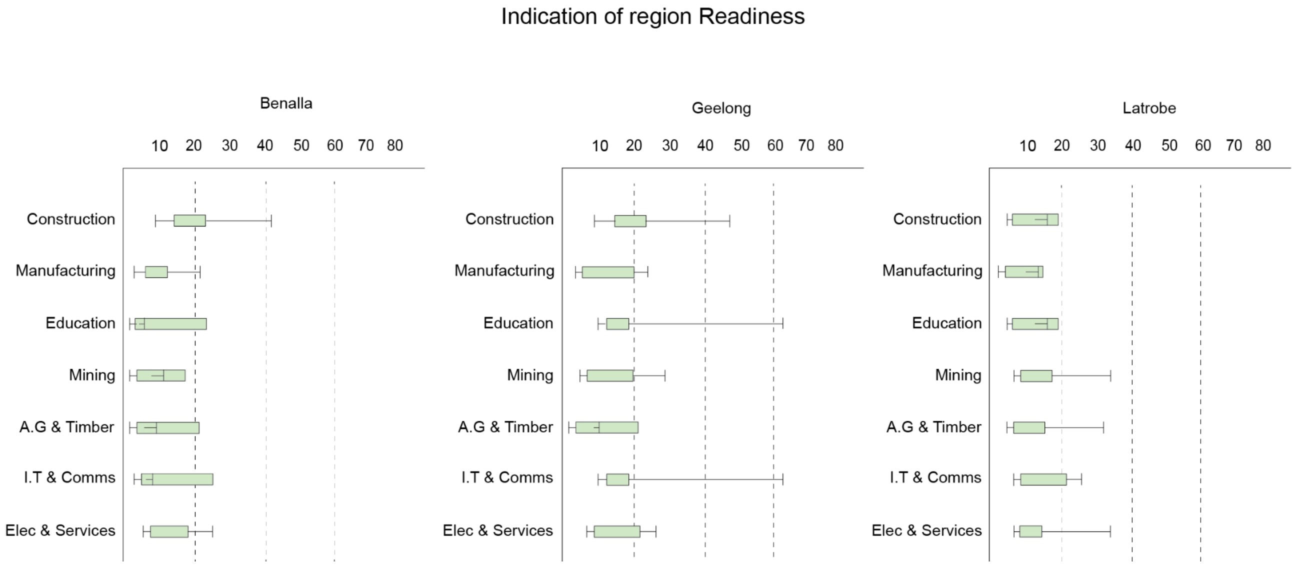


Figure 16. *Evaluation Framework Summary*

As shown through the evaluation framework (see Appendix B), Geelong offers an extensive range of rapid growth in construction, I.T, professional services & sciences, and education. Building on already established workforces, Geelong's overarching rates of growth with pockets of exponential growth provides a significant opportunity for large-scale investment into innovation and research focusing on the significant presence of well-respected TAFE and tertiary educational institutions. Additionally, Geelong's strength in the construction sector is deeply rooted in the historical and long-term development of manufacturing and construction ecosystems. Multiple statistical areas provided a variety of industrial strengths, Moolap presented overall decline in employment growth, however, due to a historical basis in manufacturing and construction Moolap presents a strong network of manufacturing concrete prefabrication and steel manufacturing, retail and distribution infrastructure while proposing significant opportunities for site renewal for recent closures of Point Henry's Alcoa site.

Latrobe Valley hosts multiple challenges for the development of an industry hub, but presents a unique opportunity to innovate extensive energy infrastructure towards green energy production. The historical foundation of energy production throughout Latrobe provides the utilisation of existing warehouses, slabs, power lines and connections, manufacturing sites with low land cost requirements, minimising any required initial capital investments. The emphasis on green energy production can be supported through Latrobe's educational institutions, facilitating upskilling in the existing trades workforce, while Federation University supports potential technological research.

Hub form design appropriate to location

Location 1: Latrobe Valley — Linear Hub

As depicted in Figure 17, a linear hub emerges as the appropriate response to the existing distribution, extraction, and processing infrastructure while still catering to the needs of established industry clusters. This spatial approach ensures that the economic development in Latrobe Valley remains aligned with the region's strengths and opportunities, contributing to a more effective and sustainable clustering strategy.

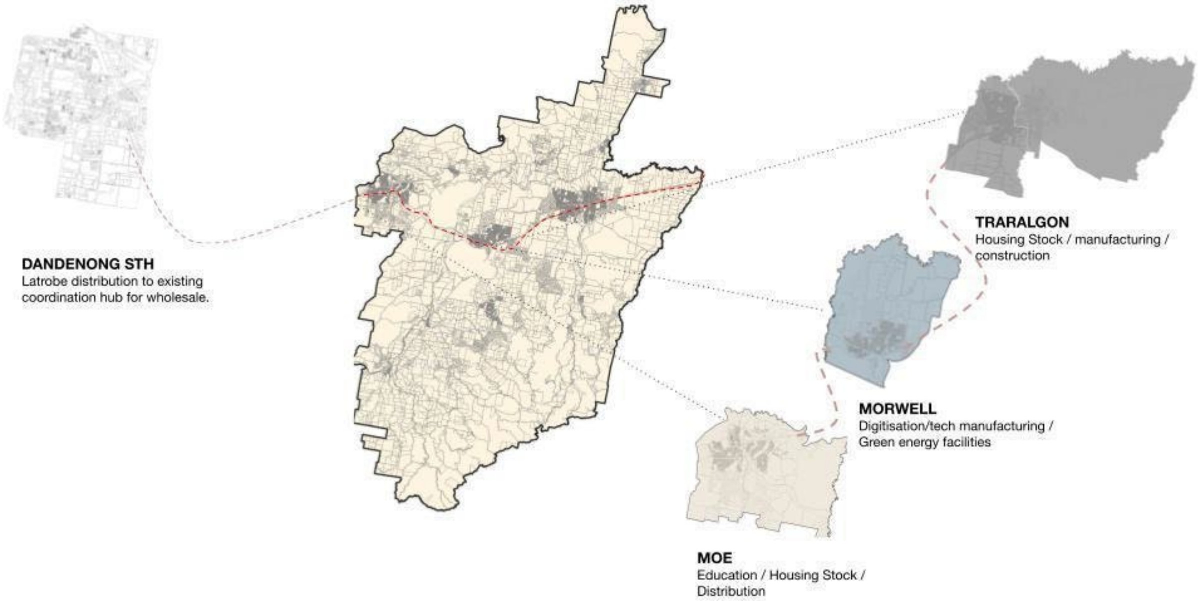
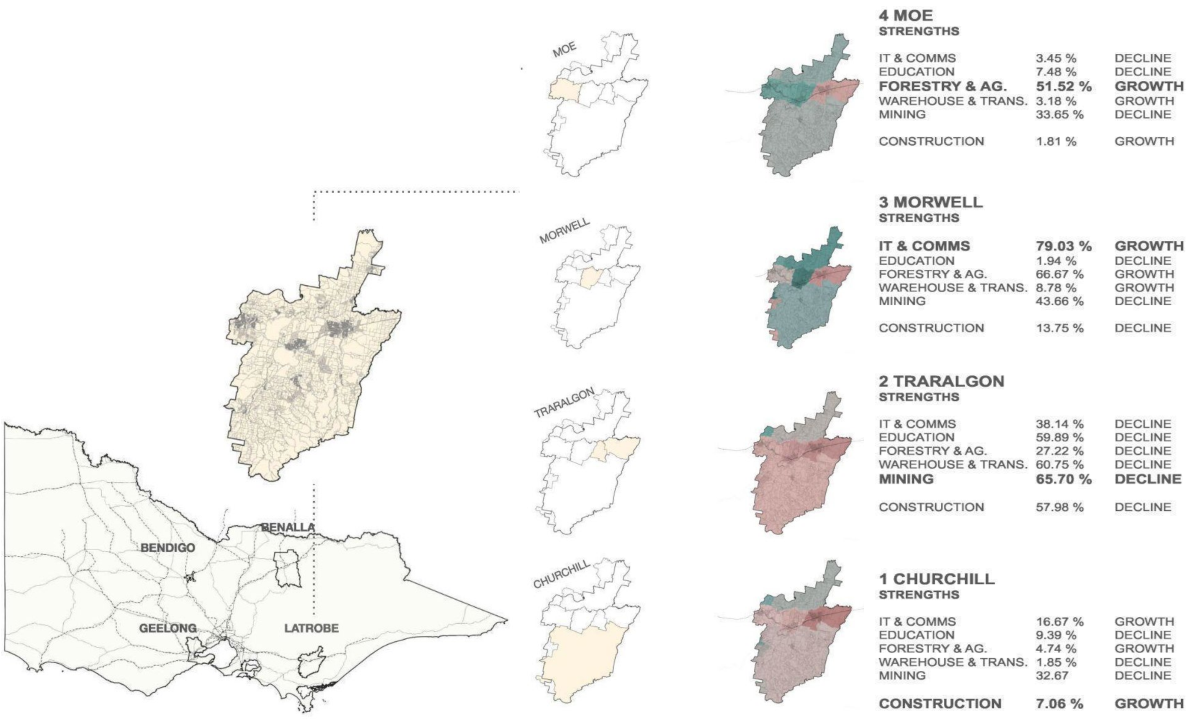


Figure 17. *Linear 'Hub'*

Due to the strong linear distribution axis, the network of exchange is primarily limited to extending beyond this parameter or moving in a different direction. As noted in Figure 18, Traralgon, Morwell and Moe have indicated different industry strengths, positioning each township as a microcosmic concentration of expertise within the linear 'production line'. Traralgon has experienced a decline in all industries but remains an attractive option for housing due to its short commuting distance and affordability. However, the high proportion of unemployed or non-working residents and low-income earners necessitates careful siting decisions to avoid displacement and address existing housing stresses in Moe and Morwell.

Alternatively, Moe and Morwell are well-structured with existing manufacturing and construction infrastructure with higher income levels and housing costs, however, being slightly more accessible to extractive areas of interest and having significant existing infrastructure in energy production, a microcosmic consolidation of green energy may be beneficial to fully utilise the extensive established infrastructure. Additionally, Morwell experienced some of Latrobe's highest rates of industry growth through IT sectors and remains directly connected to Federation University via Monash Way. As shown in International case study, The Research Triangle, the pairing of highway connectivity, solidified Tech industries and educational institutions may provide a significant inclusion to the feasibility of establishing an innovative green energy or tech hub.

Latrobe's positioning and proximity to Melbourne allows for the linear production line to connect to Dandenong, a significant allocation of industrial retailers and contractors via railway freight, which also has been allocated by Victorian Planning Authority (VPA) to increase the freight capacity. By including Dandenong as an extension of Latrobe's 'Linear Hub', it acts as a commercial distribution hub throughout the metropolitan region and integrates the linear hub to Victorian Plan authority's South East Economic Corridor (SEEC) report to develop Dandenong into a "*National Employment Innovation Cluster*" (Victorian Planning Authority, 2022, 8). Leveraging Dandenong's future NEIC developments incorporates additional connectivity to the Dandenong's nominated Education and health precincts, further enhancing research capacities through institutions Chisholm TAFE and Monash University.



4 MOE
STRENGTHS

IT & COMMS	3.45 %	DECLINE
EDUCATION	7.48 %	DECLINE
FORESTRY & AG.	**51.52 %**	**GROWTH**
WAREHOUSE & TRANS.	3.18 %	GROWTH
MINING	33.65 %	DECLINE
CONSTRUCTION	1.81 %	GROWTH

3 MORWELL
STRENGTHS

IT & COMMS	**79.03 %**	**GROWTH**
EDUCATION	1.94 %	DECLINE
FORESTRY & AG.	66.67 %	GROWTH
WAREHOUSE & TRANS.	8.78 %	GROWTH
MINING	43.66 %	DECLINE
CONSTRUCTION	13.75 %	DECLINE

2 TRARALGON
STRENGTHS

IT & COMMS	38.14 %	DECLINE
EDUCATION	59.89 %	DECLINE
FORESTRY & AG.	27.22 %	DECLINE
WAREHOUSE & TRANS.	60.75 %	DECLINE
MINING	**65.70 %**	**DECLINE**
CONSTRUCTION	57.98 %	DECLINE

1 CHURCHILL
STRENGTHS

IT & COMMS	16.67 %	GROWTH
EDUCATION	9.39 %	DECLINE
FORESTRY & AG.	4.74 %	GROWTH
WAREHOUSE & TRANS.	1.85 %	DECLINE
MINING	32.67	DECLINE
CONSTRUCTION	**7.06 %**	**GROWTH**

Figure 18. *Summary of the strengths of Latrobe Valley*
Source: Author using ABS data 2011 and 2021a SA2 Industry of Employment.

Location 2: Benalla — Networked / Decentralised Hub

Correlating with Latrobe's connection to other economic and employment regions, Benalla's industries rely heavily on connectivity to Wangaratta, Albury/Wodonga, and Shepparton to provide services, products and workforces that are outside the expertise of the Benalla demographics. The low density population of these regional satellite cities necessitates the interactivity of industry supply chains and implicated the Research Triangle again as a case study for understanding industry, residential and commercial composition within a network ecosystem.

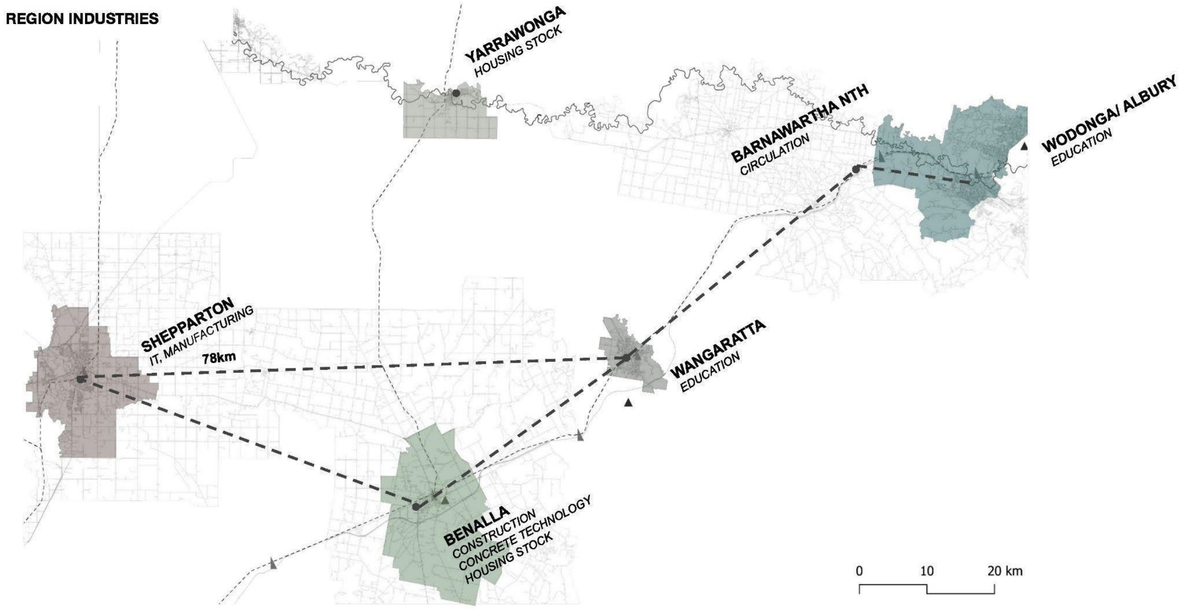
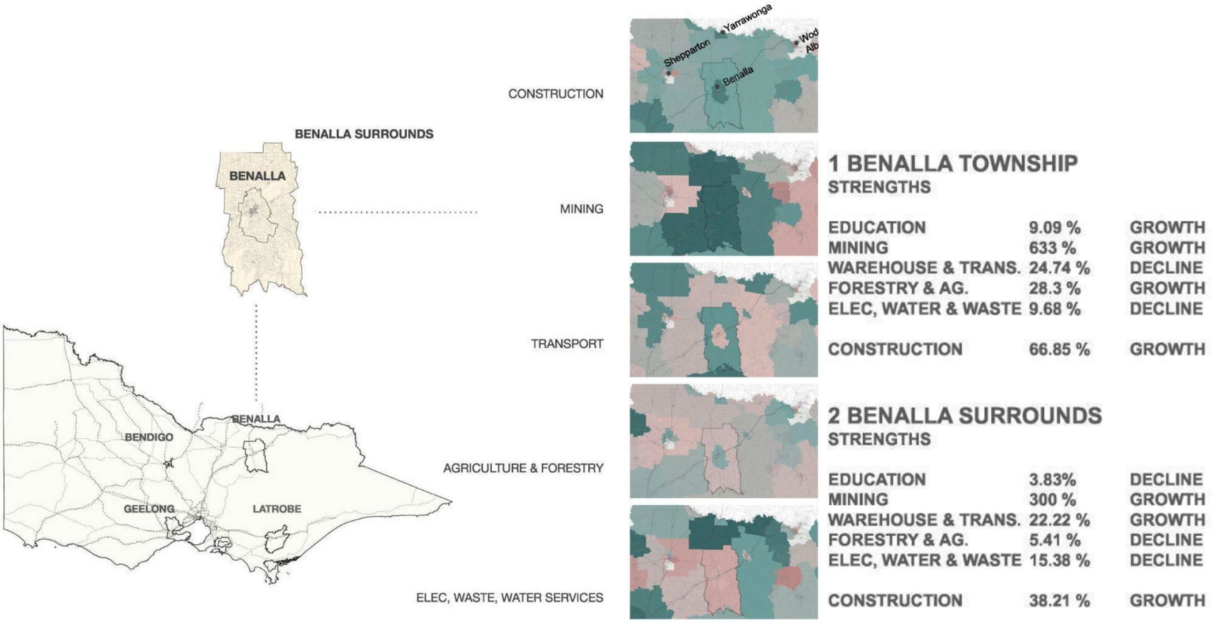


Figure 19. *Network/ decentralised hub*

The strategic positioning of Benalla within the existing distribution network of highways and railway freight plays a crucial role in its spatial organisation. These forms of freight act as arterial material supply routes to each region, granting access to imported resources, workforce, educational facilities when local sources are unattainable. In Figure 19, each township builds upon existing employment and industry factors to emphasise strengths when situated within a network. Due to the focus of Benalla in this report, each satellite town will be considered as a supportive influence for Benalla. However, as represented through the case study of the Research Triangle, directions of exchange often flow in both directions.

As seen in Figure 20, Benalla's predominant presence in concrete prefabrication, coupled with its subsidiary, LS Quarry, offers a potential opportunity to strengthen existing construction markets with minimal investment into establishing or developing distribution infrastructure. Benalla's advantageous position within the freight network provides far-reaching national access. Having a distribution hub in Barnawartha North, just West of Wodonga, a continued link of distribution has been established, however the distribution hub undermines any large-scale potential for a distribution hub in Benalla. Alternatively, the opportunity to develop prefabricated products remains a strong economic basis for developing on existing industry conditions while utilising the existing distribution hub to extend the market potentials throughout Victoria and Australia.

Benalla's operational capacity remains high, due to having no recent large-scale closures, capital investment into establishing warehouses and appropriate sites is required, however land costing is relatively cheap with expansive site potential allocated throughout Benalla. However, further investigations are needed to determine Benalla's reliance on LS Precast & LS Quarry in the construction industry to avoid potential volatility. The growth potential may lay in advancing the digitisation of prefabrication in construction, strengthening existing skill sets of Benalla and surrounding towns, while innovating a founding economic factor of the region.



1 BENALLA TOWNSHIP
STRENGTHS

EDUCATION	9.09 %	GROWTH
MINING	633 %	GROWTH
WAREHOUSE & TRANS.	24.74 %	DECLINE
FORESTRY & AG.	28.3 %	GROWTH
ELEC, WATER & WASTE	9.68 %	DECLINE
CONSTRUCTION	66.85 %	GROWTH

2 BENALLA SURROUNDS
STRENGTHS

EDUCATION	3.83%	DECLINE
MINING	300 %	GROWTH
WAREHOUSE & TRANS.	22.22 %	GROWTH
FORESTRY & AG.	5.41 %	DECLINE
ELEC, WATER & WASTE	15.38 %	DECLINE
CONSTRUCTION	38.21 %	GROWTH

Figure 20. *Summary of the strengths of Benalla*
Source: Author using ABS data 2011 and 2021a SA2 Industry of Employment.

Location 3: Geelong — Consolidated Hub

Geelong's significantly different concentrations of industry, population, and forms of material distribution signify a vastly different approach to hub development than Benalla and Latrobe. The population of Geelong being 5 times greater than Traralgon, Morwell and Moe combined, and 20 times greater than Benalla, freight and workforce is far more accessible. A diversity of relevant workforce is available throughout Greater Geelong, seeing overarching growth in the LGA, with microcosms of exponential growth. Geelong is well-equipped to support large-scale investments that promote collaboration across multiple sectors of construction and innovation. With its well-established educational capacities in tertiary education and TAFE institutions, Geelong can consolidate research, training, and industry development to emphasise its local market strengths. As depicted in Figure 21, Geelong's established manufacturing and extractive base provides a strong foundation for the prefabricated concrete industry and small retailers throughout the region. The spatialisation in Moolap highlights a minor percentual emphasis on prefabricated concrete, with supportive steel, quarries, and distribution companies dispersed throughout the consolidated region.

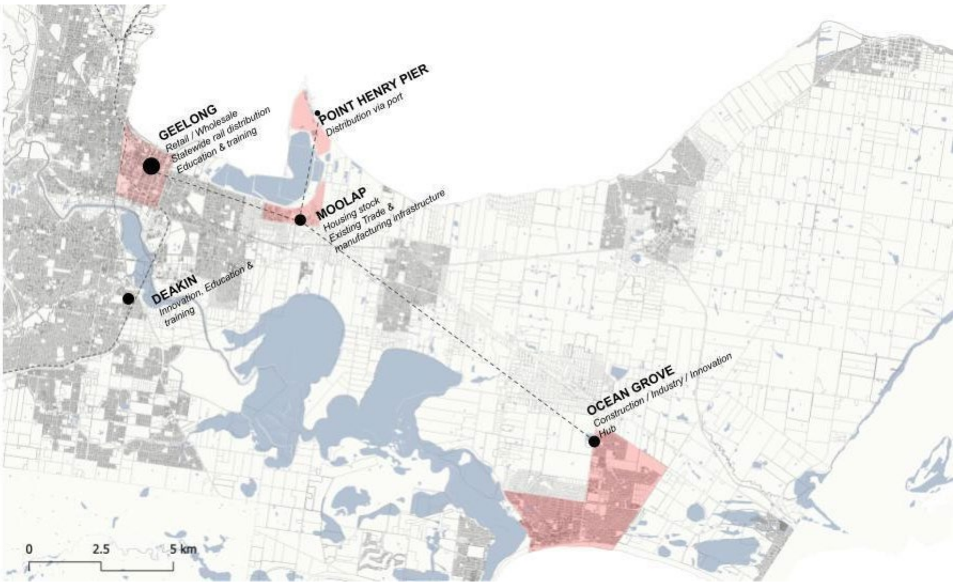


Figure 21. *Consolidated Hub*

With Moolap providing a substantial base for manufacturing and construction expertise / facilities, Ocean Grove presents one of the most expansive and rapidly growing regions in Victoria with construction growth of 484% between 2011 and 2021 and being the second highest employer. The majority of industry sectors are experiencing growth rates of over 200% with significant potential to leverage this growth into an opportunity to innovate a variety of industries and their infrastructures. Establishing a dialogue exchange between the innovative potential of Ocean Grove and respected educational institutions such as Deakin University to back the development of a consolidated construction / manufacturing hub in local areas of established workforce such as Moolap, or Corio.

Employment statistics have wavered in Moolap in conjunction with the 2014 closure of Alcoa’s Point Henry Aluminium plant that provides an additional opportunity for adaptive renewal in the construction & manufacturing markets. Availability of Alcoa’s large-scale warehouses, access to point Henry Pier and existing highway freight positions Moolap as an exceedingly unique geographical location while being posited between 2 institutions of exceptional innovative capacity, Deakin and Ocean Grove. Further analytics are required to ensure large-scale investment does not exacerbate significant housing stresses and mitigating any potential for existing workforce to be displaced. Figure 22 demonstrates a summary of the strengths of Geelong.

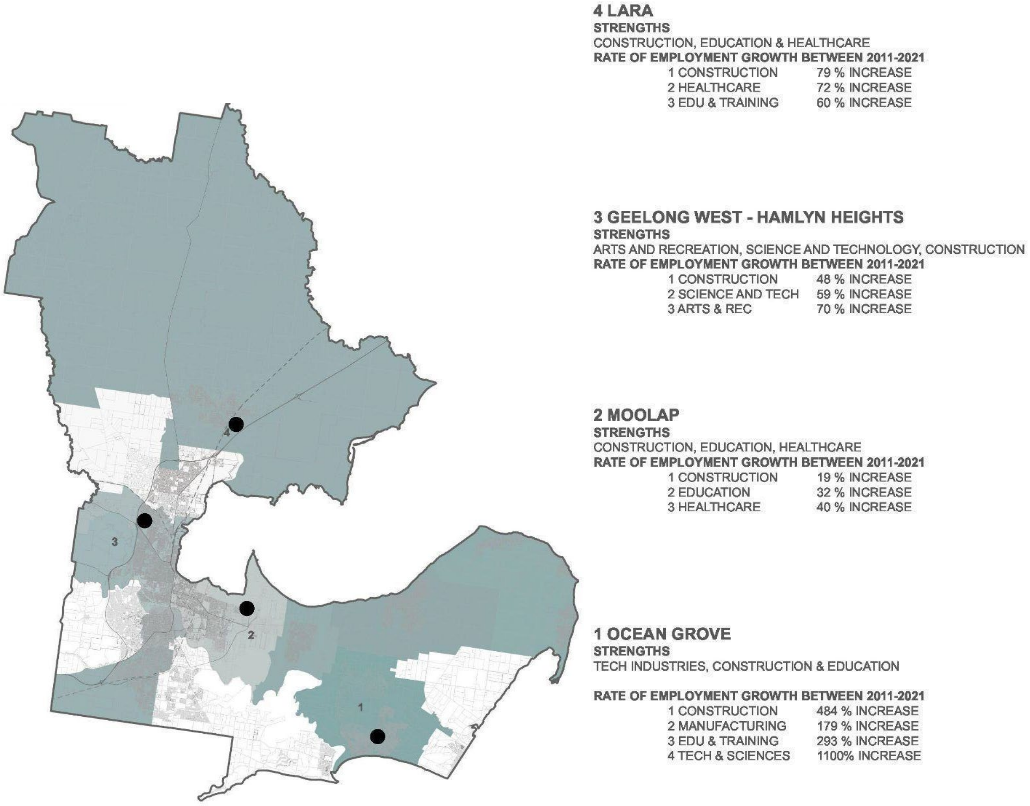


Figure 22. *Summary of the strengths of Geelong*
Source: Author using ABS data 2011 and 2021a SA2 Industry of Employment.

Supply chain maps of the 3 locations

The construction supply chain maps have been generated for the 3 locations using publicly available data sources from Victorian Government websites. These maps have been extracted based on suburb codes, and in some instances, street addresses have been used. Any missing data points have been added manually. This process has resulted in an estimate of the current capacity map, which supports the findings and recommendations presented in the next section.

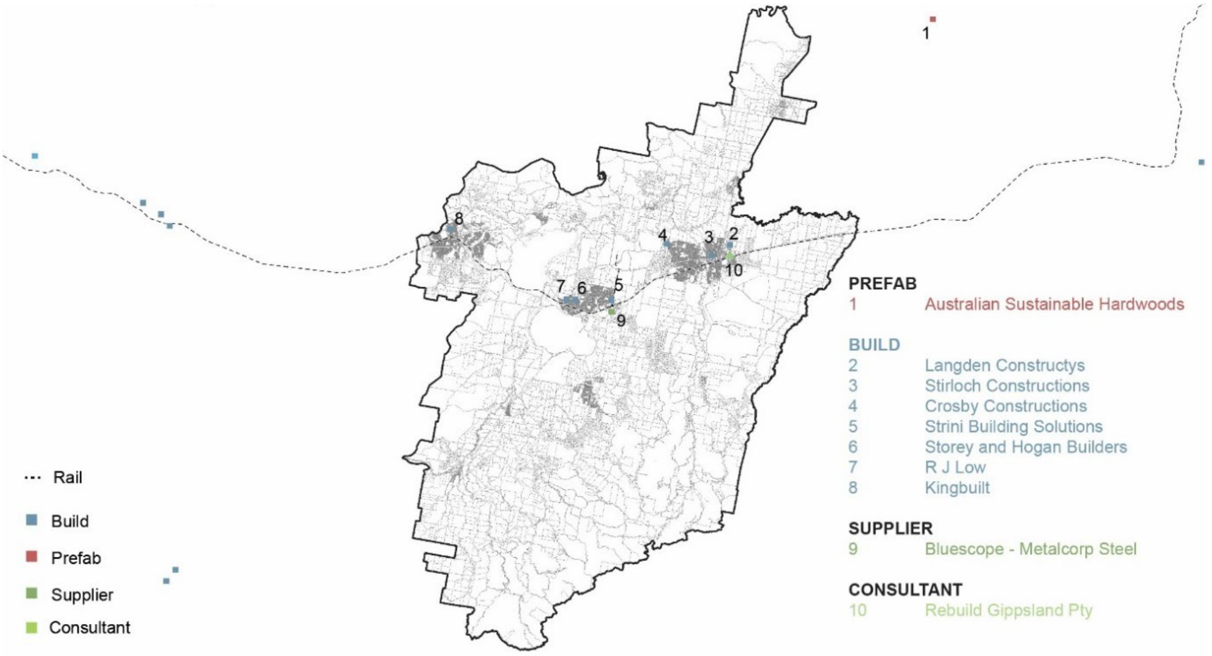


Figure 23. *Latrobe Valley construction services_ Victorian construction suppliers*

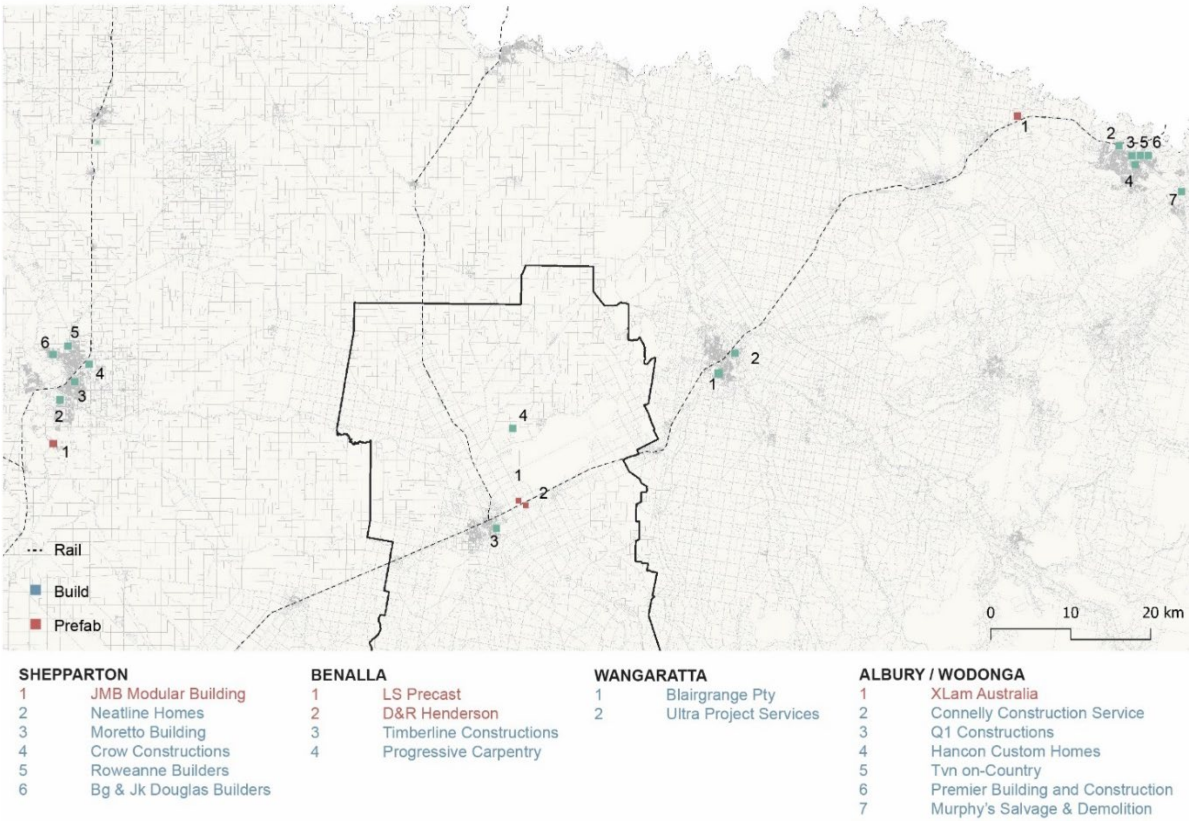


Figure 24. *Benalla construction services_ Victorian construction suppliers*

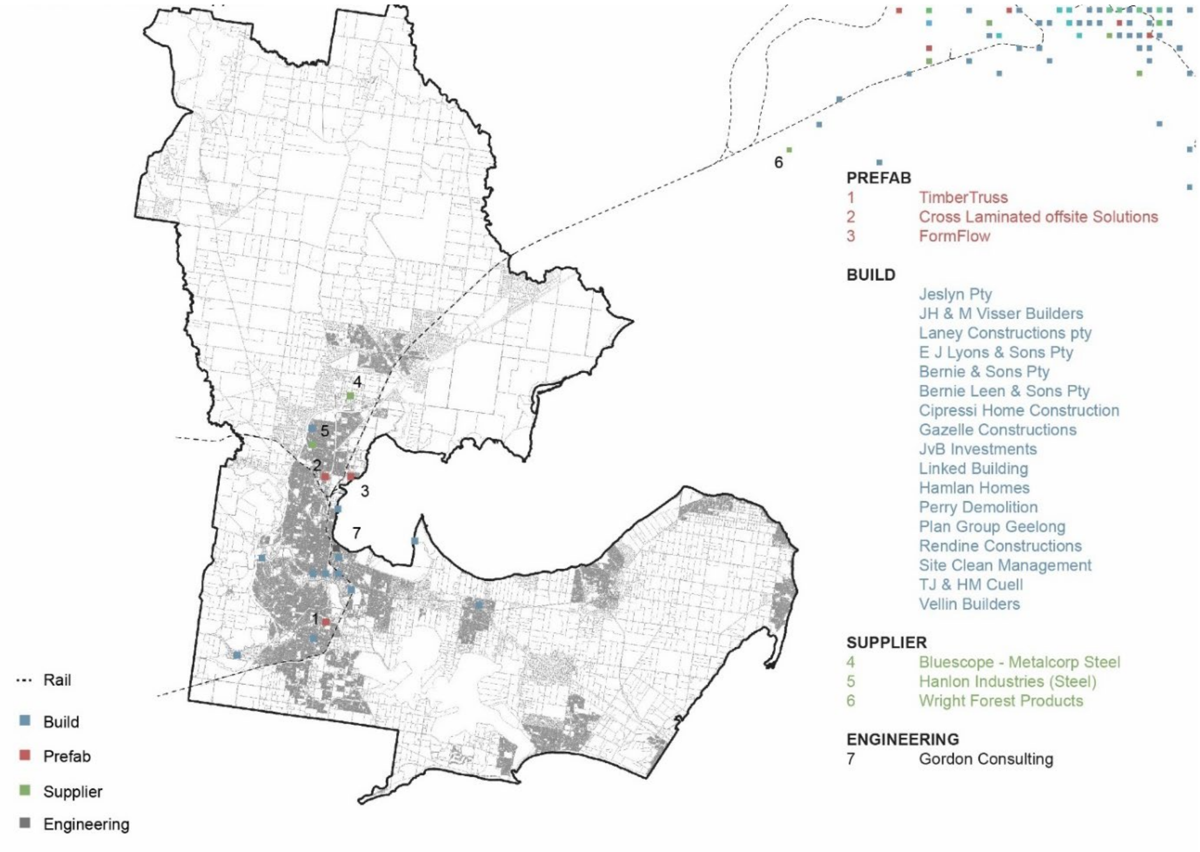


Figure 25. *Geelong construction services_ Victorian construction suppliers*

CONCLUSIONS

The success of construction hubs in Victoria depends on the mix of components associated with them. In addition to this, there is the ongoing need to sustain workforce, skills and training, affordable housing, and access to resources and materials. The research found that construction hubs are susceptible to market dynamics influences, such as resource availability, government policy, land development policy, and population density that supports the people and communities associated with them.

As identified in the responses gathered from interviews with industry stakeholders, there is a need for better value chain coordination. To elaborate, the research indicates a need to build a wider supply base, enhance supplier qualification, establish buffering warehouses near factories, coordinate through logistics companies, shorten supply chains, foster closer working relationships, and gain real-time visibility into changes and delays. Additionally, there is a push towards more standardisation in the construction industry. This could facilitate an approach towards modern construction methods and the associated efficiencies they offer, whether in terms of time, cost, or efficiency benefits.

The case studies examined the existing makeup of 3 areas. Each was found to have certain strengths and areas for improvement or better resourcing. As outlined in the recommendations, key criteria were developed for the identification and future sustainability of construction hubs at a holistic level.

Overall, the research presents a series of real-world examples of the components within a construction hub and offers recommendations on what might be required for their full utilisation. Moreover, this research outlines what is necessary to propel Victoria into a national leader for collaborative communities in our regional areas.

RECOMMENDATIONS

The final section transitions from theory to practice, presenting our recommendations that are crucial for the creation and sustenance of effective Construction Hubs in Victoria. These recommendations offer a tangible guide for policymakers, industry stakeholders, and partners, ensuring the vitality and success of Construction Hubs in the dynamic regional landscape of Victoria.

The recommendations are the aggregated findings from the multi-level analyses presented in Appendices A, B, C, D, and E of this report. The findings are presented as two sets of recommendations: first, key recommendations to assist strategic decision-making for Hub establishment, and second, granular-level recommendations for each of the three regions - Latrobe Valley, Benalla, and Geelong.

Key Recommendations to assist Construction Hub establishment decision-making

Sustainability

- **Workforce Availability and Skills:** The availability of an adequate and skilled workforce is a fundamental consideration when establishing a construction hub. Assess the region's existing pool of construction professionals and tradespeople, as well as their skills and qualifications. A robust and skilled workforce will attract construction companies and support hub development.
- **Population Density and Growth:** Evaluate both the current population density and projected population growth in the region. Areas with higher population densities and strong growth prospects are more likely to generate sustained demand for construction projects. This factor is crucial for the long-term viability of the hub.
- **Labour and Housing Affordability:** Consider the cost of labour and housing in the region. High labour costs can affect project budgets and company profitability, while expensive housing may deter skilled workers from relocating or staying in the area. Ensuring a cost-effective labour market and affordable housing options is vital for attracting and retaining both construction firms and their workforce.
- **Access to Resources and Materials:** Evaluate the region's access to essential construction materials and natural resources. Construction projects often require materials such as sand, timber, and minerals. Ensure a reliable and sustainable supply of these resources within the region to support construction activities. Access to affordable, locally sourced materials can offer cost advantages and improve the hub's competitiveness.

Market dynamics

- **Resource Accessibility:** Ensure the regional location offers convenient access to affordable and reliable energy sources, including electricity and fuel, to minimise operational expenses for the construction hub. Proximity to these resources supports cost-effective construction processes and enhances the hub's competitiveness.
- **Material Supply Chain:** Evaluate the availability and pricing of construction materials, such as timber, steel, and concrete. A robust and cost-effective supply chain for these materials is essential to maintain competitive project budgets and profitability. Establish partnerships with reliable material providers to streamline procurement processes.
- **Communication Infrastructure:** Prioritise a robust and reliable internet and communication infrastructure within the regional area. Seamless connectivity with clients, suppliers, and stakeholders is critical for efficient project management and collaboration. High-speed internet and communication networks facilitate information exchange and operational efficiency.
- **Industrial Ecosystem:** Assess the presence of key industries, manufacturers, prefab companies, and construction firms in the regional area. Collaborate with these entities to explore joint projects, shared resources, and mutual growth opportunities. Partnerships with prefab companies and construction firms can enhance the hub's capabilities and competitiveness, while strong relationships with material providers and logistics companies support efficient operations.
- **Land Availability:** Ensure the regional area has sufficient land resources and appropriate zoning regulations to accommodate the construction hub's infrastructure needs. Adequate land availability is crucial for establishing offices, workshops, storage yards, and potential expansion areas.
- **Demand Analysis:** Identify the hub's target market, considering residential, commercial, industrial, or infrastructure sectors. Align the hub's services and capabilities with the regional area's demand for

construction projects within the target market. Additionally, analyse future project pipelines and major investments in the area to strategically position the hub for long-term viability.

- **Housing Gap Recognition:** Identify housing gaps or demand-supply imbalances in the regional area. Addressing affordable housing needs or catering to specific housing segments can create a consistent demand for the construction hub's services.
- **Logistics and Distribution:** Assess the availability of delivery and distribution centres, as well as logistics companies, in or near the regional area. Proximity to these facilities streamlines the movement of construction materials, equipment, and finished products, reducing transportation costs and enhancing project deliveries.

Resources

- **Infrastructure Accessibility:** Prioritise locations with readily available built assets, including serviced and ready sites, existing buildings with adaptive capacities, and established power infrastructures conducive to green energy. These assets accelerate the setup of the construction hub, reduce initial infrastructure costs, and support sustainable development practices.
- **Educational and Research Institutions:** Choose a location near education centres and research institutions specialising in construction-related fields. These institutions provide a skilled workforce, opportunities for innovation, and access to lifelong learning programs. Collaboration with them enhances the hub's capabilities, knowledge base, and long-term competitiveness.
- **Trade Workforce and Local Supply Chain:** Assess the presence of a skilled trades workforce and a robust local supply chain, including subcontractors and suppliers. A strong trades network is vital for efficient project execution and operational support. It ensures the availability of specialised services, equipment, and materials, contributing to the hub's success.
- **Material Availability:** Consider the regional availability of construction materials such as timber, steel, and concrete. If the area has a significant timber industry, steel fabrication facilities, or concrete production, the hub can benefit from reduced costs, shorter lead times, and sustainable practices. Align the hub's specialisation with the local material strengths to optimise resource utilisation and promote environmental sustainability.

Infrastructure

- **Transportation Accessibility:** Prioritise locations with convenient access to rail infrastructure, airports, and ports. These transportation hubs facilitate the efficient movement of materials, equipment, and personnel, reducing logistics costs and supporting large-scale construction projects. This accessibility enhances the competitiveness and growth potential of the construction hub.
- **Strategic Location:** Choose a location that strategically aligns with reference points such as urban centres, transportation nodes, industrial zones, and educational institutions. Proximity to these key entities promotes collaboration, customer access, logistical efficiency, and workforce availability, all of which are vital for a thriving construction hub.
- **Efficient Logistics and Workflow:** Focus on optimising logistics and workflows within the construction hub. Implement just-in-time delivery practices, effective planning and scheduling, lean construction principles, and streamlined supply chain management to enhance operational efficiency, reduce costs, and ensure timely project completion.
- **Material Flow and Delivery:** Pay attention to material flow management and seamless project delivery. Efficient inventory management, proper material handling equipment, client coordination, and quality control measures are essential to maintain a competitive edge and meet client expectations in terms of project quality and timely delivery.

Recommendations for Location 1: Latrobe Valley — Linear Hub

Sustainability	● Focus on the development of Traralgon to stabilise the local workforce and economy. Address the decline in employment and workforce skills pool by fostering growth in this area. ● Given the relatively small demand for rental housing, strategically invest in housing projects to mitigate the rapid inflation of rentals. ● Given the limitations on timber production due to governmental restrictions, consider alternative sustainable timber practices and technologies. ● Leverage the highly mobile rural workforce from nearby LGAs. Utilise labour resources from outside Latrobe Valley to maintain labour costs at a reasonable level. ● Continue the transformation of existing infrastructures into renewable green energy production, including the development of multiple battery storage facilities and wind farms. This not only promotes sustainability but also creates jobs in the renewable energy sector
Market dynamics	● Given the strong access to distribution, proximity to raw materials, and the presence of energy production and manufacturing workforce, focus on significant investment in renewable energy networks. ● Capitalise on the large-scale closures and established infrastructure in the region. Repurpose closed facilities for new industries, research centres, or manufacturing hubs, reducing the required capital investment. ● Align region development plans for industrial zoning to support densification in Morwell, taking advantage of existing workforces. Ensure that affordable housing options are available to minimise workforce displacement. ● Leverage the direct access to the rapidly expanding Melbourne residential market through Dandenong Retail and industrial precinct. ● Develop isolated distribution hubs strategically placed within the Latrobe region to optimise the transportation of goods. Attract logistics companies to enhance the region's distribution capabilities.
Resources	● Take advantage of the large supply of suitable properties for construction hubs by promoting the adaptive reuse of recently closed energy-producing warehouses, timber producers, and the paper mill. ● Recognise the need for professional training opportunities in Latrobe. Collaborate with Federation University to expand and diversify professional training programs, addressing the gap between local employment opportunities and national averages. ● Support the growth of the tech industry in Morwell and Churchill, responding to the adaptation of renewable energies. Promote the Hi-Tech Precinct Gippsland, including the Morwell Innovation Centre and Gippsland Tech School, as a hub for tech innovation and education. ● Explore regenerative logging practices as an economic opportunity, despite recent limitations on native logging. Facilitate access to nearby timber prefabrication businesses in adjacent LGAs to support the construction sector. ● While Latrobe lacks significant quarries or areas of extraction outside of coal mining, recognise the potential in the surrounding regions. Explore partnerships and resource sharing with nearby areas, such as Geelong and Benalla, to access raw materials like stone and minerals.
Infrastructures	● Encourage the development of diversified industrial hubs in Latrobe, taking advantage of the existing urban nodes' specialisations. These hubs should capitalise on the region's established workforce and infrastructure while fostering synergies between different clusters. ● Address the limited north-south distribution paths by exploring opportunities to enhance transport infrastructure. Investigate options for expanding rail and road connections to broaden distribution paths for minerals and large-scale products. ● Collaborate with educational institutions like GOTAFE and Federation University to develop customised training programs that align with the needs of the evolving industries in Latrobe. ● Continue to invest in tech and innovation, particularly in areas like Morwell and Churchill, where there is consolidation in these sectors. Support initiatives like the Hi-Tech Precinct Gippsland to foster technology advancements and research. ● Recognise the constraints of a linear hub and work on optimising material flows within this framework. Enhance coordination between businesses to facilitate immediate material exchange and streamline workflows.

Recommendations for Location 2: Benalla — Networked / Decentralised Hub

Sustainability	● Leverage the high mobility of the local rural workforce by creating initiatives that attract workers from nearby towns like Benalla. Collaborate with local businesses like LS Precast to ensure the availability of a skilled labour force. ● Recognise that workforce growth may drive up labour costs. Develop strategies to maintain business viability while mitigating the impact of rising labour expenses, such as investing in training and automation. ● Capitalise on the significant employee population aged 15-34 to stimulate economic growth. Encourage additional growth in this demographic without altering the working demographics significantly. ● Establish the coordination hub as a supportive mechanism for existing industries like LS Precast. Foster interconnectivity between the hub and local businesses to create synergies and support growth. ● Recognise that the coordination hub may promote further agricultural development by providing a supporting industry for distribution.
Market Dynamics	● Exploit the significant solar farming presence between Benalla and Glenrowan by investing in large-scale solar energy projects. Bolster the existing network to meet the energy requirements of the construction coordination hub. ● Build on strong relations with distribution networks and ensure efficient national access. Given limited access to extractive and raw materials outside LS Quarry, prioritise streamlined logistics to minimise material-related challenges. ● Develop a robust plan for improving internet infrastructure to support the development of a digital hub. ● Utilise the availability of cheap industrial land, already zoned for construction, to establish various warehouse typologies and building uses. ● Collaborate with existing industries like LS Precast, Thales Munitions, and D&R Henderson to promote synergy and support growth. Encourage smaller assembly line companies and construction suppliers to further diversify the local industry landscape.
Resources	● Attract new industrial properties or repurpose existing ones to accommodate the needs of the construction coordination hub. ● Support Schneider Electric's production of transformers for wind farms. Explore opportunities for collaboration with local industries to foster growth and innovation in renewable energy and related technologies. ● Recognise the need for professional training facilities in Benalla, especially given the growth in professional occupations. Consider establishing partnerships with nearby institutions to provide access to professional training and tertiary research capabilities. ● Leverage connectivity to surrounding renewable energy facilities to promote the development of tech advancements in Benalla. ● Capitalise on the agglomeration of trades experts in the surrounding regions. Develop initiatives to connect local businesses with this pool of trades expertise to meet construction needs.
Infrastructures	● Continue efforts to expand and improve transportation infrastructure, especially the Hume Freeway and ARTC rail access. Prioritise extending rail connections to enhance the existing national distribution capacity. ● Develop Benalla Regional Airport as a key asset for air transportation. Explore opportunities to connect it to broader regional air networks to facilitate efficient cargo and passenger movement. ● Collaborate with surrounding townships, particularly those with established populations and infrastructure, to create a regional network that can provide services and support for the construction coordination hub. ● Invest in expanding educational and training facilities in Benalla to meet the needs of a growing workforce. ● Recognise the limitations of geographical location and focus on optimising existing infrastructure for efficient material flows. Invest in technology and processes that enhance the coordination of material movements.

Recommendations for Location 3: Geelong — Consolidated Hub

Sustainability	● Capitalise on Geelong's historical strength in multi-industry development and the availability of existing infrastructure from closed sites. Explore opportunities to repurpose these sites for new developments ● Given the potential for further growth in the workforce, it's important to manage the demand for skilled workers effectively. Collaborate with local educational institutions to provide relevant training programs that align with the needs of maturing industries. ● While Geelong has experienced a higher population growth than neighbouring rural areas, consider implementing strategies that balance population growth and urban development to avoid excessive high-density population increases. ● Encourage the construction sector to transition from traditional materials to sustainable building materials. Explore partnerships with suppliers of sustainable materials outside the local government area to meet demand. ● Anticipate potential conflicts between construction and agricultural industries, which have developed rapidly in similar areas. Collaborate with stakeholders to develop land-use planning strategies that prioritise both industries' growth without compromising resources.
Market Dynamics	● Collaborate with governmental initiatives to further encourage and support wind farm ventures in the Golden Plains. ● Capitalise on Geelong's well-developed transport infrastructure, including the port, rail, airport, and proposed Western Interstate Freight Terminal. These facilities can help alleviate potential access bottlenecks for materials, enhancing the efficiency and cost-effectiveness of the construction hub. ● Continue fostering the growth of the tech industry in Geelong, as it aligns well with the development of a construction hub. ● Engage with initiatives like the G21 Geelong Region Alliance's Industry Sector Employment program, connecting job seekers with opportunities in the construction industry. ● Leverage the existing clustering of timber and concrete prefab companies in Corio, Lara, and Moolap. Encourage collaboration and knowledge sharing among these companies to enhance efficiency and quality in prefab construction.
Resources	● Focus on converting existing industrial properties into specialised spaces for construction hubs, given the relatively large supply of suitable properties for lease in Geelong. ● Utilise the presence of modular building company Cross Laminated Offsite Solutions (CLOS) relocating into the former Ford factory. ● Foster strong ties with educational institutions like Deakin's ManuFutures and the Institute for Intelligent Systems Research and Innovation. ● Tap into Geelong's array of upskilling and training opportunities across professional and trade occupations. Collaborate with these programs to ensure a continuous supply of skilled workers for the construction hub. ● Collaborate with research centres like Deakin's Carbon Nexus to explore sustainable construction materials and techniques.
Infrastructures	● Capitalise on Geelong's existing transportation assets, such as the port, rail, airport, and road networks, to facilitate efficient material distribution for the construction hub. ● Collaborate with local industrial giants like Fleetwood, BlueScope, and Lysaght to streamline workflows and enhance logistics planning, ensuring the smooth flow of materials. ● Utilise Geelong's robust communication infrastructure to facilitate seamless collaboration among various industries within the construction hub. ● Leverage the availability of specialised equipment for material extraction, refinement, and sub-assembly to optimise material preparation and reduce costs. ● Encourage collaboration among diverse industries to create a holistic approach to construction, taking advantage of Geelong's diverse employment ecosystem.

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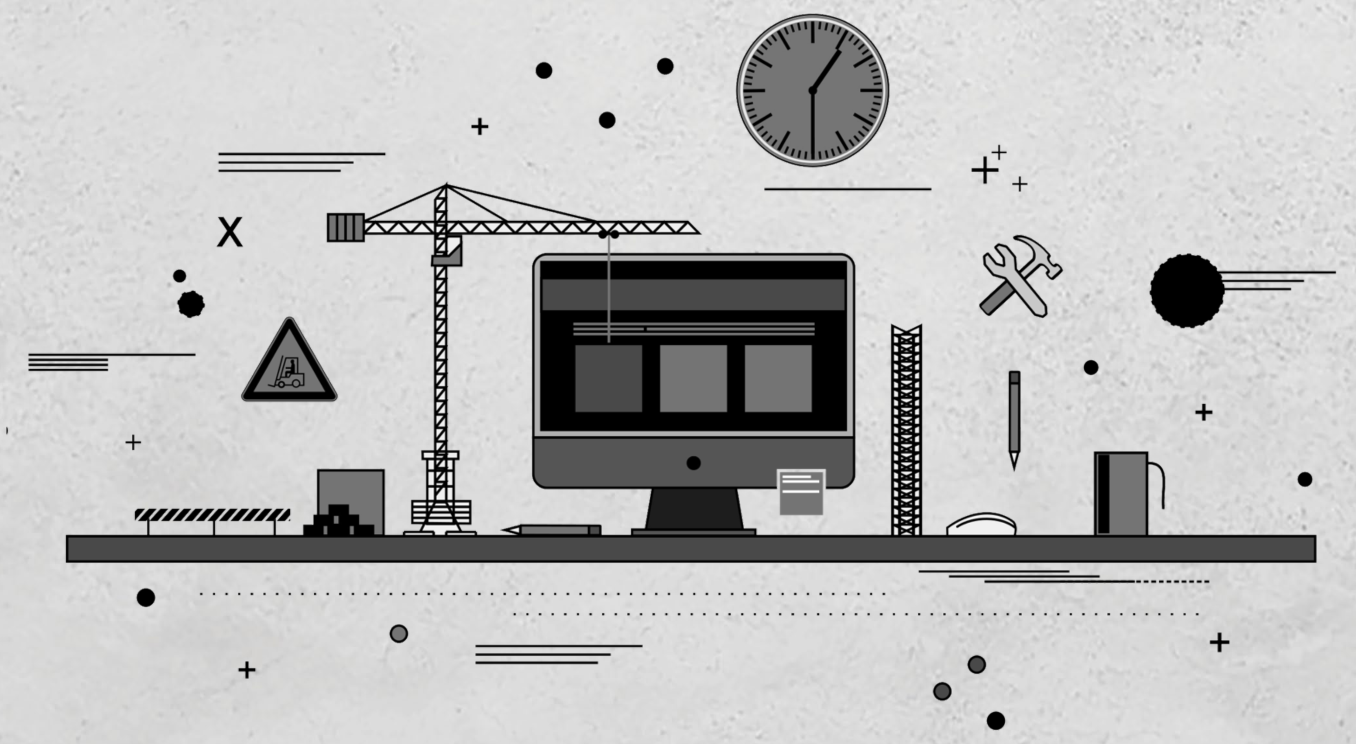
PROJECT #38.1
OFFSITE + MODULAR CONSTRUCTION HUBS

APPENDICES



Australian Government
Department of Industry, Science and Resources
Cooperative Research Centres Program

CONTENTS

A_HUBS CASE STUDIES

This section of the report outlines the intricate methodology of the developed framework, aimed at identifying key factors and procedures that contribute to the potential development of construction hubs in various areas of interest. The factors are categorised across five main parts, as indicated on the contents page: A) Hubs Case Studies, B) Place-Based Analysis, C) Socio-Economic Analysis, D) Industry Partner Interviews, and E) Evidence-Based Evaluation of Three Locations.

A) The Hubs Case Studies section serves as the foundation for the framework, featuring in-depth investigations of existing construction hubs. These case studies offer empirical evidence and insights that inform the subsequent analytical approaches and evaluations conducted in other parts of the report.

B) The Place-Based Analysis offers a comprehensive breakdown of the region-testing methodology developed in this report. It highlights the multi-scalar parameters utilised to recognise the potential for construction hub development through state-wide, regional, and local statistical analyses. The primary content within this analysis lies in the spatial representations derived from datasets provided by the Australian Bureau of Statistics (ABS) and VICdata. These spatial representations facilitate the identification of infrastructural scarcity while coordinating with socio-economic strengths and weaknesses.

C) The Socio-Economic Analysis provides context for the place-based analysis by offering an extensive historical and existing socio-economic review. this section explores the historical foundations of economic development in each target region, establishing connections between historical socio-economic trends and contemporary patterns. Moreover, these socio-economic patterns are examined across local, regional, national, and international scales to uncover the interconnectedness of economic trade and distribution.

D) The research team conducted several partner interviews, which are synthesised in this section of the report. The focus here is on key topics identified concerning the nature of construction hub development and their anticipated outcomes for this report.

E) Building on insights from the place-based analysis, socio-economic analysis, and interview findings, the research team has underscored the importance of sustainability, market dynamics, resources, and infrastructure as vital considerations for assessing the readiness of target regions. This section serves as a set of evaluation criteria for determining the viability of a construction hub within selected regions.

CONSTRUCTION LOGISTICS HUB

Bern, Switzerland

01

ACTIVITY
[✓ coordination + planning] [✓ operation + services] innovation + training commercial marketplace [✓ integrated]

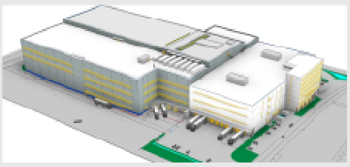
ESTABLISHMENT
[✓ physical] digital network

DRIVERS
[✓ sustainability] partnership regional development innovation digitalisation

BUSINESS MODEL
[✓ centralised] decentralised

SECTOR
[✓ public] private

GOVERNANCE
[✓ top down] middle out bottom up



The Construction Logistics Hub by Swiss Post is a strategic initiative aimed at improving the efficiency and sustainability of construction projects. These hubs centralize the sorting and assembly of building materials, allowing for just-in-time delivery to construction sites, reducing on-site storage needs, and optimizing traffic routes for construction-related transportation. Many of these hubs, including those operated by Swiss Post, prioritize sustainability by using electric vehicles (e-trucks) for material transport, resulting in reduced environmental impact and noise disruption. The streamlined logistics process helps alleviate space constraints on construction sites, contributing to smoother and more efficient operations.
Key features include:

- Material Sorting and Assembly
- Just-in-Time Delivery
- Traffic Optimization
- Reduced Environmental Impact
- Noise Reduction
- Space Efficiency

DIGITAL TWIN (DT) HUB

UK
ESTABLISHED: 2020

02

ACTIVITY
coordination + planning operation + services [✓ innovation + training] commercial marketplace [✓ integrated]

ESTABLISHMENT
physical [✓ digital] [✓ network]

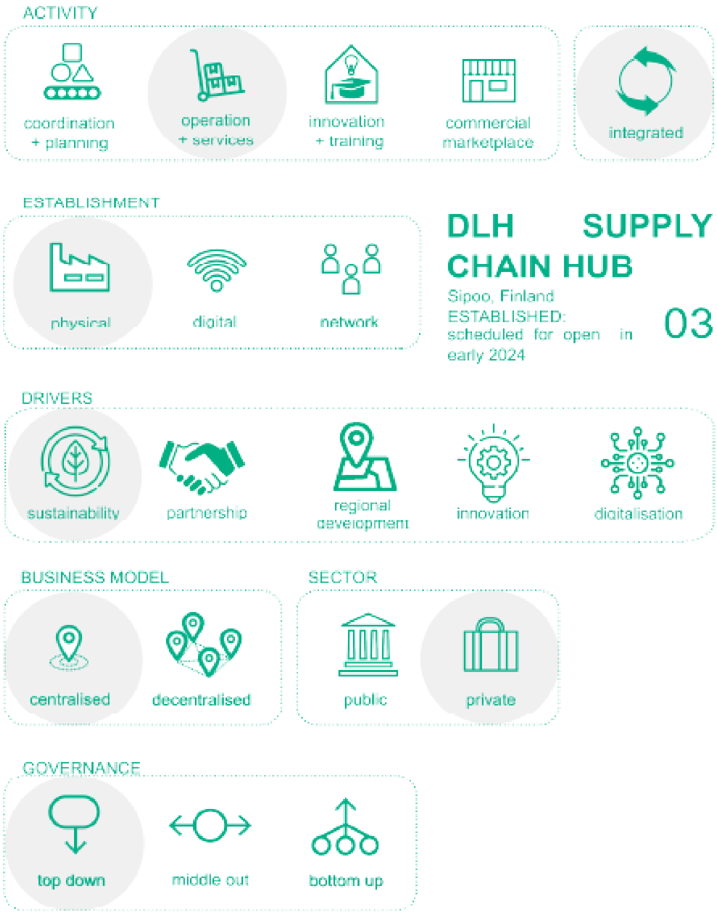
DRIVERS
sustainability [✓ partnership] regional development [✓ innovation] [✓ digitalisation]

BUSINESS MODEL
centralised [✓ decentralised]

SECTOR
[✓ public] private

GOVERNANCE
top down middle out [✓ bottom up]

The Digital Twin (DT) Hub, founded in 2020 at the University of Cambridge, has evolved into a multi-sector Industry and Catapult Network partnership housed at the Connected Places Catapult by 2022. Working in tandem with the National Digital Twin Programme, it addresses global challenges like pandemics and climate change through collaborative digital twin solutions. The DT Hub serves as a collaborative platform, fostering innovation, sharing best practices, and shaping data-sharing standards. Its next phase focuses on building advanced digital twins, guided by four core priorities: a vibrant industry-led community, a mission-driven industry voice, sector engagement, and promoting open standards and interoperability.



DLH SUPPLY CHAIN HUB

Sipoo, Finland
ESTABLISHED: scheduled for open in early 2024

03

DHL Supply Chain, a leader in contract logistics within Deutsche Post DHL Group, has announced plans to construct a state-of-the-art, carbon-neutral logistics center in Sipoo, Finland. Spanning approximately 44,000 square meters, the facility, set to open in early 2024, aims to address the limited availability of high-quality logistics space in the Helsinki metropolitan area. With the equivalent size of 6 football fields, the center will accommodate various warehousing needs, from narrow aisles to pallet storage, and provide space for hazardous materials. DHL's commitment to carbon neutrality aligns with its mission to support sustainable supply chains. The strategically located center, adjacent to key transportation hubs, will serve as a multi-user solution, offering flexibility and resource management advantages in the dynamic logistics market. When fully operational, the facility could employ up to two hundred staff members.

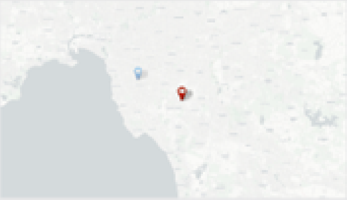
BE–ST

Built Environment – Smarter Transformation

Glasgow, Scotland

04

This international center of excellence, backed by the Scottish Government, the Scottish Funding Council, and Scotland's Enterprise Agencies, fosters collaboration among key stakeholders—industry, academia, government and public sectors, and citizens—to accelerate the transition to a zero-carbon future in the built environment. It engages with diverse organizations, from clients, architects, and engineers to manufacturers, government bodies, and academic institutions, both nationally and globally. Together, they work towards a sustainable, zero-carbon built environment that benefits communities and aligns with global sustainability goals.



CONSTRUCTION INNOVATION HUB

UK

05

ACTIVITY
coordination + planning
operation + services
[✓ innovation + training]
commercial marketplace
[✓ integrated]

ESTABLISHMENT
[✓ physical]
[✓ digital]
network

DRIVERS
[✓ sustainability]
[✓ partnership]
regional development
[✓ innovation]
digitalisation

BUSINESS MODEL
[✓ centralised]
decentralised

SECTOR
[✓ public]
private

GOVERNANCE
[✓ top down]
middle out
bottom up

In its mission to drive transformation in the construction sector, this initiative seeks to enhance the adoption of manufacturing and digital approaches, ultimately improving infrastructure delivery, resilience, and performance for the benefit of current and future generations. Supported by the Government and in collaboration with founding partners like the Manufacturing Technology Centre (MTC) and the BRE, it engages with an extensive network of over 600 organizations, including industry bodies, policymakers, practitioners, and academics, as part of the Transforming Construction Challenge. The primary objective is to continue advancing the construction industry, cultivating a market with the capacity and capability required to ensure the sector's future while addressing the increasingly complex needs of infrastructure projects. This holistic program integrates digital and manufacturing advancements and promotes value-based decision-making to enhance sector productivity, economic viability, and long-term resilience.

DANISH ADDITIVE MANUFACTURING HUB

Valby, Denmark

06

ACTIVITY
coordination + planning
[✓ operation + services]
innovation + training
commercial marketplace
[✓ integrated]

INFRASTRUCTURE TYPE
[✓ physical]
digital
network

DRIVERS
[✓ sustainability]
partnership
regional development
innovation
digitalisation

BUSINESS MODEL
[✓ centralised]
decentralised

SECTOR
[✓ public]
private

GOVERNANCE
[✓ top down]
middle out
bottom up

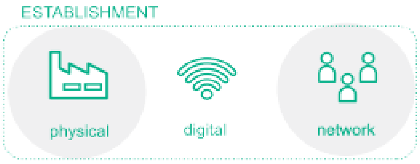
Dansk AM Hub is dedicated to propelling Denmark into a global leadership position in additive manufacturing (AM), also known as 3D printing. AM technology offers significant advantages in terms of sustainability and innovation, which can directly benefit British businesses. Serving as Denmark's central hub for AM, the organization actively advocates for the integration of AM into various business models. Through fostering collaboration and knowledge sharing, Dansk AM Hub aims to position Denmark as a prominent player in digital manufacturing, specifically in the realm of 3D printing. The hub's core mission revolves around driving innovation and sustainability, while unifying Denmark's AM ecosystem to showcase the manifold benefits of AM for businesses, customers, development, and sustainability.

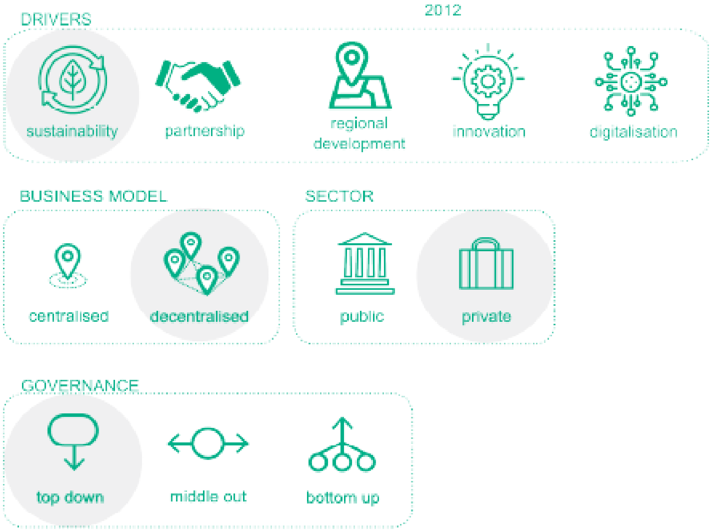
Dansk AM Hub actively promotes the integration of AM into various business models, aiming to position Denmark as a leader in digital manufacturing through 3D printing. The hub's mission is to drive innovation, sustainability, and collaboration within Denmark's AM community, showcasing the many benefits of AM for businesses, customers, development, and sustainability.

LONDON CONSTRUCTION LINK (LCL)

London, Edinburgh, Dundee, Grangemouth, Rosyth, UK
ESTABLISHED: 2012

07



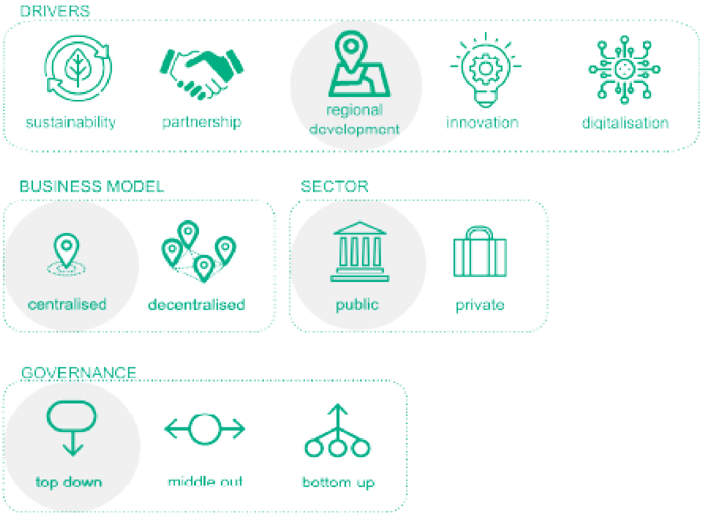


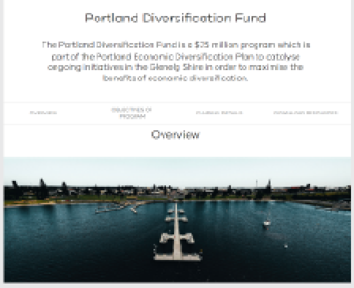
London Construction Link (LCL) serves as a strategic solution to alleviate traffic congestion in London by centralizing construction material distribution in Tilbury and efficiently delivering it through various modes of transportation, including water, rail, and road. Leveraging Tilbury's advantageous location, just 6 miles from the M25 and offering seaport, river, barge, and rail access, LCL has established a strong logistics legacy. It played a crucial role during the 2012 Olympics, Crossrail, and Tideway projects. The ongoing expansion at Tilbury2, featuring the UK's largest construction materials aggregates terminal, underscores LCL's commitment to the construction sector. Meanwhile, in Scotland, Forth Ports Grangemouth, Dundee, Leith, and Rosyth continue to provide tailored support to construction projects, with Rosyth's successful role in the Queensferry crossing project exemplifying their capabilities. Whether in London or Scotland, LCL and Forth Ports are indispensable partners for the construction industry, ensuring efficient and sustainable material supply chains.

HOUSE CONSTRUCTION HUB

Portland, Victoria

08





Portland Diversification Fund

The Portland Diversification Fund is a $25 million program which is part of the Portland Economic Diversification Plan to catalyse ongoing initiatives in the Glenelg Shire in order to maximise the benefits of economic diversification.

Overview

The Andrews Labor Government is investing $800,000 from the Portland Diversification Fund to establish a housing manufacturing hub in Portland, regional Victoria. Geelong-based manufacturer FormFlow will repurpose an unused airport hangar into this hub, which is set to produce up to 200 relocatable houses annually for the Glenelg Shire and surrounding regions. This initiative will create 50 full-time jobs and around 150 indirect jobs, introducing a new industry to the Portland district. The manufacturing hub will focus on housing for key workers, seasonal workers, National Disability Insurance Scheme participants, and emergency responses. It is part of the government's efforts to address workforce shortages and housing availability in south-west Victoria, contributing to sustainable jobs growth in the region as part of the Portland Economic Diversification Plan.

PREFABAUS

Australia

09

The Prefab Innovation Hub, introduced by Minister Karen Andrews for Industry, Science, and Technology on June 16, 2019, has been established to provide support to Australia's manufacturing and building and construction industry. Under the funding agreement with the Commonwealth, the Australian Manufacturing Growth Centre (AMGC) initially conducted a feasibility study for a manufacturing hub focused on the prefabricated building sector. The Hub's primary objectives are as follows:

Facilitating connections between the construction and manufacturing sectors to enable businesses to take advantage of advanced manufacturing processes.
Supporting the adoption of new technologies and innovations that can lead to a transformation of the industry, resulting in more intelligent, cost-effective, and sustainable construction solutions for the Australian population.
Expanding the manufactured buildings ecosystem to enhance businesses' capabilities in integrating advanced technologies and processes within the industry. This initiative aims to promote progress and innovation in both the construction and manufacturing sectors, ultimately benefiting the construction industry and Australia as a whole.

ADVANCED MANUFACTURING HUB

Northgate, Queensland, Australia

10

The Advanced Robotics and Manufacturing Hub, abbreviated as ARM, is on a mission to support manufacturers of all sizes in adopting innovative methodologies, integrating new technologies, and achieving substantial performance improvements. ARM collaborates closely with Australian companies, facilitating the seamless integration of cutting-edge technologies such as robotics, artificial intelligence, and Industry 4.0 solutions into their manufacturing processes.

The introduction of these advanced technologies holds the potential to enhance operational efficiency, workforce optimization, and overall competitiveness for manufacturers. ARM provides a comprehensive suite of services, including advanced manufacturing business readiness workshops, on-site assessments, and live technology demonstrations. For those seeking bespoke solutions, ARM offers technology accelerators and boasts an in-house team of design experts dedicated to supporting clients in achieving their specific business objectives

ACTIVITY

coordination + planning | operation + services | innovation + training | commercial marketplace | integrated

ESTABLISHMENT

physical | digital | network

DRIVERS

sustainability | partnership | regional development | innovation | digitalisation

BUSINESS MODEL

centralised | decentralised

SECTOR

public | private

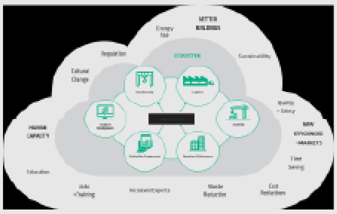
GOVERNANCE

top down | middle out | bottom up

BUILDING 4.0 CRC

Australia
ESTABLISHED:
2020

11



Building 4.0 CRC, established under the Australian Government's Cooperative Research Centre program in 2020, is poised to revolutionize the construction industry by embracing Fourth Industrial Revolution technologies. The CRC's mission is to propel the industry towards an efficient, interconnected, and customer-centric future, leveraging deep collaboration and cutting-edge technologies.
Building 4.0 CRC's objectives are:

- Cultivating a new industry culture and standard protocols to drive sector-wide transformation.
- Promoting sustainable design and construction practices to align with environmental considerations.
- Pioneering innovative building processes through technology, data science, and AI.
- Enhancing building hardware and processes, improving all aspects of key building phases.

This initiative signifies a significant step forward for the construction sector, promising an era of innovation and sustainability.

ACTIVITY

coordination + planning | operation + services | innovation + training | commercial marketplace | integrated

ESTABLISHMENT

physical | digital | network

DRIVERS

sustainability | partnership | regional development | innovation | digitalisation

BUSINESS MODEL

centralised | decentralised

SECTOR

public | private

GOVERNANCE

top down | middle out | bottom up

MONASH SMART MANUFACTURING HUB

Victoria, Australia
ESTABLISHED:
2023

12

The Monash Smart Manufacturing Hub (MSMH) offers an opportunity for businesses to optimize their processes, eliminate errors, and embrace cutting-edge efficiencies. This dynamic ecosystem brings together technology, talent, and infrastructure to facilitate insights and accelerate innovations.

By becoming an on-campus partner of MSMH, businesses gain access to state-of-the-art facilities, connect with talented students, and tap into the wealth of academic expertise available for commercialization. This collaboration aims to drive advancements in smart manufacturing and foster a thriving environment for innovation.

B_PLACE STUDY ANALYSIS

Place Study Abstract

The Place study analysis encompasses a comprehensive breakdown of the region testing methodology developed in this report, highlighting the multi-scalar parameters utilised in recognising the potential for a construction hub development through State-wide, regional, and local statistical analysis. The primary content within the place study analysis lies in the spatial representation derived from datasets provided by the Australian Bureau of Statistics (ABS) and VICdata. These spatial representations enable the identification of infrastructural scarcity whilst coordinating with socio-economic strengths and weaknesses.

The spatial study is not a definitive strategy for off-site Construction Hubs Victoria, the determination of which would require more information and research. Rather, the comparative examination of three Victorian case studies provides a framework for assessing the existing and potential capacity of different locations, enabling decision-makers to consider the range of economic, social, and infrastructural imperatives for establishing a Construction Hub in the short-term and successfully sustaining its growth into the future. The place-specific nature of the study means that an ‘apples for apples’ comparison is not possible. For example, the absence of a port in Latrobe Valley and Benalla does not necessarily mean they are less appropriate locations for a Construction Hub than Geelong. Instead the study integrates different datasets to: 1) identify existing conditions and strengths that different hub-types might build upon; and 2) demonstrate the inputs and processes that could create the conditions for a successful hub in the future.

The multi-scalar research methods recognise the multiple stakeholder-objectives that can impact on the aims and viability of a Construction Hub, as well as the timeframes needed to deliver successful outcomes. For example, government-led objectives may seek to bolster employment and training opportunities in a particular location, requiring a long-term transitioning of educational levels and workforce development geared towards advanced construction. Whereas industry imperatives may favour locations with ready assets, workforces and resources that can support shorter-term returns on investment in construction innovation. The spatial investigation integrates relevant datasets to support the multi-criteria assessments by cross-sector stakeholders.

The combination of data layers points to the place-specific opportunities that might be leveraged to establish a Construction Hub in Latrobe Valley, Benalla and Geelong, as well as inputs and processes needed to overcome the various challenges presented by the respective locations. The comparative examination also provides a roadmap for assessing other potential locations in Victoria, as more information about potential partnerships, finance, procurement methods and project pipelines emerge.

Methodology

The spatial investigation comprises three main scales:

- State-wide examination of existing infrastructure, resources and demographics: This level examines existing infrastructure, resources, and demographics across Victoria. It focuses on freight infrastructure, material resources, utilities, employment, demographics, and housing access, using datasets to isolate regions like Benalla, Geelong, and Latrobe Valley. The analysis involves studying employment fluctuations, assessing access to regional resources, and analyzing rail and road freight pathways
- Regional analysis of land-uses, actors and workforces: Building upon state-wide metrics, this scale offers a comparative analysis of specific regions. It identifies strengths and weaknesses, revealing industry-demographic relationships and infrastructural agglomeration. For instance, it examines variations in construction employment, revealing connections between local industries, resources, and established enterprises. Additional datasets, such as rental affordability, further highlight correlations between job opportunities and rent demand.
- Built assets and spatial requirements for local industries: This section emphasises involving industry knowledge in spatial development. It considers factors like workforce skill sets, warehouse typologies, municipal plans, industry ecosystems, and existing infrastructure. Industry insights contribute to tailored and forward-thinking spatial planning, helping leverage existing assets for development.

These scales, illustrated in Figures 1, 2, 3, and 4 cooperate to provide a comprehensive understanding of the potential for Construction Hubs in the selected Victorian regions. The multi-scalar approach recognizes the intricate interplay of economic, social, and infrastructural factors, enabling informed decision-making for the establishment and growth of Construction Hubs.

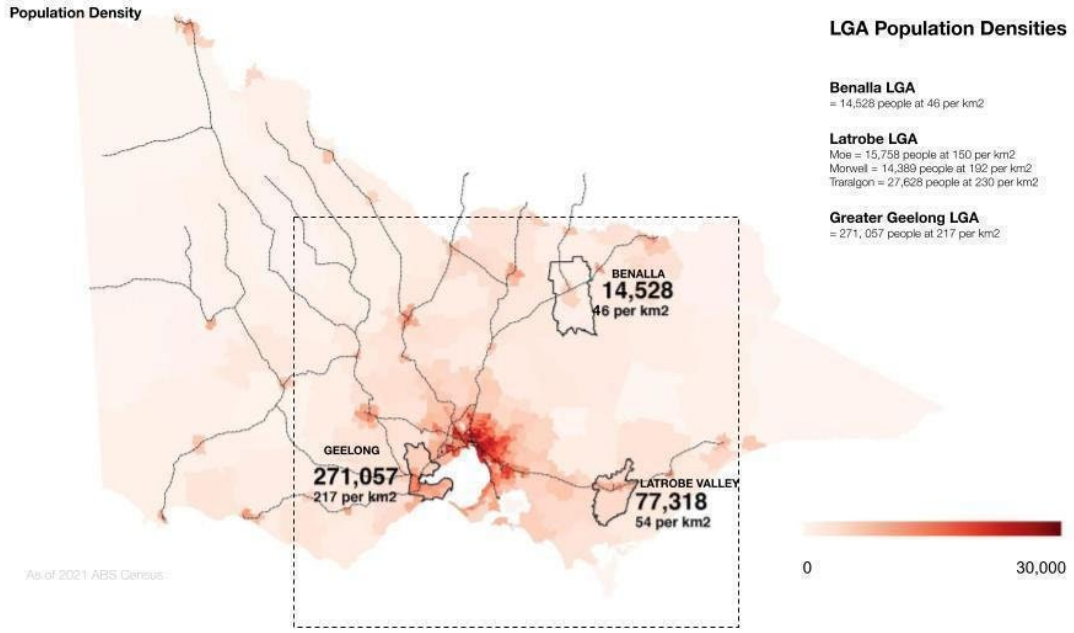


Figure 1. *Victorian Regions. Benalla, Geelong & Latrobe Valley as nominated areas of interest by the Victorian Govt, Source: Authors using 2021 General Community Profile*

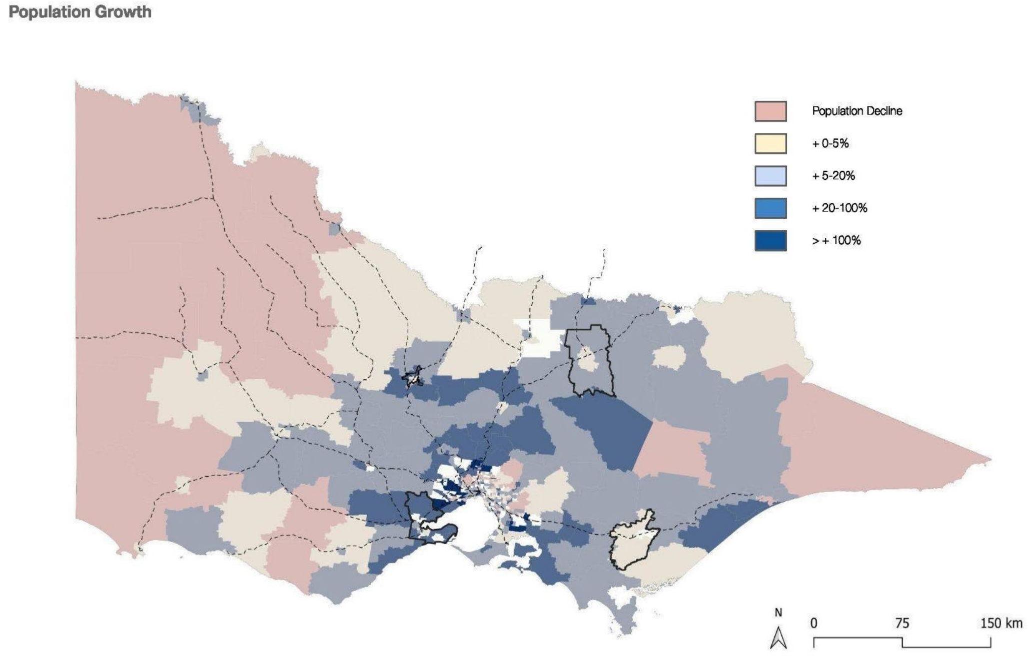


Figure 2. *Population Growth 2001 -2021. Source: Authors using ABS data 2001 - 2021*

The employment variation, depicted in *Figure 2*, showcases construction market responses across different Benalla, Latrobe Valley & Greater Geelong, with some experiencing a decline in employment while others enjoy rapid growth. By incorporating additional datasets like RAID rental affordability, a correlation between rent demand and the increase in job opportunities emerges, fostering a meaningful dialogue between these interconnected factors.

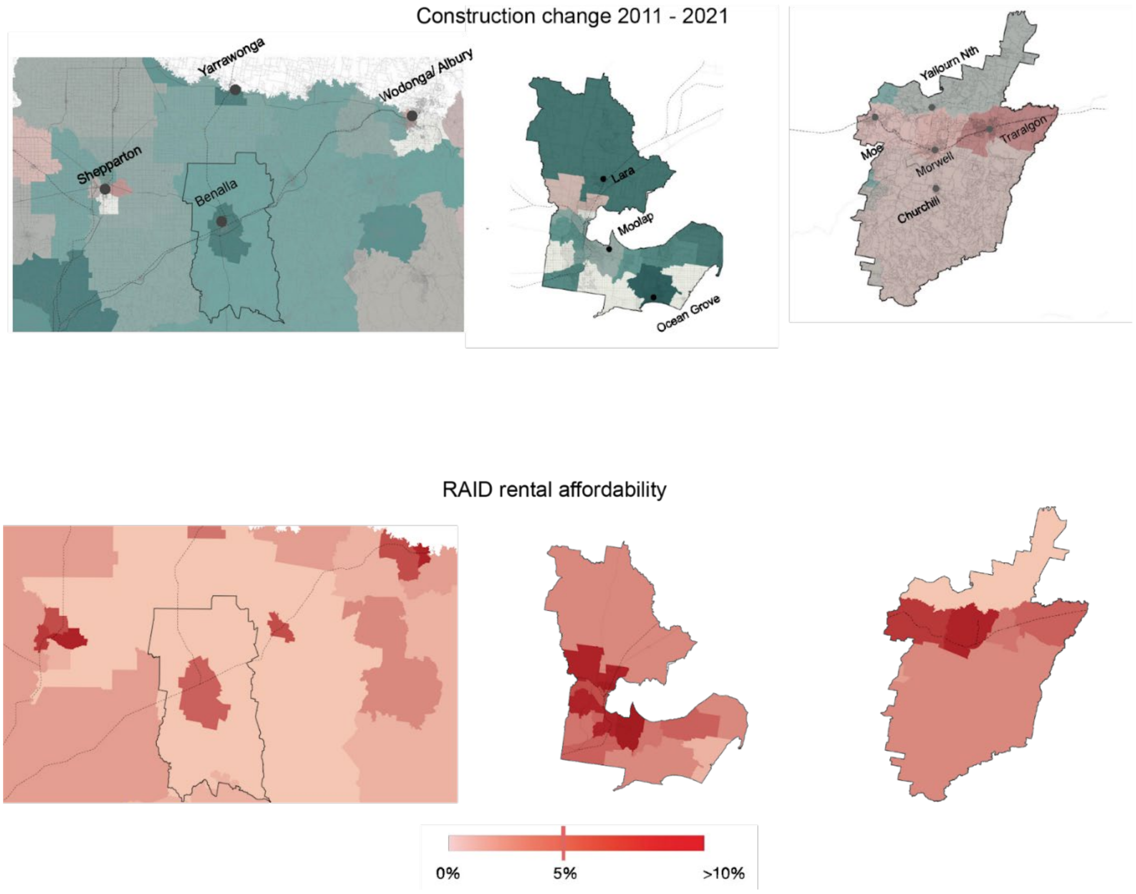


Figure 3. *Comparative overlay of 'Construction employment change' and 'RAID Rental Affordability', Source: Author using ABS data 2011 and 2021 SA2 Industry of Employment, and 2021 .*

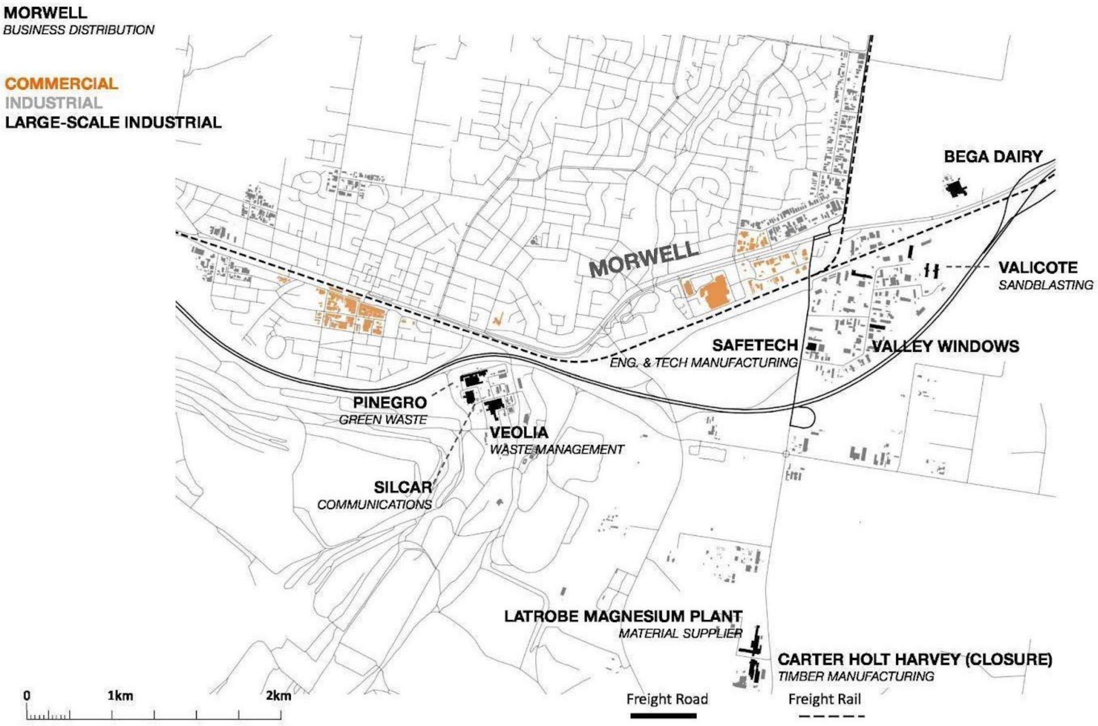


Figure 4. *Morwell Business Distribution, Source: Authors Desktop Mapping.*

Findings of state-wide analysis

Demographic Summary

Exploring the 2021 Australian Bureau of Statistics Census Data to establish a demographic context for the regions of interest. This involves analysing general population and industry workforce data to evaluate the existing workforce potential and model the industry's capabilities within the respective areas.

Benalla LGA

Benalla LGA is the smallest region in terms of total population and population density, with only 14,528 people at a rate of 6 people per square kilometre. On average, residents in the Benalla township commute an average distance of 3.39 kilometres to reach their workplaces, while those in the surrounding Benalla area travel a longer distance of 22.26 kilometres. Working age distributions of the region remain relatively consistent, with the majority of working age people being between 50 & 64.

Table 1. North Victoria Employment, Age Distribution. Source: 2021 ABS census Data.

Northern	***15 - 34 YRS***	***35 - 49 YRS***	***50 - 64 YRS***	**Total**	**% of workforce**
Bendigo	5,071	3,627	3,328	12,795	24.48%
Benalla town	**968**	**830**	**1,017**	**3,208**	**56.15%**
Shepparton	5,543	4,513	4,443	15,599	55.64%
Wangaratta	2,010	1,768	1,902	6,297	48.43%

Geelong LGA

Geelong is the largest region in terms of total population and population density, accommodating 271,057 people at a rate of 217 people per square kilometre. The region houses significant workforces in manufacturing, construction, and education/training sectors, with a notable concentration of workers aged between 15 and 34, comprising around 45% of the total regional workforce.

On average, individuals in Geelong travel on average 8.6 kilometres to reach their workplaces. Specific areas, such as Moolap, have an average work commute of 6.01 kilometres, while Bell Park and Ocean Grove have average commute average distances of 6.66 kilometres and 19.76 kilometres, respectively. Regarding Geelong's industrial buildings and zones, extensive development has taken place across all land use zones. The region prominently features urban growth boundaries that connect Rural Living zones, General Residential zones, and Industrial zoning along the inner peripheries of Geelong.

Table 2. *West Victoria Employment, Age Distribution. Source: 2021 ABS census Data.*

Western Region	***15 - 34 YRS***	***35 - 49 YRS***	***50 - 64 YRS***	**Total**	**% of workforce**
Ararat	703	510	615	1,953	42.75%
Ballarat	8,770	6,920	6,010	22,809	46.3%
Geelong	**19,780**	**16,080**	**12,899**	**51,592**	**42.86%**
Warrnambool	3,192	2,457	2,325	8,507	52.29%

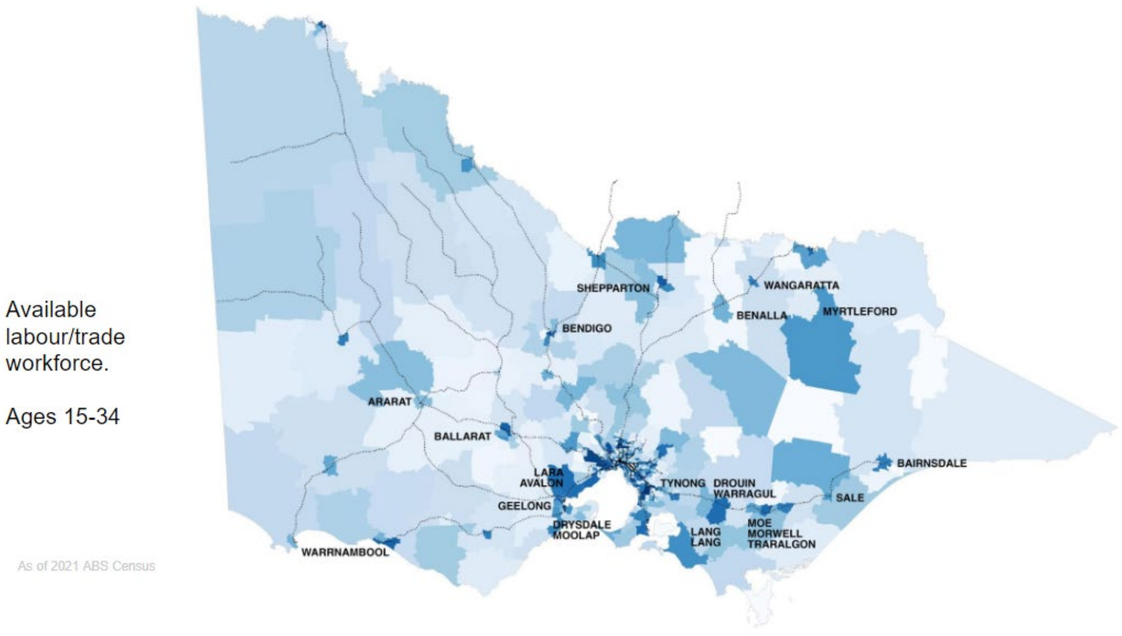


Figure 5. *Victorian Available Workforce ages 15-34, Source: Author using ABS data 2021 SA2 Industry of Employment.*

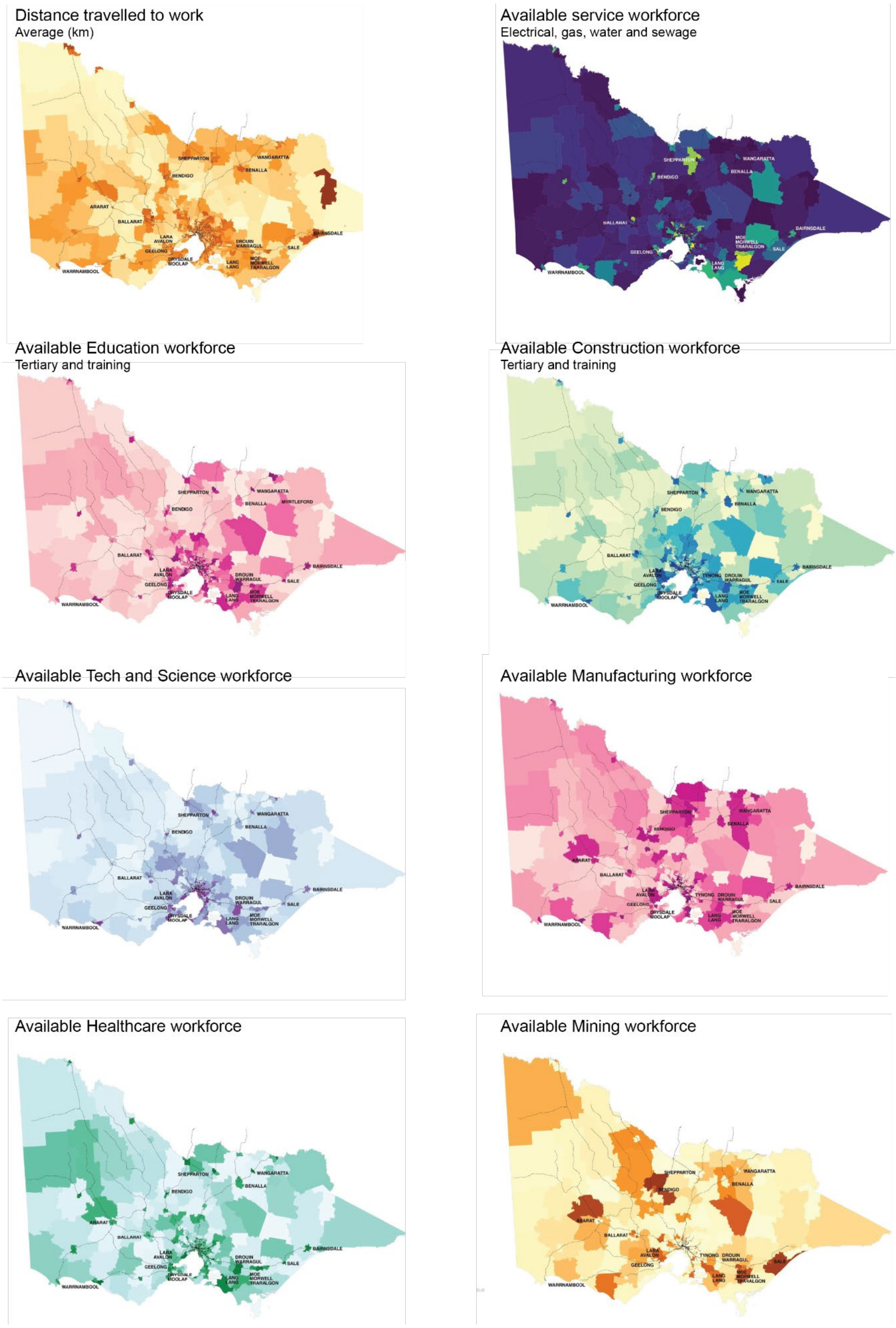
Latrobe LGA

Latrobe is the second largest region in terms of total population and the second most dense, accommodating 77,318 individuals at a rate of 54 people per square kilometre. The region boasts a significant workforce in manufacturing, construction, water/gas/electrical/waste services, and education/training sectors, with workers aged 15-64 evenly distributed among these fields, making up around 54% of the total regional workforce.

On average, residents in Traralgon commute 5.93 kilometres to their workplaces, while those in Morwell travel 5.4 kilometres, and Moe residents have an average commute distance of 15 kilometres. Surrounding regions have an average commute distance of 15.05 kilometres to reach their workplaces.

Table 3. *East Victoria Employment, Age Distribution. Source: 2021 ABS census Data.*

Eastern Region	***15 - 34 YRS***	***35 - 49 YRS***	***50 - 64 YRS***	**Total**	**% of workforce**
Latrobe	**5,840**	**4,953**	**4,792**	**16,479**	**55.64%**
Drouin / Warragul	2,714	1,903	1,818	7,062	43.95%
Tynong	476	326	399	1,358	30.24%
Lang Lang	1,338	1,155	1,202	4,059	41.17%
Bairnsdale	1,556	1,220	1,340	4,510	75.22%
Sale	1,214	948	891	3,281	53.67%



Distance travelled to work
Average (km)

Available service workforce
Electrical, gas, water and sewage

Available Education workforce
Tertiary and training

Available Construction workforce
Tertiary and training

Available Tech and Science workforce

Available Manufacturing workforce

Available Healthcare workforce

Available Mining workforce

***Figure 6**. Existing Workforce Presence 2021. Source: Authors using ABS 2021 data.*

Occupational employment throughout Victoria is represented through *Figure 6* providing high-level insight to each region’s employment and degree of established industry presence.

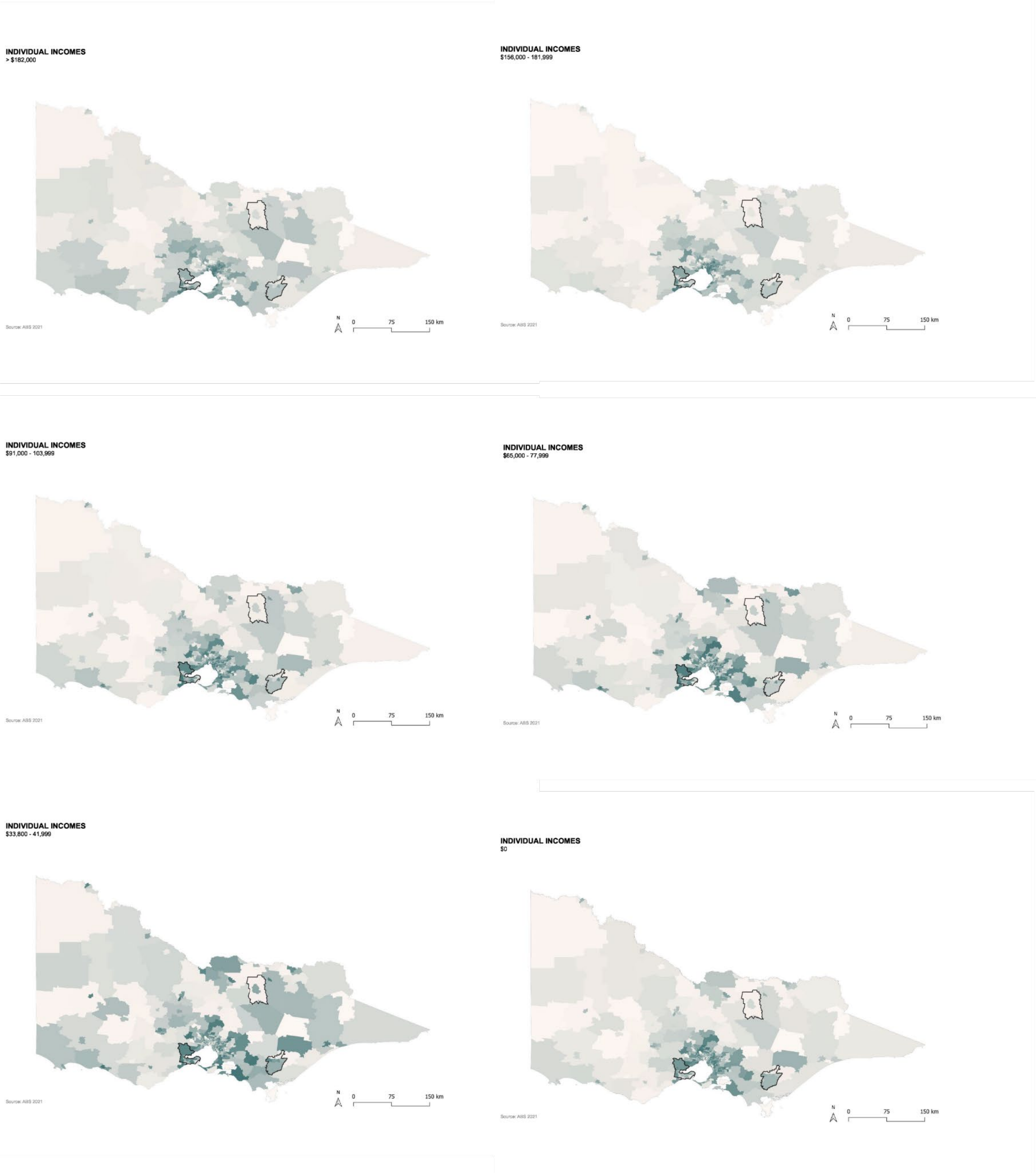
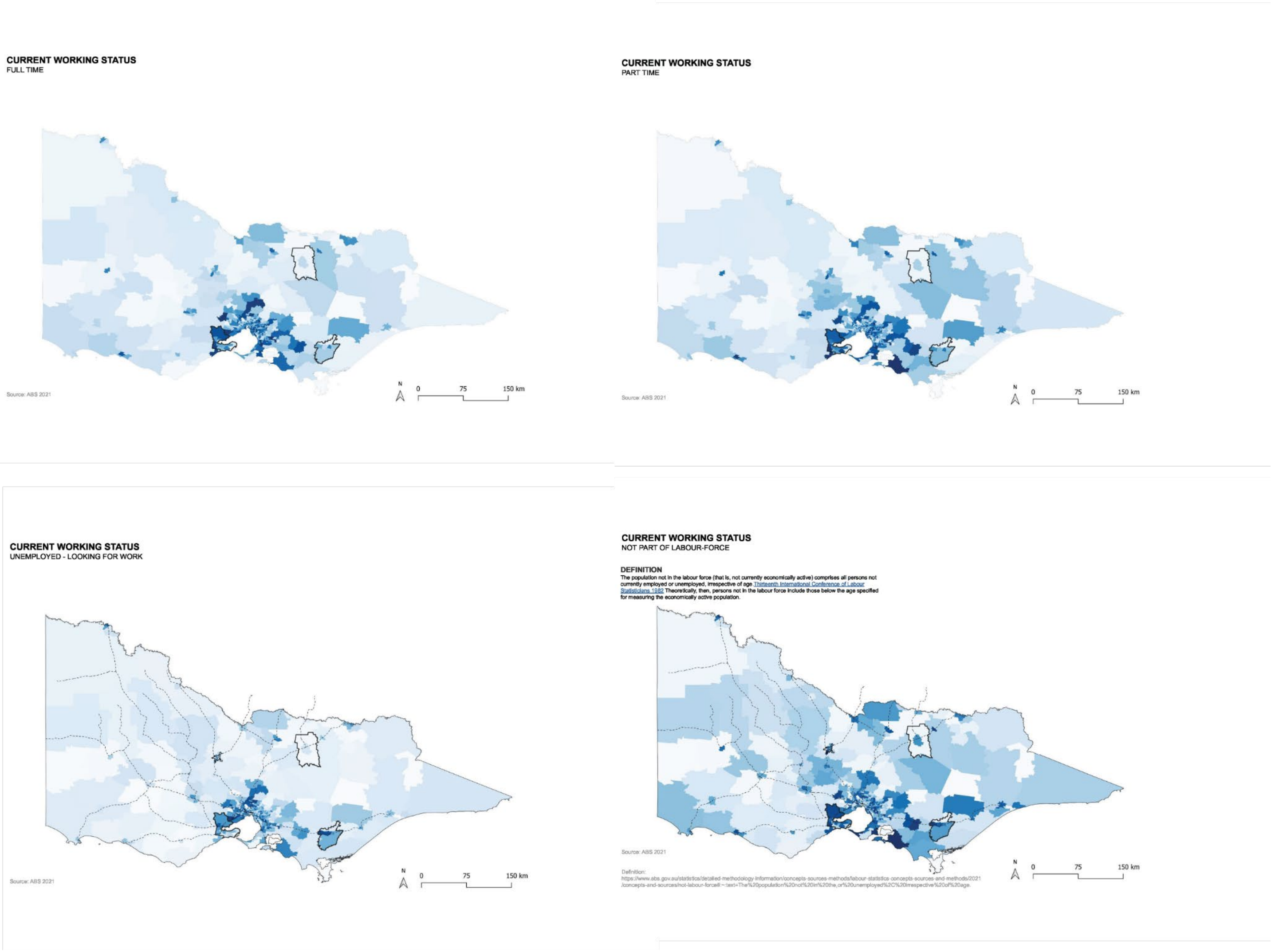


Figure 7 *Individual income Brackets 2021. Source: Author using ABS 2021 data*

Income brackets refer to an overarching distribution of wealth across Victoria. Referencing these maps provides a proportional indication of the regions affluence, additional cross referencing with job titles, land costs and employment types can begin to round-out a regions existing economic stature,



CURRENT WORKING STATUS
FULL TIME

Source: ABS 2021

CURRENT WORKING STATUS
PART TIME

Source: ABS 2021

CURRENT WORKING STATUS
UNEMPLOYED - LOOKING FOR WORK

Source: ABS 2021

CURRENT WORKING STATUS
NOT PART OF LABOUR-FORCE

DEFINITION
The population not in the labour force (that is, not currently economically active) comprises all persons not currently employed or unemployed, irrespective of age. Thirteenth International Conference of Labour Statisticians 1982 Theoretically, then, persons not in the labour force include those below the age specified for measuring the economically active population.

Source: ABS 2021

Definition:
https://www.abs.gov.au/statistics/detailed-methodology-information/concepts-sources-methods/labour-statistics-concepts-sources-and-methods/2021/concepts-and-sources/not-labour-force#:~:text=The%20population%20not%20in%20the,or%20unemployed%2C%20irrespective%20of%20age.

Figure 8. *Current Working Status 2021. Source: Author using ABS 2021 data*

Latrobe Valley reflects poor employment rates in 2021 with high proportions of ‘unemployment’ or ‘not in the workforce’ criteria. As defined by ABS, not in the labour force is a theoretically broad term used to describe people living with a disability, in retirement, care-giver, or generally unable to permanently work. The dataset provides a rudimentary overview of employment productivity within the local population, paired with other datasets such as existing industry to signify a potential for future population adaptivity to a growing industry.

Industry Employment Change 2011-2021

The Victorian Employment Change examines each industry and tracks the percentage difference in employment between 2011 and 2021 as seen in Figure 9. This provides an overall indication of how the industry market responded during this period and serves as a starting point for further investigation into specific industries or framework subsections. This analysis not only outlines potential market responses but also highlights the interconnectedness within each industry.

The industry employers considered in this stage of the analytical framework encompass a range of industry employment datasets with a particular focus Construction, Education & Training, Manufacturing, Mining, Timber & Agriculture. For further datasets on industry employment variation, please refer to the included appendices mappings.

***Figure 9.** Employment change 2011-2021, Source: Author using ABS data 2011 and 2021 SA2 Industry of Employment.*

Giving emphasis to the latter set of industries directs attention to business elements that significantly influence the construction industry or have experienced significant shifts. By comparing different industries, it becomes possible to draw proportional strengths between various localities. For instance, Benalla and Geelong LGA's demonstrate robust growth in the construction industry, while both locations see only modest growth in agriculture and timber industries. In contrast, the timber and agriculture sectors are declining in Latrobe Valley, where timber resources are abundant throughout the broader Gippsland area, indicating a shift in their utility and presence within the region. Generally, Greater Geelong's growth has strong correlations with construction industries and provides a foundation of continual development through well-established infrastructure and workforce. This is only undermined by the manufacturing industry which has previously had a strong presence throughout Geelong, but recently shifted into rapid decline as represented in Figure 9.

Though Geelong has had a significant historical foundation of manufacturing, trends in manufacturing have overarchingly declined across Victoria and the Greater Geelong LGA, proposing that additional challenges on procurement of fabricated construction goods may be limiting the opportunity to support the manufacturing industry. (2011, Inquiry into the more competitive Victorian manufacturing industry).

Mining regions throughout Victoria have also had a significant period of adaptation between 2011 & 2021. Latrobe Valley, having a significant existing mining population suffered high levels of employment loss across the entire LGA with Geelong having similar losses in sects of the region. Benalla mining increase provided some of the largest increases across Victoria however, this indicative of a small employment pool in an industry experiencing minor employment increases from 8 to 46 people.

Information Media and communications presented as the only growing industry broadly across Latrobe Valley. Likely representing a work-from-home dynamic shift imposed through the global pandemic, Latrobe Valley saw some of its strongest industry growth in technological formats. Similarly parts of Geelong also saw significant growth in the communications and IT industry.

Education and training employment variation showed significant growth in Geelong, building upon the established educational capacities of the region already. Benalla also presented a degree of educational increase, however, hosts no higher education or TAFE institutions within the LGA, requiring student populations to travel to different regions to gain additional training.

Access to Resources

Accessibility to local resources promotes efficiency, sustainability and economic development through construction industries. Incorporating access to locally sourced resources as part of the evaluation framework outlines and identifies potential limitations and opportunities in the supply chain.

Extractive Industry

Victoria boasts a diverse range of mineral deposits, offering significant variations that facilitate and support the extractive industry. The areas surrounding all three regions exhibit productive extractive potential. Notably, the Victorian government has identified specific zones as "extractive industry interest areas," with Latrobe Valley and Greater Geelong regions being denoted as such.

Figure 10 illustrates deposits of sand and stone, superimposed with the locations of current quarry licences throughout Victoria. This map highlights the valuable geological resources available for extraction within the region.

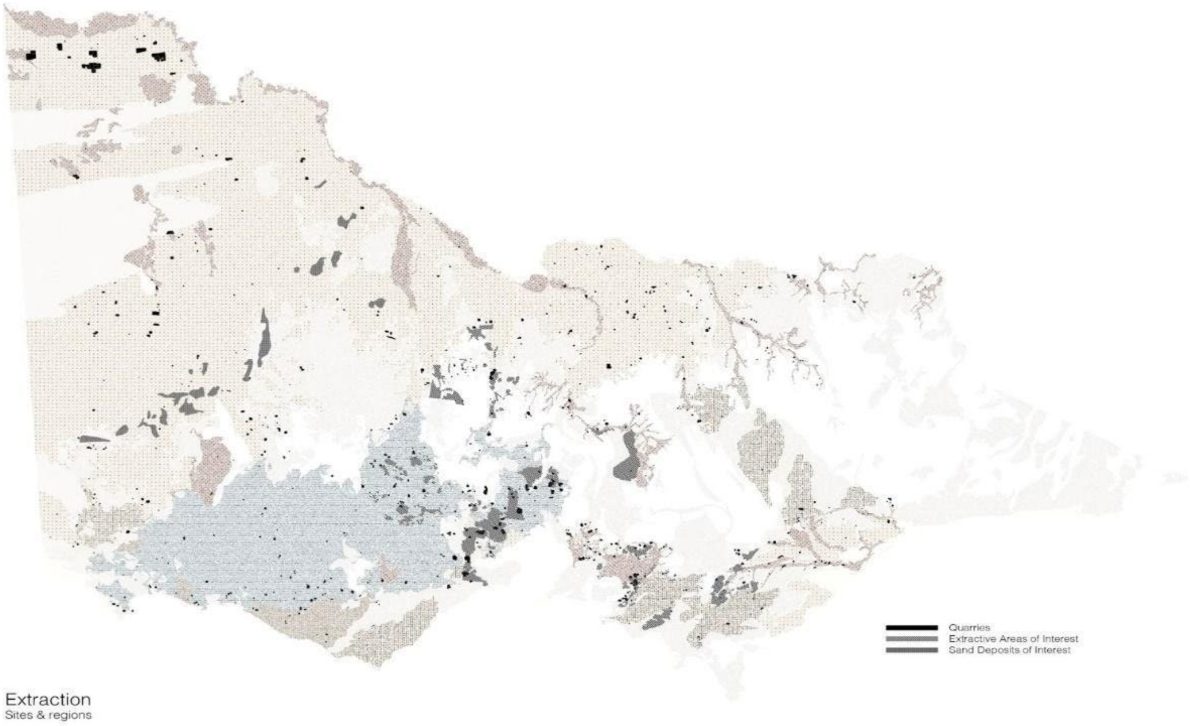


Figure 10. *Extractive areas of interest and Victorian Geology. Source: Authors using Vicdata Extractive Industry Interest Area*

Latrobe

Latrobe Valley is situated within a geological ecosystem rich in sand, clay, coal, and limestone. The abundant deposits of brown coal have positioned Latrobe as a significant energy distributor throughout Victoria. The region currently hosts nine active quarries, comprising three sandstone quarries, two granite quarries, and four stone aggregate quarries. These quarries cover an extensive area of more than 470 square kilometres, representing valuable land with extractive potential.

Forestry employment throughout Latrobe Valley has remained relatively consistent with small areas of growth throughout Victoria. However, the recent governmental decision to end native logging by 6 years to December 2023, has already implicated the closures of large-scale producers across Victoria with further limitations on potential growth in timber harvesting regions such as Gippsland and Latrobe (The Guardian, May 23).

Geelong

The Geelong region currently hosts eight operational quarries, comprising four basalt quarries, two sand quarries, and two stone aggregate quarries. These quarries cover an extensive area of over 520 square kilometres, representing valuable land with extractive potential. In terms of transportation infrastructure, the ARTC Single and Broad Gauge Rail freight line connects Geelong to Melbourne and Adelaide, facilitating efficient freight movement between these important economic hubs. It's worth noting that there is no timber harvesting within the Geelong region, with timber harvesting activities concentrated in the northern region of Staughtan Vale.

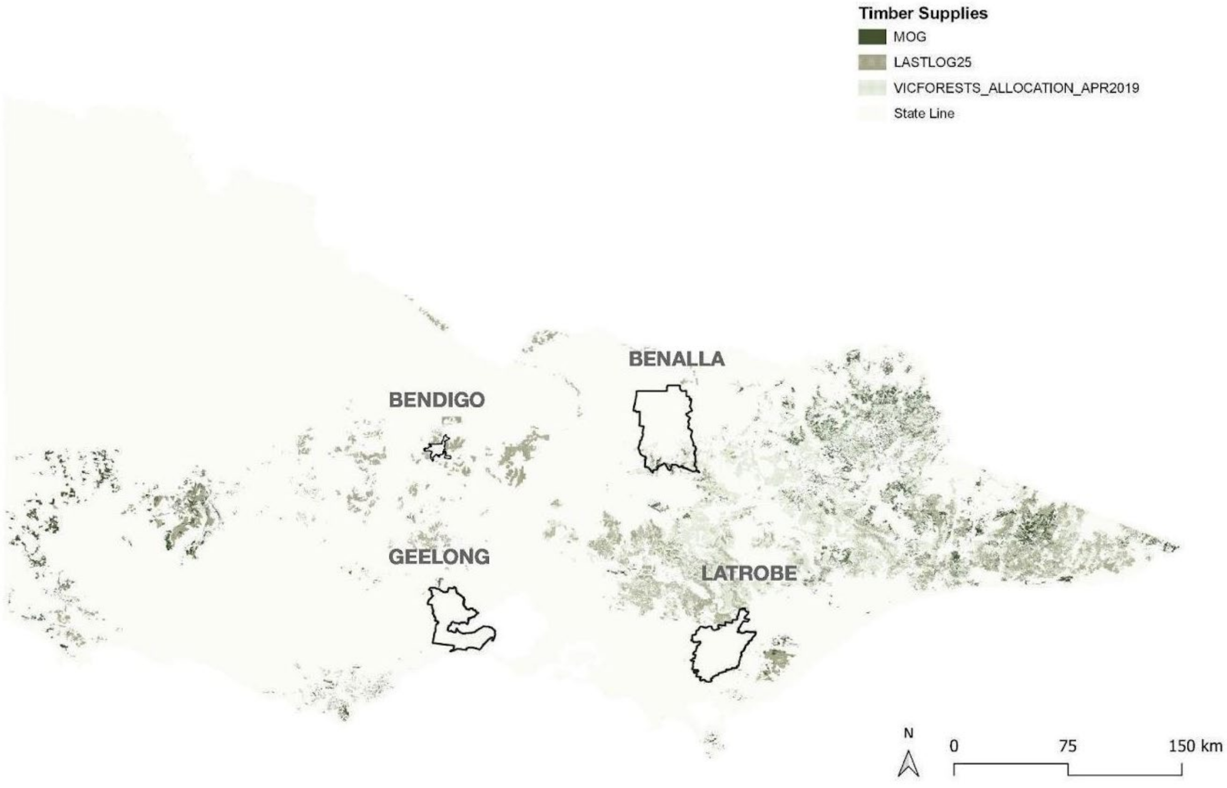


Figure 11. *Timber harvesting allocations, Source: Authors using VicData Harvested Logging Coupes*

Benalla

Within the boundaries of the Benalla Local Government Area (LGA), there are no nominated extractive assets. However, areas to the south, toward Lima South and Yarck, provide quarried stone to LS Precast, a major economic and employment presence in Benalla. The region features three granite-based quarries, with one located to the north and two situated to the south of the town. These quarries are utilised for producing crushed road-metal and aggregates for concrete.

Regarding transportation infrastructure, the ARTC Single Gauge Rail freight line connects via Benalla, establishing a vital transportation link to Melbourne, Sydney, and Brisbane, supporting efficient freight movement between these key locations.

Although no significant extractive areas of interest have been identified within Benalla LGA, there is an Old-growth protection area at Mount Samaria State Park in the southwest, while harvested timber and allocated harvest zones are located in the southeast Tatong area.

Wind Resources

Renewable energy offers significant incentives for investors, operators and communities surrounding a future Construction Hub. Firstly, industry and governments alike are restructuring their operational models to mitigate the future cost imposed associated with carbon intensive activities. Secondly, district-wide energy systems have the potential to provide broader benefits to surrounding communities, fostering local support and laying the groundwork for an ecosystem of future collaborators.

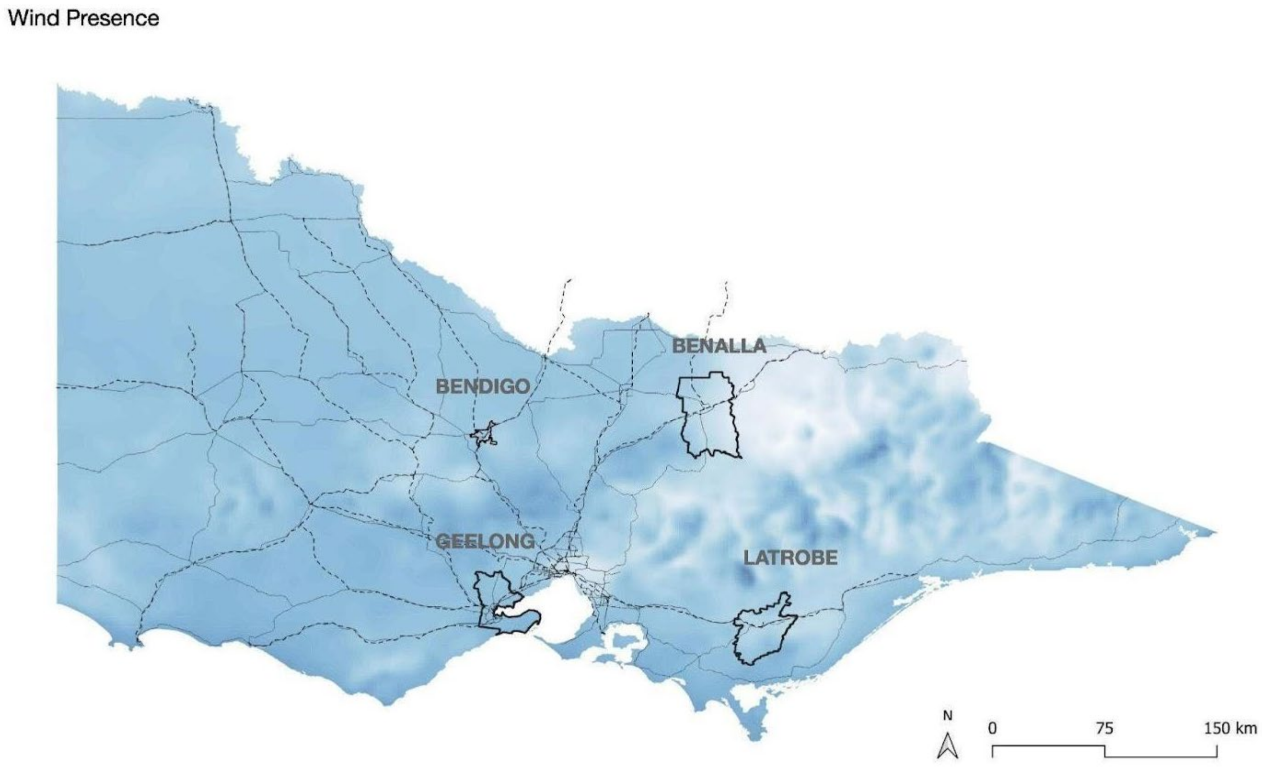


Figure 12. *Average Victorian Wind speeds, Source: Vicdata using Average Modelled Wind Speeds (m/s) for Victoria*

Wind energy offers a significant opportunity for renewable energy production across Victoria. The establishment of wind farms in the South Gippsland areas has introduced a promising prospect for generating alternative energy, moving away from the historical reliance on brown coal energy production. Figure 12 reveals that Latrobe and Geelong experience relatively high average wind speeds, while Benalla exhibits some of the lowest.

Considering the broader Victorian scale, this data supports the rationale for exploring the potential of wind farm development in various regions across Victoria. The presence of favourable wind conditions in specific areas highlights the feasibility and benefits of embracing wind energy as a renewable and sustainable power source throughout the state.

Distribution Infrastructure

To provide a comprehensive understanding of each rural/urban centre's industrial output, the inclusion of material and trade distribution paths are included to assist in tracking how extracted, manufactured goods are distributed between economic regions. Primary methods of rail freight, highway freight and shipping have been mapped as means of efficient pathways of physical discretion. As an indication of import/ export points through a national or international system of exchange please refer to the appendices for commercial airports.

Figure 13. *Highway & Rail freight lines & Ports, Source: Author using VicData Principal Freight Network 2021 Road, Rail and Places.*

Benalla possesses the necessary distribution infrastructure to function as a logistics hub. However, the presence of an existing logistics hub, located 30 minutes to the north in Wodonga, potentially undermines the utility of Benalla as a standalone hub. Despite this, Benalla's strategic positioning offers the potential to serve an operational area that extends inland northwards through Yarrawonga and into New South Wales, instead of relying solely on the coastal rail line through Wodonga.

In contrast, Latrobe features a rail line that extends in an East/West direction and is well-connected to a primary highway heading in the same direction. This interlinkage between more regional locations and the city opens up possibilities for enhanced connectivity and economic activity in the area.

Rental affordability

The rental affordability mappings illustrate the proportion of total housing that exceeds 30% of household incomes, which is typically regarded as the standard for determining affordable rental access. The figure shows that areas with higher percentages of housing costs beyond affordability are concentrated around townships and densely populated regions. These findings reflect socio-economic indicators and offer valuable insights into the income distribution in different locations. In the Latrobe Valley, there is a significant portion of housing categorised as 'un-affordable.' In Geelong, a similar trend of unaffordable housing is observed, which may be influenced by factors beyond the socio-economic conditions and begin to reflect high significantly higher population density, indicative of housing demand.

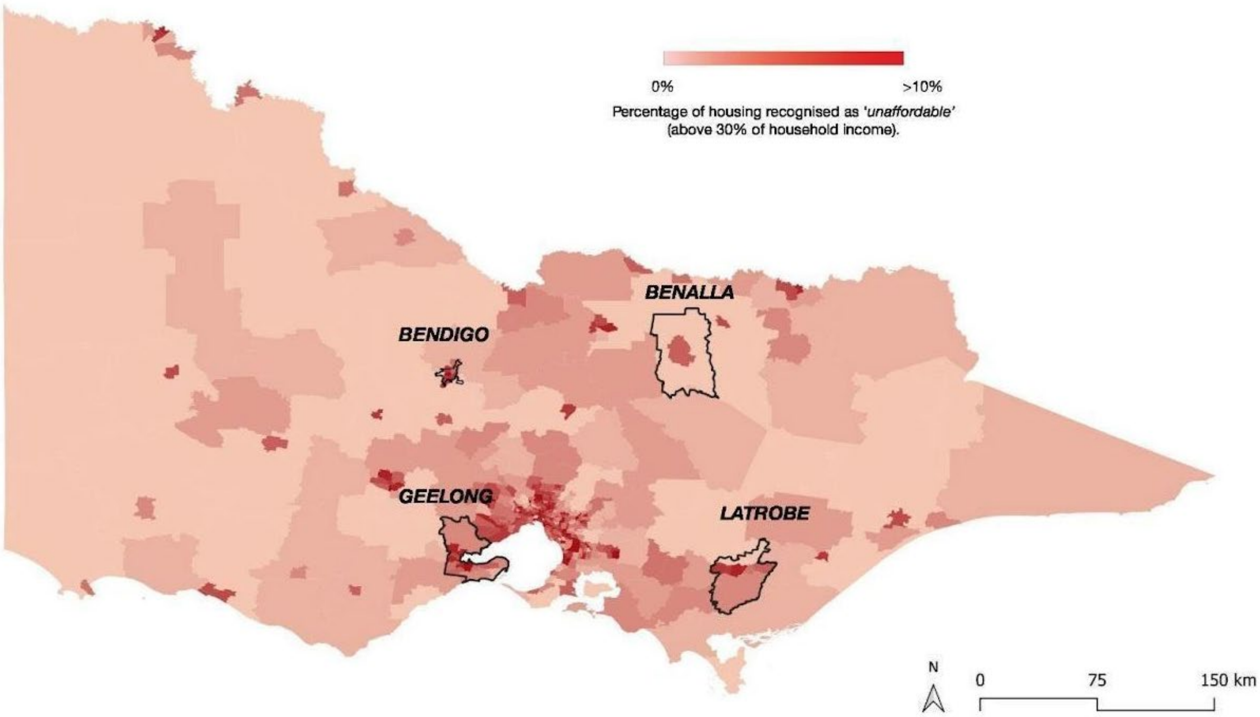


Figure 14. *RAID Rental Affordability, Source: Author using ABS 2021 data Rent affordability indicator (RAID).*

Individual Income

Similarly, incomes also show a similar trend in relation to the density of population in different areas. The individual income located in the appendices reveals that Benalla and Latrobe have lower concentrations of incomes, while Geelong consistently shows higher income statistics. All three Local Government Areas (LGAs) have a significant number of low-income earners falling in the $33,800-41,999 range, indicating that this is the primary income bracket for residents in Latrobe, Benalla, and Geelong.

Employment type

Forms of employment through Victoria follow similar trends between full time, part time and unemployed looking for work. As seen in the appendices figure… can been seen indicating Benalla and Geelong having primary employment types of part time and full time with Latrobe having a significant jump in people looking for work.

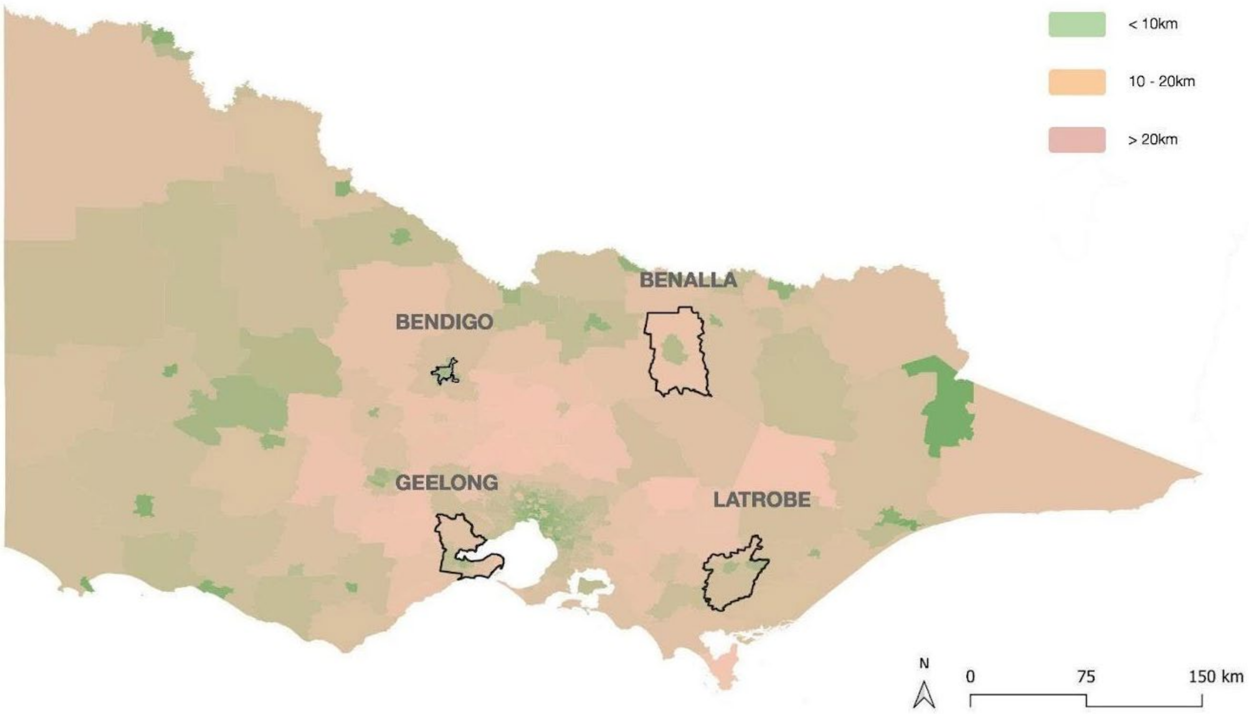


Figure 15. *Commuting Distance (km) to work, Source: Author using ABS data 2021 SA2 Distance and method of travel to work.*

Commute to work

The data on commuting to work indicates the average distance (km) people travel to their workplaces. In Benalla township and certain areas of Latrobe, the required commuting distances are notably lower. This observation holds particular significance in comprehending the distribution of employment types and the concentration of major employers within these townships' spatial layout. For instance, in Benalla, the primary employers are in healthcare, construction, and manufacturing sectors, and due to the minimal distances people have to travel to work, it can be inferred that these industries are more closely integrated into the spatial fabric of the region compared to other areas.

Educational facilities & student population

The operational capacities and presence of educational facilities play a crucial role in shaping the potential growth of a region. By examining the TAFE and higher education institutions in Benalla, Latrobe, and Geelong, we can gain insights into the upskilling opportunities available in each area, which can indicate their areas of specialisation.

Regional areas like Benalla and Latrobe demonstrate a notable emphasis on Trades and construction education, as evidenced by the presence of GOTafe and trade schools depicted in Figures 16 and 22. Latrobe's Federation University stands as the sole tertiary educational facility within the region. Student enrolment rates also reflect the level of participation in education within these areas, with Geelong showcasing one of the highest student densities in Victoria as seen in Figure 16.

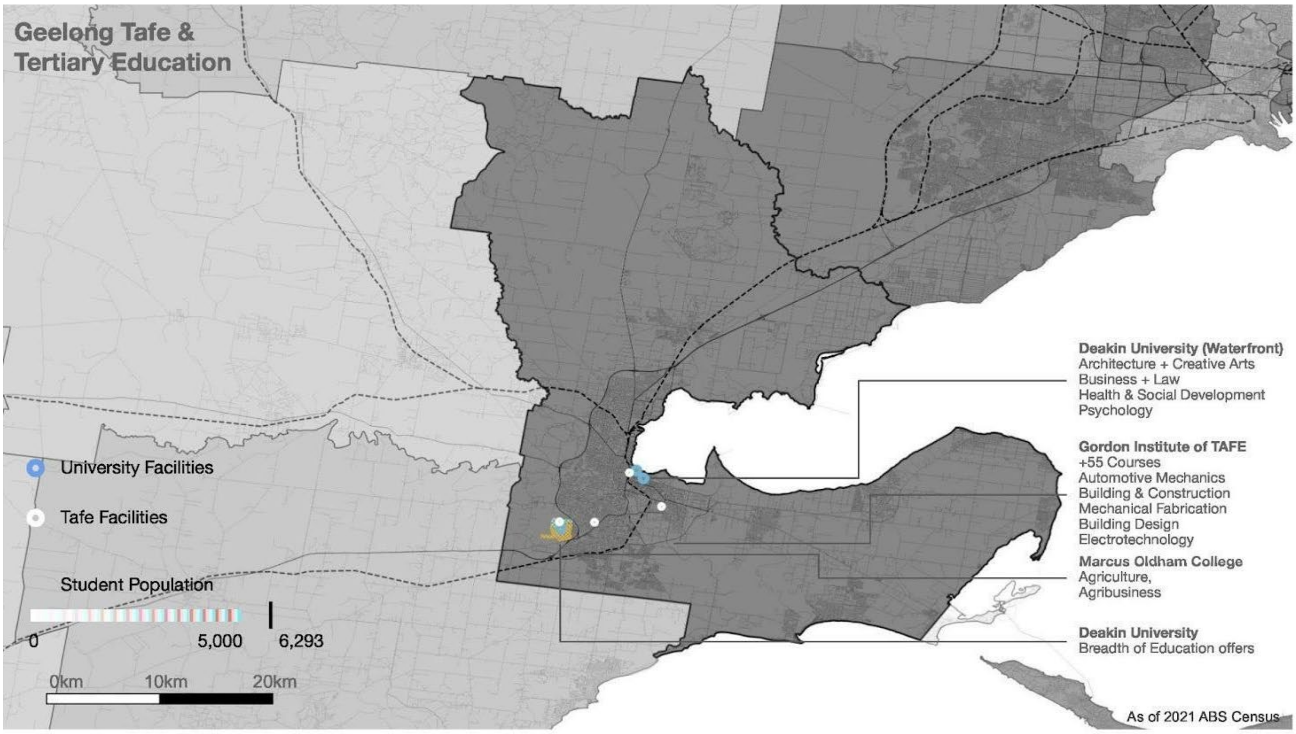


Figure 16. *Geelong Student Population & Educational institutes, Source: Author using Vocational education and training course enrolments by industry and occupation and Find My Local Tafe*

Contractor Register

The contractor supplier register comprises a list of 'pre-qualified' suppliers of construction works and services utilised in government building projects. This dataset serves as a valuable resource to analyse and visualise the concentrations of contractors who possess the necessary capital and business infrastructure to undertake substantial projects across Victoria. As depicted in Figure 17, Benalla and Latrobe show limited operational capacity at this scale. However, by considering the surrounding areas, a comprehensive ecosystem of contractor relationships can be established, as contractors extend their serviceable range due to their closer proximity to various regions.

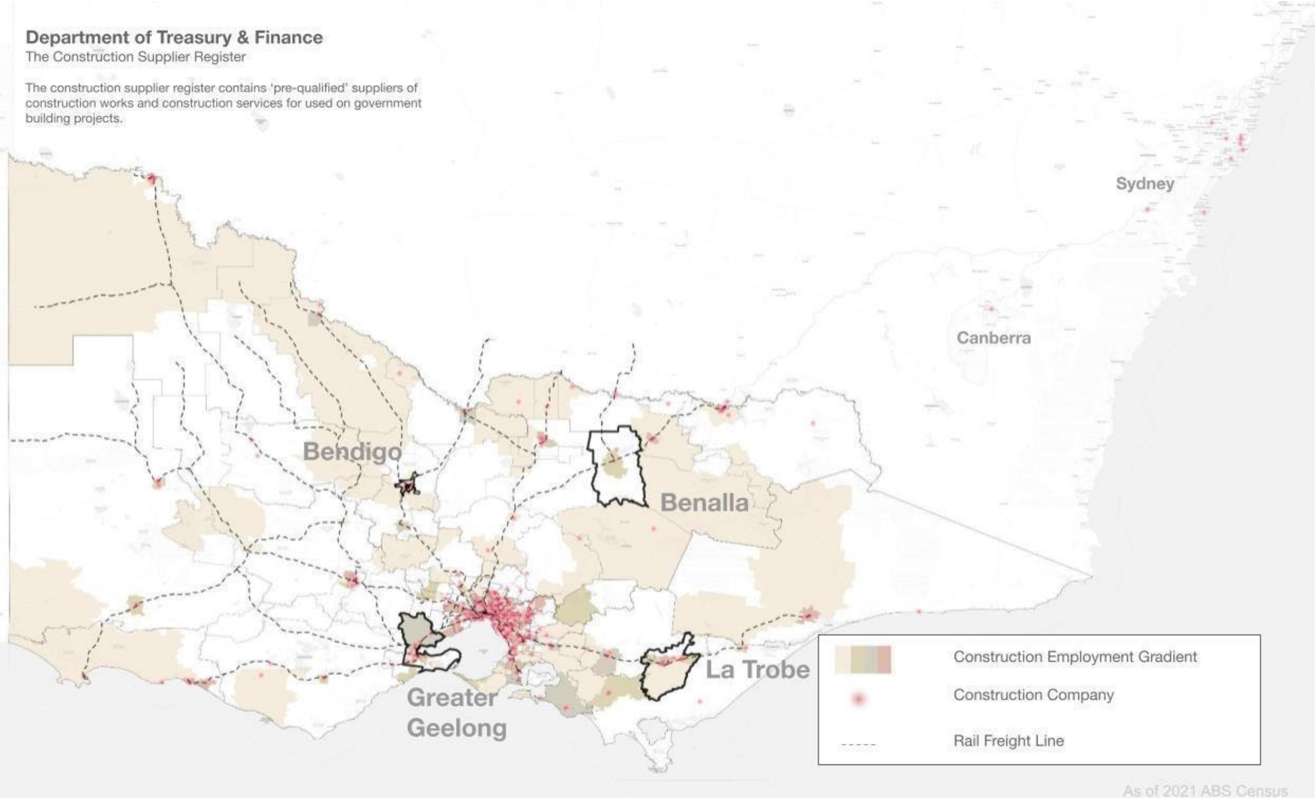


Figure 17. *Contractor suppliers VIC, Source: Authors using Doi Prequalified Consultants*

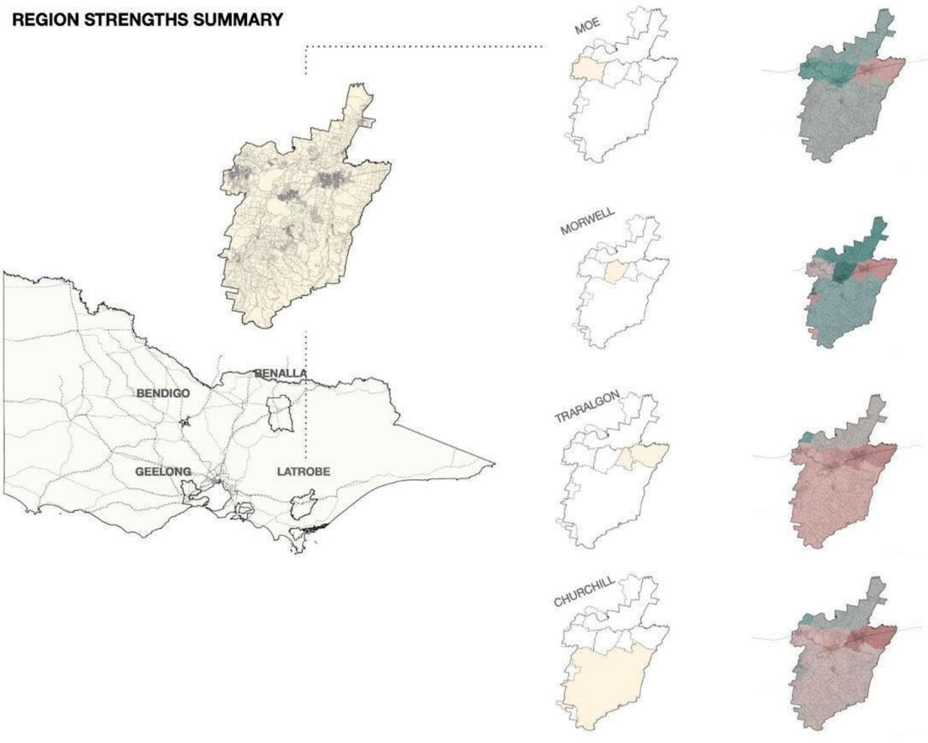
Application of evaluation framework

Latrobe Valley

Employment

As seen in Figure 18, employment trends in Latrobe Valley indicate an economically challenging region, as various industries experience decline or minimal growth, except for Information Media & Telecommunications and Timber & Agriculture. Historically, the mining trades and electrical production have served as stabilising economic factors due to the region's significant extractive areas of interest and mining allocations. However, these industries have seen a significant decline, while Information Media & Telecommunications have shown growth, indicating a shift away from an economy primarily based on extraction and electrical supply towards an establishment of IT management and maintenance services.

Existing industries like timber & agriculture continue to retain their economic significance in Moe and Morwell, but Traralgon faces declining conditions across all industries. The region has witnessed substantial declines due to recent closures of large businesses that are no longer operational. At the regional scale, market responses can be observed within the Local Government Area (LGA), providing insight into the establishment or expansion of various industries.



4 MOE
STRENGTHS

IT & COMMS	3.45 %	DECLINE
EDUCATION	7.48 %	DECLINE
FORESTRY & AG.	**51.52 %**	**GROWTH**
WAREHOUSE & TRANS.	3.18 %	GROWTH
MINING	33.65 %	DECLINE
CONSTRUCTION	1.81 %	GROWTH

3 MORWELL
STRENGTHS

IT & COMMS	**79.03 %**	**GROWTH**
EDUCATION	1.94 %	DECLINE
FORESTRY & AG.	66.67 %	GROWTH
WAREHOUSE & TRANS.	8.78 %	GROWTH
MINING	43.66 %	DECLINE
CONSTRUCTION	13.75 %	DECLINE

2 TRARALGON
STRENGTHS

IT & COMMS	38.14 %	DECLINE
EDUCATION	59.89 %	DECLINE
FORESTRY & AG.	27.22 %	DECLINE
WAREHOUSE & TRANS.	60.75 %	DECLINE
MINING	**65.70 %**	**DECLINE**
CONSTRUCTION	57.98 %	DECLINE

1 CHURCHILL
STRENGTHS

IT & COMMS	16.67 %	GROWTH
EDUCATION	9.39 %	DECLINE
FORESTRY & AG.	4.74 %	GROWTH
WAREHOUSE & TRANS.	1.85 %	DECLINE
MINING	32.67	DECLINE
CONSTRUCTION	**7.06 %**	**GROWTH**

Figure 18. *Latrobe Valley. Region Strengths, Source: Author using ABS data 2011 and 2021 SA2 Industry of Employment.*

Resources, Land-use & Infrastructure

Earth Resources Victoria has identified Latrobe as a region of significant interest for future extraction of quarried materials. The area has historically relied on significant deposits of brown coal as its economic foundation. Currently, existing and identified zones of extractive interest indicate promising future potential for the development of the extractive industry throughout the region. Despite the employment decline resulting from the closure of the Hazlewood mine and energy production, the strong existing distribution infrastructure offers an opportunity to bolster the economic resilience of the extractive industries.

Moreover, while Latrobe is bordered by allocated areas of native hardwoods and pine, many of these timber allocations have been recently harvested within the past 25 years or are designated as Old Growth areas. With the government ban on logging of native timbers (Morton, Ore, Karp. 2023), this restricts potential harvesting in the surrounding regions without significant zoning alterations. Careful planning and zoning adjustments may be required to ensure sustainable and responsible timber harvesting practices while preserving the natural environment.

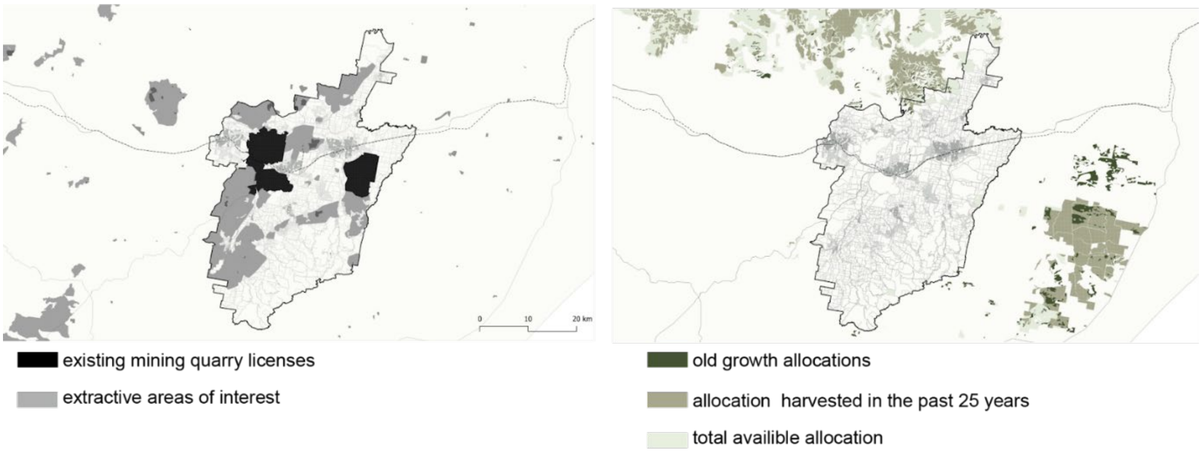


Figure 19. *Latrobe Valley, Extractive areas of interest & Timber allocations, Source: Author using Vicdata Extractive Industry Interest Area and Harvested logging coupes.*

Figure 20. *Latrobe Valley, Continual connection, Moe, Morwell & Traralgon Industrial zoning, Source: Author using Vicdata Vicmap Planning - Planning Scheme Zone Polygon.*

When it comes to its built infrastructure, Latrobe has a significant historical background as a centre for power generation and heavy industry. As a result, the region is filled with numerous existing industrial structures and infrastructures, both operational and closed, which sets it apart from neighbouring areas.

Moreover, Latrobe proudly boasts some of the largest industrial zoning overlays in the state, with a considerable portion of these zones currently vacant. These areas are well-connected by rail and road freight, enhancing their accessibility and potential for future development. The region exhibits a diverse range of industrial zones, with smaller pockets located on the outskirts of Moe, Morwell, and Traralgon. Additionally, a vast industrial zone is situated in the southeast of Morwell.

Furthermore, special use zones within Latrobe are dedicated to the region's power industry, particularly sites of power generation and mining operations, further emphasising the area's historical and ongoing significance in these sectors.
Moe - the industrial zone and structures are positioned to the north of the town, somewhat separated from the commercial centre. Within this area, smaller workshops predominantly house mechanics and smaller fabricators. With a small number of long factories facilitating an engineering firm. Towards the western part of the town, there is an amalgamated factory that used to be a spinning mill but is now closed.

Morwell - To the northeast of the town, small workshop structures align parallel to the freight rail, while pockets of industrial areas are located to the west. The southern and southeastern parts of the town are characterised by an extensive industrial region that comprises a series of long factories, warehouses, timber yards, and depot sites.

Traralgon - The primary industrial zone of the town lies to the northeast and houses long factories, warehouses, timber yards, and depot sites. This industrial area is interconnected with the town's commercial centre and stretches along the Princes Highway.

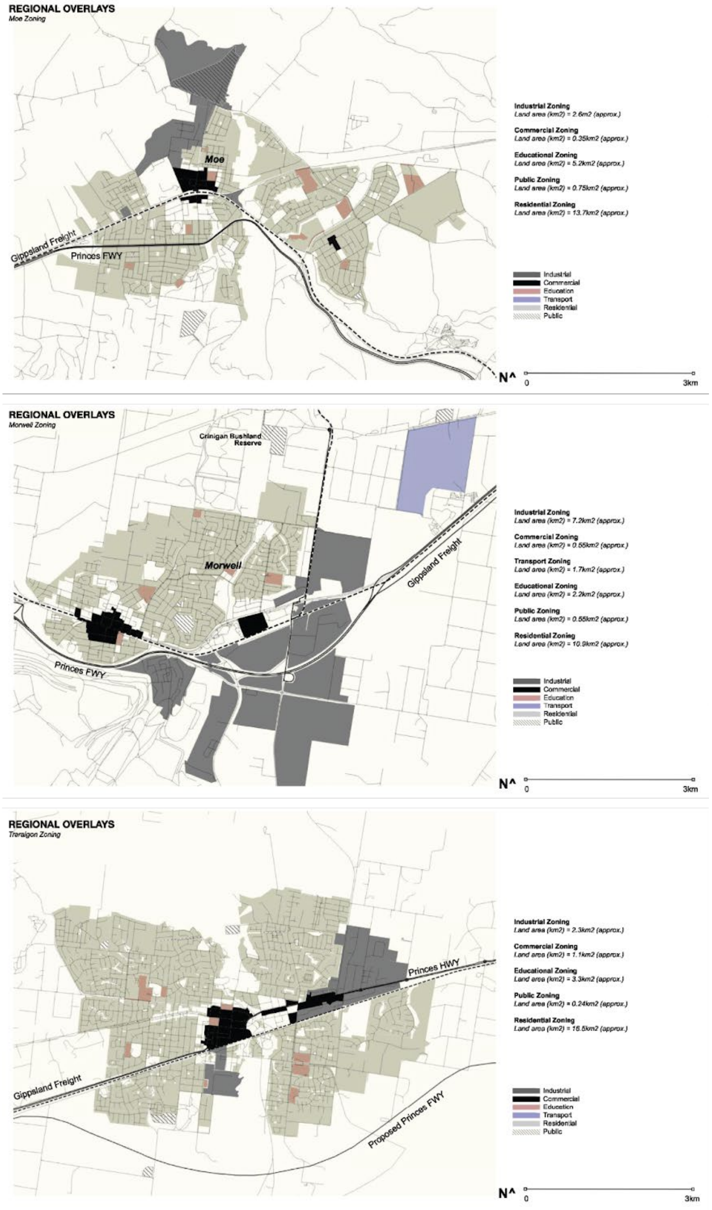


Figure 21. *Latrobe Valley, partitioned, Moe, Morwell & Traralgon Industrial zoning, Source: Author using Vicdata Vicmap Planning - Planning Scheme Zone Polygon.*

The strongest economic areas within Latrobe also present the strongest opportunities to develop on exciting Tafe facilities to develop skilled trades labour. Additionally, the commuting distance in Morwell and Moe remains the lowest with the highest percentage of 'Unaffordable" housing. By overlaying these datasets, a spatial relationship of commercial, residential and industrial infrastructure reiterates a pivot away from a consolidated Construction Hub within one of the minor towns and begins to emphasise the importance of an adaptive spatial organisation.

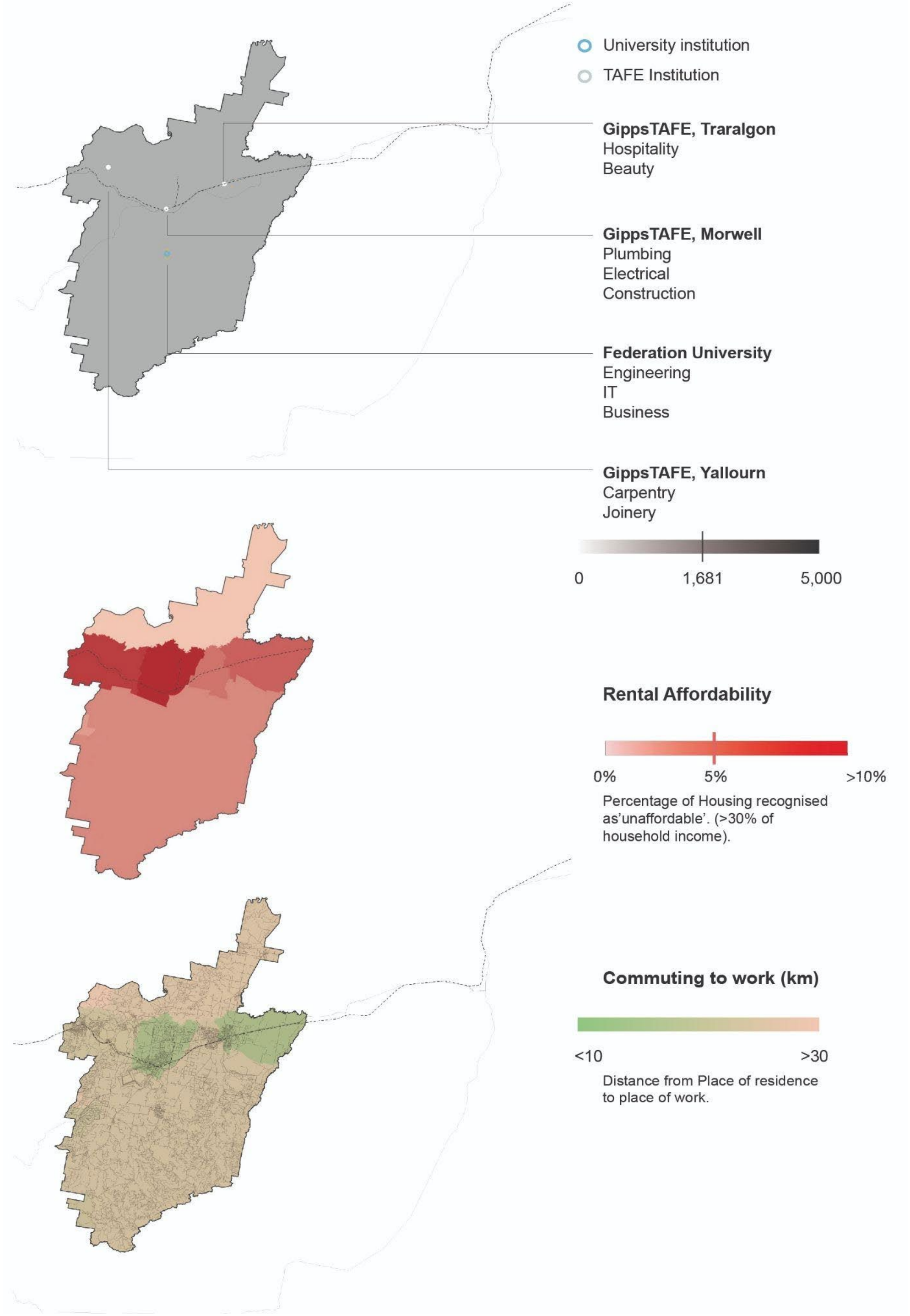


Figure 22. *Education, Commuting distance and RAID Overlay, Source: Author using ABS Rent affordability indicator (RAID), ABS average distance travelled to work (km), and Vocational education and training course enrolments by industry and occupation.*

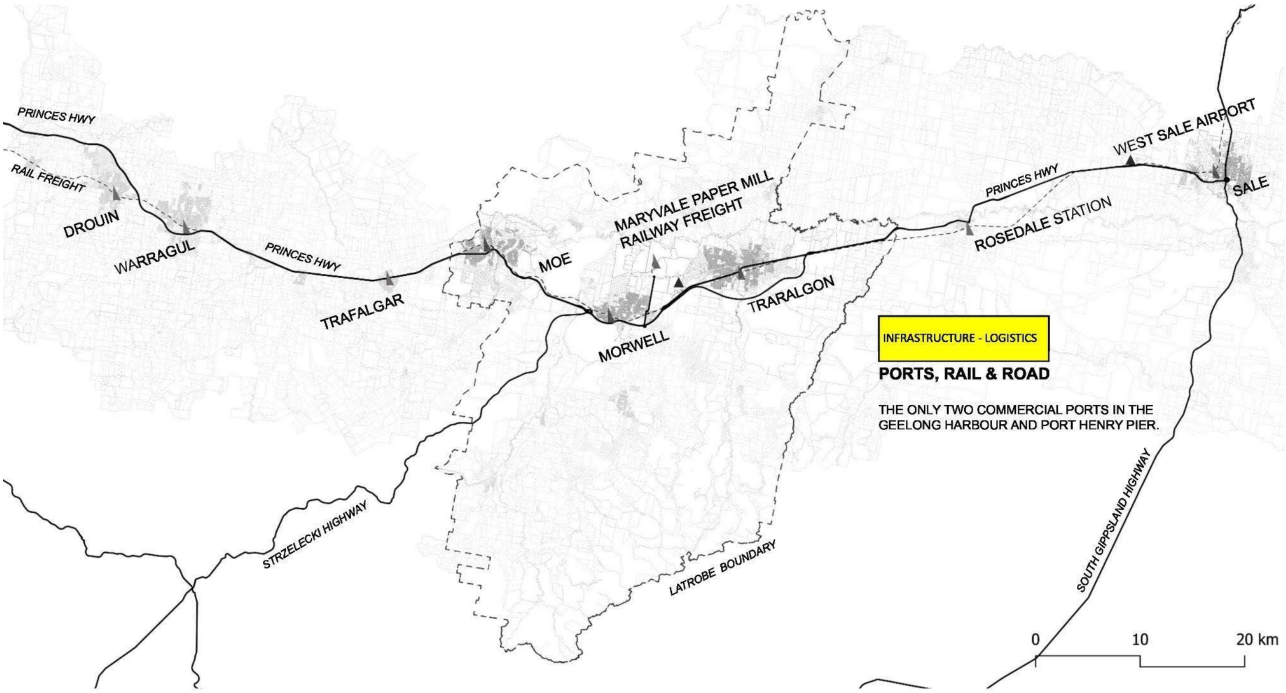


Figure 23. *Latrobe Distribution Network. Source: Author using Vicdata 2021 & desktop Mapping*

Industry Closures

The distribution of businesses across the region has substantial implications for the urban landscape. In Morwell, as depicted in Figure 25, there is a considerable presence of manufacturing, fabrication, and construction industries. However, when considering the recent employment decrease in the region, the closures of significant businesses like Hazlewood or Carter Holt Harvey could be a potential reason behind the decline in employment throughout Latrobe. These large-scale businesses have historically provided extensive employment opportunities across multiple industries, and their closures can result in an overall decline in employment fluctuations.

The construction supplier register and the primary employers locations around the region quantify the potential readiness of existing infrastructure as they represent the latent opportunity to harness existing pieces of infrastructure and present workforces.

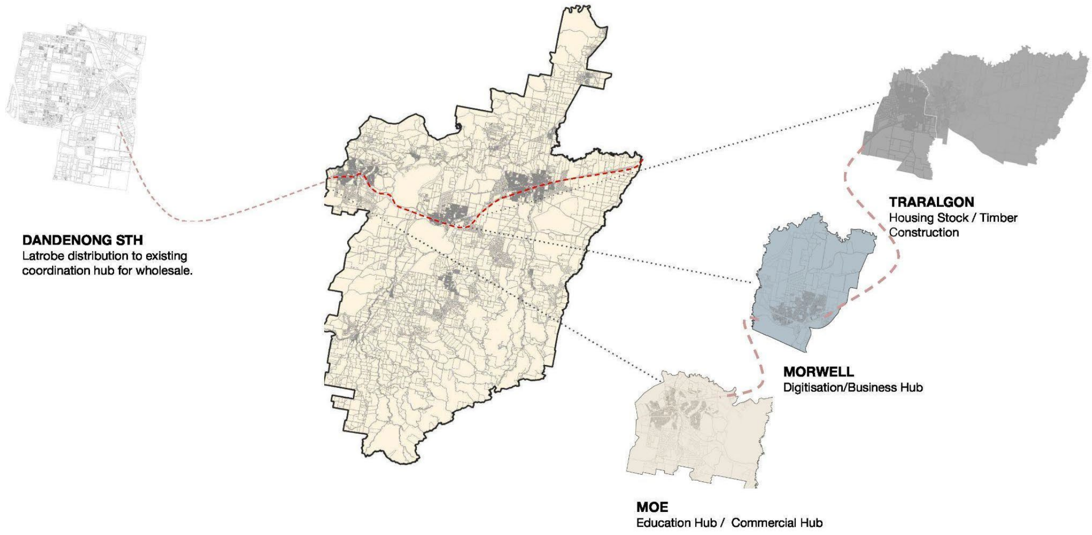


Figure 24. *Latrobe to Melbourne. Source: Author using Vicdata ABS Employment 2011-2021 data*

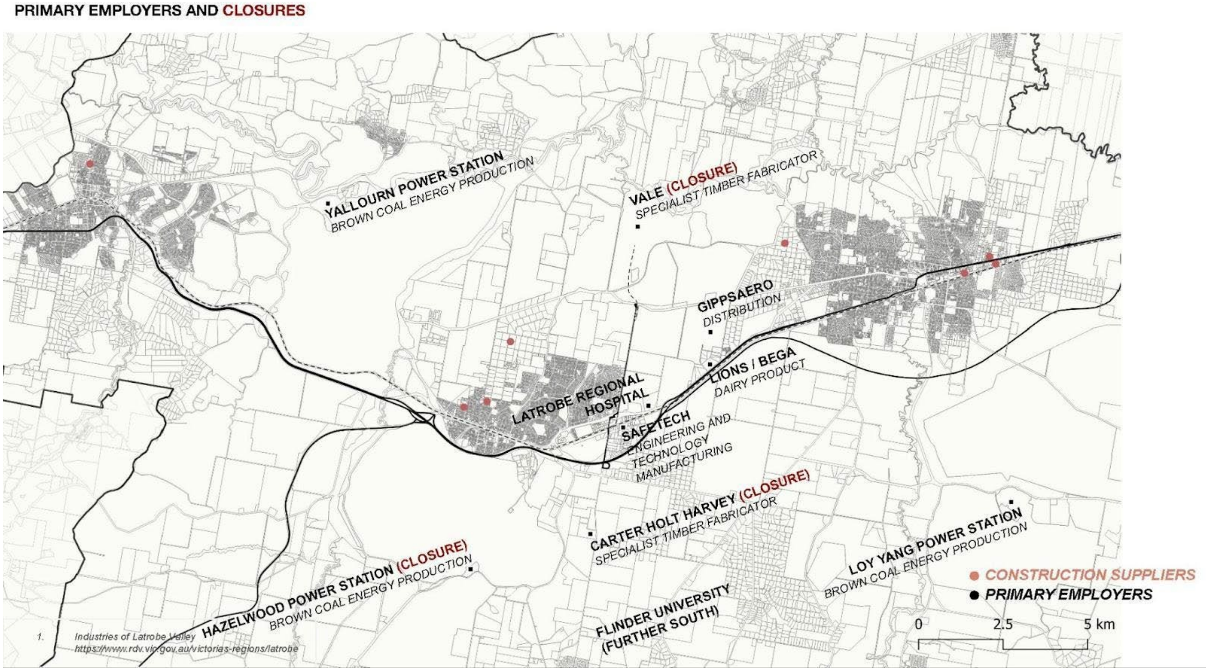


***Figure 25.** Latrobe Primary Employers and closures, Source: Author using Desktop mapping.*

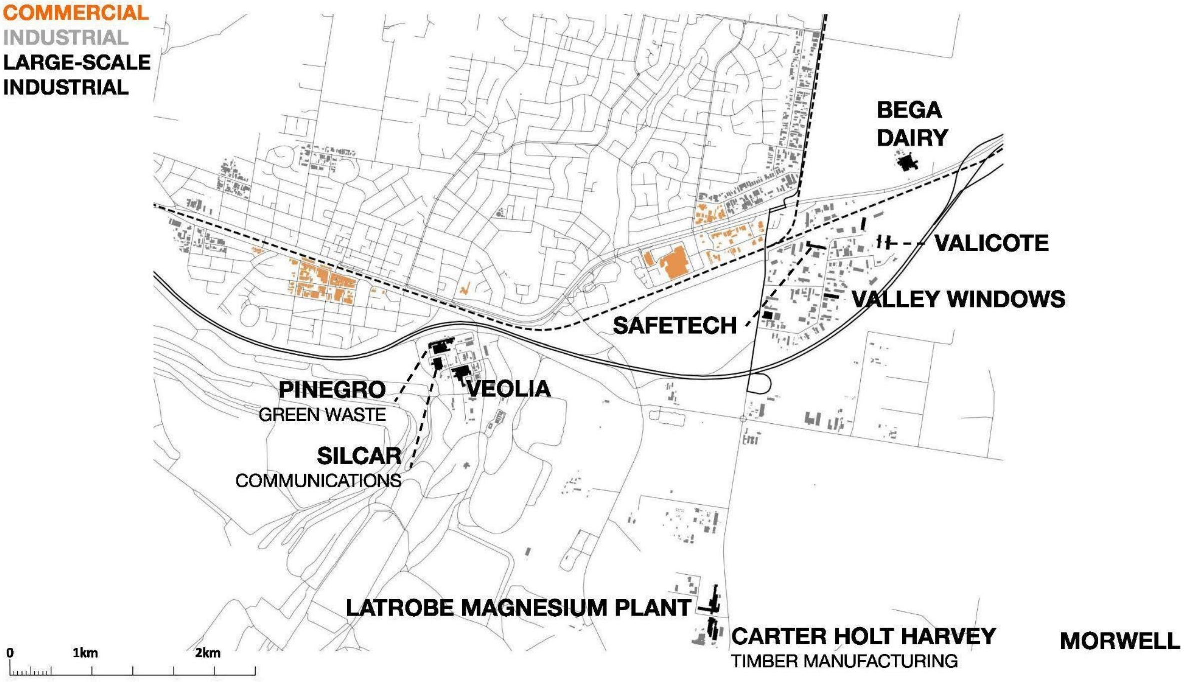


***Figure 26**. Morwell industrial and waste facilities. Source: Authors using desktop mapping and Vic data 2016*

Onsite requirement studies

Quantified analysis of the site requirements of a nominated industry, the timber industry has a significant existing presence throughout Latrobe therefore a significant supplier in the Gippsland region has been utilised as an expression of a ‘large-scale’ distributor's needs.

In coordination with the international case-studies, Ash retail Centre provides some foundational understanding of site requirements and site uses. Storage capacities both internally and externally have been highlighted as important operational factors for Victorian timber businesses with a consolidation of typological infrastructure that can facilitate sub-assembly lines and streamlined pick-up drop off lines of distribution via truck.

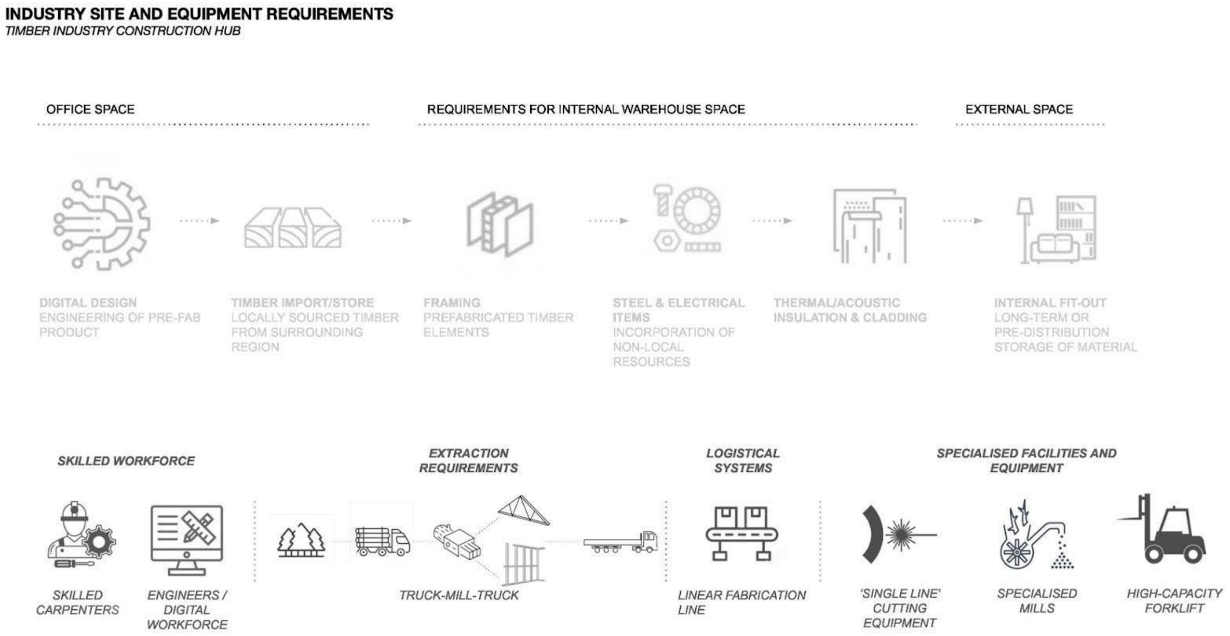


Figure 27. *Timber specialist sub-assemblies and equipment, Source: Author.*

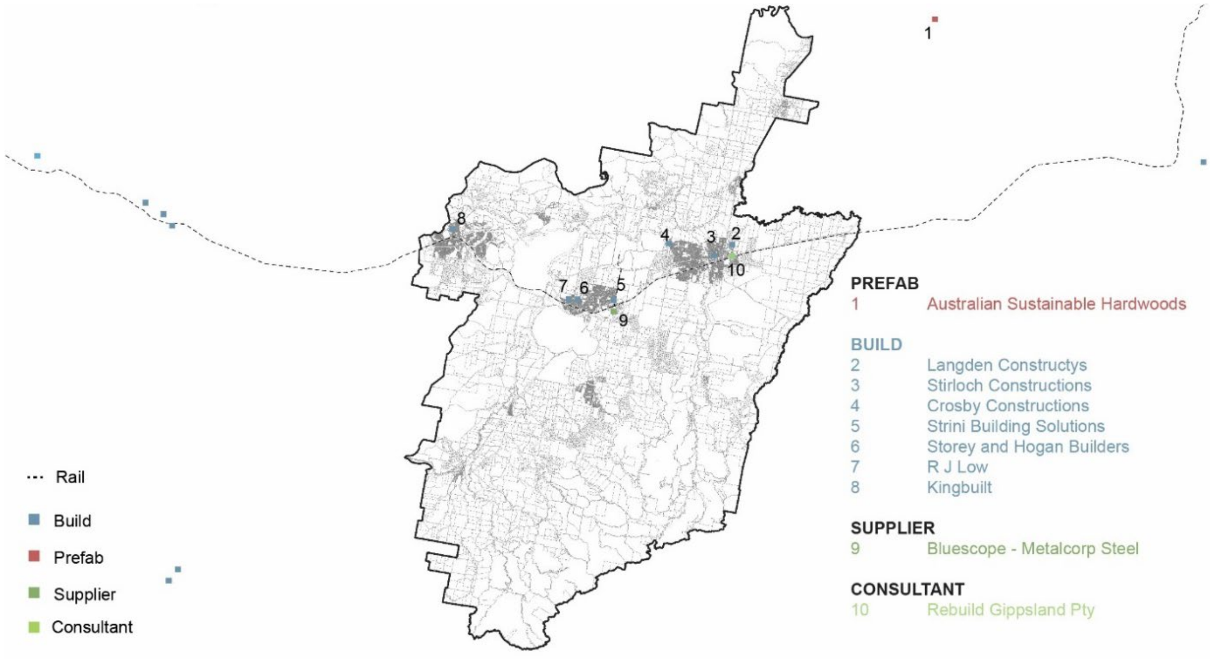


Figure 28. *Latrobe Valley construction services_ Victorian construction suppliers. Source: Authors*

Figure 29. *Ash Retail Centre spatial analysis, Source: Author Using Desktop Mapping*

Significant land requirements are needed for the site itself, with specialised equipment being integrated into the site for moving lumber around the significant square meterage. Internal storage required for milled timber and to house any specialist equipment for the milling process.

Benalla

The employment trends in Benalla exhibit noteworthy variations in industries surrounding construction, with construction itself experiencing a higher than average rate of growth at over 66%. There is strong support from industries involved in extractive processes and distribution, despite only modest population growth. Recognising the stagnation of population growth and the increase in employment across multiple industries, the two datasets suggest that the region possesses latent skill sets that can be adapted for applications in the construction industry or that the employment shift is being caused by workers residing outside the Benalla LGA.

1 BENALLA TOWNSHIP
STRENGTHS

EDUCATION	9.09 %	GROWTH
MINING	633 %	GROWTH
WAREHOUSE & TRANS.	24.74 %	DECLINE
FORESTRY & AG.	28.3 %	GROWTH
ELEC, WATER & WASTE	9.68 %	DECLINE
CONSTRUCTION	66.85 %	GROWTH

2 BENALLA SURROUNDS
STRENGTHS

EDUCATION	3.83%	DECLINE
MINING	300 %	GROWTH
WAREHOUSE & TRANS.	22.22 %	GROWTH
FORESTRY & AG.	5.41 %	DECLINE
ELEC, WATER & WASTE	15.38 %	DECLINE
CONSTRUCTION	38.21 %	GROWTH

Figure 30. *Benalla Industry strengths, Source: Author using ABS data 2011 and 2021 SA2 Industry of Employment.*

The exponential growth of the Benalla extractive industry can be attributed to the establishment of LS Precast in 2018. This development also led to significant employment contributions in manufacturing and construction, subsequently making the construction industry the second-largest employer behind 'healthcare and social assistance' by 2021. Due to the vacancy of resources in the areas, the region promotes itself as a potential hub of skilled workers across a range of industries.

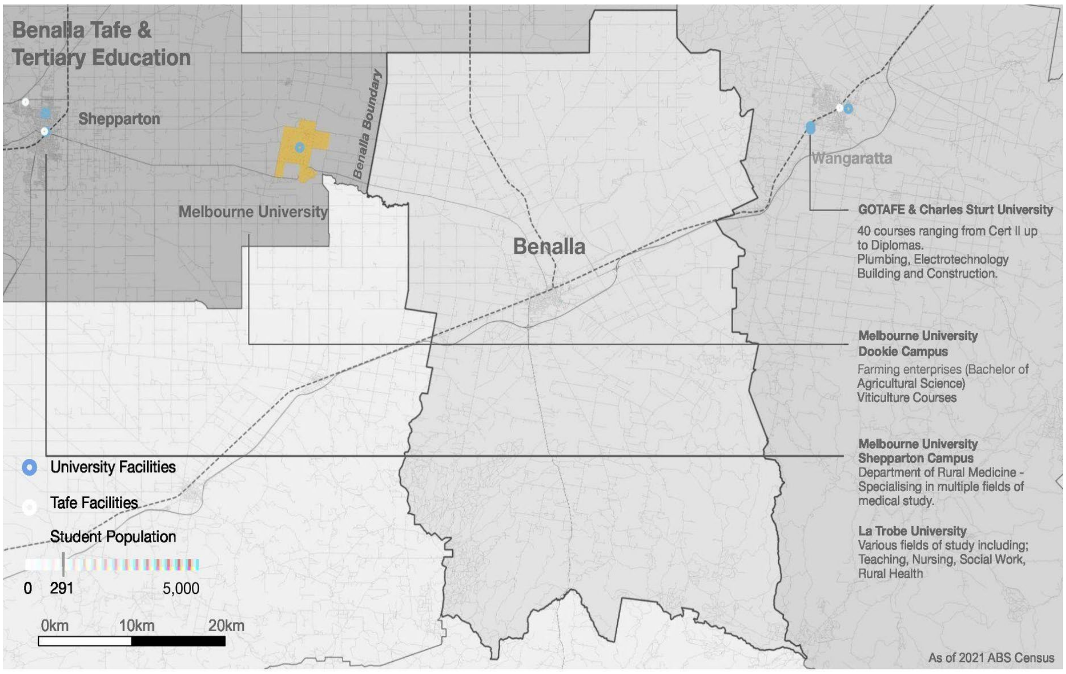
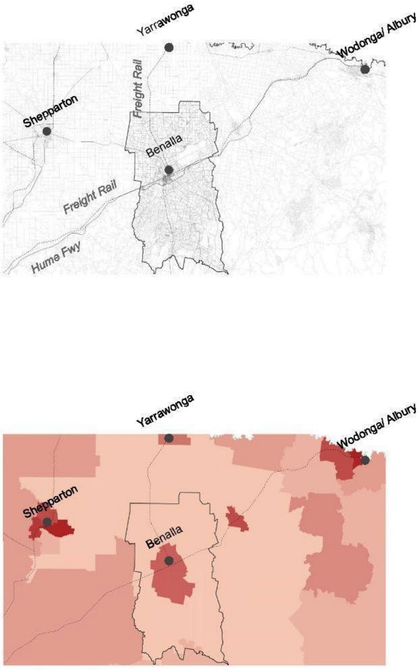


Figure 31. *Benalla Student population & educational facilities. Source: Authors using ABS data and Desktop Mapping*

Resources, Land-use & Infrastructure

Industrial land in the town is distributed in various pockets, primarily located to the northern boundary, along with an industrial strip extending from the commercial centre towards the east and southeast, running parallel to the southern commercial strip. Additionally, there is an expansive special use zone situated to the far north, housing the Thales munitions manufacturing and testing site.



INFRASTRUCTURE

PORTS, RAIL & ROAD

ACCESS TO DISTRIBUTION LINES THROUGH RAIL FREIGHT, HIGHWAY AND AIRPORT

RENTAL COST

RENTAL AFFORDABILITY

PROXIMITY TO EMPLOYMENT, AMENITIES SIGNIFICANTLY DECREASES THE AVAILABILITY OF AFFORDABLE HOUSING. THIS IS INCURS AS BUFFER AROUND EACH TOWNSHIP OF HIGHER COST OF LIVING REQUIREMENTS.

Figure 32. *Distribution methods and RAID affordability overlay. Author using ABS Rent affordability indicator (RAID) and Desktop Mapping.*

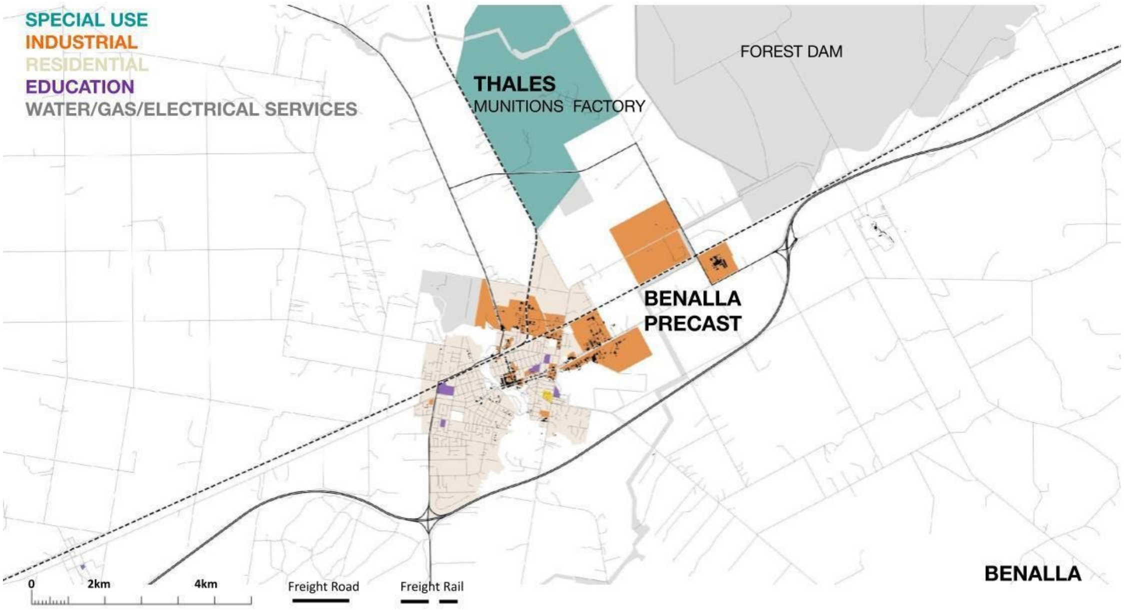


Figure 33. *Benalla Land Usage. Source: Author using Vicdata, Vicmap Planning - Planning Scheme Zone Polygon.*

Throughout the town, workshops are scattered across the south-east and north, interspersed between larger-scale depots, factories, and timber yards. The longer factories in the outskirts of the southern part of town are utilised for electrical component manufacturing and the production of grain/stock feed materials with the exception for LS Precast.

As seen in the following Figure 34, LS Precast holds a significant portion of land on the North East side of Benalla township. The scale of LS Precast, along with its capacity to supply prefabricated concrete to the West Gate tunnel project, necessitated the extension of the railway line to directly connect with the site, integrating cranes and specialised equipment onsite.

Established in 2018, LS Precast operates as a subsidiary of a larger organisation that also owns LS Quarry in Yarck and Lima South. These quarries provide the necessary aggregate and construction materials for the production of prefabricated concrete. This expansion into the region marked the first time LS Precast established an employment presence in mining there, potentially contributing to the considerable industry growth in the area.

Figure 34. *Benalla Industrial Large scale Warehouse, Source: Author Using Vicdata and Desktop Mapping.*

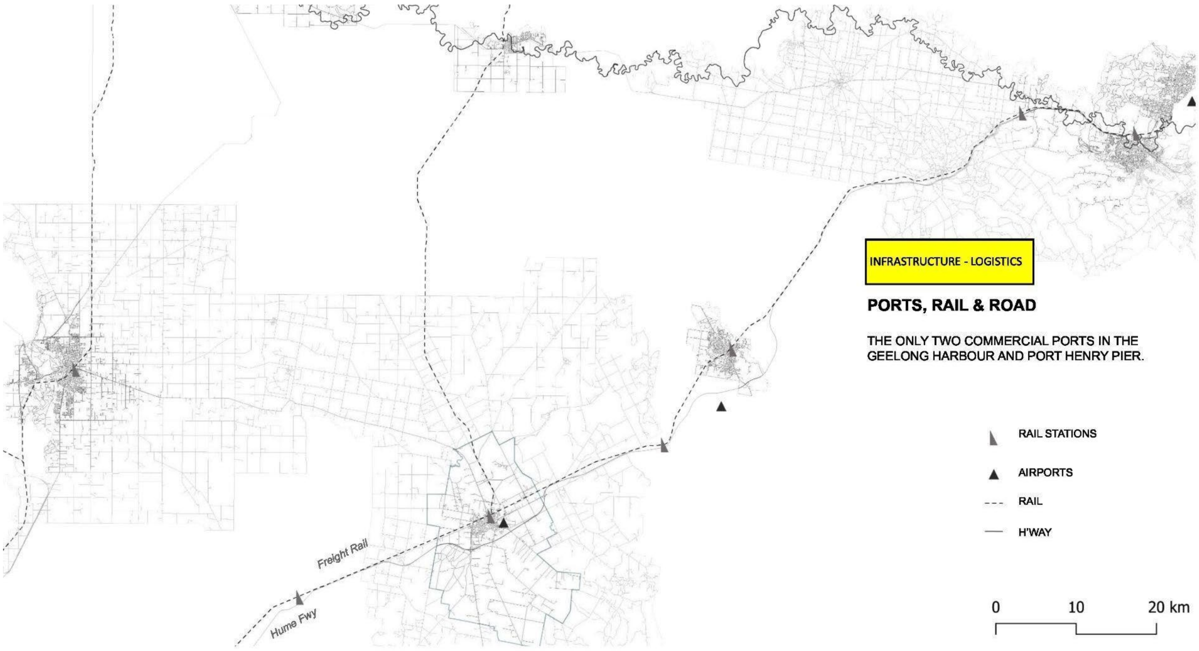


Figure 35. *Distribution Infrastructure, Source: Author using VIC data and Desktop mapping*

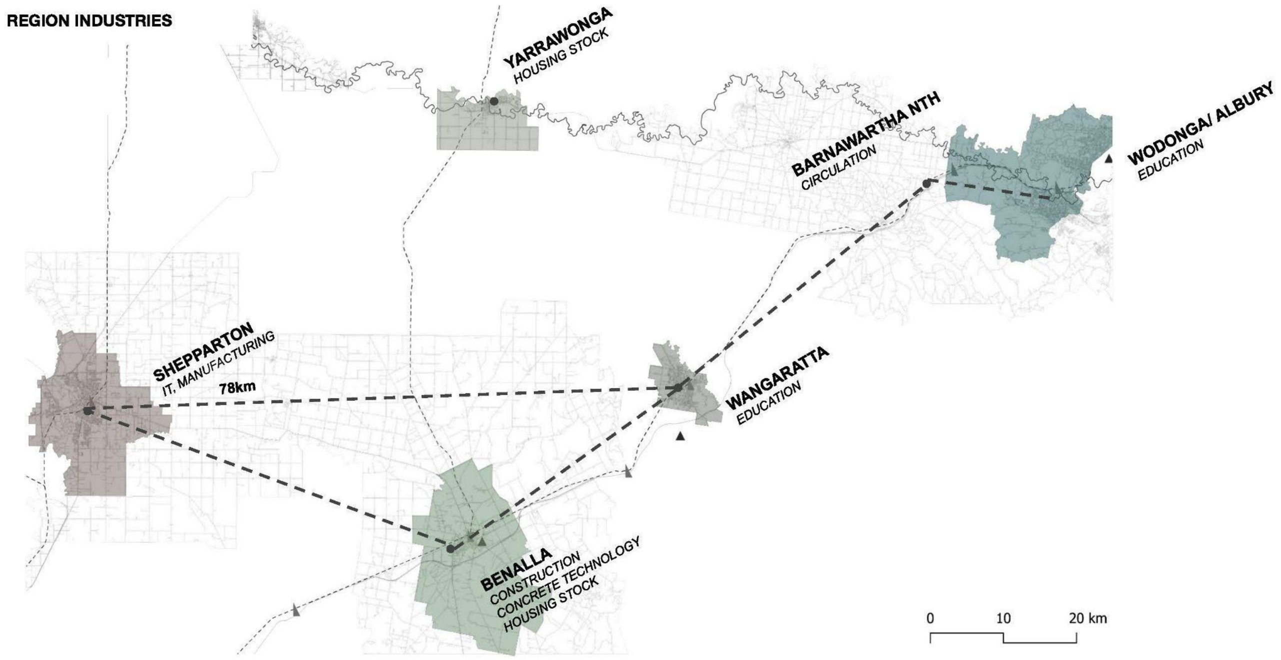
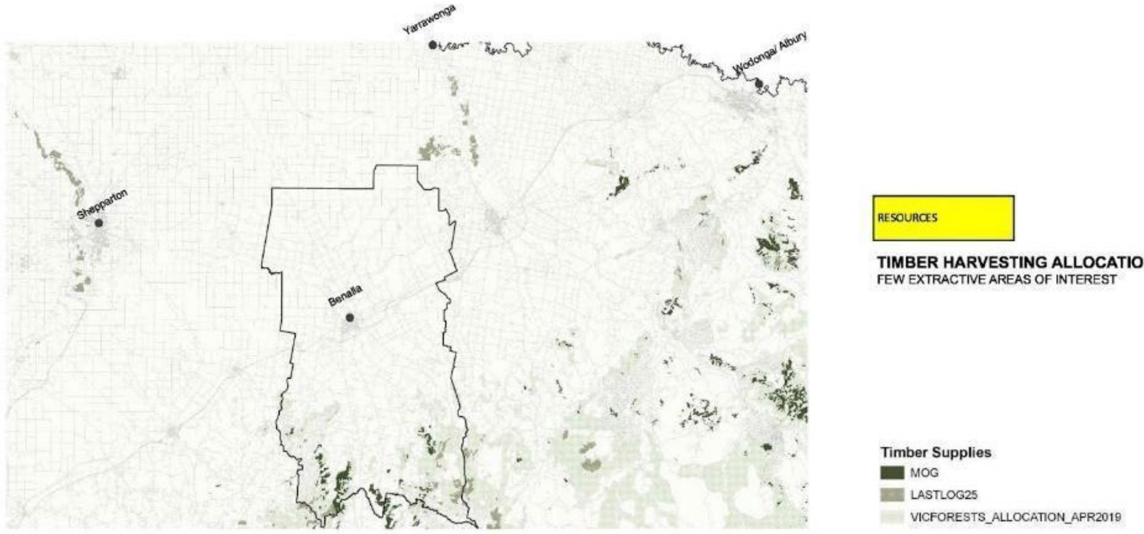


***Figure 36**. Region Specialisations. Source: Authors using report framework testing criteria.*

Resources

The natural resources surrounding Benalla are scarce, with the government designating only a minimal area as extractive zones of interest, primarily with small extractive allocations. This limitation significantly restricts the opportunity to expand beyond the existing LS Precast infrastructure. Moreover, timber allocations in the South East of Benalla, adjacent to Mount Samara state park, are also limited due to the government's ban on native logging, leaving only a small portion of harvestable timber outside of this restriction.



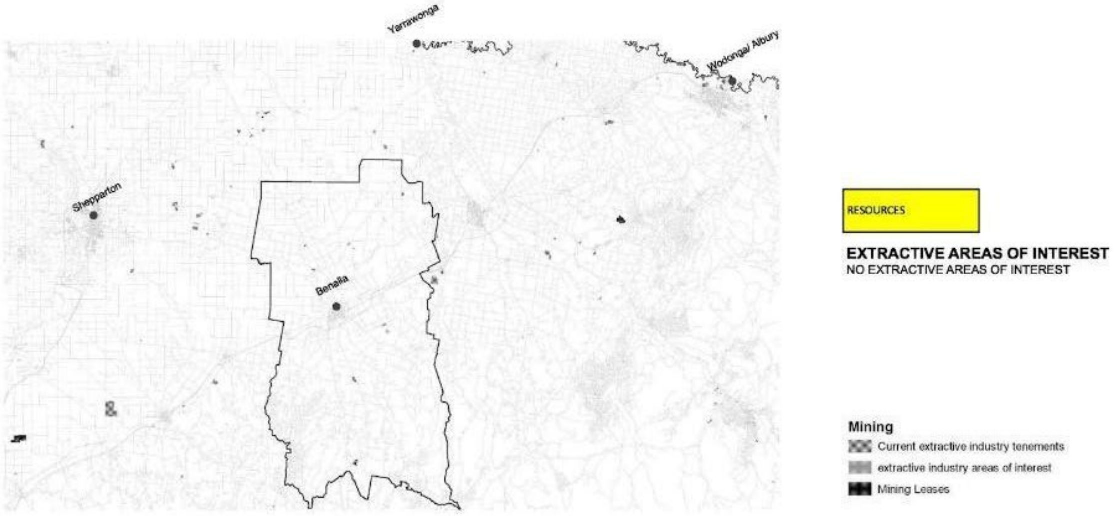


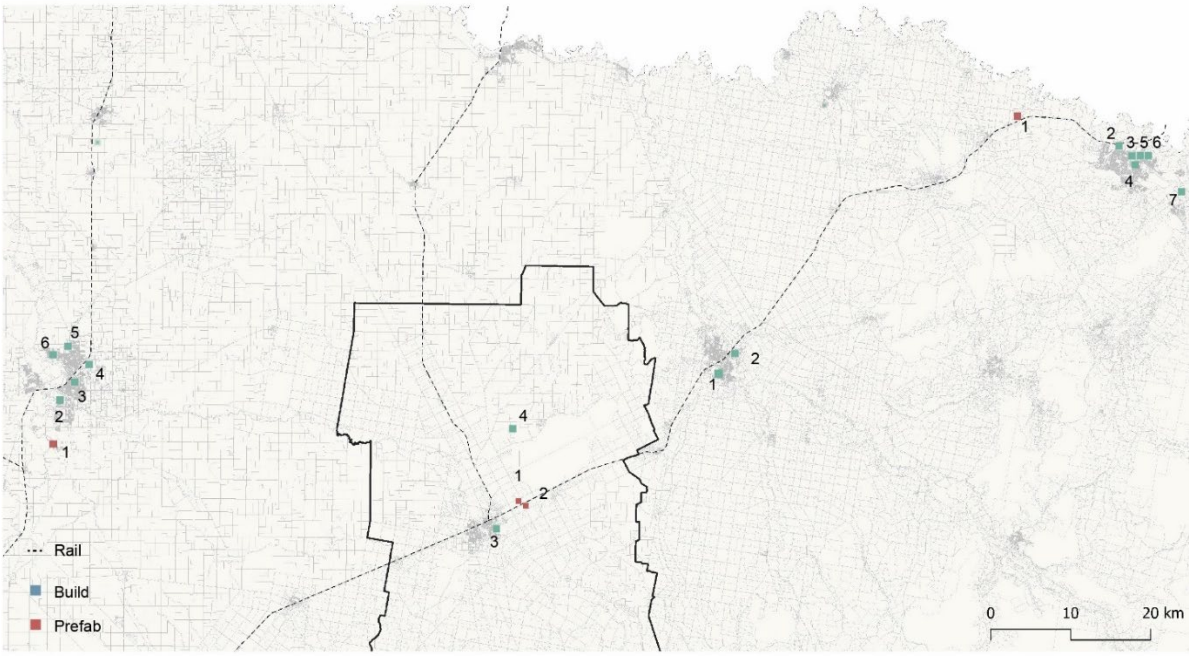
Figure 37. *Benalla Resource allocations, Source: Author using Vicdata Extractive Industry Interest Area and Harvested logging coupes*

Industry Closures & Opportunities

Between 2011 and 2021, the manufacturing sector experienced a decline in employment by 30%; however, it still remains one of the main employers in the region, ranking behind healthcare and construction. The area houses prominent companies such as LS Precast, Schneider Electric, Thales Munitions, and D&R Henderson, which have maintained consistent employment levels. In particular, Thales Munitions had a remarkable year of exports in 2021 (Thales, 2021).

Figure 38. *Concrete Sub Assembly and specialised equipment, Source: Author.*

The close proximity of these industries to one another establishes a substantial foundation of existing infrastructure, which can be adapted with relatively low capital investment to foster a broader exchange of knowledge and manufacturing capabilities. The agglomerative effects of clustering similar businesses within the same industry category can facilitate the growth of supportive primary, secondary, and tertiary businesses, creating a holistic network of manufacturing and construction.



SHEPPARTON		**BENALLA**		**WANGARATTA**		**ALBURY / WODONGA**	
1	JMB Modular Building	1	LS Precast	1	Blairgrange Pty	1	XLam Australia
2	Neatline Homes	2	D&R Henderson	2	Ultra Project Services	2	Connelly Construction Service
3	Moretto Building	3	Timberline Constructions			3	Q1 Constructions
4	Crow Constructions	4	Progressive Carpentry			4	Hancon Custom Homes
5	Roweanne Builders					5	Tvn on-Country
6	Bg & Jk Douglas Builders					6	Premier Building and Construction
						7	Murphy's Salvage & Demolition

Figure 39. *Benalla construction services_ Victorian construction suppliers. Source: Authors*

Onsite requirement studies

As previously outlined, LS Precast plays a crucial role in Benalla's economy and employment, particularly in the manufacturing and construction sectors. The spatial requirements for industries involved in large-scale production of prefabricated materials can be adapted from LS Precast's site model to accommodate prefabricated timber materials. However, special attention needs to be given to internal storage requirements for timber goods to prevent degradation, which is not a concern with concrete products.

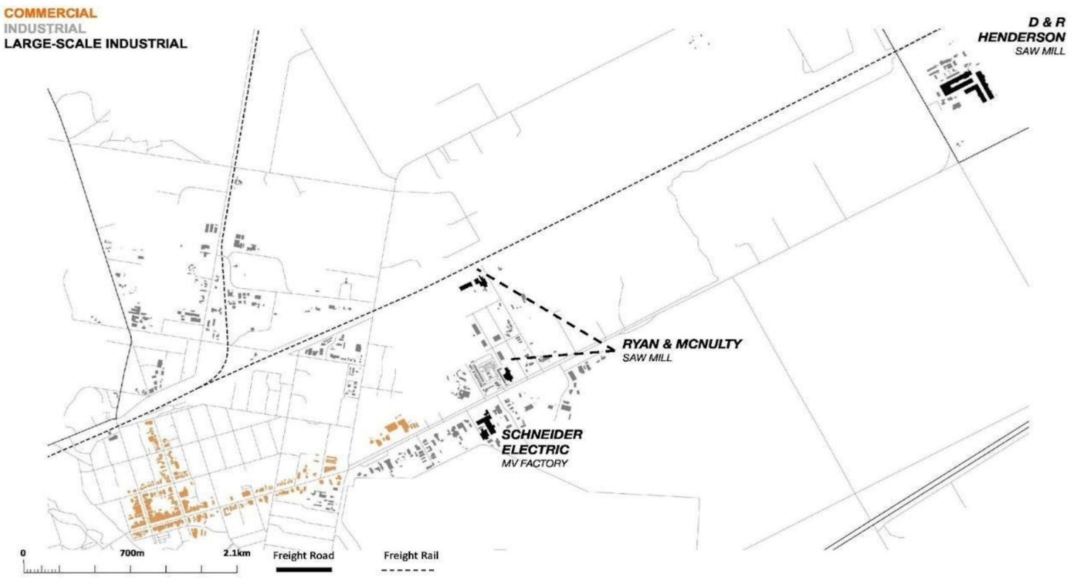


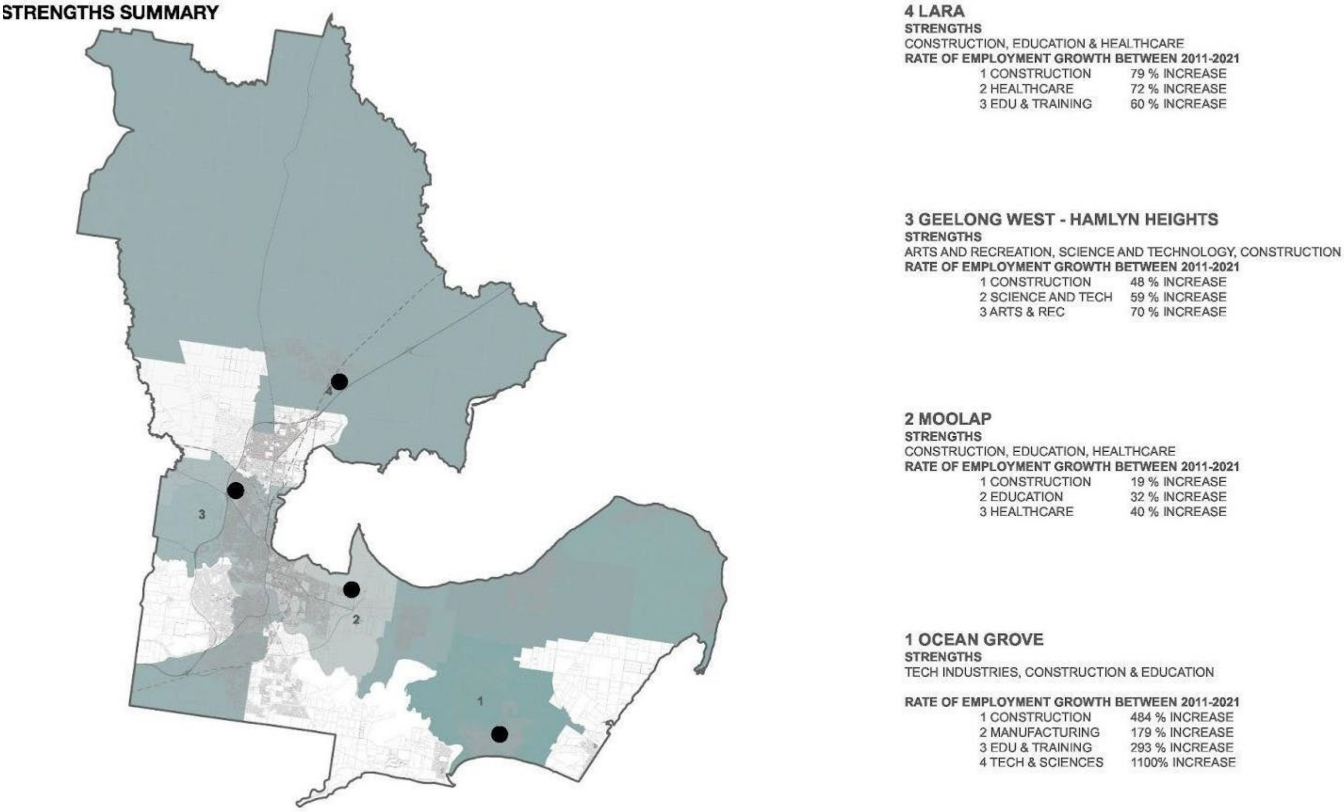
Figure 40. *Benalla Commercial, Industrial, Large-scale industrial building distribution, Source: Author using Vicdata, Vicmap Planning - Planning Scheme Zone Polygon.*

Through the examination of LS Precast's spatial layout, valuable insights have been gained regarding the significance of the sub-assembly line for both concrete and timber products. Old Castle Infrastructure has highlighted the importance of having ample internal space for controlled curing stages in the sub-assembly of concrete prefabrication. This flexible space can be reconfigured to accommodate other utility spaces, facilitating the integration of timber or electrical goods into the manufacturing process.

***Figure 41.** LS Precast spatial analysis, Source: Author Desktop Mapping*

Geelong

Geelong's Local Government Area (LGA) accommodates a substantial population divided into several statistical areas. This division offers a more focused examination of the geographical distribution of employment variations. Overall, Greater Geelong has displayed remarkable resilience, as many industries like construction, education, and technology have witnessed significant growth. Moreover, when certain industries faced challenges or declined, the employment exchange within Greater Geelong's boundaries acted as a buffer against a substantial regional decline. This dynamic is evident in the rapid expansion of multiple industries in Ocean Grove, as it helped mitigate the overall loss of work in the area.



4 LARA
STRENGTHS
CONSTRUCTION, EDUCATION & HEALTHCARE
RATE OF EMPLOYMENT GROWTH BETWEEN 2011-2021

1 CONSTRUCTION	79 % INCREASE
2 HEALTHCARE	72 % INCREASE
3 EDU & TRAINING	60 % INCREASE

3 GEELONG WEST - HAMLYN HEIGHTS
STRENGTHS
ARTS AND RECREATION, SCIENCE AND TECHNOLOGY, CONSTRUCTION
RATE OF EMPLOYMENT GROWTH BETWEEN 2011-2021

1 CONSTRUCTION	48 % INCREASE
2 SCIENCE AND TECH	59 % INCREASE
3 ARTS & REC	70 % INCREASE

2 MOOLAP
STRENGTHS
CONSTRUCTION, EDUCATION, HEALTHCARE
RATE OF EMPLOYMENT GROWTH BETWEEN 2011-2021

1 CONSTRUCTION	19 % INCREASE
2 EDUCATION	32 % INCREASE
3 HEALTHCARE	40 % INCREASE

1 OCEAN GROVE
STRENGTHS
TECH INDUSTRIES, CONSTRUCTION & EDUCATION

RATE OF EMPLOYMENT GROWTH BETWEEN 2011-2021

1 CONSTRUCTION	484 % INCREASE
2 MANUFACTURING	179 % INCREASE
3 EDU & TRAINING	293 % INCREASE
4 TECH & SCIENCES	1100% INCREASE

Figure 42. *Geelong industry strengths, Source: Author using ABS data 2011 and 2021 SA2 Industry of Employment.*

In contrast to the overall poor performance of the Manufacturing sector across Victoria, Ocean Grove stands out as one of the few areas where manufacturing has experienced an impressive growth rate of 179%. This growth indicates a positive response to industry-wide developments in the region. Additionally, several industries closely aligned with construction have also seen substantial growth, with construction itself witnessing a remarkable 484% increase, transport/warehousing growing by 135%, and education expanding by 293%.

The most significant rates of growth in Ocean Grove are observed in the tech and business sectors, with professional, scientific, and technical services experiencing a substantial 1100% growth, and Financial and Insurance Services seeing a 1500% increase. Although these industries are not yet the leading employers in Ocean Grove, they signal the establishment of new sectors within the region, with a pre-existing workforce of 720 employees in professional services and 281 in finance as of 2021. Comparatively, the construction market remains on par with healthcare employment but is witnessing substantial growth.

Moolap has provided Geelong with a consistent base of manufacturing and construction employment. Whilst seeing minimal growth between 2011 and 2021, an existing ecosystem of manufacturing and construction businesses has provided construction services throughout the southern reaches of Greater Geelong additionally acting as a sales and retail hub for industrial goods.

Resources, Land-use & Infrastructure

Geelong Port presents considerable commercial opportunities with multiple piers and commercial licences for import and export activities. Although some piers, like Port Henry Pier, have been closed, their reinstatement offers advantageous placement due to their proximity to existing infrastructure, resources, and the available workforce.

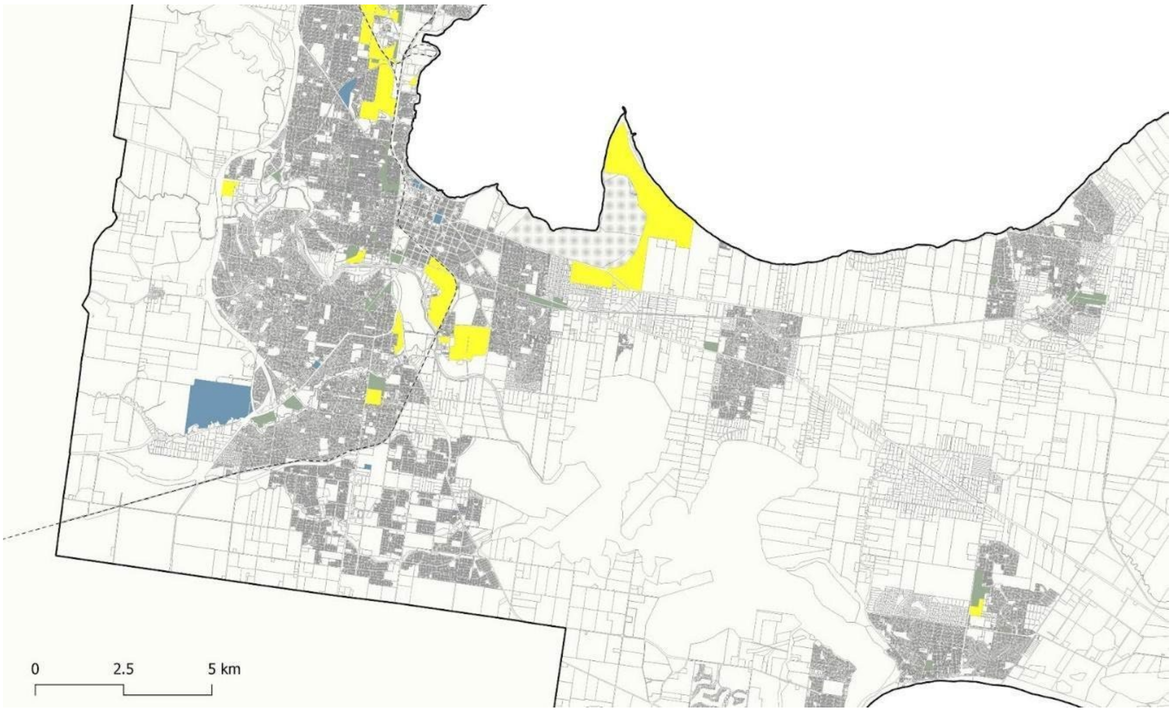


Figure 43. *Geelong Industrial land usage, Source: Author using Vicdata Vicmap Planning - Planning Scheme Zone Polygon.*

Throughout Geelong, various areas contain industrial land, situated in Lara, Corio, Norlane, Ocean Grove, and South Geelong. Notably, smaller workshops are prominent in Norlane and southern Corio, while Breakwater and South Geelong also host these smaller workshops. Moreover, there are vast special use zones surrounding Avalon airport and Moolap. In Lara and Corio, larger-scale depots, factories, storage structures, and timber yards are prevalent. These areas also accommodate longer factories used for vessel engineering and larger-scale steel fabrication manufacturing. Meanwhile, Moolap offers significant existing infrastructure that supports construction and manufacturing industries, including concrete prefabrication and extractive processes.

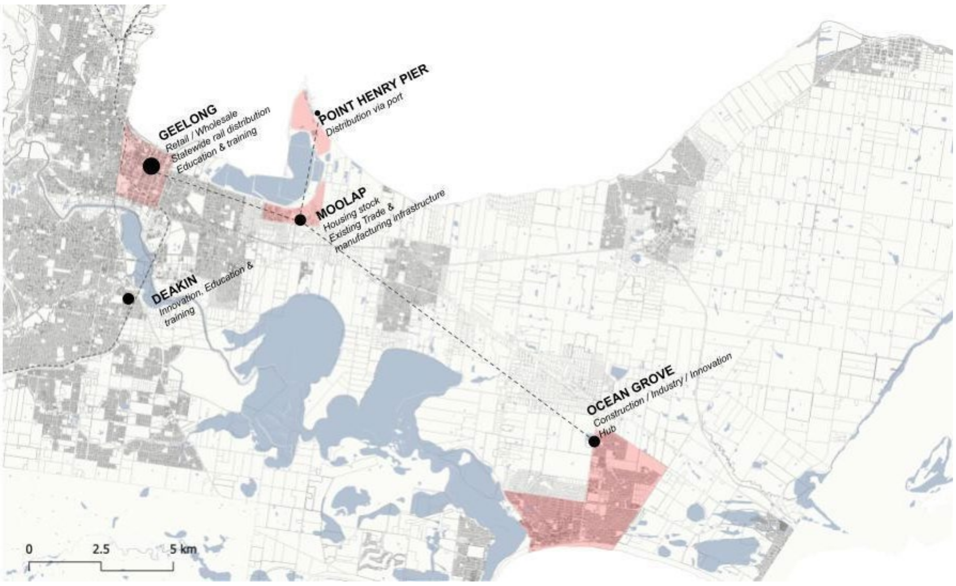


Figure 44. *Consolidated Hub, Source: Authors.*

Figure 44 shows a rudimentary organisation of existing economic considerations in the surrounding regions of South Geelong. The evaluation criteria and testing framework have identified portions of employment change, existing infrastructure, significant employers and manufacturing densities that can implicate the distribution of secondary supportive industries surrounding a potential construction hub development. In this instance, a consolidated hub has been identified as a potential opportunity in Moolap due to the historical development of infrastructure, and existing skilled workforce.

Resources

Geelong possesses substantial areas of extractive significance and already showcases some of Victoria's most notable quarries and extractive locations. The considerable expansion of extractive allocations facilitates the availability of more quarried materials to support the rapidly growing construction and manufacturing industries in the region. Geelong's extractive zones consolidate along the western boundary of Greater Geelong, ensuring convenient access to existing ecosystems of construction and manufacturing. Additionally, these areas benefit from their proximity to the National rail and highway freight network.

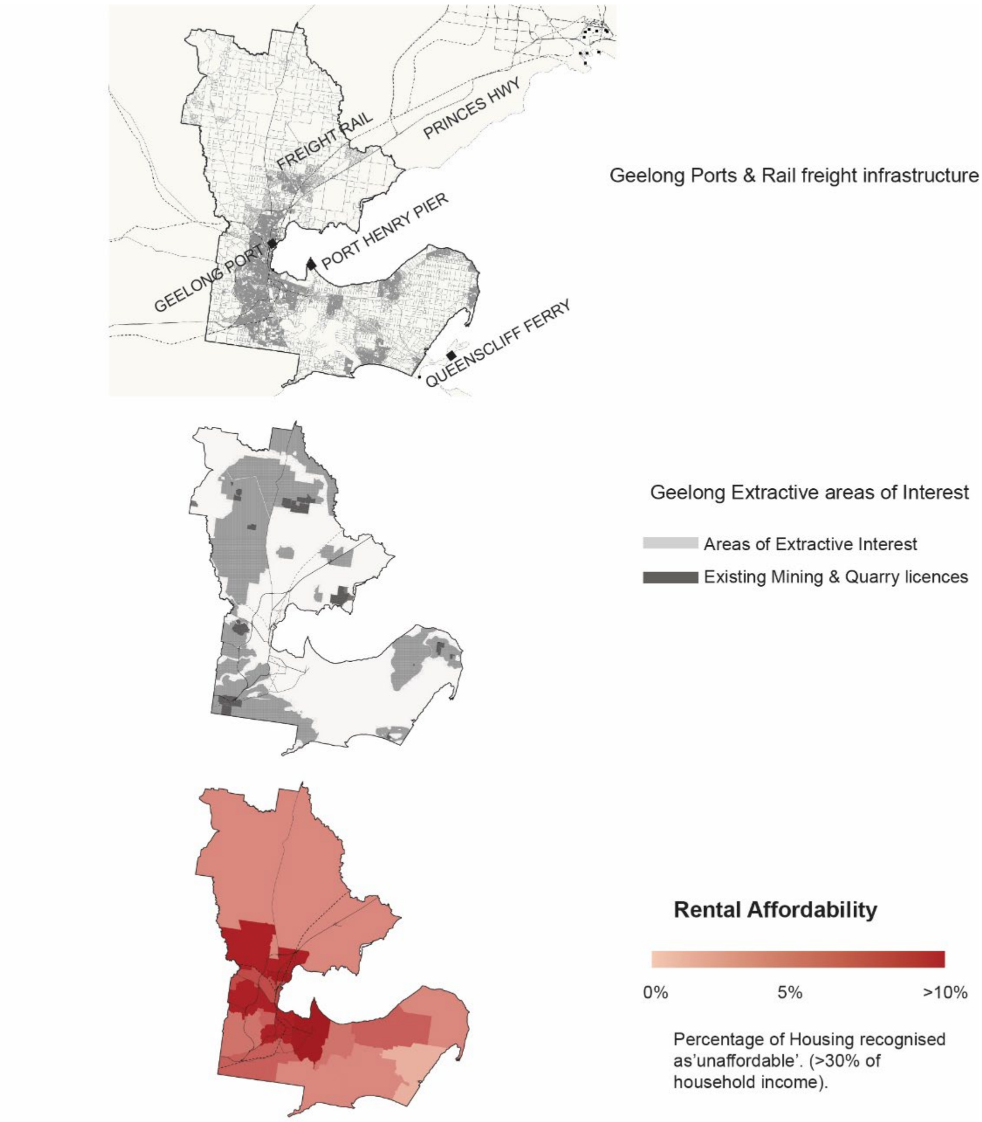


Figure 45. *Distribution network & Extractive areas of interest Overlay, Source: Author using Vicdata Extractive Industry Interest Area and Desktop mapping*

Industry Closures & Opportunities

The abundance of jobs in Greater Geelong is primarily due to the strong presence of the construction and manufacturing sectors, which have established thriving economic ecosystems across Geelong's Local Government Area (LGA). The recent closure of Alcoa on Port Henry in 2014 presents a significant opportunity to utilise the existing industrial land adjacent to Port Henry and highway for development purposes. Although the railway to Point Henry has been disconnected and transformed into a rail trail, the primary distribution lines along the highway remain operational, with the potential to reinstate the port for import and export activities. Furthermore, the Moolap area houses a minor construction and manufacturing precinct, contributing to a diverse range of existing infrastructure that supports various industries in the region. This diverse infrastructure supports the continued growth and development of an economic and industry cluster in Greater Geelong.

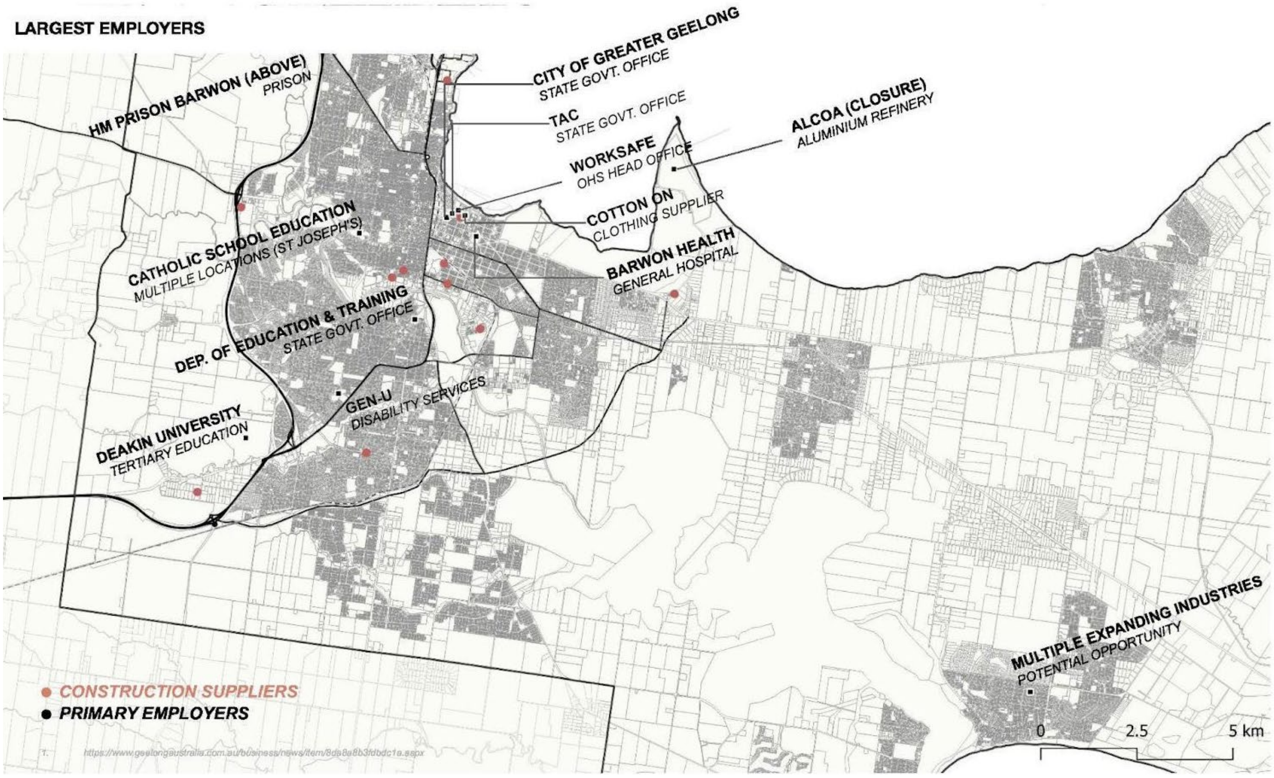


Figure 46. *Geelong Primary Employers and Closures. Source: Author using Desktop mapping.*

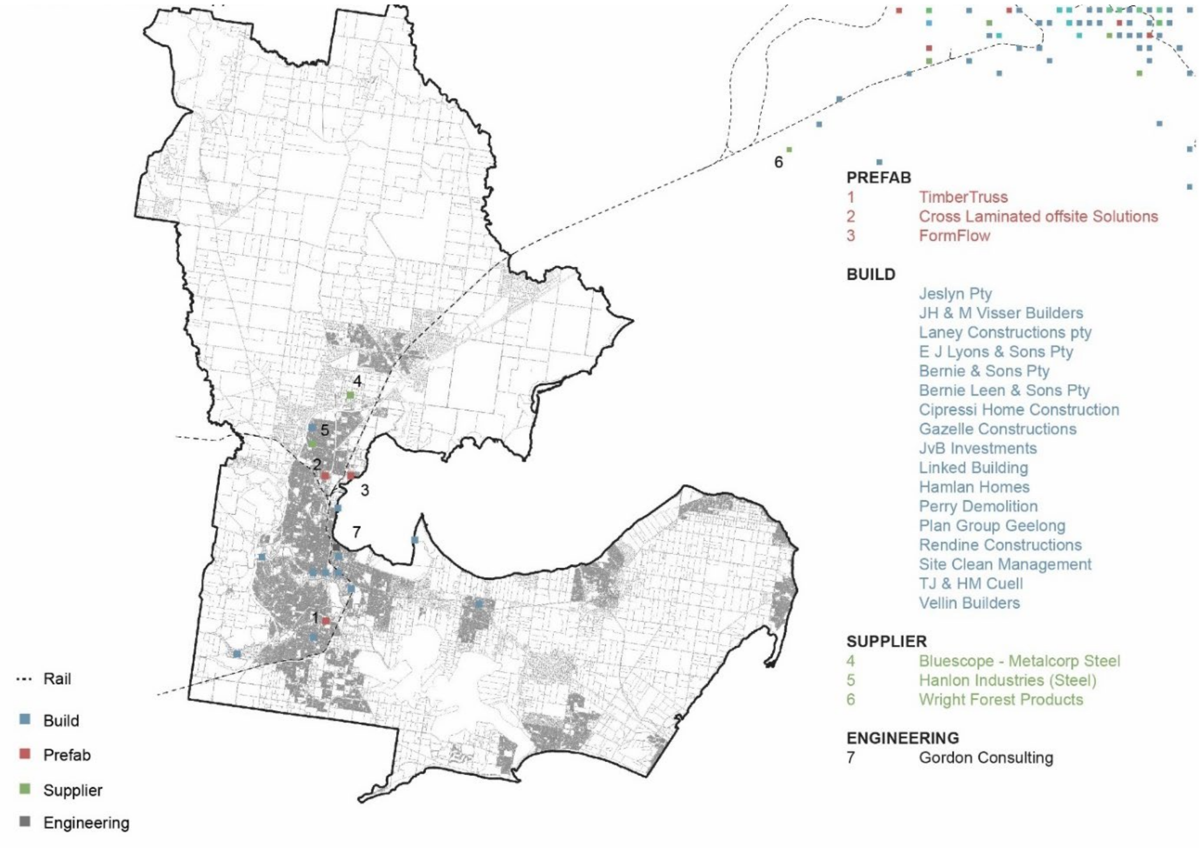
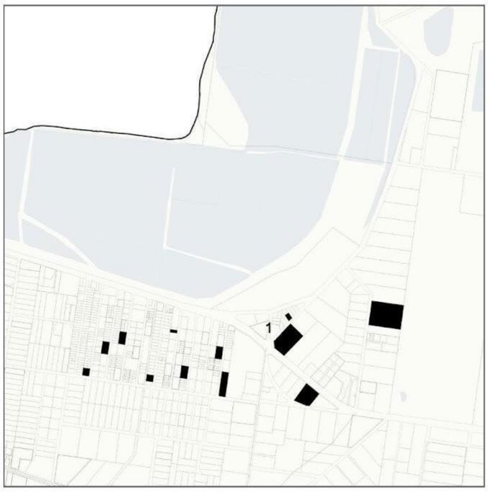


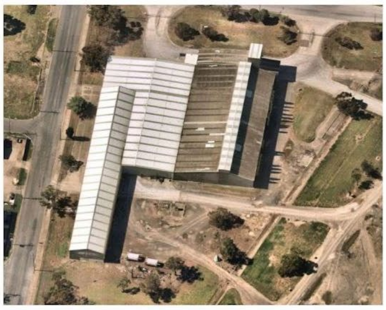
Figure 47. *Geelong construction services_ Victorian construction suppliers.* Source: Authors

Onsite requirement studies

The robust construction and retail sectors in Moolap lead to distinct spatial considerations for the development of a construction or commercial hub when compared to Benalla and Latrobe. The spatial overlap between these areas necessitates a unique approach to address specific spatial needs. Unlike the focused spatial requirements seen in Latrobe and Benalla, which primarily revolve around the functionality of typical businesses within specific industries, Geelong's diverse economic strengths allow for a consolidation that goes beyond specialised equipment and sub-assembly lines. Instead, it enables the incorporation of multiple factors from various industries to establish a more integrated and consolidated ecosystem.

MOOLAP - STEEL SERVICE SUPPLIERS





GEELONG INDUSTRIAL BUILDING TYPOLOGIES

Sawtooth Factory / Large-Span Footprint

Typical floor area: 1500 – 3000m²

TypicaL ceiling height: 6 – 9m

Primary material and structure: Steel frame with corrugated steel clad.

Typical use: Electrical utility manufacturing, large-scaled steel, timber & concrete fabricators.

MOOLAP - CONCRETE SERVICE SUPPLIERS

GEELONG INDUSTRIAL BUILDING TYPOLOGIES

Large-scale Amalgamated Factory

Typical floor area: 80,000 – 200,000m²

Typical ceiling height: 10 - 15m

Primary material and structure: Steel frame with corrugated steel clad.

Typical use: Large-scales timber, concrete and steel manufacturing

Figure 48. *Existing Steel & Concrete manufacturing, Moolap. Source: Author using Desktop mapping*

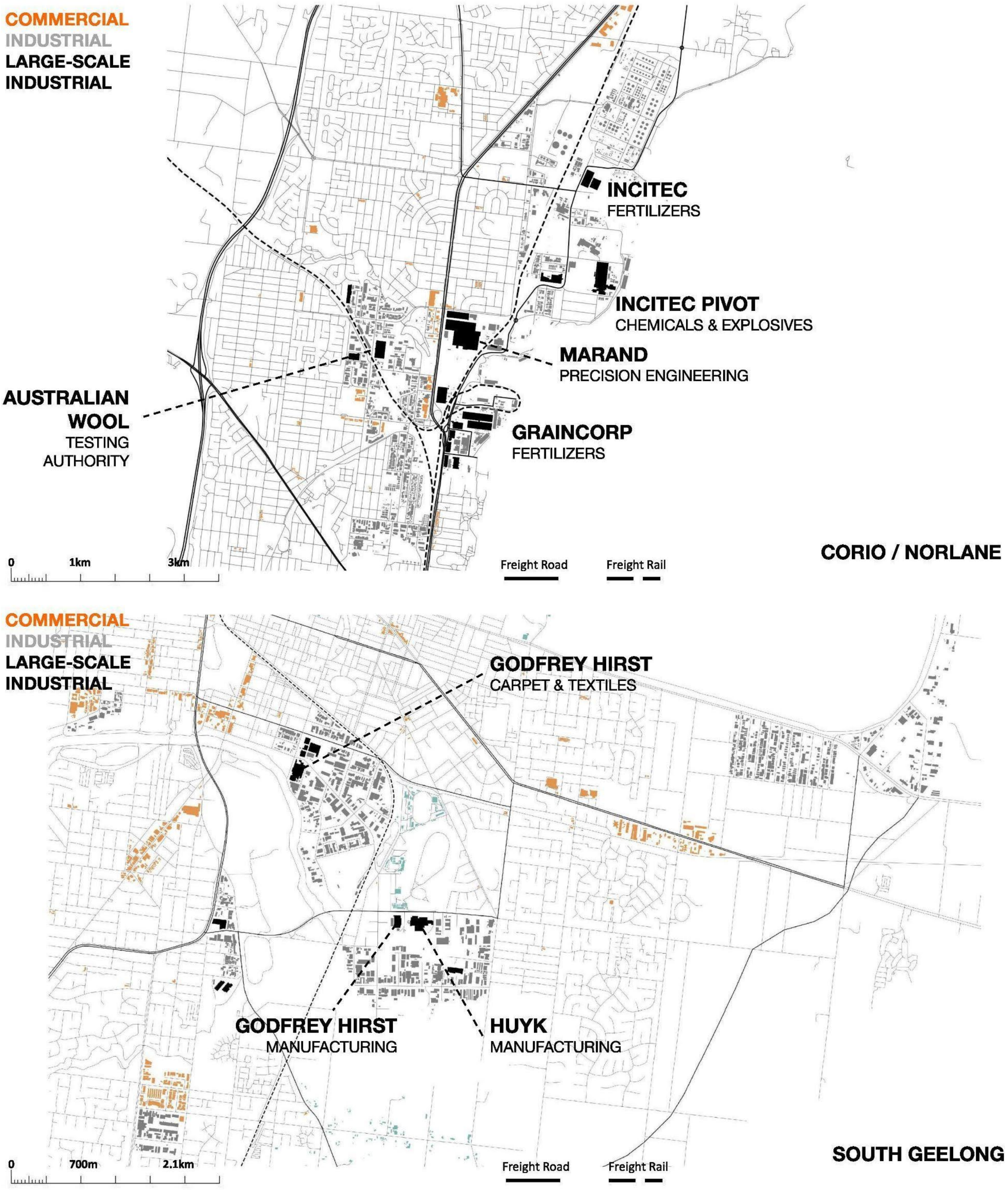


Figure 49. *Industrial Makeup of Inner Geelong Suburbs. Source: Author using VIC data & desktop mapping*

Figure 50. *Evaluation Framework Summary, Source: Authors.*

C_SOCIO-ECONOMIC ANALYSIS

Historic-economic development patterns

Review of literature historical economic development patterns in Victoria; Economic history scoping

White settlement of Victoria was built on the prosperity of the wool industry, the gold discoveries of the 1850s, and the hostile dispossession of the Indigenous population. In the late 1820s, the arrival of increasing numbers of free settlers in the convict colony Van Diemen's Land (Tasmania) triggered Australia's first economic boom (Belich 2007). British investment in roads, bridges, and other infrastructure prompted a rush to occupy land for pastoral use. Suitable land on the island was occupied so quickly that pressure was placed on the New South Wales government to extend settlement to the southern coast of the mainland. When squatters from Van Diemen's Land, acting independently without government authority in acquiring land illegally from the Wurundjeri population established a camp on the Yarra River in 1835, the event signified that 'the continent was fully open to conquest' (Boyce 2011, xi).

Melbourne's location at the top of Port Phillip Bay positioned it as the centre of Victoria, with a hinterland that included the goldfields, rich pastoral land to the west, and grasslands beyond the Great Dividing Range. The gold rushes pushed Melbourne past Sydney to become Australia's largest city and its financial capital – Sydney overtook Melbourne in terms of population around the turn of the 20th century, but had to wait another seven decades to become the nation's dominant financial centre. By the end of the 19th century, both Sydney and Melbourne had close to half a million – the 46th and 47th most populous cities in the world (Chandler 1987, 492). Wool was Australia's most valuable export, but the leading source of investment was the urban sector, associated construction, manufacturing and service industries (Butlin 1964). The depression of 1890s – felt most severely in Melbourne – signalled the end of a 30-year boom, but the development of refrigerated shipping for meat and dairy products and the rise of the Western Australian goldfields provided new export activities that allowed growth to continue, albeit at a slower pace (Belich 2007).

Like Australia's other capital cities, Melbourne was the gateway to a rural hinterland, at which primary products were between various forms of land-based transportation and ocean-going ships, then distributed to external markets. The capital was home to commercial service providers such as banks, merchant and insurance houses, firms that stored and processed rural output, and small-scale manufacturers of food and drink, clothing, boots and shoes, and building materials for the local market.

In 1901, 2.3 million people—61 per cent of the Australian population—lived in areas inland of the Great Dividing Range where the most important pastoral, agricultural, and mining industries were located. In an era when roads were generally poor and people could travel conveniently only short distances by horse and cart or bicycle, hinterland towns, most of no more than thousand inhabitants, were important centres of economic and civic activity, providing supplies and services that producers needed on an everyday basis. These towns were established when transport and manufacturing technologies were simple and services were consumed on the spot, at the same time and location as they were produced. Small towns contributed to the development of frontier regions in important ways. When towns were founded at river crossing points for travelling stock, storekeepers worked actively to promote agricultural settlement and offered credit to selectors. Income from farms and the farm workers who lived in towns circulated around the local community.

The population of the bush increased to 3.3 million over the next hundred years, but in that time the capital cities increased their population from 1.3 million to 12.3 million. As a result of the growth of the capital and provincial cities and towns along the coast, the proportion of the Australian population living in inland regions dwindled to 17 per cent (Frost 2008, 2013).

By WWI, Melbourne's economy had recovered from the depression of the 1890s, with the metropolitan population reaching 593,000 by 1911. The city benefited from large areas of vacant land that was accessible by public transport, having been subdivided during the land boom of the

1880s. Electrification of the suburban rail and tram network, which began in 1911, and track duplication and level crossing removal on busy rail lines, allowed commuters to travel further in a given time period, which encouraged the development of distant suburbs. In the interwar period, Australian manufacturing prospered in clusters of industries in metropolitan locations that grew around new technologies of electricity and the internal combustion engine (Merrett and Ville 2011). Melbourne's total population grew by 460,000 between 1922 and 1947, driven by in-migration of people born in Australia and natural increase (Merrett 1978, 191). In the economy of the 'Fordist' city, national, state, and local governments were central players, attracting international manufacturers and immigrants to suburban fringes through protective tariffs, building areas of public housing, and providing essential high-cost infrastructure. As the production of standardised goods reduced inefficiency and costs, well-paid industrial workers became consumers, as well as producers, of cars and domestic appliances. Between 1947 and 1971, Melbourne's population doubled, from 1.2 million to 2.4 million (Frost 2013).

By the 1920s, technological and global forces were at work that would weaken the traditional link between farm output and economic activity in country towns. After their youthful growth spurts, most country towns settled into periods of much slower growth, and at times declined. Country people welcomed new railways, cars and trucks, improved roads and more sophisticated farm equipment because they made bush life easier and less isolated. However, these technologies undermined businesses in nearby small towns and their communities, as rural consumers now had more choice as to where they could shop, obtain healthcare and other services, and spend their leisure time. These same technologies were to the advantage of capital cities and coastal industrial centres, enabling them to build new factories and worker housing on cheap peripheral land. Tariff protection and increases in the rate of immigration from overseas also favoured the capitals. Manufacturing in small country towns, which had prospered when technology was simple and transport costs were high, now found it difficult to compete with metropolitan firms that could achieve economies of scale.

As wool and wheat prices boomed in the 1950s, country towns enjoyed a period of prosperity and growth. Some towns attracted industries that were seeking cheap land. After Bruck Mills opened a new factory at Wangaratta in 1947, around a thousand jobs were created, and the city's population rose from 5,700 in 1945 to 13,800 in 1961 (Whittaker 1963, 172-3). However, country towns were the product of an era in which land was taken up and improved using simple, labour-intensive technology. Shearing, mining, ploughing and harvesting was hard physical work. Towns were built close to areas of primary production when transport and manufacturing technology was primitive and local producers were protected by distance. As this economy matured, the demand for rural labour, the links between rural output and local employment, and the protection offered to small towns all declined. Although the number of rural workers and farms remained stable until the 1970s, the subsequent period of inflation and the increasing deregulation of the Australian economy encouraged an increase in average farm size. The number of Australian farms declined by around one quarter from the early 1980s to the early 21st century (Productivity Commission 2005). As the Australian economy created new jobs in services, a growing proportion of which was located in Sydney, Melbourne and Brisbane, nearly all country communities battled to keep their young people. In Victoria, the population of Buloke, West Wimmera and Yarriambiack shires fell by 30 per cent, mostly due to emigration of people in the 0–24 and 55 and over age groups (McCann 2005).

Prefabrication in the housing and construction industries: a short global and Victorian history

Introduction

Almost from the dawn of mass urban industrial societies in Europe and the West in the nineteenth century, architects, planners and urban theorists have dreamt of utilising the knowledge and skills of factory-based production to update and improve the efficiency of the housing and construction sector. As architectural historian Florian Urban argued in his 2011 global history of mass prefabricated housing, providing accessible, relatively affordable and sanitary housing for workers in the emerging mass cities of Europe and the United States was one of the great 'social questions' of the second half of the nineteenth century and the first decades of the twentieth (Urban 2011).

Such theorists argued that a solution to the long-standing desire to improve housing conditions could be found by adopting new technologies and materials such as reinforced concrete and new mass production techniques modelled on the ideas of among others Frederick Winslow Taylor and Henry Ford. In the case of construction, and especially residential housing construction – the industry that capitalism had seemingly 'forgotten' (Greig 1995) such was its ongoing emphasis on artisanal traditions - the idea was that just as the manufacture of clothes, cars and other goods had been revolutionised by methods of factory production, so too could commercial and residential constructions be made more efficient if component parts were created in a factory. Whole buildings, or major component parts could then be transferred to a site where final assembly would take place, using machinery rather than skilled labour. In the residential construction sector, the adoption of new material and mass production techniques, whether complete structures or component parts such as floors and walls, would see housing moving into the industrial age and become in architectural theorist Le Corbusier's famous words 'machines for living in'.

As advocated by Le Corbusier and other European Modernists, such ideas and techniques were most obviously suited to the mass production of high-rise and high-density dwellings for poorer urban working-class people, especially those displaced by war damage and later as part of an effort to improve living conditions as part of both the post-war Welfare State in Western Europe, North America and Japan. More ubiquitously in Eastern Europe, especially the Soviet Union, adoption of these methods became symbols of socialist modernisation (Sammartino 2017). Elsewhere in Asia, South America and Africa such methods were utilised in newly decolonised nations as part of a post-colonial modernising development process (Urban 2011). While most of these initiatives were government-led, the private sector was often central to these processes, especially in Britain either as producers of components or as builders contracted to local or national government housing agencies (Finnimore 1989). Across the world, however, there are multiple examples of private sector initiatives to industrialise middle-class, single family suburban house construction. The best known of these is American businessman William Levitt who famously demonstrated in his early post-World War Two developments in Pennsylvania and Long Island that provided enough serviced lots were available, mass production methods and the use of machinery in construction could be applied to single-family middle-class suburban housing projects (Gans 2017).

Australia and Victoria

In Australia, prefabrication for residential housing has a history that goes back to the earliest days of invasion/settlement. By necessity, new European arrivals had to bring their shelters with them, at first in the rather primitive form of tents but also in the shape of larger pre-cut structures that could be assembled on site. In Victoria, Wattle House, a wooden prefabricated house brought from England to Australia in the 1840s and erected on site in Jackson St, St Kilda for local businessman Samuel Jackson is a good example of this phenomenon, as is the cast iron Corio Villa (1855), built in Edinburgh and shipped to Geelong for Commissioner of Crown Lands William Gray. While Corio Villa is the oldest and only known surviving prefabricated cast iron house in Australia, in the gold rush period when shelter was in short supply, the importation of iron houses, such as those owned by the National Trust in Coventry St, South Melbourne (1853), was a regular occurrence.

While these are examples from the nineteenth century, as in Europe and North America, the use of prefabrication and industrialised building techniques in Victoria is mostly a twentieth century and indeed a post Second World War phenomenon. As in other places this was frequently a response to either a severe housing shortage or part of a Modernist-inspired effort to alleviate or eradicate substandard dwelling conditions, especially in older inner-city regions. Experiments in the industrialisation and prefabrication of housing in Victoria in the early post-war years included the 'Beaufort' steel house produced in the former Beaufort bomber factory in Port Melbourne, alongside similar houses produced by airline company Ansett and the Myer Emporium (O'Hanlon 1998). So too, in the 1940s and early 1950s potential British migrants recruited to work for the Victorian Railways and other semi-government authorities were encouraged to bring their own pre-cut houses with them to Australia as part of a program dubbed 'Operation Snail' (O'Hanlon 1998).

The biggest and most well-known initiative in this field is, however, the 'Concrete House Project' undertaken by the Housing Commission of Victoria (HCV) between the 1940s and the early-1970s. At first focussing on tilt-slab single-family concrete houses in what are now middle-ring suburbs such as Box Hill and Maidstone in Melbourne, by the 1950s the production of these houses on huge estates on suburban fringes of Melbourne, in Geelong, the LaTrobe Valley and elsewhere became a central feature of a Victorian-government sponsored program of industrialisation and decentralisation. International investors were lured to Victoria with the promise of cheap land to build factories and a readily-accessible local workforce. Employees, including new international immigrants, would in turn be attracted to these places by the promise of new, cheap and subsidised rental or owner-occupied single-family accommodation in these concrete houses.

The best-known and most infamous of these Victorian government initiatives remains the later move by the HCV towards what it called ‘slum reclamation’, the wholesale clearing of older, sometimes substandard housing in Melbourne’s inner suburbs and their replacement with Le Corbusier-inspired high-rise public housing blocks. From the first of these, the 16-storey Emerald Hill in South Melbourne, the Housing Commission built more than 40 mid-and high-rise public housing towers in fourteen suburbs across the inner city across an almost fifteen year period from the mid-1950s through to the early 1970s. They also built numerous low-rise (two, three and four storey- blocks) in the same inner suburbs and multiple other locations across Melbourne. All were made of concrete and prefabricated in the Commission’s factory in Holmesglen before being transported for erection on site.

Initially considered a success and a cost-effective solution to what seemed to be an intractable housing problem, the HCV program, its *raison d’etre* and the processes were extolled in a Victorian government funded film, *The City Speaks* produced by Crawford Productions in 1965. As with similar programs around the world, by the late-1960s the HCV began to attract criticism for the authoritarian bureaucratic process involved in classifying and ‘reclaiming’ older housing, its insensitivity to local needs, and the perceived inhumanity of its Modernist architectural form before it was discontinued in 1972. Some critics also noted that the industrialisation of the building process underpinning the program by necessity required the constant declaration of new slum areas that needed to be rebuilt. Rather than had been the case in the past when demand for new dwellings prompted the search for new sources of efficient supply, in Victoria and elsewhere by the late 1960s the need to keep concrete house factories operating at full capacity became a key motivator in maintaining these programs. Supply had in effect overtaken demand as the driving principle behind the need to pursue industrial building techniques (Willingham, O’Hanlon 2004, Mills 2010).

With the demise of the HCV concrete housing project in the early 1970s and the retreat of the state from overt direct involvement in the economy as neoliberalism became orthodoxy, mass housing and industrial building methods went into decline in the Victorian residential housing industry in the 1970s and 1980s before staging a major comeback in the 1990s and beyond, most notably in the multi-unit residential sector which ballooned, especially in the inner suburbs. As the city deindustrialised and globalised rapid population growth and demand for new dwellings from new arrivals into the city, especially from gentrifiers and students arriving as part of the emerging market in international education. In response, developers (almost all from the private sector) experimented with new and updated techniques in construction, including the use of precast concrete walls and floors in multi-unit and multi storey residential buildings (O’Hanlon 2018). Other developers have updated and patented new versions of old ideas about the prefabrication of whole dwellings in factories which can then be craned into place on site, thus speeding up production (Unitised Building). More commonly, especially in the single-family sector, component parts such as wall, window and door frames, roof trusses and internal fittings such as bathroom fittings, cupboards and shelving have been standardised and produced off site. Other building firms, especially those that operate in the semi-institutional and demountable dwelling sector produce kit buildings and houses in factories that like those of Operation Snail can be transported and re-transported to new sites as necessary.

Major infrastructure projects in transport are also increasingly using off-site and modular construction techniques. The concrete viaducts used in construction of elevated road and rail bridge including those associated with West Gate Tunnel project, the Level Crossing Removal Project, the Metro Tunnel, and the Suburban Rail Loop are manufactured by LS in Benalla.

Benalla

Benalla is a rural city located around 200 kilometres north-east of Melbourne. The area is a mostly flat floodplain of the Broken River catchment that adjoins the Great Dividing Range to the north and west. The local settlement was established as a shire in 1869, made a borough in 1949 and a city in 1965. Between 1994 and 2002 Benalla was incorporated into the shire of Delatite before acquiring a current administrative status of a separate rural city. As a rural city it covers an area of 2,353 square kilometres.

Economy

Benalla developed as a service centre for the neighbouring farming community and as a junction on the Melbourne-Sydney railway. The local agricultural sector originally included grain production and cattle grazing, but later wine making, and dairying gained economic importance. The main railway line reached Benalla in 1873, with a branch line to Yarrawonga completed in 1886, then extended across the NSW border to Oaklands in 1932 (Dunlop 1973). Now disused, a railway between Benalla and Tatong to the south opened in 1914. Benalla railway station hosted a locomotive depot; this was closed in 1990. With the development of road transport Benalla became an interception point for two busy road corridors: the Hume Highway linking Melbourne to Sydney and the Midland Highway starting at Geelong and arcing across country Victoria towards the Victorian Alps.

In addition to agriculture and transportation Benalla attracted secondary and tertiary industries in the post-1945 period. A clothing factory was opened in 1945. Operating initially as Latoof and Callil, it engaged many women from the Benalla Migrant Camp. In the 1980s, the factory became Perfectfit, employing up to 250 people, before shutting down in more recent times. In 1975 Schneider Electric commenced production of electrical transformers in its Benalla plant which is still operational today (Electric 2023) An ammunition factory sited in rural surroundings north of the city began production in 1993. The facility is owned by Thales Australia, and it manufactures ammunition, explosive ordnance, and other munitions (Inc 2023).

LS Precast is a major employer in Benalla. Owned and run by local operator, Ashley Day, who also owns LS Quarry, the plant is located in Lima South. Completed in 2018 with Victorian Government support, the facility is the largest of its kind in the Southern Hemisphere (Premier of Victoria 2018). Capable of producing over 1,500 tonnes of concrete product per day it includes a concrete batching plant, large sheds for precast concrete production, offices, precast product storage, and maintenance areas. To serve LS Precast some improvements were made to local infrastructure. Qube Logistics constructed an intermodal terminal in the former goods yard of the Benalla railway station. The terminal receives containerised cement and fly ash from New South Wales for the factory (Observations 2019). Separately, a new 700 metre siding was built from the existing rail line to provide direct access to the precast facility so that the concrete segments can be directly loaded from it onto freight trains and transported to Melbourne (Premier of Victoria 2018).

While LS Precast produces precast elements for large infrastructure projects Australia wide, the West Gate Tunnel project is its main customer. It was planned that all 65,000 concert segments for the West Gate Tunnel would be transported to Melbourne via the existing rail network. Yet, some heavy loads were considered to be too big to go by rail and too heavy to cross the Pranjip Creek Bridge on the Hume Freeway. These ‘superloads’ – 460 in total – had to be detoured through the small towns of Longwood and Locksley five times a week over two years, to the dissatisfaction of the local communities (Aldridge 2020).

The opening of LS Precast created up to 400 new jobs, which were mostly taken by residents of regional communities, not only from Benalla but also from nearby Euroa, Shepparton, Yarrawonga, and Wangaratta (Precast 2019). Along with this newly opened facility, housing construction generates a strong and increasing demand for labour in Benalla. A growth in the number of dwellings can be used as a proxy of this demand. The number of separate houses in Benalla increased at a faster rate than population growth. While over the period of 1996-2021 the population increased by 71 percent, this category of dwelling nearly doubled in size by showing an increase of 97 %. An increase in the category of medium density dwelling – terrace houses, units, and apartments – was less rapid, yet still significant at 45 percent.

Geelong

Geelong is a large port city located in south-western Victoria, about 75 km from the Melbourne CBD. Established in the 1840s at the western end of Port Phillip Bay it is often named as the 'Gateway City' because of its proximity to the regional significant centres of Ballarat, Torquay, and Warrnambool. Administratively, it is part of the City of Greater Geelong – a Local Government Area that covers an area of 1,247 square kilometres. The LGA was formed in 1993 from the amalgamation of some rural shires and separate small urban municipalities forming Geelong.

Economy

The Geelong economy prospered initially by trading and processing wool. The first wool mills opened in the 19th century and the city gained recognition of the wool centre of the world. Virtually all wool stores and wool mills had been closed by 1980, due to removal of protecting traffic and changing technologies. Apart from wool, Geelong benefited from its location on Victoria's southern coastline; the Port of Geelong is the sixth largest in Australia by tonnage and Victoria's second biggest port. The port now handles more than 10 million tonnes of product and deals with around 600 vessel visits annually.

Geelong also developed as an important railway junction. It is a major stop on the Western standard gauge railway line. Converted from broad gauge in 1995, the line links Melbourne with Adelaide and Perth. There are also railway lines that connect Geelong with Warrnambool and Ararat.

Manufacturing started to develop rapidly from the 1920s. A number of the large manufacturing companies were established there - Ford Motor Company's vehicle plant, Alcoa aluminium smelter (closed in 2014), fertiliser plants, Fyansford Cement works, the Shell refinery, and others. The manufacturing sector dominated the local economy up until the early 21st century, when most heavy industry shut down due to Federal government tariff reform. Most woollen mills closed in 1974 and hectares of warehouse space in the city centre were left empty after wool-handling practices changed. Australian Portland Cement Company closed in 2001.

Geelong's more recent progress has been as a centre of advanced manufacturing (such as the aerospace industry at Avalon Airport and Ford RD), construction, financial and insurance (GMHBA), education (Deakin University), and healthcare (Barwon Health).

In recent years Greater Geelong has experienced some of the strongest economic growth in Australia. The city has had the highest growth across all three major economic indicators of Gross Regional Product (GRP), jobs and employed residents compared to similar regions and cities across Australia. Greater Geelong has an estimated GRP of $15.4 billion, 120,000 local jobs and 19,600 businesses. Local labour market conditions are strong with unemployment at historic lows of 2.5 percent, 1.7 points lower than the Victorian rate and 1.9 points lower than Australia. Youth unemployment is 6.3 percent, 4.1 points lower than Victoria. Job advertisements and demand for labour are at record highs, with 10,550 new jobs advertised in the June 2022 quarter.[1]

Latrobe

The Latrobe Valley is a river valley and an inland district in the Gippsland region, 130 kilometres east of Melbourne. Geographically it is nestled between the Baw Baw Rangers to the north and Strzelecki Ranges to the south. The district is administratively incorporated into Latrobe City LGA which covers an area of 1,426 square kilometres and. Legislated in 1994 Latrobe comprises four major urban centres: Churchill, Moe/Newborough, Morwell and Traralgon and it is the fourth-largest city in regional Victoria by population.

Economy

Coal mining started developing in the late nineteenth century. Private open-cut mines provided fuel for the Victorian Railways. The Victorian Government established an Electricity Commission in 1918, later renamed as the State Electricity Commission (SEC). It became the sole agency in the state for electricity generation, transmission, distribution, and supply. SEC runs mines and power

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stations in the Latrobe Valley. Timber-cutting and paper mills Australian Paper Manufacturers, a large public company, established the Maryvale Paper Mill, between Traralgon and Moe, in 1937.

After 1945 the Latrobe Valley consolidated a major industry hub. A major factor was the SEC's dramatic expansion of activities. New open-cut coal mines and power stations in the Valley. Hazelwood, Yallourn W, and Loy Yang power stations built in the 1960s-80s. In the 1970s around 20 percent of the working population in the Latrobe Valley was employed by the SEC.

Privatisation and economic downturn. Privatisation and deregulation of the SEC began in the mid-1990s. Since the sale of SEC to private interests, some of the plants have been closed, including the Morwell power station and briquette factory in 2014, and Hazelwood power station in 2017. All paper mills have also been closed in the area.

Key industry sectors include health care, power generation, retail, timber mills, agriculture, dairy, timber, information technology, engineering and education. The valley provides 85% of Victoria's electricity and has a substantial engineering sector supporting the power generation and food processing industries, etc.

Socio-economic analysis and results

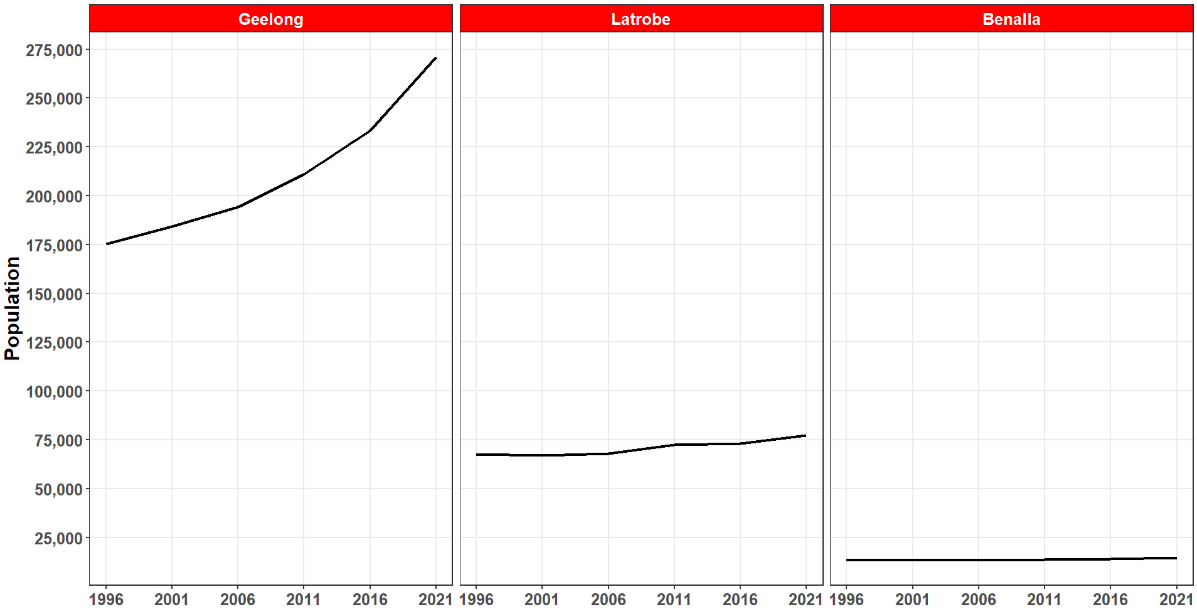

Figure 51. *Population of Geelong, Latrobe and Benalla, 1996-2021. Source: Authors using ABS 2006, 2021 data.*

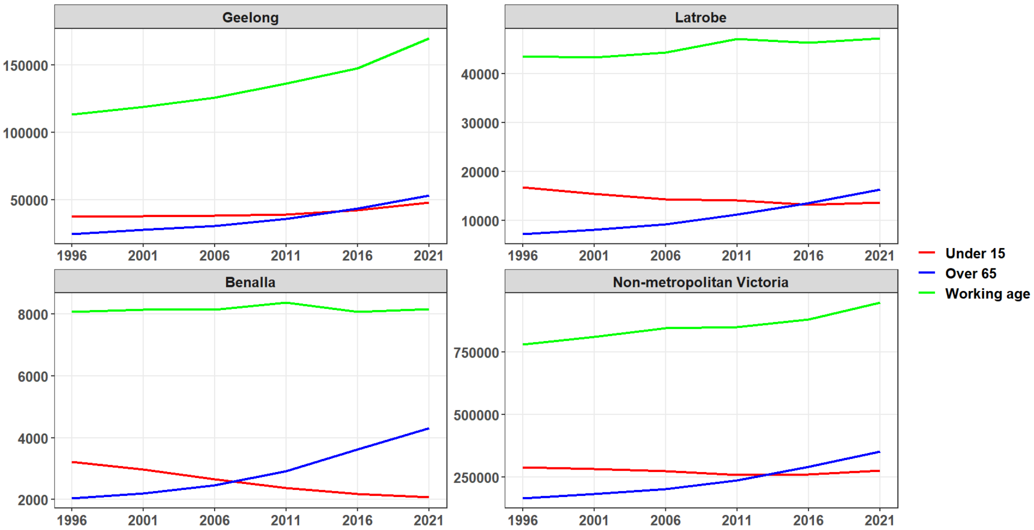

Figure 52. *Key demographic statistics, main age groups. Geelong, Latrobe, Benalla, and non-metropolitan Victoria. 1996-2021. Source: Authors using ABS 2006, 2021 data.*

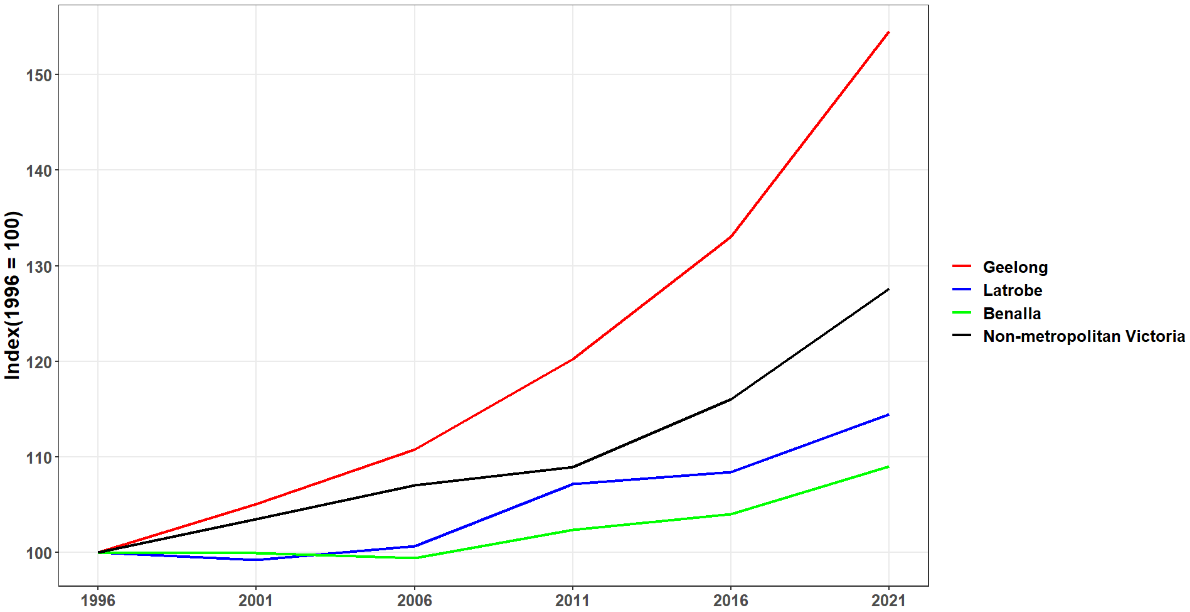

Figure 53. *Gross regional product of Geelong, Latrobe, Benalla, and non-metropolitan Victoria. Index of changes. 1996-2021. Source: Authors using Regional Development Victoria (RDV) 2021 data.*

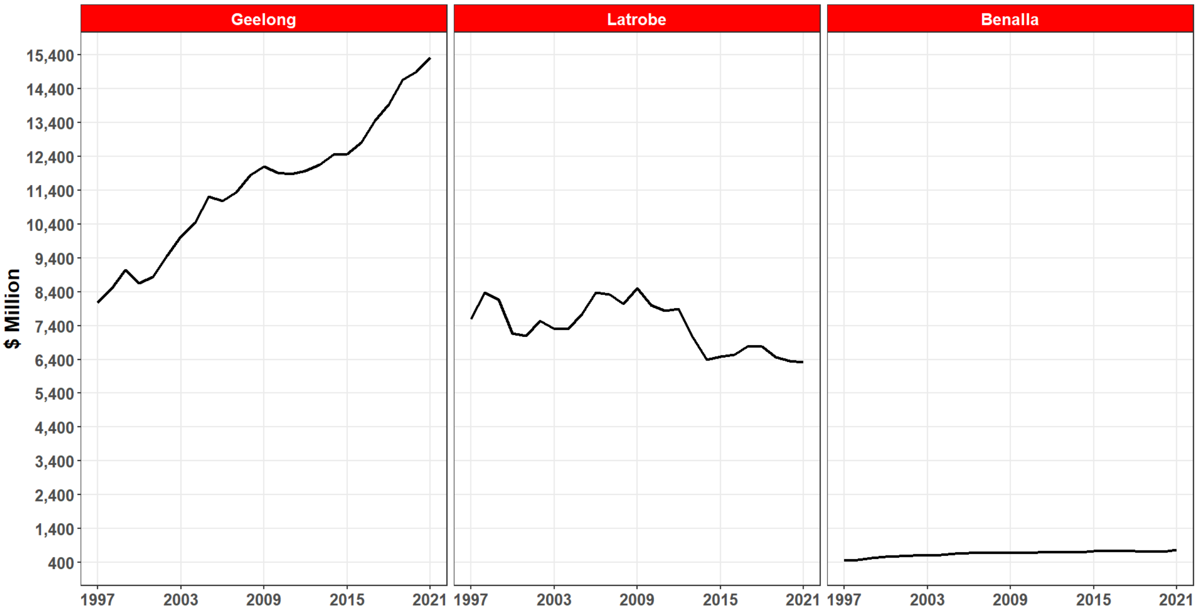

Figure 54. *Gross regional product of Geelong, Latrobe, and Benalla, 1997-2021. Source: Authors using Regional Development Victoria (RDV) 2021 data.*

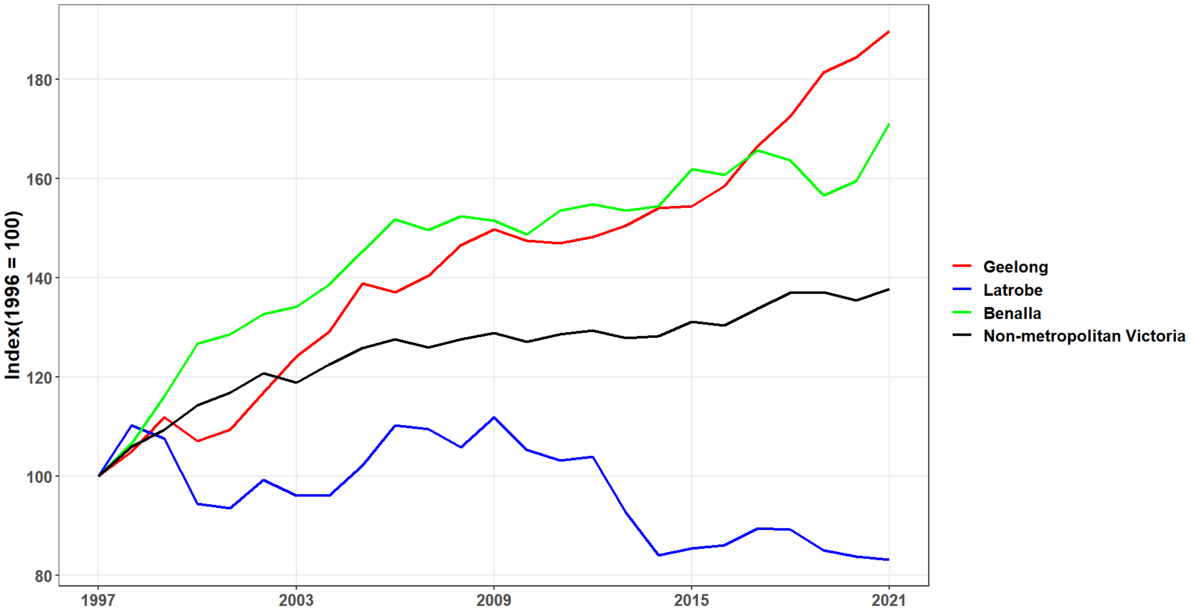

Figure 55. *Employment in Geelong, Latrobe, Benalla, and non-metropolitan Victoria. Index of changes. 1996-2021. Source: Authors using ABS 2006, 2021 data.*

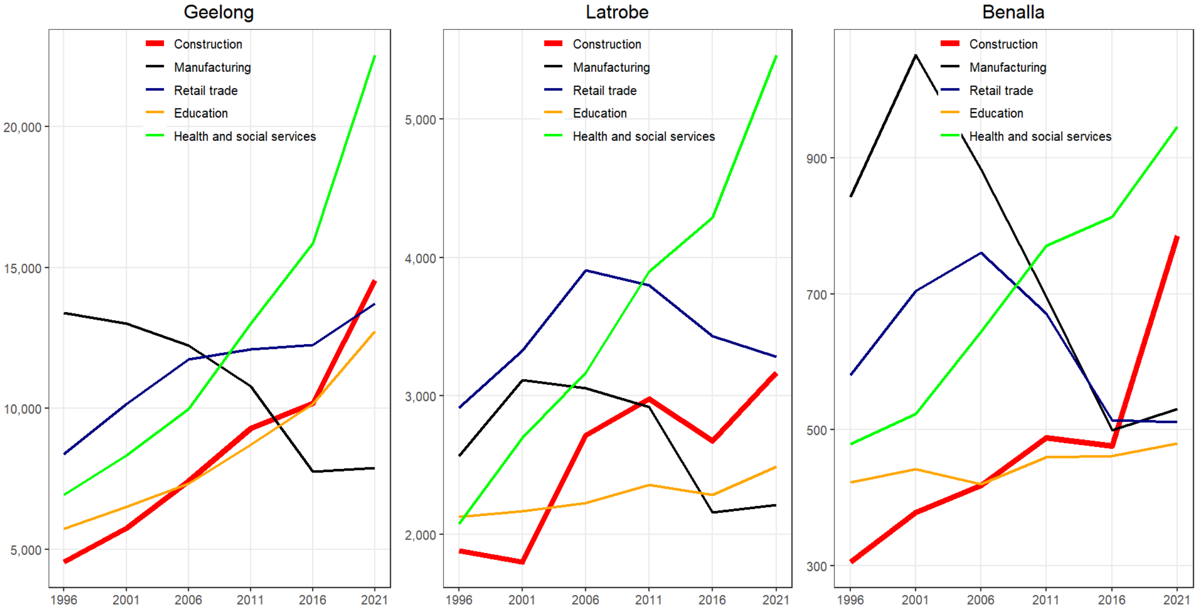

Figure 56. *Employment in five largest local industries. Geelong, Latrobe, and Benalla. 1996-2021. Source: Authors using ABS 2006, 2021 data.*

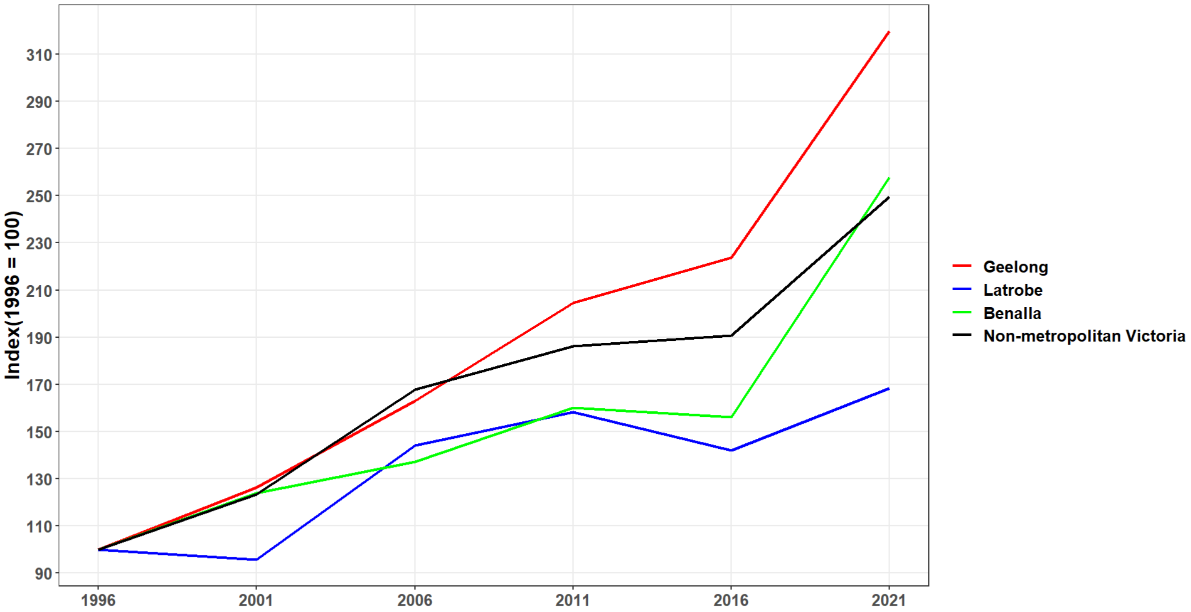

Figure 57. *Employment in the construction industry. Geelong, Latrobe, and Benalla. Index of changes. 1996-2021. Source: Authors using ABS 2006, 2021 data.*

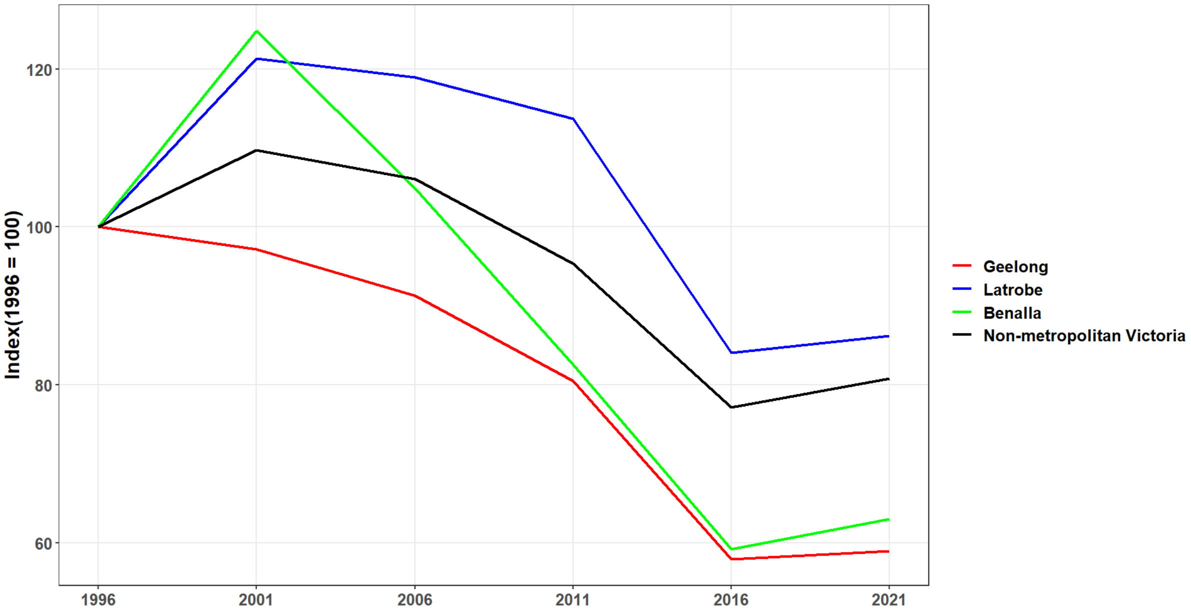

Figure 58. *Employment in the manufacturing industry. Geelong, Latrobe, and Benalla. Index of changes. 1996-2021. Source: Authors using ABS 2006, 2021 data.*

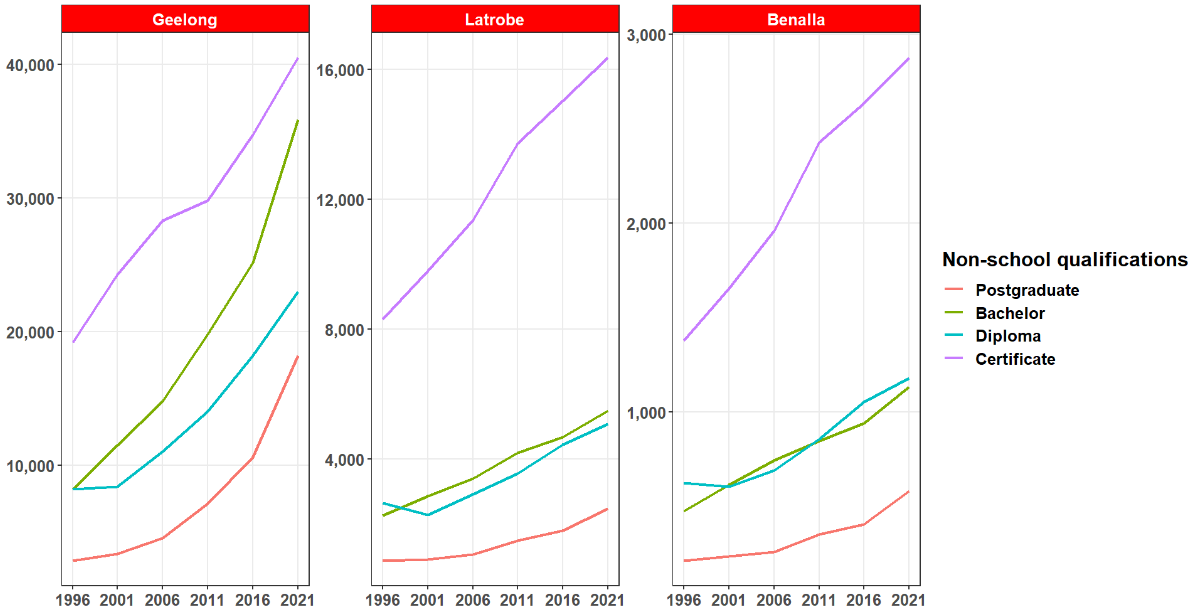

Figure 59. *Number of people with non-school qualifications. Geelong, Latrobe and Benalla. 1996-2021. Source: Authors using ABS 2006, 2021 data.*

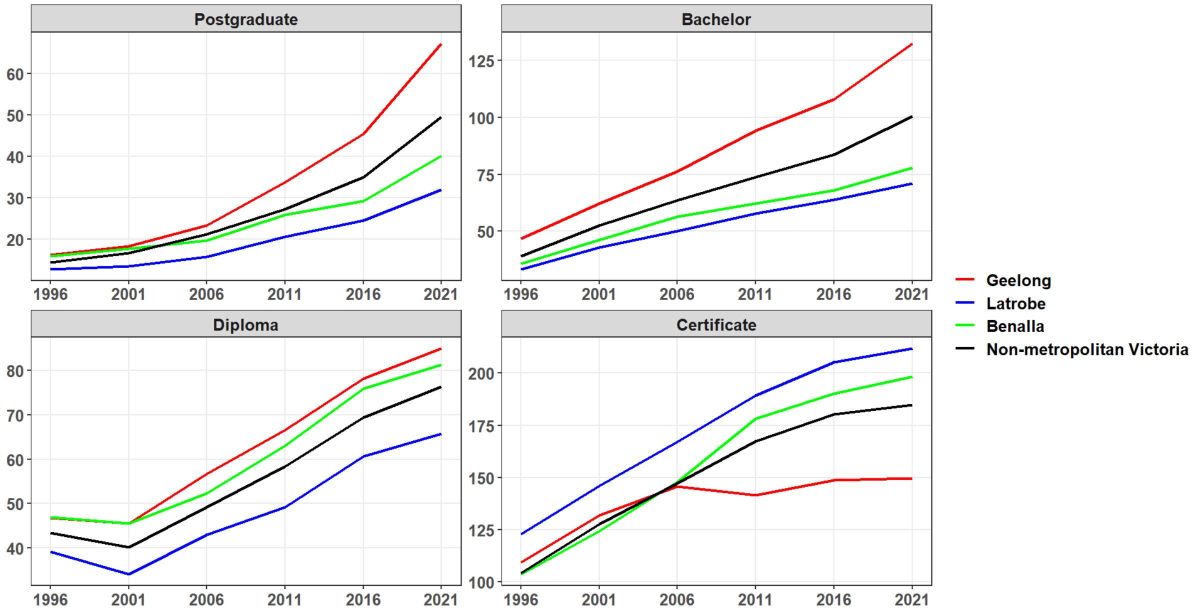

Figure 60. *Number of people with non-school qualification per 1000 residents. Geelong, Latrobe, Benalla and non-metropolitan Victoria. 1996-2021. Source: Authors using ABS 2006, 2021 data.*

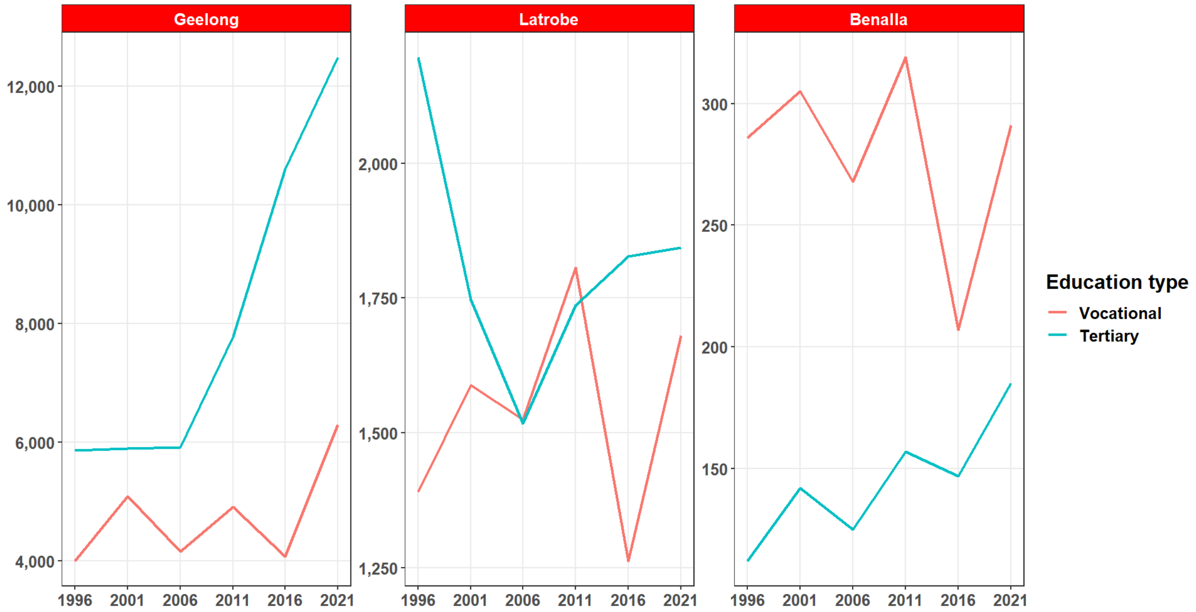

Figure 61*. Number of non-school students. Geelong, Latrobe, and Benalla. 1996-2021. Source: Authors using ABS 2006, 2021 data.*

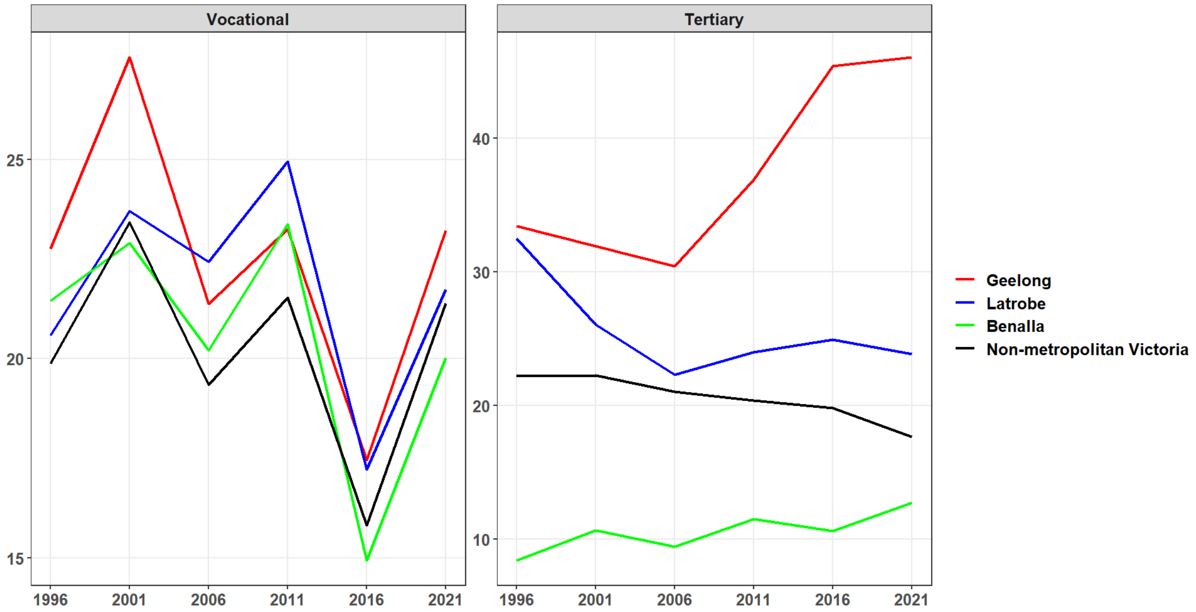

Figure 62*. Non-school student density per 1,000 residents. Geelong, Latrobe, Benalla and non-metropolitan Victoria. 1996-2021. Source: Authors using ABS 2006, 2021 data*

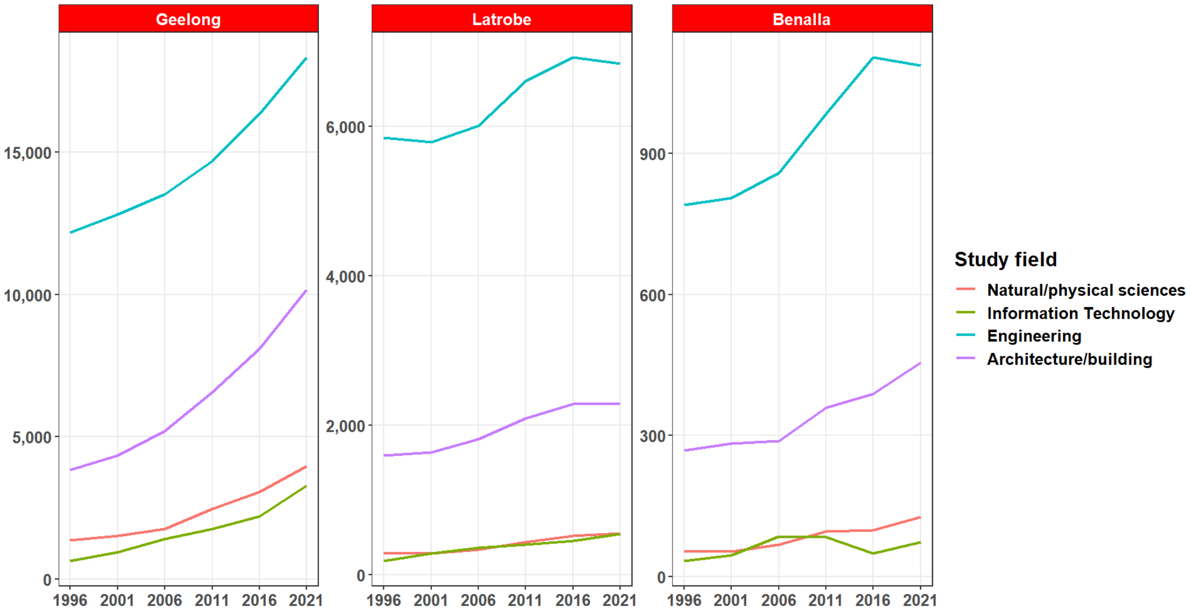

Figure 63. *Highest non-school qualification of residents in Geelong, Latrobe and Benalla. Selected fields of study. 1996-2021. Source: Authors using ABS 2006, 2021 data*

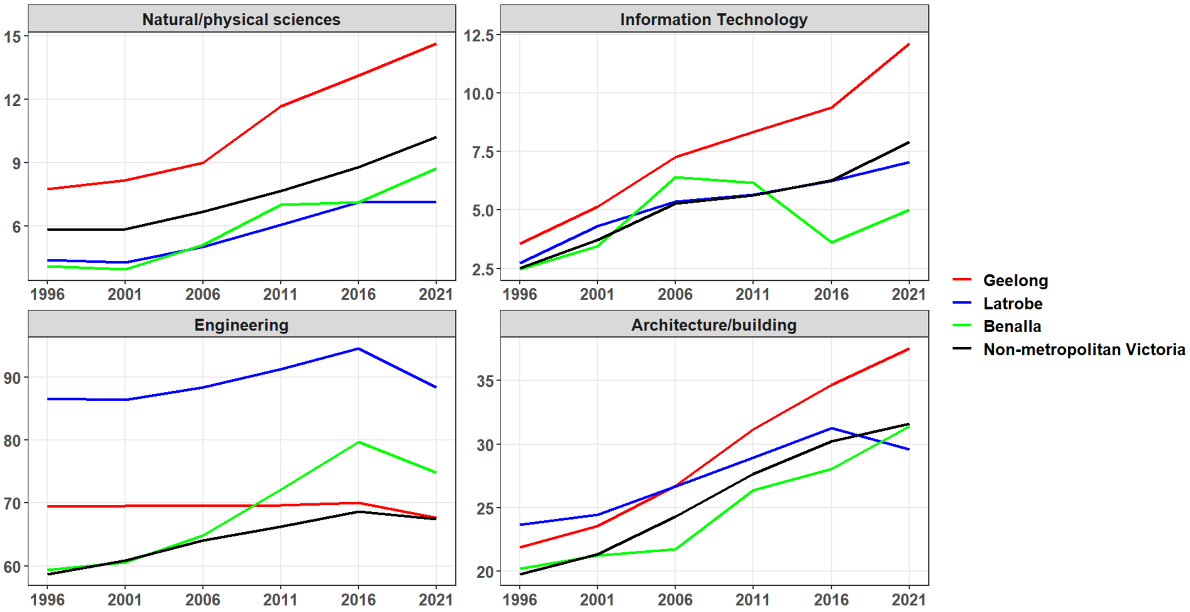

Figure 64. *Selected types of qualification per 1,000 residents in Geelong, Latrobe, Benalla, and non-metropolitan Victoria. 1996-2021. Source: Authors using ABS 2006, 2021 data*

D_BUILDING 4.0 CRC INDUSTRY PARTNER INTERVIEWS

The research team conducted two rounds of interview workshops with industry partners: Supply Chain workshops (involving two companies) and Industry workshops (involving three companies). The frequency of topic mentions by industry partners is depicted in Figures 65 and 66.

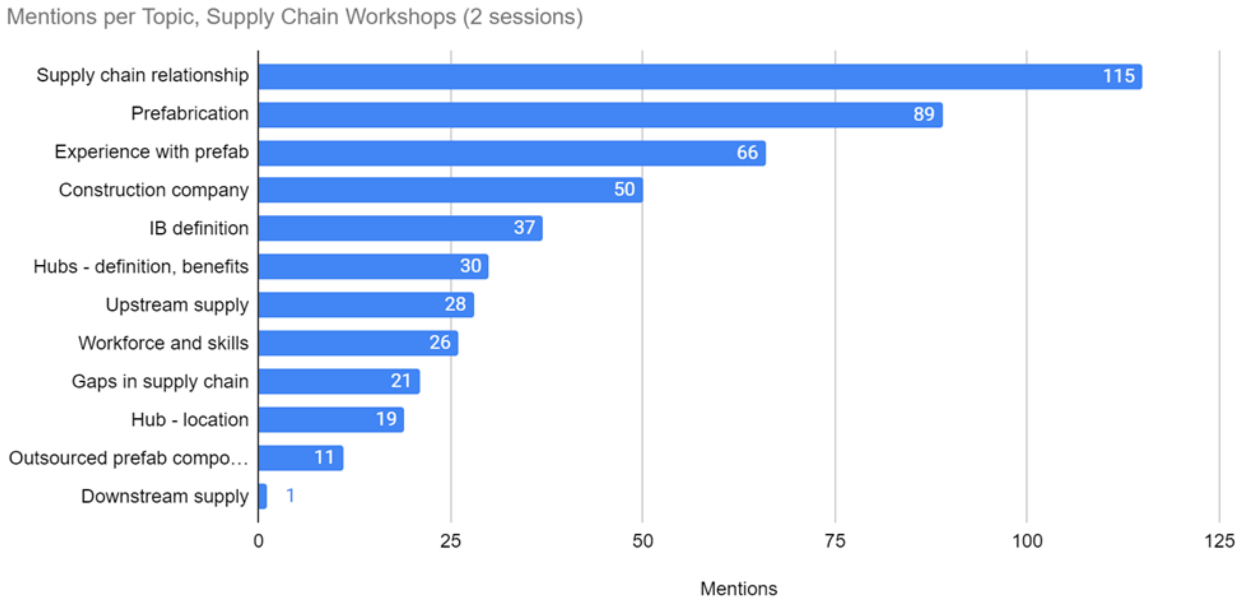

Figure 65. *Mentions per topic, Supply Chain workshops (2 sessions).*

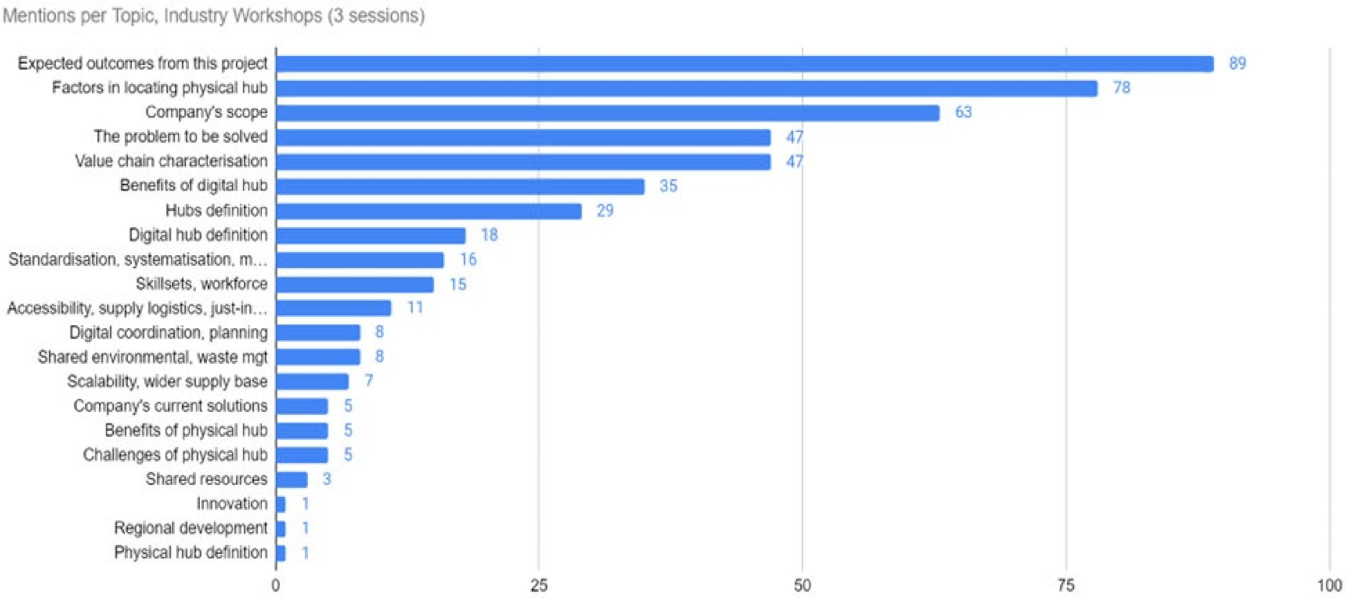

Figure 66. *Mentions per topic, industry workshops (3 sessions).*

Hub location

During the interviews, participants were asked about the criteria for defining the location of a hub. Two criteria were equally mentioned: proximity to the supply chain and accessible transport routes. Skilled workforce was identified as the third criterion, followed by central location and areas with anticipated population growth. Notably, three responses indicated the idea of having multiple hubs around Victoria, potentially in different regions such as West, East, and South, each region coordinating its own hub.

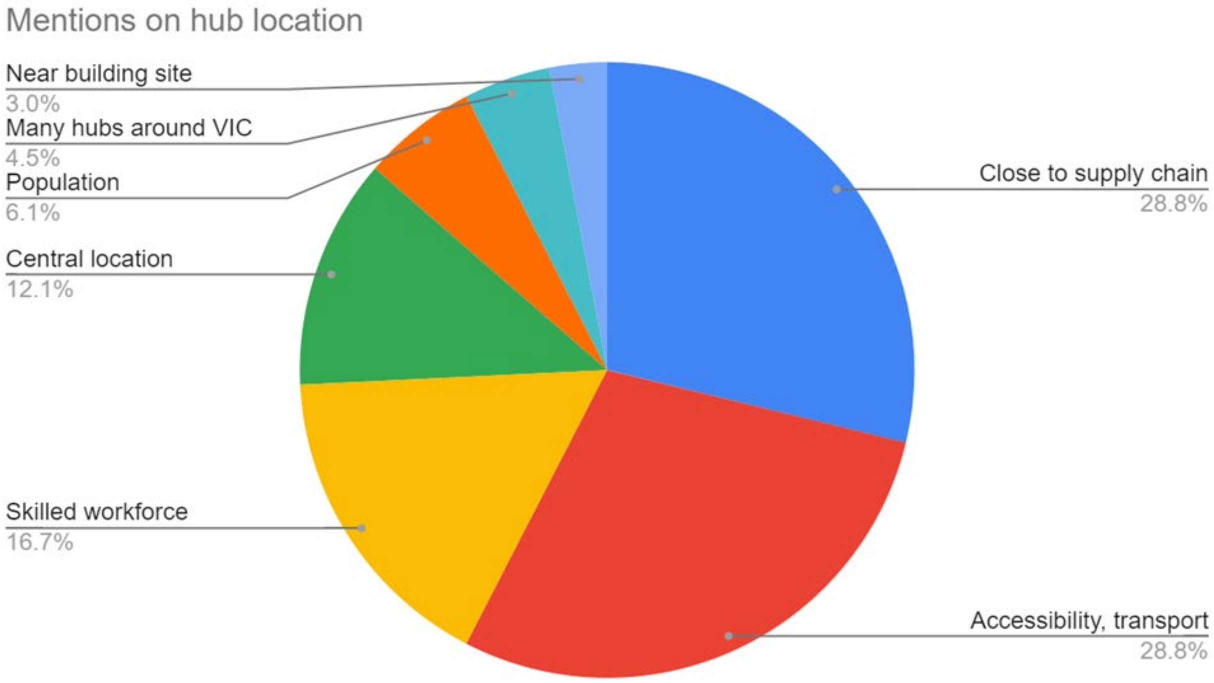

Figure 67. *topics mentioned as the most relevant for the location of a physical hub.*

Expected outcomes of this project

Interviewees' responses concerning the anticipated outcomes of the project mainly centered around value chain coordination (Figure 68). The responses touched on various aspects, including building a wider supply base, enhancing supplier qualification, establishing buffering warehouses near factories, coordinating through logistics companies, shortening supply chains, fostering closer working relationships, and gaining real-time visibility into changes and delays.

Industrial, modular, and standardisation aspects were also frequently mentioned. These topics encompassed concepts such as a product platform approach, reduction in required components and assemblies, transitioning from traditional construction to modular or product platform construction, standardisation, systematisation, creating a shared library of resources, and mapping common procedures. Additionally, opportunities for partnership and knowledge sharing, involving joint ventures and collaboration with suppliers, were highlighted.

Other topics that emerged include quality improvement, skilled workforce attraction, waste and emissions reduction, cost reduction, transport and accessibility enhancement, upskilling, scalability, and reduced design effort.

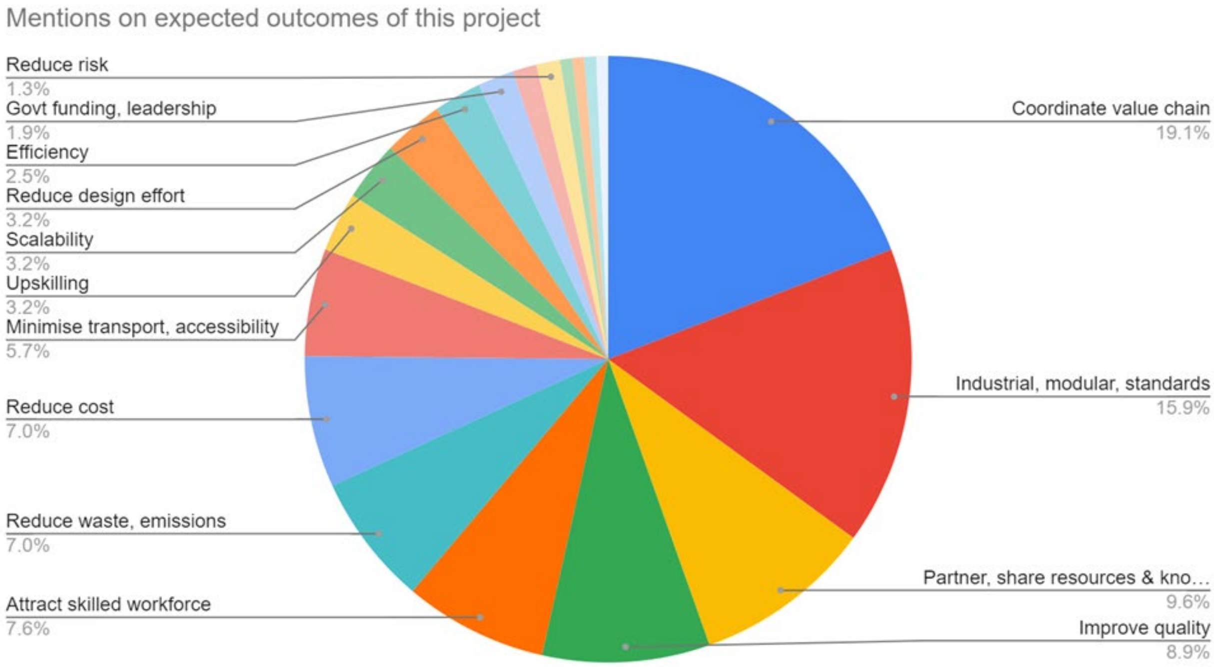

Figure 68. *topics mentioned as the expected outcomes of this project.*

Definition of Industrialised Building

In response to questions about the definition of industrialised building (Figure 69), a range of industrial techniques were mentioned. These included manufacturing thinking, Lean Construction, Just-in-Time delivery, minimising on-site work, production-like approaches, repeatability, modular construction, and product platform concepts.

Standardisation emerged as the second key theme, involving both component and process standardisation. This encompassed design consistency, component integration, reduction in necessary components, modular product platform design, and standardised procedures.

Logistics tracking, closely linked to industrialisation and standardisation, was identified as a third key aspect. This encompassed sub-assembly SKU numbers, naming conventions, complex logistics exercises, and precise naming conventions.

Other topics that surfaced include waste reduction, value chain coordination, meeting quality standards, maximising value addition, improving quality, automation, transport minimisation, and change management.

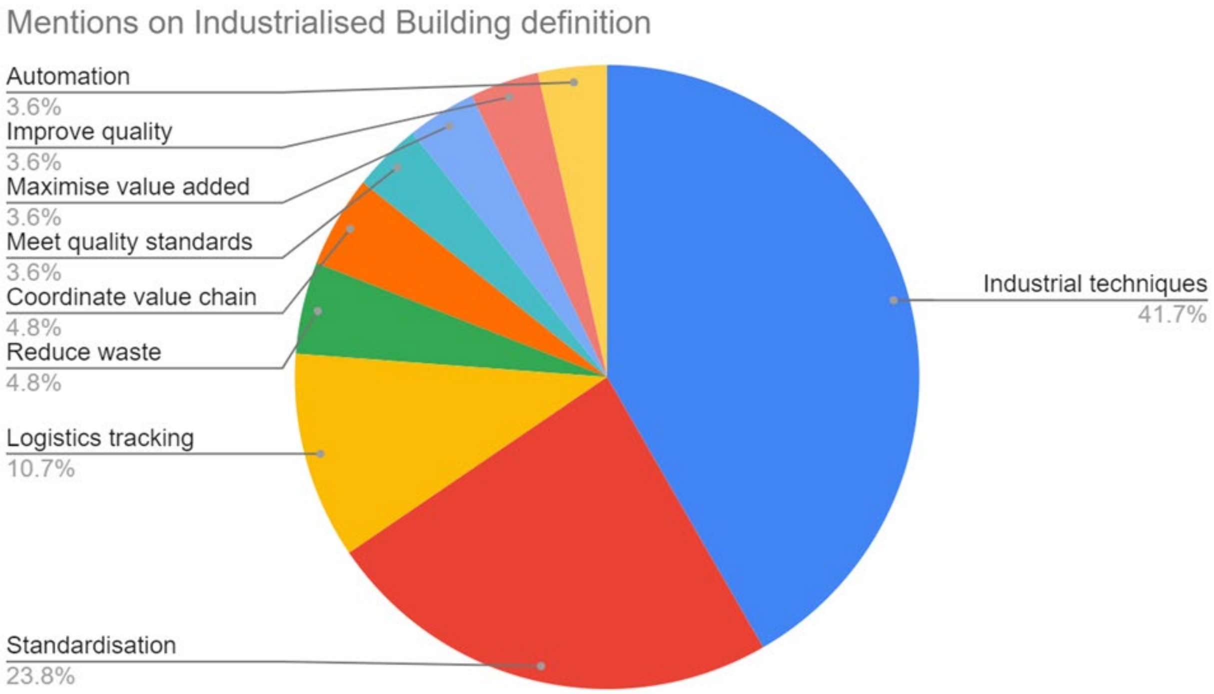

Figure 69. *Mentioned topics on digital hub definition and benefits.*

Definition and benefits of a Digital Hub

The interviewees' perspectives on the definition and benefits of a digital hub (Figure 70) primarily highlighted its role as a marketplace for connecting various market players. This involved categorising suppliers based on capabilities, building contractor networks, bidding for project opportunities, and providing insights into market trends.

The concept of using a digital hub for tracking construction processes, including mapping procedures from project start to finish, was the second most mentioned aspect.

Other points raised include the digital hub as a repository of performance standards met by products and components, a tool for tracking component status and location during manufacturing and logistics, a data analysis platform, a means for networking, forecasting, environmental impact tracking, collaboration, and more.

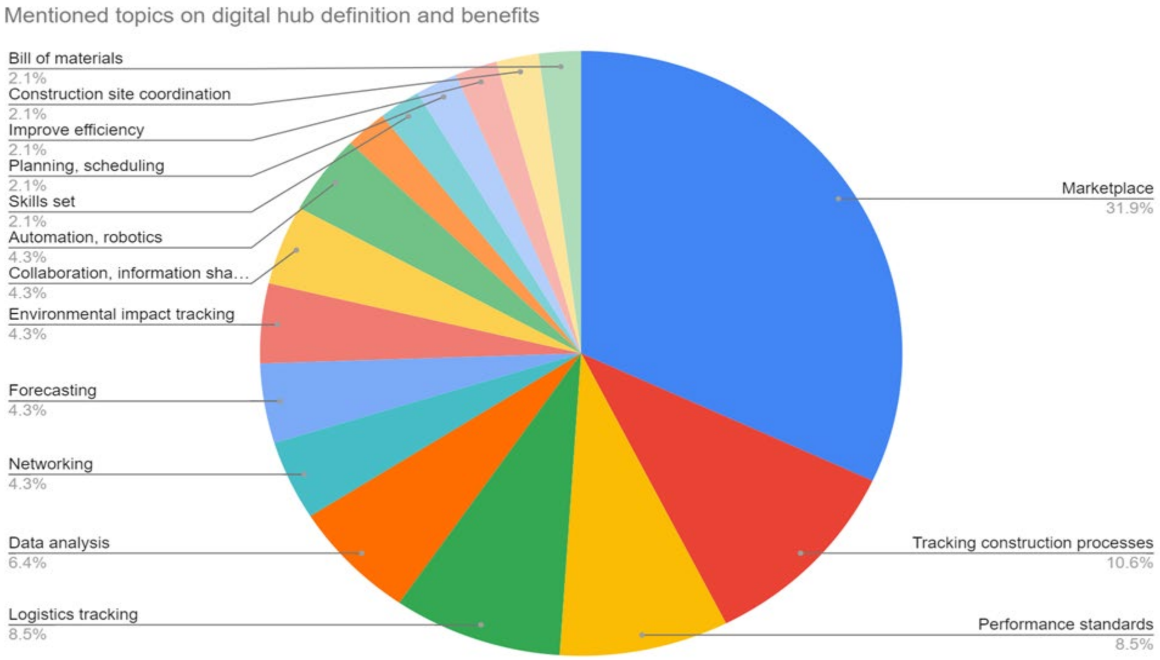

Figure 70. *Mentioned topics on digital hub definition and benefits.*

E_EVIDENCE-BASED EVALUATION OF THE THREE LOCATIONS

Building upon the insights gained from the place study, socio-economic, and interview analyses, the research team has identified sustainability, market dynamics, resources and infrastructure as crucial considerations to assess the readiness of target regions of interest. This section serves as a benchmark of evaluation criteria for identifying the viability of a construction hub within selected regions.

R	READY	Menial targeted development required
P	PARTLY	Some Industrial-wide development required
N. R	NOT READY	Significant overarching and targeted development required

Location 1: Latrobe Valley

Criteria 1: Sustainability

Sub-criteria		**R - 'READY' VALUE**	**P- 'POTENTIAL' VALUE**	**N.R - 'NOT READY' VALUE**	**Evidence Location**	**Spatial and Statistical evidence.**
Social	Available workforce			Workforces decline in most industries.	Figure 6	Mapping: *Existing Workforce Presence 2021.*
	Latent skills			Decline in employment of the area indicates dispersing workforce skills pool. Especially in Traralgon	Figure 9	Mapping: Employment change 2011-*2021.*
	Cost of workforce			Moe & Morwell remain higher employers, hub development may inflate costs in the 'high demand' areas		
	Population density (current and projected population)		Development in Traralgon may stabilise workforce and economic attributes		Figure 2	Mapping: *Population Growth*

	Demographic (age, gender, income)	Age distribution is relatively even. By developing a hub, the population could push towards a more ‘productive’ demographic.			Table 1,2 & 3. Figure 7	Mapping: *Available Workforce (Age) & Individual Incomes*
	Employment		Hub placement can create catalyst for multi-industry growth. Informing linear distribution line		Figure 8	Mapping: *Current Working Status*
Environmental	Pollution			Will create more hydrocarbons? Diesel consumption and requirements for bituminous upkeep.	Figure 10, 11 & 19	Mapping: *Timber Harvesting Allocations & Extractive Areas of Interest*
	Agriculture		Develop existing supply chain lines for agricultural distribution. Infrastructural support could diversify		Figure 9 & 18	Mapping: *Employment Change & Latrobe Industry Strengths 2021*
	Natural resources		Further development of existing extraction and timber industry with potential to expansion		Figure 10, 11 & 19	Mapping: *Timber Harvesting Allocations & Extractive Areas of Interest*
Economic	Cost of workforce		Moe & Morwell remain higher employers, hub development may inflate costs in the ‘high demand’ areas. Rural workforce is highly mobile, around 6,000 people commute from the nearby LGA’s to Latrobe valley for work. That is the region can use labour resources from outside and this would maintain the labour cost on the same level		Figure 6	Mapping: *Existing Workforce Presence 2021.*
	Housing affordability	Small regions of Traralgon can create endemic housing stock areas to substantiate development in more industrialised areas. Housing cost is within the means of majority. The population cohort of owned outright recorded the largest percentage change in Latrobe, showing a 12% increase from 2016.				
	Rental cost	There is a relatively small demand for rental housing as only 23 % of local population live in rental properties	As per the above, strategic investment may mitigate rapid inflation of rentals		Figure 14 & 22	Mapping: RAID *Rental Affordability*
	Energy cost		Recent closures of energy plants.			
	Material cost			Significant closures in the extractive industry, limiting current availability and increasing cost. Governmental limitation on old growth harvesting further limits timber production	Figure 19	Mapping: *Timber Harvesting Allocations & Extractive Areas of Interest*

Criteria 2: Market dynamics

Sub-criteria		**R - 'READY' VALUE 66-99%**	**P- 'POTENTIAL' VALUE 33-66%**	**N.R - 'NOT READY' VALUE 0-33%**	**Evidence Location**	**Spatial and Statistical evidence.**
Supply	Energy costs		Large-scale closures and established infrastructure reduce required capital investment, however significant investment required to establish renewable energy networks is required.		Figure 25	Latrobe Primary Employers and Closures
	Material costs	Strong access to distribution, and proximity to extractive / harvestable raw materials.			Figure 13 & 23	Victorian Highway, Rail freight and ports & Latrobe distribution Network
	Internet		developed infrastructure present, significant improvement of the internet access would require significant development of existing infrastructure		Figure 9	Construction Employment Change 2011-2021
	Land use	Significant opportunity to develop on existing frameworks and infrastructure due to multiple large-scale manufacturing, production closures			Figure 25	Latrobe Primary Employers and Closures
	Construction material providers		Significant allocations of extraction and logging coupes. Governmental restrictions limit logging Old growth activity in the future, however significant extraction and harvesting allocations remain stable		Figure 11, & 19	Victorian timber allocations & Latrobe Valley extractive areas of interest & Timber allocations
	Key industries and manufacturers, industries, prefab companies,	Strong presence of energy production and manufacturing workforce to fuel market growth.			Figure 21 & 25	Moe Morwell & Traralgon industrial zoning. & Latrobe Primary Employers and Closures
	Prefab companies			No significant presence of available prefabrication companies	Figure 25	Latrobe Primary Employers and Closures
	Construction companies		Some clustering of existing businesses with potential capacities as secondary or tertiary positions within a construction hub. These are		Figure 18 & 25	Latrobe Valley industry strengths & Latrobe Primary

			spread throughout Moe, Morwell and Traralgon rather than consolidated within a region			Employers and Closures
	Delivery and distribution centres			No isolated 'distribution hubs' through Latrobe region.		
	Logistics companies and pipeline		Strong linear access in East-West direction through ARTC rail and Highway. Arterial roads connect North and South. Minimal presence of logistics companies		Figure 20 & 23	Latrobe Valley, continual connection & Latrobe Distribution Network
Demand	Target market		direct access to rapidly expanding Melbourne residential market through Dandenong Retail and industrial precinct		Figure 24.	Latrobe to Melbourne
	Hub activity and product		Multiple construction suppliers, struggling workforce employment		Figure 17	Construction suppliers register, VIC.
	Future pipelines	region developmental plans for industrial zoning supports the densification through the Morwell region, highlighting existing workforces.			Latrobe.VicPlan	
	Housing gaps			Moe and Morwell experiencing low levels of affordable housing, Traralgon being the most affordable presents the strongest potential as a housing consolidation potentially minimising displacement	Figure 22 & 18	RAID affordability & Latrobe Region strengths
	Major investments	Transformation of existing infrastructures to renewable green energy production (Multiple battery storage &Wind farms)			Figure 25	Latrobe Primary employers and Closures

Criteria 3: Resources

Sub-criteria		**R - ‘READY’ VALUE 66-99%**	**P- ‘POTENTIAL’ VALUE 33-66%**	**N.R - ‘NOT READY’ VALUE 0-33%**	**Evidence Location**	**Spatial and Statistical evidence.**
Built assets	Serviced and ready sites		Currently there are 21 factory, warehouse & industrial properties for lease in Traralgon & Latrobe City - Greater Area, VIC. This indicates a relatively large supply of suitable properties for construction hubs.		Comm. Real-estate	
	Buildings	Due to the recent closures of multiple energy producing warehouses, timber producers, and the paper mill, multiple opportunities remain available for adaptive reuse.			Figure 25	Latrobe primary employers and closures
	Power infrastructures				Figure 25	Latrobe primary employers and closures
Services	Education centres		Latrobe's highest occupational employer, however remails significantly lower than the national average. Federation University provide the only local opportunity for professional training		Figure 18 & Figure 22	Latrobe Valley Industry Strengths & Education and RAID overlay
			Access to multiple educational institutions for innovative development and research. diversity of training in professional and trades occupations		Figure 22	Education, Commuting & and RAID overlay
			general access to upskilling and further training through both professional ad trades occupations		Figure 22	Education, Commuting & and RAID overlay
	Research centres		Menial development of tech industries, however, tech growth showed consolidation through Morwell and Churchill potentially responding to Federation University and the tech adaptation to renewable energies		Figure 22	Education, Commuting & and RAID overlay
		Opened in 2020 Hi-Tech Precinct Gippsland includes the Morwell Innovation Centre, Gippsland Tech School, and TAFE Gippsland Morwell Campus.			Figure 22	Education, Commuting & and RAID overlay
		Federation University runs Morwell Innovation Centre			Figure 22	Education, Commuting & and RAID overlay
	Trades			Wavering employment accross the board in trades, however a large pool of existing workforce in manufacturing and extraction occupations	Figure 6, 9 & 18	Existing Victorian Employment & Employment change. Latrobe Valley Industry Strengths

			Large amount of raw material and extractive interest areas nominated, however recent government funding and interests have changed that limit the opportunity to continue developing these existing industries		Figure 6, 9 & 18	Existing Victorian Employment & Employment change. Latrobe Valley Industry Strengths
					Figure 6, 9 & 18	Existing Victorian Employment & Employment change. Latrobe Valley Industry Strengths
Materials	Timber		Extremely large harvestable allocations surrounding Latrobe, however recent limitations on native logging restrict economic production of logging within the region. potentially implicating the closures of multiple business in the area already.		Figure 10, 11, 22 & 23	Victorian extractive areas of interest and Timber allocations. & Latrobe Valley Education, commuting & RAID overlay. & Latrobe Valley Distribution network
			Limited access through Moe, Morwell and Traralgon to timber prefabrication businesses. Large presence in adjoining LGA's		Figure 10, 11, 22 & 23	Victorian extractive areas of interest and Timber allocations. & Latrobe Valley Education & RAID overlay. & Latrobe Valley Distribution network
			Regenerative nature of logging remains a better opportunity than extractive quarries, however native logging restrictions limit gross logging capacities throughout Victoria. Regions surrounding Latrobe still provide some of Victorias largest harvesting allotments and pose the smallest carbon implication for transporting the timber from Geelong and Benalla.		Figure 10, 11, 22 & 23	Victorian extractive areas of interest and Timber allocations. & Latrobe Valley Education & RAID overlay. & Latrobe Valley Distribution network
	Steel					
			Multiple sub-assemblies requiring steel elements throughout businesses in Latrobe.		Figure 25	Latrobe Primary employers and Closures
	Concrete			No large precast concrete suppliers within the region.	Figure 20, 21 & 25	Latrobe Valley, Moe, Morwell and Traralgon Industrial Zoning & Latrobe Valley Primary employers and recent closures
			Some batching plants and concrete production within the region, however limited access to diversity of different businesses		Figure 20, 21 & 25	Latrobe Valley, Moe, Morwell and Traralgon Industrial Zoning & Latrobe Valley Primary employers and recent closures
				No significant quarries or areas of extraction outside of energy production (coal mining).	Figure 20, 21 & 25	Latrobe Valley, Moe, Morwell and Traralgon Industrial Zoning & Latrobe

						Valley Primary employers and recent closures

Criteria 4: Infrastructures

Sub-criteria		**R - 'READY' VALUE 66-99%**	**P- 'POTENTIAL' VALUE 33-66%**	**N.R - 'NOT READY' VALUE 0-33%**	**Evidence Location**	**Spatial and Statistical evidence.**
Accessibility	Roads	Princes Highway provides access to Melbourne via Dandenong. linear highway access connection areas far east to Dandenong			Figure 13 & 23	Victorian & Latrobe's Distribution network
	Rails		Linear access along the same route as the Princes highway. No north-south distribution paths limiting access to distribute minerals, and large scale products		Figure 13 & 23	Victorian & Latrobe's Distribution network
	Airports	Latrobe regional airport			Figure 13 & 23	Victorian & Latrobe's Distribution network
	Ports			No Ports	Figure 13 & 23	Victorian & Latrobe's Distribution network
Location	Geography		Large areas of extractive areas of interest within Latrobe and timber allocations surrounding the LGA.		Figure 10,11 & 19	Victorian Natural resources & Latrobe's Natural resource allocations overlay
	Reference points (adjacencies, strategic points)		Muti-nodal regions of densification spread throughout the LGA. Each urban fabric providing a different niche of specialisation reflective of the established workforce.		Figure 18, 24 & 25	Latrobe Valley Region strengths, Latrobe to Melbourne, Latrobe Primary Employers and Closures
			Established ARTC rail through Dandenong provides an opportunity to retail within Melbourne. Highway connectivity spreading from Melbourne to Eastern VIC via the Princes Highway limits accessibility north and south.		Figure 23	Latrobe Valley Distribution network
		Each 'urban node' holds a specialisation in established industrial makeup, expansive industrial zoning with a central planning scheme to develop Morwell's industrial precinct. Strong potentials to develop synergies between each cluster or facilitate further growth between them.			Figure 18, 24 & 25	Latrobe Valley Region strengths, Latrobe to Melbourne, Latrobe Primary Employers and Closures
			GOTAFE and Federation University		Figure 22	Education and RAID overlay
Logistics	transportation		ARTC National access via rail. Latrobe regional Airport and Princes HWY		Figure 23	Latrobe Valley Distribution network
		Multiple points of access through each region of Moe, Morwell or Traralgon. Highway and Rail access remain well established to Melbourne			Figure 18, 23 & 24	Latrobe Valley region strengths, Distribution infrastructure & network
		Rail and highway remains well established and streamlined to			Figure 23	Latrobe Valley distribution network

		Melbourne, Significant improvements North and south may be required to broaden distribution paths				
	workflows	High levels of diversity in the existing employment ecosystem are present. This facilitates a diversity of workflows through the logistical distribution and the subassemblies required to construct elements of prefab construction.			Figure 27 & 38	Timber and concrete subassembly / specialised equipment
			Large scale enterprise and businesses provide a foundation of logistical planning and streamlined workflow organisation. The presence of Multiple regional organisations provides an opportunity to build on a diversity of different workflows and identify a streamlined adaptation to respond o a hub development.		Figure 21 & 25	Latrobe Valley industrial zoning, Primary employers and recent closures
		Communication infrastructure is well established in The northern areas of Latrobe with limited, but rapidly growing workforce throughout the region facilitating businesses to communicate and collaborate seamlessly online.				
			Latrobe hosts a significant body of manufacturing and production infrastructure. Optimisation in waste management systems, workflows and distribution systems can be optimised through these existing industries.		Figure 26	Morwell Industrial and waste facilities
	distributions flows			Rail and road access provides the infrastructure of Latrobe to cost effectively distribute a diversity of large and small scale materials and products to Melbourne. Thus gaining access to national and international distribution facilities. However distributions outside of Melbourne remains significantly limited	Figure 23	Latrobe Valley Distribution network
				Linear East to West rail and road distribution limits the ability for logistical distribution outside of Melbourne. Whilst the infrastructure provides a streamlined method of distribution, limited competing businesses limits the utility of competitive environment.	Figure 24	Latrobe to Melbourne
			Various Warehouse and storage typologies are available around Latrobe. Opportunities to locate within a close		Figure 25 & 26	Latrobe Primary employers and recent closures,

			proximity are spread throughout multiple industrial estates. Planned expansions to industrial zoning may broaden this around Morwell, However land costs around Morwell and Moe may remain a limiting factor due to land costing			Morwell industrial and waste facilities
	delivery flows		Seamless delivery of construction projects can be attained through collaboration of multiple industries and a streamlined production / sub-assembly production lines. Latrobe hosts an extremely strong presence of production infrastructures, businesses and potential growth due to the historical presence of manufacturing, construction and energy production. The delivery of construction projects requires to be delivered in conjunction with these existing infrastructures and account for the significant amount of recent closures within the region.		Figure 18, 27 & 38	Latrobe region strengths Timber and concrete subassembly / specialised equipment
	material flow			Efficient material flows in the context of a Linear hub facilities immediate material exchange and remain less efficient that other spatial organisation such as the 'consolidated hub'. Due to the geographical location Latrobe, ARTC linear access to Melbourne limits the distribution and access of materials significantly.	Figure 19 & 23	Latrobe Natural resources & Distribution network
			Material extraction, refinement and milling requires significant specialised equipment. Latrobe hosts a breadth of sub assembly specialised equipment as well as servicing businesses to continue operations. Sub assembly lines throughout Latrobe support the manufacturing of Timber, steel and concrete elemental construction feeding into larger prefabrication potentials.		Figure 19, 23, 27 & 38	Latrobe Natural resources & Distribution network, Latrobe region strengths Timber and concrete subassembly / specialised equipment

Location 2: Benalla

Criteria 1: Sustainability

Sub-criteria		**R - 'READY' VALUE**	**P- 'POTENTIAL' VALUE**	**N.R - 'NOT READY' VALUE**	**Evidence Location**	**Spatial and Statistical evidence.**
Social	Available workforce	The successful operation of LS Precast shows the local rural workforce is highly mobile and is willing to travel from nearby towns to Benalla			Figure 6	Mapping: *Existing Workforce Presence 2021.*
	Latent skills	Ls precast			Figure 9	Mapping: Employment change 2011- *2021.*

	Cost of workforce		Growth driving up workforce wages. Ramifications in business viability due to labour costs can be implicated.			
	Population density (current and projected population)		Foundational amenities and housing is existing.		Figure 2	Mapping: *Population Growth*
	Demographic (age, gender, income)	Significant employee population of 15-34. Additional growth in this area is likely to cause economic growth without significant alteration in working demographics			Table 1,2 & 3. Figure 7	Mapping: *Available Workforce (Age) & Individual Incomes*
	Employment	The coordination hub would act as a supportive mechanism for existing ind. Potentially interconnected with ls precast			Figure 8	Mapping: *Current Working Status*
Environmental	Pollution			Will create more hydrocarbons? Diesel consumption and requirements for bituminous upkeep.	Figure 10, 11 & 37	Mapping: *Timber Harvesting Allocations & Extractive Areas of Interest*
	Agriculture	A coordination hub may promote further agricultural development as it provides a supporting industry for distribution.			Figure 9 & 30	Mapping: *Employment Change*
	Natural resources			Does not provide significant distribution lines of raw materials through vic.	Figure 10, 11 & 37	Mapping: *Timber Harvesting Allocations & Extractive Areas of Interest*
Economic	Cost of workforce			Small labour pool, inflation of demand could happen relatively easily.	Figure 6	Mapping: *Available Workforce*
	Housing affordability	Demand for rental properties in Benalla is relatively small. The 2021 census shows that only 20 % of local population live in rental properties. By contrast, the relevant figure for Melbourne is 30 %. Limited housing stock, possibility of inflation with minor population increases				
	Rental cost	Housing cost is within the means of majority. The population cohort of rent-free recorded the largest percentage change in Benalla, showing a 19.1% increase from 2016.			Figure 14 & 32	Mapping: RAID *Rental Affordability*
	Energy cost	Local renewable energy supply. Existing infrastructure and plan connection to broader Vic				
	Material cost		Limited access to raw materials may drive a competitive market in accessing them. Whilst concrete is readily available through LS Precast,		Figure 37	Mapping: *Timber Harvesting Allocations*

			timber materials may be bottlenecked due to the lack of plantation allocations in the surrounding region, compounded with recent bans on native logging.			*& Extractive Areas of Interest*

Criteria 2: Market dynamics

Sub-criteria		**R - 'READY' VALUE 66-99%**	**P- 'POTENTIAL' VALUE 33-66%**	**N.R - 'NOT READY' VALUE 0-33%**	**Evidence Location**	**Spatial and Statistical evidence.**
Supply	Energy costs		Significant solar farming presence between Benalla and Glenrowan, Large-scale investment would be required to bolster the existing network and mitigate energy requirements		Glenrowan-solar-farm	
	Material costs		Strong relations to distribution networks and national access. Relatively poor access to extractive and raw materials outside of LS Quarry		Figure 13, & 33	Highway & Rail Freight Lines & Ports
	Internet		developed infrastructure present, significant improvement of the internet infrastructure is required to support a large development of a digital hub		Figure 17	Construction Employment Change
	Land use		No recent closures, however, access to various warehouse typologies and building uses can be established on cheap(er) large plots of land already industrially zoned		Figure 33	Benalla Land Usage
	Construction material providers		Limited access to Natural resources, LS Precast access to quarried stone through subsidiary LS Quarry provides most stable access to raw materials. Thus open to fluctuations outside this market		Figure 34 & 40	Benalla Industrial Large scale warehouse& Benalla Commercial, industrial and Largescale industrial building distribution
	Key industries and manufacturers , industries, prefab companies,	LS Precast / Quarry, Thales Munitions, D&R Henderson			Figure 33, 34 & 36	Benalla Land usage, industrial Large scale warehouse, Region Specialisations
	Prefab companies	LS Precast and D&R Henderson with multiple smaller assembly line companies for elemental fabrication			Figure 33, 34 & 36	Benalla Land usage, industrial Large scale warehouse, Region Specialisations
	Construction companies	Few smaller construction suppliers located around Benalla and surrounding region			Figure 39	Benalla Construction Services
	Delivery and distribution centres	Large distribution hub North of Benalla in Barnawartha North.			Figure 35 & 36	Distributions Infrastructure, Region Specialisations

	Logistics companies and pipeline		All distribution companies are located in surrounding towns of Benalla. Infrastructure is developed to support the efficacy of the surrounding infrastructures.		Figure 36	Region Specialisations
Demand	Target market	Limited current capacity, however potential for further nation growth and continual export of manufactured good.				
	Hub activity and product		Region specialisation in concrete prefabrication. limited opportunity to build on latent construction skillsets outside of this niche.		figure 17, 30 & 36	Construction suppliers register, VIC. Benalla Industry Strengths & Region Specialisations
	Future pipelines		VPA has nominated through the 2019 urban growth strategy to develop residential land and highlight potential areas of 'utilisation'.		Urban-Growth-Strategy-Analysis-Report	
	Housing gaps		Benalla hosts a relatively high amount of 'affordable' housing with large plots of land.		Figure 32	Distribution Methods and RAID affordability overlay
	Major investments		Numerous small - medium scale building and infrastructure developments. Nothing notable. Continued concrete production in LS Precast for the West Gate Tunnel project.		Benalla-concrete-manufacturing	Big Build & Benalla development Plan

Criteria 3: Resources

Sub-criteria		**R - 'READY' VALUE 66-99%**	**P- 'POTENTIAL' VALUE 33-66%**	**N.R - 'NOT READY' VALUE 0-33%**	**Evidence Location**	**Spatial and Statistical evidence.**
Built assets	Serviced and ready sites			Currently there are just 3 Factory, Warehouse & Industrial Properties for Lease in Benalla	industrial-warehouse/	
	Buildings			do not think these are available		
	Power infrastructures			Schneider Electric that is based in Benalla produces transformers for wind farms	clean-energy-infrastructure/	
Services	Education centres		Professionals represent the highest employment occupation of 2021, growing significantly from 2016. However still remains lower that the national average by a large portion. No facilities in Benalla that train professional occupations		Figure 9 & 31	Employment change 2011-2021 & Benalla Student Population & educational facilities.
			Goulburn Ovens Institute of TAFE has a campus in Benalla. however, multiple Tafes are within reach of surrounding cities with tertiary research capacities in Albury / Wodonga		Figure 31	Benalla Student population and facilities

				restricted upskilling and further training through both professional ad trades occupations	Figure 30 & 31	Benalla industry strengths & Benalla Student population and facilities
	Research centres			Menial development of tech industries throughout Benalla. Connectivity to surrounding renewable energy facilities provides a foundation for development of tech advancements	Figure 30 & 31	Benalla industry strengths & Benalla Student population and facilities
	Trades		Benalla has a limited supply of contractors available, however agglomerated with the surrounding regions, the accessibility to a vast pool of trades experts is supported.		Figure 6 & 30	Victorian workforce & Benalla industry strengths
			Growing industry of warehousing and transport in Benalla regional areas, however direct access to ARTC rail and highway provide further input to the existing supply chain		Figure 13 & 31	Highway & Rail freight & Ports Benalla industry strengths
Materials	Timber		Harvestable timber allocations remain on the border of the Southern reaches of Benalla surrounds. limited advantage can be nominated to the timber industry		Figure 10, 11 & 37	Victorian Extractive area of interest, Timber Harvesting allocations & Benalla Resource allocations
			smaller timber construction businesses within the region, with D&R Henderson acting as a keystone timber presence		Figure 10, 11 & 37	Victorian Extractive area of interest, Timber Harvesting allocations & Benalla Resource allocations
			Limited access to the raw material, however due to the presence of D&R Henderson, existing supply chains remain established. This implicated the carbon efficiency of the timber product		Figure 10, 11 & 37	Victorian Extractive area of interest, Timber Harvesting allocations & Benalla Resource allocations
	Steel					
			Menial steel supplier presence outside Delatite steel providers. Importation of products is required however established supply chains can be assumed due to the manufacturing of steel products in Benalla			
	Concrete	Extremely strong Concrete precast presence from quarry extraction through to product delivery.			Figure 33, 34, 40 & 41	Benalla Land usage, Benalla industrial large scale warehouses, Benalla building distribution, LS Precast Spatial Analysis

		All batching, material and product storage and provided onsite of LS Precast.			Figure 33, 34, 40 & 41	Benalla Land usage, Benalla industrial large scale warehouses, Benalla building distribution, LS Precast Spatial Analysis
			LS Quarry being the most significant quarry in the region. smaller tertiary companies acting as supportive capacities.		Figure 33, 34, 40 & 41	Benalla Land usage, Benalla industrial large scale warehouses, Benalla building distribution, LS Precast Spatial Analysis

Criteria 4: Infrastructures

Sub-criteria		**R - ‘READY’ VALUE 66-99%**	**P- ‘POTENTIAL’ VALUE 33-66%**	**N.R - ‘NOT READY’ VALUE 0-33%**	**Evidence Location**	**Spatial and Statistical evidence.**
Accessibility	Roads	Hume Freeway provides access to Melbourne,. Extending north provides access to National distribution routes.			Figure 13 & 35	Victorian & Benalla's Distribution network
	Rails	ARTC rail access connecting to Melbourne and to a national rail distribution network. distribution lines through the Eastern coast via Albury NSW. Additional line more inland via Yarrawonga			Figure 13 & 35	Victorian & Benalla's Distribution network
	Airports	Benalla regional airport			Figure 13 & 35	Victorian & Benalla's Distribution network
	Ports			No Ports	Figure 13 & 35	Victorian & Benalla's Distribution network
Location	Geography		Limited access to both timber and extracted minerals.		Figure 10,11 & 37	Victorian Natural resources & Benalla's natural resource allocations
	Reference points (adjacencies, strategic points)			A small population with consolidated centre In Benalla. Multiple townships surrounding Benalla provide more significant opportunities to service due to the more established population and infrastructure investments.	Figure 33, 34 & 40	Benalla Land usage, industrial Large scale warehouse, Benalla Commercial, industrial, Largescale industrial building typologies
		Immediate access to both ARTC rail and highway networks. Close proximity to an established distribution hub in Barnawartha North that facilitates existing infrastructure and distribution framework.			Figure 35	Benalla distribution Network
			no formalised consolidation of industrial areas, however, existing businesses operate within a collaborative scale.		Figure 35, 40	Benalla Land usage, Benalla commercial, industrial, large-scale industrial warehouse

				GOTAFE is the only education institution in the region.	Figure 31	Benalla student population & education facilities
Logistics	transportation		ARTC National access via rail. Benalla regional Airport and Hume HWY		Figure 35	Distribution infrastructure
		Access to ARTC rail and highway remain high. Land costs and availability provide opportunities to develop a site within proximity to rail and highway simultaneously			Figure 35	Distribution infrastructure
		Benalla distribution paths are streamlined with the established infrastructure. As was he case with LS Precast, adaptations to the rail may be a viable option to create direct access to the ARTC national rail.			Figure 35	Distribution infrastructure
	workflows		Construction Hub workflows have been streamlined and established in prefabricated concrete elements. These workflows can provide a baseline for further development		Figure 27 & 38	Timber and concrete subassembly / specialised equipment
			Large scale enterprise and businesses provide a foundation of logistical planning and streamlined workflow organisation. The presence of LS Precast and LS Quarry indicates potential growth on existing workflows.		Figure 33	Benalla Land usage
		Communication infrastructure is well established in Benalla township, with limited workforce and infrastructure in the surrounding region facilitating businesses to communicate and collaborate seamlessly online.			Figure 30	Benalla Industry Strengths
			Benalla hosts a significant body of industry facilitating a 'nose to tail' production in concrete production line having the capacity for continual improvement in waste management systems, workflows and distribution systems		Figure 33 & 37	Benalla land usage, Benalla resource allocations
	distributions flows		Rail and road access provides the infrastructure of Benalla to cost effectively distribute a diversity of large and small scale materials and products nationally.		Figure 35	Distribution infrastructure
			Barnawartha North's logistics hub provides national distribution workflows. Whilst the infrastructure provides a streamlined method of distribution, limited competing businesses limits the utility of competitive environment.		Figure 36	Region Specialisations
		Various Warehouse and storage typologies are available around Benalla. Opportunities to locate within a close proximity and distribution lines remains highly accessible			Figure 33 & 34	Benalla land usage & Benalla industrial large scale warehouse
	delivery flows	Seamless delivery of construction projects can be attained through collaboration of multiple industries and a streamlined production / sub-assembly production line. Benalla has monopolised these infrastructures to develop			Figure 36	Region specialisations

		concrete prefabrication, requiring an intrinsic connection between a successful construction hub and the existing concrete industry				
	material flow		Efficient material flows in the context of a de-centralised hub facilities higher distribution of knowledge exchange whilst material flows remain less efficient that another spatial organisation such as the 'consolidated hub'. Due to the geographical location Benalla, these distances cannot be further optimised, however the existing infrastructure remains very well interconnected through ARTC		Figure 13, 30 & 35	Highway and freight lines, Benalla Industry strengths, Distribution Infrastructure
			Material extraction, refinement and milling requires significant specialised equipment. Benalla hosts a breadth of sub assembly specialised equipment as well as servicing businesses to continue operations. Sub assembly lines throughout Benalla support both timber and concrete prefabrication.		Figure 27 & 38	Timber and concrete subassembly / specialised equipment

Location 3: Geelong

Criteria 1: Sustainability

Sub-criteria		**R - 'READY' VALUE**	**P- 'POTENTIAL' VALUE**	**N.R - 'NOT READY' VALUE**	**Evidence Location**	**Spatial and Statistical evidence.**
Social	Available workforce	Significant local workforce across all industries. Change in employment indicates transfer of skills between regions			Figure 6	Mapping: *Existing Workforce Presence 2021.*
	Latent skills	Strong historical base of multi-industry development. Vast site closures provide potential developments with existing infrastructure (some sites have been demolished however)			Figure 9	Mapping: Employment change 2011-*2021.*
	Cost of workforce		Further workforce demand could significantly increase workforce wages (this can be offset by growing supply of labour in Geelong)			
	Population density (current and projected population)		Development of regional areas may mitigate the increase of high-density pop, - still the growth of population in greater Geelong has been much higher than in neighbouring rural areas		Figure 2	Mapping: *Population Growth 2001-2021*
	Demographic (age, gender, income)		Workforce majority in 15-34. Menial alteration to existing demographics to shift social values.		Table 1,2 & 3. Figure 5	Mapping: *Available Workforce (Age) & Individual Income brackets*
	Employment	Geelong has had low unemployment levels in the past ten years. In part, that is because many displaced manufacturing workers have found employment in new industries. Potential reinstatement of old sites to facilitate further growth in maturing industries. Working populations are distributed heavily towards fulltime or looking for fulltime employment			Figure 8 & 7	Mapping: *Current Working Status 2021 & Individual Income Brackets 2021*
Environmental	Protection overlay			Construction mechanisms have been dependant on importing timber for sustainable construction materials. Opportunity to transition to sustainable building materials requires significant import from outside of the LGA	Figure 10, 11,12 & 45	Mapping: *Extractive Areas of Interest, Avg Wind speeds, distribution infrastructure*
	Agriculture			Contesting of agricultural land may arise as the construction and agricultural industries have rapidly developed in similar	Figure 9 & 42	Mapping: *Employment*

				statistical areas. Potentially reinforcing demand for agricultural land.		*Change & Industry Strengths*
	Natural resources			Large areas of extractive interest. Mineral and stone natural resources as a supply for concrete technologies. As local resources surround the extraction of minerals and stone, sustainable practices remain rudimentary	Figure 10, 11 & 45	Mapping: *Timber Harvesting Allocations & Extractive Areas of Interest*
Economic	Cost of workforce		As mentioned above a general growth of labour supply and a general growth in labour demand can balance each other so that the cost of labour would stay the same in the Geelong area.		Figure 6	Mapping: *Existing Workforce Presence 2021.*
	Housing affordability		As mentioned above a general growth of labour supply and a general growth in labour demand can balance each other so that the cost of labour would stay the same in the Geelong area.			
	Rental cost		Actually, demand for rental properties in Geelong is smaller than in Melbourne. In Geelong home ownership rate is higher than in Melbourne (33 % and 28 %, respectively, as the 2016 and 2021 censuses show). Actually, demand for rental properties in Geelong is smaller than in Melbourne. In Geelong home ownership rate is higher than in Melbourne (33 % and 28 %, respectively, as the 2016 and 2021 censuses show). There is also a substantial absolute increase in the number of fully owned and mortgaged properties in Geelong between 2016 and 2021. This evidence suggests that overall housing affordability is not a major problem for Geelong.		Figure 14 & 45	Mapping: RAID *Rental Affordability*
	Energy cost	Low cost energy consumption - viva energy runs Geelong refinery which supplies 50 percent of Victoria's fuel needs. The company plans to establish Geelong energy hub that would include a gas terminal and a solar energy farm.				
	Material cost		Significant extractive industries mitigate transportation costs for concrete. However, steel requires national or international import and timber import from other regions implication distribution costs		Figure 10,11	Mapping: *Timber Harvesting Allocations & Extractive Areas of Interest*

Criteria 2: Market dynamics

Sub-criteria		**R - ‘READY’ VALUE 66-99%**	**P- ‘POTENTIAL’ VALUE 33-66%**	**N.R - ‘NOT READY’ VALUE 0-33%**	**Evidence Location**	**Spatial and Statistical evidence.**
Supply	Energy costs		Significant existing interest into developing wind farms in Gloden Plains. This interest indicates long term governmental production and allocations that may assist in mitigating inflation of energy costs		golden-plains-wind-farm	
	Material costs		Poor direct access to raw materials. Geelong port, airport, rail freight and highway mitigate potential accessibility issues to multiple materials that drives up costs however, bottlenecks in sourcing is still subject. Bottlenecks are unlike to take place due to developed transport infrastructure: Geelong port is the Australia’s six largest port. Pacific National runs a large North Geelong yard. The Western Interstate Freight Terminal at the cost of 1.5 billion is proposed to be built in the close proximity to Geelong.		Figure 13, & 33	Highway & Rail Freight Lines & Ports
	Internet	Well established infrastructure, increasing tech industries and development of access to the web			Figure 9	Employment change 2011-*2021.*
	Land use	Already in place due to industrial development in the past			Figure 43, 46, 47, & 48	Geelong Industrial land Usage, Geelong Primary Employers, Victorian Construction services, Existing Steel and concrete manufacturing
	Construction material providers		Limited direct access to natural resources. Importing of various materials would be required		Figure 17	Construction suppliers register, VIC.
	Key industries and manufacturers, industries, prefab companies,	G21 Geelong Region Alliance, In collaboration with construction business the City of Greater Geelong leads Regional Industry Sector Employment program that connects job seekers with construction industry employment opportunities.				
	Prefab companies	Significant clustering of timber and concrete prefab companies throughout Corio, Lara and Moolap			Figure 42	Industrial makeup of Inner suburbs of Geelong
	Construction companies	Presence of existing companies with potential capacities as secondary or tertiary positions within a construction hub. These are spread			Figure 17	Construction suppliers register, VIC.

		throughout multiple industrial estates of Corio, Lara and Moolap				
	Delivery and distribution centres	Large scale distributors presenting as primary logistics				
	Logistics companies and pipeline	Geelong Port, Potential re-opening of Point Henry, Geelong access to National ARTC railway and highway, multiple airport availability distribution			Figure 45	Distribution Network & Extractive areas of interest overlay
Demand	Target market	there is a large local residential market, which will expand in the future	direct access to rapidly expanding Melbourne residential market		Figure 1 & 2	Victorian Regions population Densities & Population Growth 2001-2021
	Hub activity and product	Broad range of prefabricated products with variety of construction suppliers to carry out skilled work			Figure 17	Construction suppliers register, VIC.
	Future pipelines	High proportions of industrial and residential development in future pipeline. combined with other building types, 19.9 B investment			geelongdataexchange	
	Housing gaps			Highly unaffordable, pockets of 'more-affordable' housing existing in peripheries of Geelong however strong emphasis on individual displacement will need to be integrated to decision framework	Figure 3 & 14	Comparative overlay of construction employment & RAID Rental affordability. & Victorian RAID affordability
	Major investments	157 local projects with the total value of 16.2 billion have been already proposed, approved or commenced.			geelongdataexchange	

Criteria 3: Resources

Sub-criteria		**R - 'READY' VALUE 66-99%**	**P- 'POTENTIAL' VALUE 33-66%**	**N.R - 'NOT READY' VALUE 0-33%**	**Evidence Location**	**Spatial and Statistical evidence.**
Built assets	Serviced and ready sites		Currently there are 38 Factory, Warehouse & Industrial Properties for Lease in Geelong, VIC 3220 (commercialrealestate.com.au). This indicates a relatively large supply of suitable properties for construction hubs.		industrial-warehouse/	

	Buildings	A Geelong modular building company - Cross Laminated Offsite Solutions (CLOS) currently relocating in 2023 into a 20,000sqm space at the iconic Ford factory			CLOS building	
	Power infrastructures	The historic former Ford Motors factory was re-established as a manufacturing hub as Danish energy giant Vestas recently commenced building wind turbines on the site			renewable-energy-hub-opens-in-Geelong/	
Services	Education centres	High presence of skilled workforce in multiple areas of professional employment. Established workforce also growing throughout Geelong in a diverse range of occupations			Figure 6, 9 & 42	Existing Workforce presence 2021, Employment change 2011-2021, & Geelong Industry Strengths
		Well established presence of educational facilities for further innovation on both 'research' and construction. Multiple institutions provide a significant body of innovative potential			Figure 16	Geelong Student Population and Educational institutions
		Vast array of upskilling and further training through both professional and trades occupations			Figure 16	Geelong Student Population and Educational institutions
	Research centres	Large variety of businesses that can develop elements of construction technology				
		Geelong hosts a few research centres: Deakin's manufacturing innovation incubator Manufactures; Institute for Intelligent Systems Research and Innovation, and Carbon Nexus			Figure 16	Geelong Student Population and Educational institutions
		See the entry above			Figure 16	Geelong Student Population and Educational institutions
	Trades	Geelong has readily available trades workforce. Contractors and trade specialists			Figure 17, 42 & 46	Construction suppliers and Industry strengths, & Geelong Primary Employers and Closures
		Significant body & growth of existing workforce across multiple occupations with easy access to the distribution ARTC railway.			Figure 42 & 45	Geelong Industry Strengths & Distribution Network
Materials	Timber			All availability to timber markets requires imported materials. Timber materials are often imported internationally or from other regions of VIC	Figure 11	Timber harvesting allocations
		Significant infrastructures and businesses set up for timber prefabrication			Figure 11	Timber harvesting allocations
				The import of timber undermines a lot of the renewable and regenerative	Figure 11	Timber harvesting allocations

				factors of timbers carbon footprint due to the required transport.		
	Steel					
		Steel retailers 'salt & pepper' distribution throughout the industrial regions of Geelong. Material requiring to imported internationally and interstate.			Figure 48	Existing Steel and Concrete Manufacturing (Moolap)
	Concrete	Multiple Precast concrete specialists spread throughout industrial regions of Geelong.			Figure 45, 48 & 49	Geelong Primary employers and Closures, Existing Steel & Concrete manufacturing, Industrial makeup of inner Geelong suburbs
		Batching plants and other concrete 'producers' spread throughout the Geelong region. This provides additional material supply to precast businesses.			Figure 45, 48 & 49	Geelong Primary employers and Closures, Existing Steel & Concrete manufacturing, Industrial makeup of inner Geelong suburbs
		Large-scale and long-established quarries throughout the Greater Geelong LGA. licences and mining tenements continuing to growth in number			Figure 45, 48 & 49	Geelong Primary employers and Closures, Existing Steel & Concrete manufacturing, Industry makeup of inner Geelong suburbs

Criteria 4: Infrastructure

Sub-criteria		**R - 'READY' VALUE 66-99%**	**P- 'POTENTIAL' VALUE 33-66%**	**N.R - 'NOT READY' VALUE 0-33%**	**Evidence Location**	**Spatial and Statistical evidence.**
Accessibility	Roads	Immediate access to arterial roads and national highways.			Figure 13 & 45	Victorian & Geelong's Distribution Network, Extractive areas of interest & RAID
	Rails	ARTC access through central and North Geelong. limited access to South Geelong restricting National rail network access.			Figure 13 & 45	Victorian & Geelong's Distribution Network, Extractive areas of interest & RAID
	Airports	Avalon airport provides national air connectivity			Figure 13 & 45	Victorian & Geelong's Distribution Network, Extractive areas of interest & RAID
	Ports	Geelong Port providing international import/export distribution flows.			Figure 13 & 45	Victorian & Geelong's Distribution Network,

						Extractive areas of interest & RAID
Location	Geography		Significant areas of extractive areas of interest, potentially limited capabilities to harness these regions fully. Timber harvesting is not present.		Figure 10,11 & 45	Victorian Natural resources & Geelong's Distribution Network, Extractive areas of interest & RAID
	Reference points (adjacencies, strategic points)	Geelong city s a primary economic central point within the LGA. Additional smaller nodes of urban densification are recognised surrounding the LGA			Figure 1, 13 & 43	Victorian Regions & population densities, Victorian Rail & Freight, Geelong Industrial Land usage
		South Geelong lacks connectivity to the ARTC National rail, Arterial highways splay throughout greater Geelong acting as the primary connections. Geelong port provides a significant economic node of distribution and opportunity to distribute resources and products.			Figure 13 & 43 & 45	Victorian Freight, Geelong Industrial Land use, Geelong distribution networks
		Multiple different industrial ecosystems composing of a different combination of industrial businesses makeup up Geelong.			Figure 42, 46 & 49	Geelong Industry Strengths, Geelong Primary employers, Industrial Makeup of inner Geelong
		Multiple TAFE's, Deakin University			Figure 42 & 45	Geelong Industry Strengths, Geelong Primary employers
Logistics	transportation	Arterial roads connecting to broader regions, ARTC rail 1 hour transit from Melbourne CBD, Avalon Airports			Figure 13 & 42	Victorian and Geelong Distribution Networks
			Whilst distribution lines are available, proximity to them is costly, and scarce. obtaining a site adjoining either highways, port, airport or national rail remains to be a significant hurdle to overcome. however, the infrastructure is present and very well connected to a broad ecosystem		Figure 13 & 42	Victorian and Geelong Distribution Networks
			Existing infrastructure is streamlined. Access to Highway, rail, port and airports is significantly limited in the southern regions of Geelong.		Figure 13 & 42	Victorian and Geelong Distribution Networks
	workflows	High levels of diversity in the existing employment ecosystem are present. This facilitates a diversity of workflows through the logistical distribution and the subassemblies required to construct elements of prefab construction.			Figure 27 & 38	Timber and concrete subassembly / specialised equipment
		Large scale enterprise and businesses provide a foundation of logistical planning and streamlined workflow organisation. The presence of National business such as Fleetwood, BlueScope, Lysaght (and others) indicates the presence of business that can operate in these capacities.			Figure 45	Geelong Primary employers and closures
		Communication infrastructure and workforce are spread throughout Geelong. Due to established Communication infrastructure and ability to continually develop them in future, immediate correspondence and collaboration can be established throughout Greater Geelong.				
		Geelong hosts a significant body of industry facilitating a 'nose to tail' production line having the capacity for continual improvement in waste management systems, workflows and distribution systems			Figure 6, 42, 47	Existing Workforce presence, Geelong Industry strengths, Geelong Construction Services
	distributions flows	Rail, Road, Port and airports in Geelong situate Geelong as one of the most accessible regions in Victoria. The diversity of distribution			Figure 13 & 45	Victorian & Geelong's Distribution network

		methods facilitates cost effective material distribution nationally and internationally.				
		Logistics hubs with significant distribution assets in Port, Rail and Road permeate Geelong and the surrounding industrial regions. Optimised distribution flows with a diversity of logistics companies to undertake the work provide competitive environment to continue the most cost effective and efficient system.			Figure 13 & 45	Victorian & Geelong's Distribution network
		Various Warehouse and storage typologies are available around Geelong. Opportunities to locate within a close proximity are spread throughout multiple industrial estates. however, access may be limited to excessively high land costs			Figure 49	Industrial Makeup of Geelong Inner suburbs
	delivery flows	Seamless delivery of construction projects can be attained through collaboration of multiple industries and a streamlined production / sub-assembly production line. Geelong hosts all of these infrastructures, businesses and potential growth due to the diversity of the construction and manufacturing industry within Greater Geelong.			Figure 42, 45	Distribution Network and Extractive areas of interest overlay, Geelong Primary employers, Industrial Makeup of inner Geelong
	material flow	Efficient material flows in the context of a consolidated hub provide a cost-effective spatial organisation of exchange. Short or direct exchanges of material provides high productivity and material management.			Figure 13, 42 & 45	Victorian Freight network, Geelong Industry Strengths & Geelong distribution network
		Material extraction, refinement and milling requires significant specialised equipment. Geelong hosts a breadth of sub assembly specialised equipment as well as servicing businesses to continue operations. Sub assembly lines throughout Geelong support steel, timber and concrete fabrication with endemic consolidations of each in different industrial zones.			Figure 27 & 38	Timber and concrete subassembly / specialised equipment

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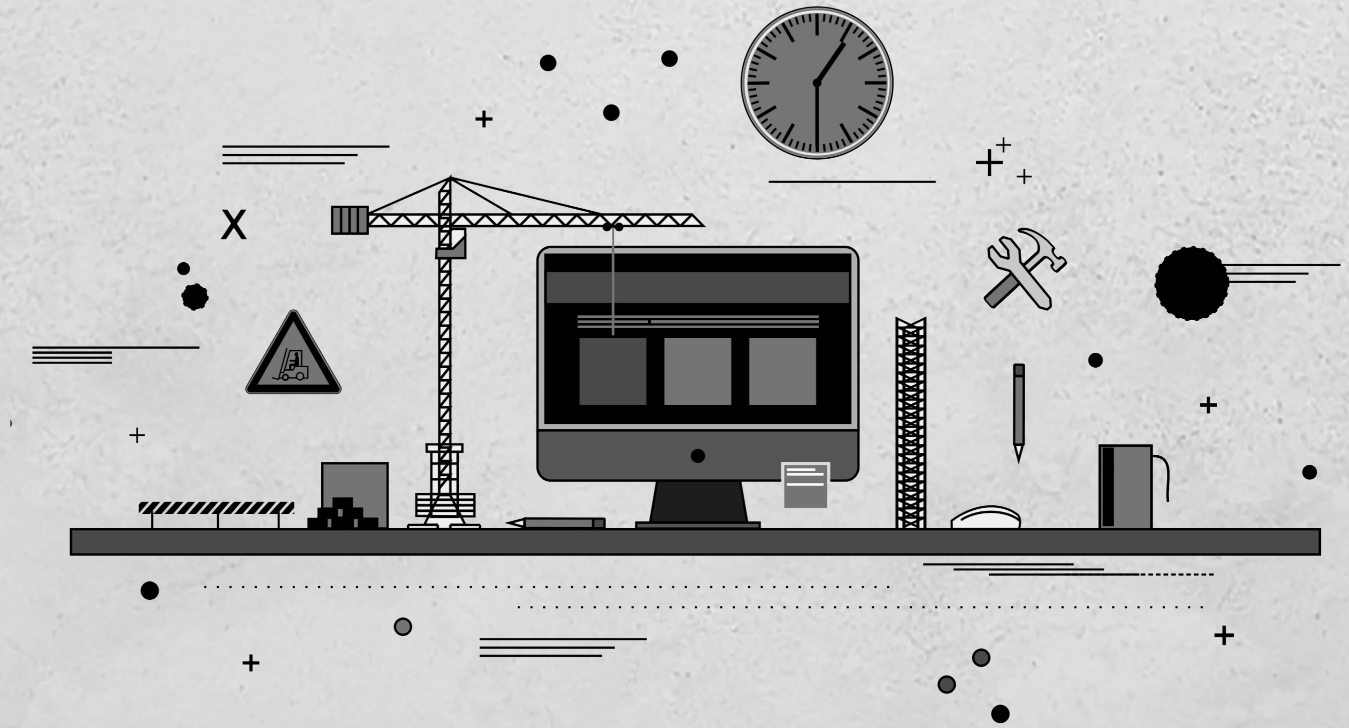
PROJECT #38.2
BENEFITS OF DIGITAL BUILD AND CONNECTED DATA

FINAL REPORT



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ABBREVIATIONS

ACC	Autodesk Construction Cloud (Fleetwood)
ACF	Asset Classification Framework – to be defined in the contract (recommendation 2.3 in the new legal provisions for digital assets, August 2022)
ACIM	Asset Condition and Investment Modelling
AIM	Asset Information Model. Takes place during the operational phase of the project. AIM includes relevant data and information generated from as-built PIM which is integrated with other asset-management tools and systems. The contents of the AIM are specified by the AIR. The AIM is used daily by the organisation's operators, asset managers, end users and facility managers.
AIR	Asset Information Requirements AIR typically includes asset register; data schemas/standards; confirmation of how many information fields is required as a minimum in the asset register; costs associated with each item; whether a parent and child breakdown are required; managerial information; financial information; commercial information; technical information and legal information. Appendix 2: AIR template.
AM	Asset Management
AMAF	Asset Management Accountability Framework (aligns with VDAS)
AMCA	Air Conditioning and Mechanical Contractors' Association
API	Application Programming Interface
B&C	Building & Construction
BAU	Business as usual
BCA	Building Code Australia
BCF	BIM Collaboration Format
BIM	Building Information Modelling
BMS	Building Management System --A building management system (BMS) provides automated control of energy efficiency and occupant comfort from a single digital interface (def from https://www.energy.gov.au/business/equipment-and-technology-guides/building-management-systems)
bSDD	buildingSMART Data Dictionary
CAD	Computer Aided Design
CO	Construct Only
CAPEX	Capital Expenditure

CDE	Common Data Environment (all information systems need to communicate with each other in a structured way) CDE is at the core of the delivery process, ensuring that the production of information is managed and exchanged in a consistent manner. The collection of systems and technologies that service an organisation and its user groups is called the operational CDE. (VDAS part B page 63
CMMS	Computerised Maintenance Management System
CRM	Customer Relationship Management
CTO	Chief Technology Officer
D&B	Design and Build
D&C	Design and Construction
DAM	Digital Asset Management
DCS	Distributed Control System
DDoS	Distributed Denial-of-Service is a malicious attempt to disrupt normal traffic to a web property
DE	Digital Engineering
DEEP	Digital Engineering Execution Plan (Appendix 6 DEEP template)
DEER	Digital Engineering Evaluation and Response
DELWP	Department of Environment, Land, Water and Planning
DfMA	Design for Manufacture and Assembly
DMSF	Decision Making Support Framework
DT	Digital Twins are realistic digital representations of physical things. They unlock value by enabling improved insights that support better decisions, leading to better outcomes in the physical world (From Gemini Principles p. 6)
DTF	Department of Treasury and Finance
EIR	Exchange Information Requirements (also known as employer information requirements or client information requirements) example appendix 5
EMS	Enterprise Management System (Fleetwood)
EPD	Environmental Product Declaration
ERP	Enterprise Resource Planning (Fleetwood)
ESD	Environmentally Sustainable Design

FM	Facilities Management
FP	Fire Protection
GIS	Geographical Information System
HVAC	Heating, ventilation, and air conditioning
IAQ	Indoor Air Quality
ICT	Information & Communications Technology
IFC	Industry Foundation Classes (open data format—supports interoperability)
IM	Information Model
GWR	Gateway Review Process
HVAC	The Heating, Ventilation and Air Conditioning (HVAC) Centre of Excellence
KDP	Key Delivery Points
LOD	Level of Development
LXRP	Level Crossing Removal Project (LXRP)
MEP	Mechanical engineering & plumbing
MIDP	Master Information Delivery Plan
MM	Maintenance managed item is an asset or component that exists generally at the lowest level in the asset hierarchy
NATSPEC	National Building Specification
NEIC	Fishermans Bend National Employment and Innovation Cluster
O&M	Operations & Maintenance
OCC	Onsite Construction
OIR	Organisational Information Requirements
OPEX	Operational Expenditure
OPV	Office of Projects Victoria (established the Digital Build Program in 2020 to implement the VDAS Guidance and Offsite Construction methods for Victorian Government infrastructure projects).
OSC	Offsite Construction
P3D	Project Development & Due Diligence Guidelines (covers 75 separate technical project ‘elements’, including information management plan, digital engineering and information requirements)

PACF	Prescribed Asset Classification Framework
PH	Passive House
PIM	Project Information Model also known as relationship map (covering all types of file formats, from simple text and spreadsheet files to more complex drawing and geospatial vector data formats). Takes place during the delivery phase of the project.
PIR	Project Information Requirements
PLQ	Plain Language Questions (example in Appendix 3)
PLM	Project Lifecycle Management (Fleetwood)
POE	Post-Occupancy Evaluations
PPA	Post Project Aftercare
PPP	Public Private Partnership
RACI	Responsible, Accountable, Consulted and Informed (checklist)
RC	Reinforced Concrete
TEI	Total Estimated Investment
TIDP	Task Information Delivery Plan
UFAD	Underfloor Air Distribution
VBIS	Victorian Government's Virtual Building Information System VBIS is freely available and system-agnostic standards. It provides a means to classify asset data. It integrates data sources across systems to provide a balanced asset view. Data includes equipment, asset registers, operation and maintenance procedures, technical data sheets, schedules of equipment, briefs, specifications, reports, commissioning, warranty information and real-time performance data.
VDAS	Victorian Digital Asset Strategy (lifecycle has 7 stages p. B.24)
VDC	Virtual Design & Construction
VGLS	Victorian Government Library Service opv.vic.gov.au
VMIA	Victorian Managed Insurance Authority (VMIA)
VPS	Victorian Public Service http://www.vic.gov.au/information-managementwhole-
VRV	Variable Refrigerant Volume
WBTD	Woodside Building for Technology and Design

EXECUTIVE SUMMARY

Sub-project 38.2 aims to create pathways for Victoria's digital transition by developing a systematic understanding of the benefits of integrated project data management.

The project has critically examined the existing digital models of building projects to register the industry challenges while capturing, identifying, and mapping the broader benefits of digital build through a socio-technical approach. The socio-technical investigation facilitates a more enhanced industry-government communication/collaboration to increase the adoption of digital build while supporting the wider community, innovations and productivity, and environmentally and socially sustainable outcomes.

The investigation, which involved a survey, interviews and analysis of case studies, identified both operational and systemic challenges associated with the take-up digital build and connected data. The integrative examination of digital build case studies, organisational processes and contexts, and stakeholder knowledge and inputs has led to the identification of digital build tools adopted in building projects, as well as a register of benefits that can encourage higher levels of take-up by industry and inform government investments.

Key Findings

- Digital Tools & Processes: BIM tools are increasingly used for various aspects of construction projects, notably in coordination, conflict resolution, and sequence optimisation. Mechanical, Electrical and Plumbing (MEP) and Fire Protection (FP) systems are often complex, and digital tools offer significant time and cost benefits in these areas.
- Integration and Standardisation: While BIM tools are gaining traction, their integration with CDEs is limited. Achieving broader benefits, such as effective knowledge sharing and supply chain integration, requires more comprehensive digital adoption at the organisational level, supported by industry-wide standardisation.
- Stakeholder Insights: The stakeholder survey indicated that simplifying the Victorian Digital Asset Strategy (VDAS) could facilitate wider adoption. The study also recommends benchmarking digital build against traditional methods to make a strong case for investment.
- Project-Specific Factors: Case studies, such as WBTD and Cowwarr Primary School, demonstrated that the efficacy of digital build is influenced by various project-specific factors including objectives, funding, and stakeholder groups.
- Future Focus Areas: Based on the case studies and stakeholder inputs, the study identifies key areas where government and industry should focus their investments to accelerate the adoption of digital technologies.

Evidence-Based Quantified Benefits

Following thorough analyses of multiple case studies focused on the viability of digital build and connected data environments, significant quantified benefits have been observed. These benefits are particularly notable in the complex sectors of Mechanical, Electrical, and Plumbing (MEP), where advanced coordination and conflict resolution methods were implemented.

- Use of Integrated Data Environments can expedite project completion by up to 4 months (as evidenced in the Woodside Building for Technology Design case study, Table 8)
- A total of 483 issues were identified prior to construction of the Shanghai Disaster Recovery Centre, as opposed to 131 during construction, illustrating the preventive capabilities of CDEs (Table 13).

- Only 2 RFIs were recorded as opposed to 200-300 in similar scale projects, reducing administrative overhead (as evidenced in the Healthcare Project in California, USA project, Table 22).
- Construction time was reduced by 65 days for the Shanghai Disaster Recovery Centre (Table 23), which could significantly decrease the project's carbon footprint.
- Overall cost savings of 2.91% were recorded in the Mechanical, Electrical, and Plumbing (MEP) trades for the Shanghai Disaster Recovery Centre (Table 23).
- Reduced rework resulted in cost savings of $50,000 for the United School District in Los Angeles project (Table 17).
- Shortened construction duration saved an additional $10,000 for the United School District in Los Angeles project (Table 17).
- Visualisation of the complex underground electrical system led to cost savings of $250,000 for the United School District in Los Angeles project (Table 17).
- Savings due to sequencing and conflict checking in MEP/FP systems resulted in $4 million for the United School District in Los Angeles project (Table 23).
- A notable reduction in injuries with only one recordable injury in 203,448 work hours for the Healthcare Project in California, USA project, Table 22).

Key Recommendations

Digital Leadership

- Sponsor certified training programmes for construction professionals to enhance their digital skills, leveraging partnerships with educational institutions and industry bodies.
- Initiate pilot projects that not only assess the Victorian Digital Asset Strategy (VDAS) but also demonstrate the practical benefits of digitalisation in construction.
- Collaborate with industry stakeholders to formulate digital transformation roadmaps and guidelines, providing a comprehensive pathway for industry transition.

Integrated Data

- Emphasise the use of Common Data Environments (CDEs), establishing best practices for effective data collaboration and management among project teams.
- Advocate for standardised data formats and protocols, such as Industry Foundation Classes (IFC) for BIM, to ensure interoperability across diverse software platforms.
- Develop data-sharing agreements and protocols to facilitate secure and efficient data exchange throughout the project lifecycle.
- Invest in data analytics platforms capable of distilling actionable insights from integrated project data for superior decision-making.

Productivity Enhancement

- Promote lean construction principles, offering training and resources to facilitate streamlined workflows and waste reduction.
- Incentivise the investment in digital tools and emerging technologies such as robotics and AI to significantly boost productivity levels.
- Endorse collaborative project management platforms to enhance coordination and communication among project stakeholders.
- Define industry-standard performance benchmarks and KPIs, encouraging teams to continually assess their performance against these metrics.

INTRODUCTION

Industry and Government Challenges

The fourth industrial revolution (Industry 4.0) is about digital transformation (Ghobakhloo, 2020). The digital age presents vast opportunities for the construction sector to optimise access to the wide array of knowledge sources, such as regulations, standards, policies, building codes, case studies and technical guides, along with geospatial data and supply chain information. The use of building information modelling (BIM), new data sources and analytical processes are being implemented throughout the industry. Even so, knowledge in the construction industry has a poor reputation for being inaccessible, unstandardised and fragmented (Construction Knowledge Task Group, 2022). Despite significant investment, the construction industry is one of Australia's low digitisation sectors (Barbosa et al, 2017).

Global construction productivity has only grown by 1% in over 20 years compared with 3.6% in the manufacturing sector (Barbosa et al, 2017). Revenue from Australia's construction industry in Australia is expected to fall at an annualised rate of 1.5% through the end of 2022-23, to a total of $453.0 billion. Revenue is forecast to edge up at an annualised rate of 1.1% over the 5 years through 2027-28, to reach $478.1 billion. Working smarter from the application of digital technologies and improved data management is critical for the construction industry given the downturn in activity that has threatened the ability of many construction firms to continue operating solvently (Kelly, 2023).

The Victorian Digital Asset Strategy (VDAS), along with the Digital Asset Policy (2021), are blueprints to guide the digital information management approach of Victorian Government Departments, corporations, authorities, and other bodies under the Financial Management Act 1994 (Vic), by developing capital investment projects of ≥ $10 million (Victoria State Government, 2020a; 2021). According to the VDAS, the earlier in an asset's lifecycle that the VDAS is adopted the more value will be delivered (Victoria State Government, 2020b). The VDAS and the Digital Asset Policy are based on the international standard, ISO 19650, and detail the approach to naming conventions for information consistency, and information management processes across project lifecycle stages (International Organization for Standardization, 2018).

While the VDAS sets out vital processes for safeguarding digital systems that enable monitoring and improvements in the creation and management of infrastructure assets in Victoria, there is a lack of adoption of digital build in the building industry. Building on the VDAS, the Office of Projects Victoria (OPV) launched the Digital Asset Policy (2021), which provides clear information management requirements to improve the planning, design and delivery of Victorian infrastructure projects. This project supports Victoria's transition towards digitally built infrastructure by documenting the benefits of digital build and digital data management from several case studies, which are required to encourage industry investment and consequently, the transition from their traditional design-bid-build process.

Aims and Deliverables

Sub-project 2 aims to create pathways for Victoria's digital transition by developing a systematic understanding of the benefits of integrated project data management. The project has critically examined the existing digital models of infrastructure assets to register the industry challenges while capturing, identifying, and mapping the broader benefits of digital build through a socio-technical approach. The socio-technical investigation aims to improve industry-government communication/collaboration. This can increase the adoption of digital build along with supporting the wider community, innovations and productivity, and environmentally and socially sustainable outcomes.

The key objectives of the project were to:

- Examine the digital models of building assets that hold real-time information
- Document the achievements and gains of technology demonstration projects, including opportunities for standardised Building Information Modelling (BIM).
- Analyse, learn and demonstrate the benefits of digital build tools for wider industry adoption.
- Examine the practical implications and challenges of adopting sustainable data assets within, and between, the complex ecosystem of stakeholders in digital build projects.
- Explore wider community benefits e.g. professional communities, cross disciplinary project communities, and citizen communities affected by building projects.
- The deliverables include reporting on the different types of benefits of digital build and connected data from real-world case studies, as well as stakeholder roles and responsibilities, which are listed in Table 1.

Table 1. *Deliverables of the project*

Benefits of digital build and connected data	Stakeholder roles and responsibilities
• Increased outputs resulting from improved project delivery (cost and time, quality, risk-mitigation), technical efficiency/progress, asset performance and changed organisational structures. • Financial advantages resulting from technology adoption and increasing returns to scale (size of organisation, unit cost of production). • Other benefits such as improved decision-making, improved safety, reduced waste, improved communication, and improved stakeholder engagement.	• Strategic actors who determine long-term whole of government budgets, strategic infrastructure needs and approaches. • Project teams who develop, procure and deliver Victorian infrastructure. • Asset managers and end users who impact on and/or are impacted by the operational, environmental and community performance of infrastructure assets.

Methods

An overview of the methods adopted in this project, including a timeline of integrated activities of the digital build and connected data components, is presented in Figure 1.

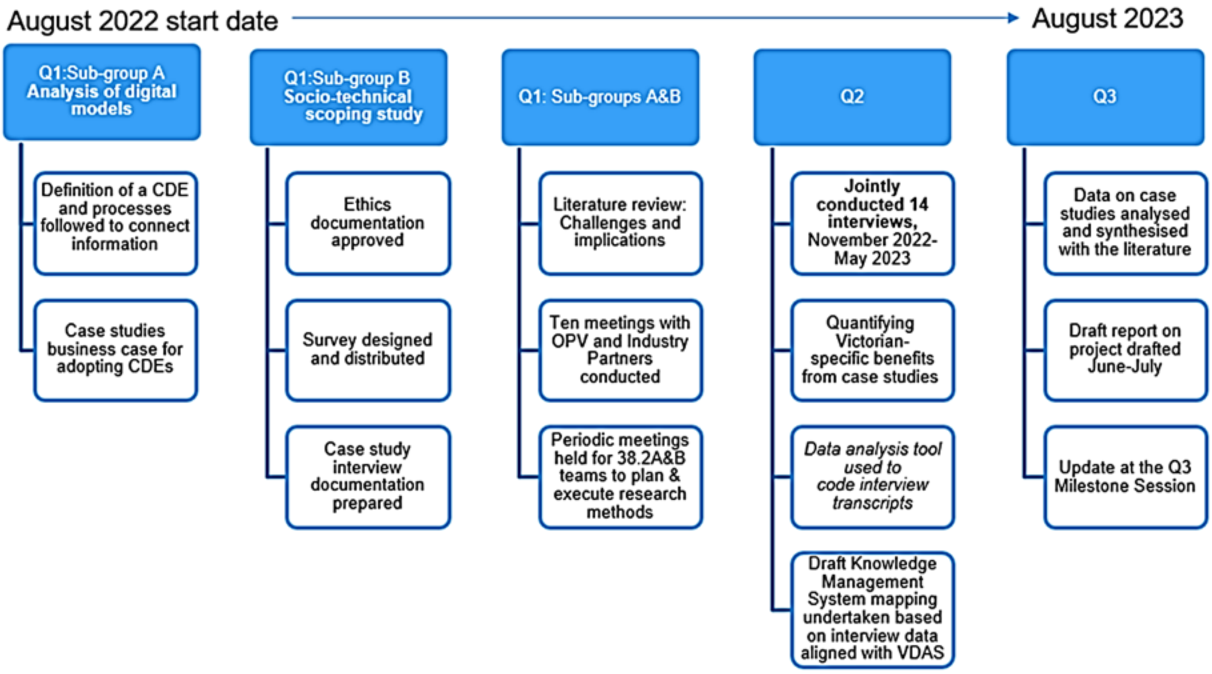


Figure 1. *Overview of the methods adopted in this project and timeline of activities*

A literature review was undertaken to understand the current state of international research on information management of a built asset, the extent to which the building and construction industry is employing digital asset management, and common data environments and platforms being adopted in these projects. This review provided a guide on the types of metrics being used to assess the benefits of digital build over the traditional design and construction process.

These metrics were then utilised to guide the digital build discussion in the interviews conducted with the stakeholders to identify opportunities for quantifying the benefits of digital build pertaining to the specific business cases provided, namely the Woodside Building for Technology and Design (WBTD), Pathway 144 and the Small School projects. The goal was to obtain metrics by benchmarking the digital build process against the traditional design and construction process.

Detailed assessments of the provided models from the abovementioned case studies (except Pathway 144, where the models were not accessible) were conducted to report the benefits attributed to the integration of the Building Information Model (BIM) with a Common Data Environment (CDE) for managing information of a built asset over the traditional design/construction method. The most comprehensive model provided was that of the WBTD, which aimed to achieve Passive House Verification while expediting the design/construction of the building within 15 months. This deadline could not have been achieved without the adoption of digital build, given the significant number of conflicts/issues identified between numerous trades (see Digital Build Case Studies).

A socio-technical scoping study was undertaken in parallel to the assessment of digital models employed by the case studies. Socio-technical research is qualitative research to investigate the mutual benefits gained from the combination of social and technical elements (Emery, 1980). Qualitative methods, in particular a case study approach, are appropriate for analysing complex situations and are recommended in construction research to enhance findings (Barrett & Sutrisna, 2009). The research techniques employed by this project included a survey and interviews to inform the case studies (detailed below), and a literature review.

A summary of the topics covered in the extensive literature review undertaken is provided in Table 2. The literature search was undertaken in the commercial databases Scopus and Web of Science to explore recent national and international research in the construction sector. Google Scholar was used to find related research literature. Market research and company reports were obtained from Internet searches. An Endnote database with 200 references including peer reviewed journal articles and research reports was compiled.

Information generated from the 10 meetings and workshops held with key staff from the OPV and industry partners involved in the project (was also a key research resource for the sub-project.

Table 2. *Literature search study concepts*

Focus	Subtopics	Filter topics
Construction or Building	Digital build or BIM or digital assets or digital transformation or digital twin	Benefits, challenges, implications, opportunities
	Supply chain or procurement	
	Data, information or knowledge management	
Living buildings	Communities or stakeholders	

Survey

To gain an understanding of the uptake of the VDAS by stakeholders an online survey was undertaken during September 2022 until January 2023. The survey was organised in 7 sections that aligned with the VDAS stages, including: 1. Brief, 2. Concept, 3. Definition, 4. Design, 5. Build and Commission, 6. Handover and Closeout, and 7. Operations and Maintenance. The survey was based on key steps from the VDAS to determine what implications and challenges exist for stakeholders to put the policy into practice. Qualtrics survey software was used to host, distribute and analyse the survey responses. The survey results informed a socio-technical study that followed.

The stakeholder audience for the survey included asset managers, facility managers, heads of engineering, engineering managers, digital engineers, VDAS champions, maintenance managers, architects, project directors, project managers, legal advisers, sponsors, designers, data custodians, data stewards, external contractors, project contractors, external builders, construction managers and other key staff involved in the exchange of connected data in a building project. An invitation to participate in the survey was distributed to a mailing list provided by the Office of Projects Victoria (OPV). The Master Builders Victoria also distributed the survey to their members engaged in digital build, and the survey was posted on the Building 4.0 CRC website and newsletter.

A copy of the Survey Instrument is in Appendix 1 and a detailed analysis of the survey's results is in Appendix 2.

Case Studies

Three case studies were undertaken over the period November 2022 to May 2023 (Figure 2).

	Woodside Building for Technology and Design	Pathway to 144	Small School Project
			
Type:	Research Institution	144 Mental Health Beds Project	State Capital Program
Partner:	Lendlease Monash University	Lendlease	Fleetwood
Status:	Nine interviews conducted	Two interviews conducted	Three interviews conducted

Figure 2. *Case studies undertaken*

Fourteen interviews in total were undertaken. Nine interviews were conducted for the Woodside Building for Technology and Design (WBTD) case study, 2 interviews were held for the Pathway to 144 case study, and 3 interviews for the Small School case study.

For the WBTD case study, the interviewees from Lendlease comprised 3 senior project managers, one technology in property manager, 3 engineers (2 were digital engineers) and 2 Monash University academic users of the building. For the Small School project, the first interview was with the Fleetwood Head of Design, and the following 2 interviews were with the Fleetwood Head of Design and the Virtual Design Construction Manager. For the Pathway to 144 project, 2 interviews were held, the first was with the Project Director, Victorian Health Building Authority and the second was with a Lendlease Construction Manager. Questions focused on the use of connected data and information management for the project case study. The questions were designed to explore the implications and challenges of adopting sustainable data assets amongst stakeholders in digital build projects. Each interview took approximately one hour.

The interviews were semi-structured, and participants responded to questions that were relevant to their experience in the field. The open-source tool, Taguette, was used for qualitative data analysis of each interview transcript. The interview questions are available in Appendix 3. The interviews took place during November 2022 until June 2023.

LITERATURE REVIEW

Adoption of best practices, such as implementing the VDAS, along with suitable *technology*, *people* and *content* elements in the Victorian construction industry has the potential to replace laborious, inefficient and costly information management approaches with speedy, reliable automated procedures (Victoria State Government, 2020a). Digital technology for asset management utilises developments in Industry 4.0 such as the Internet of Things (IoT), Artificial Intelligence (AI) and Building Information Modelling (BIM) to generate a digital replica of an asset, which is then updated in real-time to reflect the usage and condition of the asset (Arisekola & Madson, 2023).

Challenges and Implications

Adoption of Digital Technologies

There are numerous reviews and market reports on the key challenges of adopting sustainable data assets within digital build projects. The major barriers to change include the lack of leadership support (Deloitte Access Economics, 2023), sourcing expertise and the uncertainty of the required technical skills and capabilities (Akanmu et al, 2021), lack of system integration, platform interoperability, low standardisation, concerns with cybersecurity (Deloitte Access Economics, 2023; Olanipekun & Sutrisna, 2021), inconsistent understanding of digital and Industry 4.0, the reluctance of staff to change, limited time, lack of budget and the lack of functionality with existing technology to replicate ISO 19650 information management tasks (Deloitte Access Economics, 2023).

This inconsistent understanding and lack of standardisation are evident from the ambiguous definitions of common terms; Digital Build and Common Data Environment (CDE) being prime examples (Table 3). Difficulties also arise due to the complex interrelationships between technologies required for the digitalisation and automation of processes (Figure 3).

Table 3. *Ambiguities in the definitions of digital build and common data environment*

Term	Definition	Source
Digital Build	A digital build entails a collaborative approach to working and applying digital processes to enable productive methods of planning, designing, constructing, operating, and maintaining assets throughout their life cycle.	Adapted from the Digital Asset Policy
	A means to harness the wealth of data and information being created by systems used for building—to achieve high performing assets, smart cities, a digital economy, connected citizens and other wide-ranging benefits.	Adapted from Centre for Digital Built Britain
Common Data Environment	The collection of systems and technologies that service an organisation and its user groups is called the operational CDE.	VDAS part B, page 63
	Single source of information used to collect, manage and disseminate documentation, the graphical model and non-graphical data for the whole project team. Creating this single source of information facilitates collaboration between project team members and helps avoid duplication and errors.	Autodesk
Connected Data	Digital information that can be processed by human or automatic means and accessed in real-time on demand. Available at the point of need.	Adapted from VDAS part C, page 163

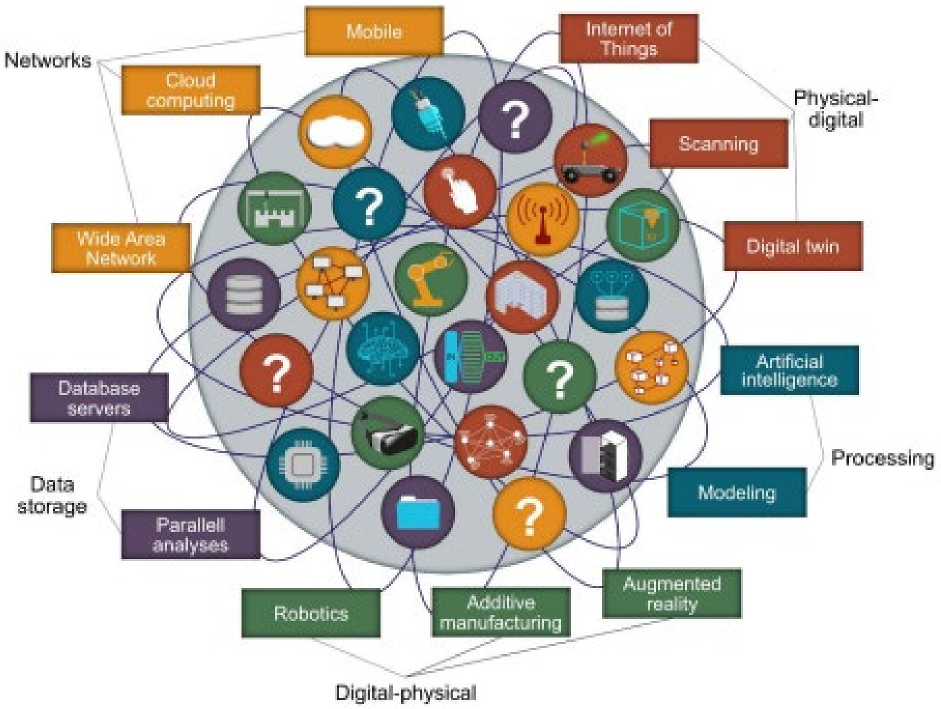


***Figure 3.** Illustration of the interrelationships between technologies required for the digitalisation and automation of processes*
Source: Schönbeck, 2022.

Building Information Modelling (BIM)

Asset Information Requirements (AIR) are part of the BIM process, defining the graphical and non-graphical data, information and documentation needed for the lifetime operation and management of a built asset. ISO 19650 defines AIR as 'information requirements in relation to the operation of an asset' (Designing Buildings Ltd, 2022). Resources such as the *NATSPEC National BIM Guide* and the *Asset Information Requirements Guide* provide best practice examples to support the Australian construction industry (Australasian BIM Advisory Board, 2018; NATSPEC Construction Information Systems Limited, 2023).

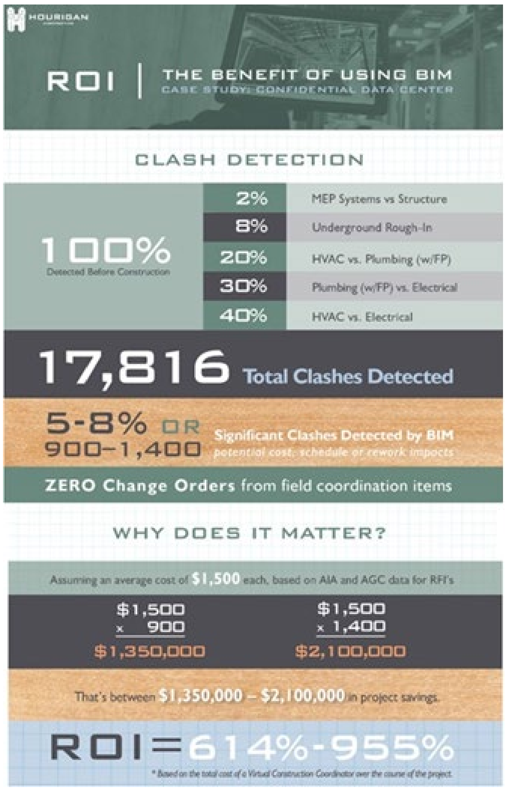
There is a prolific amount published locally and internationally on AIR and the BIM process that complement the release of ISO 19650-1 and ISO 19650-2 in 2018. Definitions of BIM imply that BIM should conceptually be used across all phases of an asset’s life cycle. In practice, however, its usage beyond the design and construction phases is low (Hosseini et al, 2021; Hosseini et al, 2018; Pärn et al, 2017).

The opportunity to apply BIM for asset design, sustainability practice and optimisation approaches for construction manufacturing have been reported (Al-Saeed et al, 2020; Schimanski et al, 2019). It is essential for a structured work method to gain a common interdisciplinary language and understanding between the project that can be communicated through a BIM process roadmap (Andersen & Findsen, 2019).

While significant progress has been made in the application of BIM, limitations to its managerial, technological and collaborative capabilities continue at the project and operational levels (Hosseini et al, 2021). The concept of digital engineering has emerged to address these limitations. Conceptually, digital engineering aims to address BIM's shortcomings by focusing on the strategic and business-oriented aspects of major infrastructure assets (Victoria State Government, 2020a).

However, based on industry data from the American Institute of Architects and Association of General Contractors (Figure 4), if implemented efficiently, BIM has the potential to overcome significant costs during the construction phase:

- Clashes (issues on a construction job) are estimated to have an average cost of $1,500 per instance.
- Since these issues can incur significant time, costs and resources, automated clash detection using BIM technology can be a critical part of the design and construction process.
- Project teams can highlight clashes that can significantly impact a project early on. For example, owner revisions or additions can easily be adjusted, without resulting in a high dollar hit to the project plan.
- Project sequencing also benefits from the use of BIM. By virtually roughing-in various systems before physically laying the materials, issues can be discovered and addressed before becoming costly and time-consuming, thereby improving productivity.
- There is also value in defining the life-cycle needs for the building, preventing rework and making the facility habitable for years to come. A virtual model ensures an effective facility, promotes safety and reduces downtime due to standard maintenance needs.



HOURIGAN

ROI | THE BENEFIT OF USING BIM
CASE STUDY: CONFIDENTIAL DATA CENTER

CLASH DETECTION

100%
Detected Before Construction

2%	MEP Systems vs Structure
8%	Underground Rough-In
20%	HVAC vs. Plumbing (w/FP)
30%	Plumbing (w/FP) vs. Electrical
40%	HVAC vs. Electrical

17,816 Total Clashes Detected

5-8% OR 900–1,400 Significant Clashes Detected by BIM
potential cost, schedule or rework impacts

ZERO Change Orders from field coordination items

WHY DOES IT MATTER?

Assuming an average cost of $1,500 each, based on AIA and AGC data for RFI's

$1,500 × 900 = $1,350,000

$1,500 × 1,400 = $2,100,000

That's between $1,350,000 – $2,100,000 in project savings.

ROI=614%-955%

*Based on the total cost of a Virtual Construction Coordinator over the course of the project.

Figure 4. *Benefits of using BIM*
Source: American Institute of Architects and Association of General Contractors.

Stakeholders

Typical stakeholders of a building project usually include clients, developers, architects, designers, engineers, contractors, suppliers, end-users, government and public. Developing and operating assets require that data and information be accessible to stakeholders. Getting the right data and information to the right stakeholder available at the point of need is a major challenge (Hosseini et al, 2021).

The unclear separation of responsibilities held by each stakeholder and legal concerns with projects compounds the complexity of the relationships (Alaloul et al, 2020). Companies within the construction industry are mostly made up of SMEs, which restricts their ability to invest in technologies. SME construction companies are often dependent on governing bodies and authorities to provide support for implementations through funding programs and partnerships (Alaloul et al, 2020).

"A collaborative setting such as the early contractor involvement (ECI) means that knowledge interchange during the tender period plays a more important role, so much so that it should be fully integrated into the project team. Owing to the increased importance of leveraging knowledge at the

ECI tender stage, knowledge from different stakeholders and disciplines needs to be fully and holistically integrated, not only to accommodate the transition of knowledge between ECI stages, but to also ensure knowledge is retained and reused through future projects (Hastie et al, 2017)".

Standardisation and Governance

Standards Australia has flagged the vital need for improved business intelligence and more data-driven decision-making for the construction industry. The construction sector will need to think beyond digital technologies and achieve a deeper, more focused understanding of data (Standards Australia, 2023).

The Virtual Buildings Information System (VBIS) was developed with the support of the Victorian Government. The VBIS provides a classification and linking of asset data in disparate systems. VBIS has a standard convention for asset record labelling, or tagging, and a logical creation of a consistent data hierarchy. This system makes possible the retrieval of useful information from a range of applications including BIM and Facilities Management (FM) systems to link to associated data sets seamlessly, regardless of the stage of the building lifecycle (Virtual Building Information System, 2022). Case examples and presentations of VBIS adopted in BIM, procurement and maintenance systems are available on the VBIS website (Virtual Building Information System, 2022).

Big Data is the ability to process and extract useful insights from large amounts of data. Even though vast amounts of data are generated throughout the life cycle of a building, the adoption of Big Data technology in this sector lags the advances achieved in other industries (Bilal et al, 2016).

Nine projects are reported in an Australian study that provide the 'how' of benefits management for digital transformation spanning engineering to asset management (Love & Matthews, 2019). The authors argue that putting in place governance structures and processes that can be used to measure and manage expected benefits of a digital investment that align with its strategy and goals, should be a priority (Love & Matthews, 2019).

Surveyed Benefits of Digital Build and Connected Data

Key quantitative and qualitative benefits from implementing digital build and systems to generate connected data are also summarised in this section, which are taken from recent research undertaken by VicRoads (Hampson & Shemery, 2018), market research by Deloitte Access Economics (Deloitte Access Economics, 2023), KPMG (KPMG, 2021) and other published papers as detailed in the listing within Section 3.2. The distribution of benefits resulting from the adoption of digital build are illustrated in Figures 5 and 6, whereby most benefits are realised from productivity gains.

From the analysis of eleven case studies, widespread examples of information management (IM) enabled productivity gains were found. This includes quantitative evidence which suggests the use of IM could potentially secure between £5.10 and £6.00 of direct labour productivity gains for every £1 invested in IM, and between £6.90 and £7.40 in direct cost savings (from reductions in delivery time, labour time and materials). They also found evidence of cost savings at various stages of the asset lifecycle, ranging from 1.6% to 18%, which depend on the lifecycle stage of every £1 of direct productivity gain in the design, construction and maintenance of newly built assets enabled by IM. These savings could potentially translate into an additional £3.70 in annual UK GDP in 2051 (expressed in real terms in 2021 prices). This suggests that the returns to the UK economy could be a multiple of any direct productivity gains in the construction sector that are enabled by IM. To date, there has been limited research aimed at quantifying or valuing the cost savings or increased revenues associated with IM at the organisational level. Access to information (as data) of the right quality and at the right time, in a format that is trusted by all parties, is increasingly recognised as a critical enabler to the construction sector's digital transformation and optimisation of the performance of built assets. While there has been a step-change in the way that information is created and used by the sector over the last 10 years, there remains limited evidence on the holistic benefits of these practices, which are listed hereafter (KPMG, 2021).

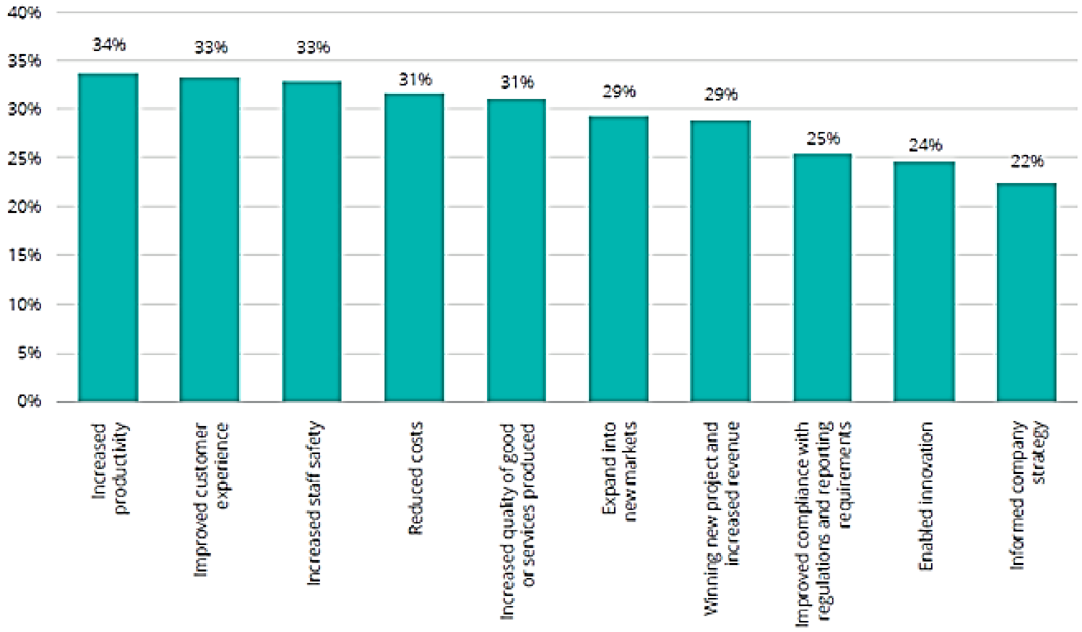


Figure 5. *Business benefits resulting from the adoption of digital build/technologies*
Source: Deloitte Access Economics, 2023.

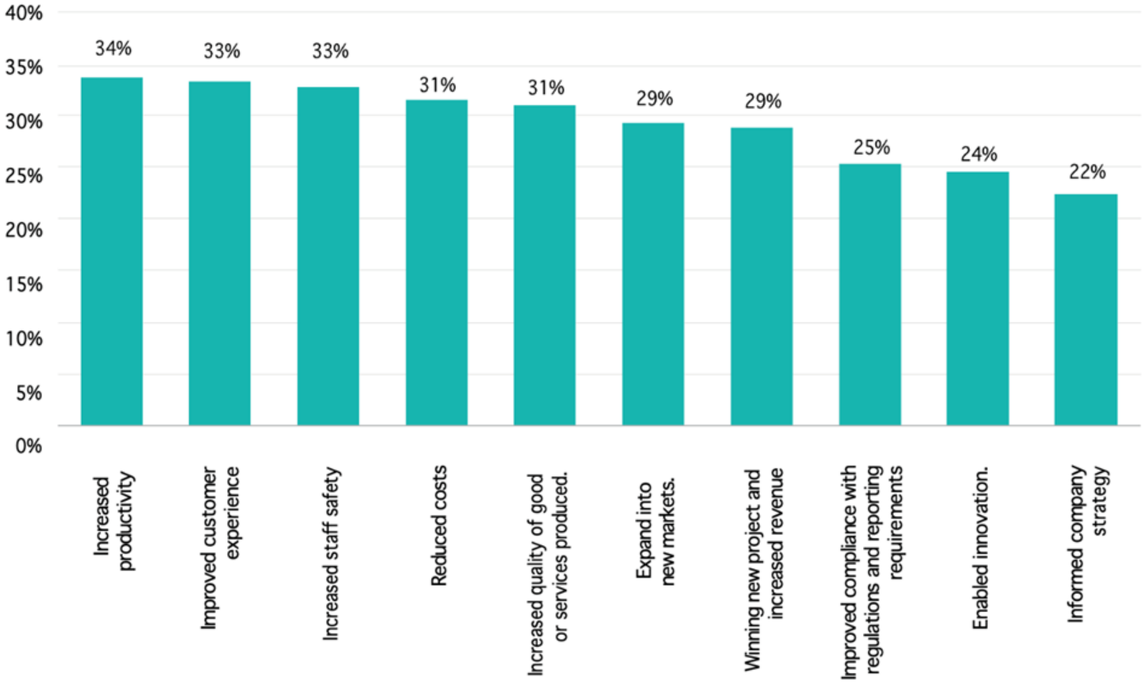


Figure 6. *Business benefits resulting from the adoption of digital build/technologies*
Source: Deloitte Access Economics, 2023.

Productivity

- Reduction in time responding to Requests for Information (RFI)
- Reduction in time spent searching and assessing information
- Reduction in data verification
- Maximising reuse of data (e.g. kit of parts, design calculations across different projects)
- Expediting Design for Manufacture and Assembly (DfMA), which has capacity to achieve productivity boosts 5-10 times compared with conventional building processes
- Reduction in variations
- Faster programming and improved/more effective scheduling
- Better scenario analysis and optimisation of the construction sequence, enabling overall faster project delivery
- More efficient reporting on project progress and performance
- Minimise duplicative efforts
- Reduced tender and design review time
- Attracting new projects and increased revenue
- It is estimated that 65% of the companies lack proper time and cost optimisation because of traditional document management systems. Three-stage BIM methodology has reduced the time for document processing up to 75% for the stakeholders involved (Lazaro-Aleman et al, 2020)

Capital costs

- Reduction in clashes/rework
- Digital engineering allows Design and Construct of the project virtually, and to identify and eradicate errors before doing the physical work on site
- Reduced waste due to reduction in errors

Operations and maintenance costs

- Better safety and crisis management through information accessibility and virtual scenario training
- More accurate planned maintenance through better analysis of network asset performance, and being able to predict failures and take preventative actions that improve levels of service and lowers costs
- Lower operational costs through improved digital asset utilisation
- Lower operational costs through more efficient physical asset management and improved identification and evidence-based prioritisation of maintenance and renewal spend, with outcomes able to be quantitatively measured
- Reduction in time spent addressing asset failures
- Seamless transfer of asset information, minimising manual processing
- Better change control of asset configuration and greater traceability of asset history
- Potential for 3D printing of replacement components, creating ongoing savings and driving efficiencies

Community Benefits

- Increased productivity right through the asset life cycle will reduce total expenditure which will allow the same dollar spend to go further and thereby achieve improved customer outcomes
- Increased quality of goods or services produced
- Clients are experiencing benefits of BIM in quality assurance and buildability from effective information management that enables clients to reuse the information from the BIM models in other forms, such as simulation and for data reuse when the project becomes operational (Andersen & Findsen, 2019)
- Circular economy is a means to achieve an economic system based on the preservation of natural resources and the prevention of waste, through closed-loop strategies, by-product exchange, product reuse, and materials recycling (Giorgi et al, 2022). Digital building and connected data systems in the building industry can underpin the participation in the circular economy throughout the building value chain.

- Social value as a community benefit derived from generating “value for money” in the delivery of construction services is reported in previous research (Burke & King, 2015). Construction services worldwide are adopting digital twin and industry 4.0 enablers to provide real-time multi-asset connectivity, simulation, and decision support functionalities (Hu et al, 2022)“ that have flow-on benefits in the form of living buildings that help to achieve sustainability and are of benefit to wide-ranging communities (Burbridge, 2017; Ghobakhloo, 2020; Martek et al, 2022).
- The Victorian State Government’s Digital Asset Policy has the potential to achieve a vast range of community benefits to State Departments and Agencies, the economy, society and the wider environment through greater investment in construction sector information management (Victoria State Government, 2020a). Such wide-ranging community benefits can help towards achieving the United Nations (UN) Sustainable Development Goals (SDG). Recent doctoral research highlights the relevance of the UN SGD 17 to the construction industry, and the opportunity for stakeholders to improve their partnerships and information management practices to contribute to sustainable development (Schönbeck, 2022).

Intangible Benefits

- Improved communication and cooperation among project teams and stakeholders
- Enhanced reputation for the business
- Increase in knowledge capture
- Enabled innovation
- Informed company strategy
- Digital twin technology has the potential to minimise mistakes and reduce duplicated effort in the construction sector and decrease the need for redoing work (Nalioğlu et al, 2023).

Current State of International Research on Information Management of a Built Asset

This section reviews the state of international research on the information management of a built asset and the extent to which it is being considered in research. The goal is to identify the types of information management practices that are being used to integrate different aspects of digital build and connected data, such as BIM and digital twins, to provide a central source of information as stipulated in the VDAS stages (brief, concept, definition, design, building and commission, handover and closeout, and operations and maintenance). Several case studies of building projects (as aligned with the Building 4.0 CRC) exploring digital build and connected data are selected and explored in detail in Section 4 in terms of the challenges, methodology, benefits and lessons learned.

BIM has been the focus of researchers in the last 10 years (Craig & Sommerville, 2006; Demian & Walters, 2014; Dixit et al, 2019; Fazli et al, 2014; Guillen et al, 2016; Hajian & Becerik-Gerber, 2009; McArthur, 2015; Olawumi & Chan, 2019). However, information management has been studied for more than 30 years (Björk, 2002; Craig & Sommerville, 2006; Demian & Walters, 2014; Dixit et al, 2019; Fazli et al, 2014; Guillen et al, 2016; Hajian & Becerik-Gerber, 2009; McArthur, 2015; Olawumi & Chan, 2019; Rezgui et al, 1998). A timeline of research on the information management of a built asset is presented in Table 4. It can be noted most research in this field focused on the Building and Commission stage of VDAS (Stage 5) prior to 2005. During the last 15 years, research has been focusing more on design (Stage 4), Handover and Closeout (Stage 6), and Operations and Maintenance (Stage 7). The following benefits were reported from these studies:

- Avoid redundant works, and waste of time and cost (Demian & Walters, 2014; Fazli et al, 2014)
- Support decision making in real-time (Craig & Sommerville, 2006; Demian & Walters, 2014; McArthur, 2015; Rezgui et al, 1998)

- Real-time project information management (Craig & Sommerville, 2006; Demian & Walters, 2014; Hajian & Becerik-Gerber, 2009; McArthur, 2015)
- Reduce total cost, save delivery time of documents (Björk, 2002; Craig & Sommerville, 2006; Demian & Walters, 2014; McArthur, 2015)
- Increase collaboration and integration among project members (Craig & Sommerville, 2006; Demian & Walters, 2014; McArthur, 2015)
- Assist in asset management (post construction phase) (Guillen et al, 2016)
- Integration of facility management and BIM (Dixit et al, 2019)

Table 4. *Timeline of research on information management of a built asset*

Timeline	**1995-2000**	**2000-2005**	**2005-2010**	**2010-2015**	**2015-Now**
Research focus	Information management	Electronic Document Management (EDM) on construction management	Real-time project information management	Building information modelling (BIM) framework	BIM framework BIM for asset management BIM for facility management
Alignment/ similarities with VDAS stages	Stage 5	Stage 5	Stage 5, 6, 7	Stage 4, 5, 6, 7	Stage 4, 5, 6, 7
Reference	(Rezgui et al, 1998)	(Björk, 2002)	(Craig & Sommerville, 2006; Hajian & Becerik-Gerber, 2009)	(Demian & Walters, 2014; Fazli et al, 2014; McArthur, 2015)	(Dixit et al, 2019; Guillen et al, 2016; Olawumi & Chan, 2019)

To achieve the aforementioned benefits to stakeholders, the following technologies and frameworks were used:

- Information management systems and BIM (Demian & Walters, 2014)
- 7D BIM framework (McArthur, 2015)
- BIM-project information management framework (BIM-PIMF) (Olawumi & Chan, 2019)
- Integration between advanced field data acquisition technology and Building Information Modelling (BIM) (Hajian & Becerik-Gerber, 2009)
- BIM as asset management tool (Guillen et al, 2016)
- Information management system (Craig & Sommerville, 2006)
- Electronic document management (Björk, 2002)
- Construction modelling and methodologies for intelligent integration of information (COMMIT) (Rezgui et al, 1998)

Applying information management for a built asset results in quantified benefits from different building projects (Craig & Sommerville, 2006), civil projects (Whyte & Donaldson, 2015), factories (Barlish & Sullivan, 2012), healthcare facilities (Olofsson et al, 2007) and schools (Kuprenas & Mock, 2009). Consistent with the previous findings, these projects are applying information management systems (Craig & Sommerville, 2006) and digital modelling (BIM) (Barlish & Sullivan, 2012; Kuprenas & Mock, 2009; Olofsson et al, 2007; Whyte & Donaldson, 2015) to benefit stakeholders during Stage 4, 5 and 6 of VDAS. The benefits of each project are listed in Table 5.

Table 5. *Quantitative research on applying information management for a built asset*

Project	Location	Project value	Saving/benefit	Technology / VDAS Stage
M75 motorway (Rezgui et al, 1998)	UK	£110M	Saving 0.5% of project cost (£600,000)	Information management systems Stage 4–6
Building project (Whyte & Donaldson, 2015)	Western Australia	Project A: A$6.7M Project B: A$20M	25% reduction in drafting/modelling 0.7% saving of project cost	Digital model (BIM) Stage 4–6
Compare completed non-BIM and BIM projects (semiconductor factory) (Barlish & Sullivan, 2012)	USA	–	50% reduction in number of RFI tools (3 in BIM and 6 in non-BIM projects) 42% reduction in change orders (change orders incur 12% of non-BIM project costs and only 5% of BIM project costs). 67% reduction in behind standard schedule (the percentage of behind standard schedule is 15% in non-BIM and 7% in BIM projects)	Digital model (BIM) Stage 4–6
Compare Non-BIM and BIM design at bidding stage of a project (Barlish & Sullivan, 2012)	USA	–	31% increase in A&E cost 34% increase in 3D model creator 5% reduction in construction costs (contractor costs) Overall: 2% reduction in total design and construction costs	Digital model (BIM) Stage 4
Compare completed and on-going non-BIM and BIM projects (Barlish & Sullivan, 2012)	USA	–	50% increase in number of tools for RFIs (2 tools in non-BIM projects and 3 tools were used for BIM projects) 70% reduction in change orders (change orders incur 23% of non-BIM project costs and only 7% of BIM project costs). 6% reduction in construction costs 1% reduction in total design and construction cost	Digital model (BIM) Stage 4–6
MEP coordination of a healthcare project (Olofsson et al, 2007)	USA	$96.9M	20-30% labour savings for all MEP subcontractors 100% pre-fabrication for the plumbing contractor Increased safety (only 1 recorded injury) Reduced rework (less than 0.2% rework for the whole project) Reduced RFI (benefits for the general contractor and architects/engineers as no/minimal number of conflicts need to be resolved) Reduce change orders (worth 1%-2% of the MEP system) 6 months reduction in the schedule $9M savings in total cost of the project (approx. 10%).	Digital model (BIM) Stage 4–5
Public school construction project (Kuprenas & Mock, 2009)	USA	$320M	Saving $4.5M from inter-trade coordination (conflict checking and visualisation) Saving $350,000 from intra-trade coordination (reduced rework, shortened construction time, visualisation, sequencing).	Digital model (BIM) Clash detection Stage 4–5

Digital Asset Management for Building and Construction Projects

Digital Asset Management (DAM) systems play a crucial role in the engineering industry. With the complex nature of engineering projects and the need to manage a wide range of technical documents, CAD files, schematics, and other digital assets, DAM provides a centralised and efficient solution (Love et al, 2016). Engineers, designers and project managers can easily access and share critical information, ensuring accuracy, version control, and compliance throughout the product development lifecycle (Karim et al, 2021). DAM systems also enable collaboration among teams, allowing them to work seamlessly and efficiently, resulting in improved project timelines and outcomes (Roberts et al, 2018). By providing a structured and organised repository for digital assets, DAM enhances productivity, reduces errors and streamlines the overall engineering processes (Austerberry, 2006).

Further, DAM systems in the engineering industry help preserve valuable intellectual property and knowledge. Being able to store, categorise, and retrieve digital assets, such as past project files, design specifications, and technical documentation, organisations can tap into institutional knowledge and leverage previous work for future projects (Claman, 2007). DAM facilitates knowledge sharing and ensures engineering teams can access historical information, enabling them to build on existing expertise and make informed decisions (Cywin et al, 2011). DAM systems also help maintain compliance with regulations and industry standards by tracking document revisions, managing access permissions, and ensuring data security for sensitive engineering assets. Table 6 presents examples of industry applications of digital asset management developed by engineering consultants and their reported benefits (Collberg et al, 2011).

Table 6. *Examples of industry applications of digital asset management*

Example	Developer & Project	Benefits	VDAS Stage
Reveal	Robert Bird Group Multiple building projects (Donnelly, 2022)	Create a virtual environment where design and construction planning and solutions can be viewed, developed and coordinated in real-time. Review model progress, coordinate and iterate on master plans, inform and refine design decisions, and validate construction methodologies. Site logistics preparation, materials scheduling, as well as for site induction and training; helping to ensure greater safety.	4–6
Digital Twin	AURECON WestConnex New M5 – Sydney, Australia – $4.3B – 2015 to 2019 (Aurecon, 2022)	Accelerated risk assessment and production time Predictive maintenance Real-time remote monitoring Better team collaboration Better financial decision-making	1–6
Neuron	ARUP Water Cube – National Aquatics Centre – Beijing Olympic Green, China – 2003 to 2008 One Taikoo Place – Hong Kong – 2015 (Arup, 2023)	Neuron can help to save up to 30% electricity consumption for a typical existing commercial building. Cooling load prediction accuracy of Neuron vs real operation were within 5%. The highly automated analysis process of Neuron makes it feasible for even the unexperienced operators to easily monitor and operate the chiller plant system, saving their labour input.	7
Autodesk Construction Cloud/BIM 360	AECOM Barclays Center Arena $450M (Ginsberg, 2020)	32% increase in productivity $4.5M cost savings Increased coordination between stakeholders Geometric cost certainty	4–6

Common Design/Data Environments and Platforms

In the construction industry, the efficient and effective management of project data is critical to the success of projects. Central to this need is the concept of the Common Data Environment (CDE), a key innovation aimed at improving data transparency, accountability and collaboration. The idea of a CDE, as proposed by ISO 19650, is to expose all relevant data as a single source of truth, fostering seamless data exchange and continuous collaboration among stakeholders. In practice, however, the available CDE tools implement these requirements in different ways, leading to a range of user experiences and varying levels of efficiency and effectiveness.

Current industry practice sees construction information being stored in multiple sources concurrently, leading to issues with data accountability, transparency and reliability. To address these challenges, the use of novel technologies, such as blockchain, has been suggested as a potential solution, as it could provide the means to streamline data storage and retrieval processes, and enhance the overall integrity of the data (Jaskula et al, 2022). Several popular information management platforms on the market are reviewed herein. The reported benefits by the building industry mainly stem from the adoption of Autodesk Construction Cloud.

Autodesk Construction Cloud (Figure 7): This is a comprehensive field and project management solution (AUTODESK Construction Cloud, 2023a). It centralises all project information, including plans, documents, and models, into a single platform. It offers advanced analytics and reporting capabilities, providing insights into project performance, progress tracking, and resource utilisation. Some users have reported a learning curve and occasional performance issues. Several case studies that used Autodesk Construction Cloud:

- Using BIM 360 within Autodesk Construction Cloud™, Arpada digitised reporting across 25 sites, improving site safety by 75% and saving more than 100 hours and 3000€ per month (AUTODESK Construction Cloud, 2023b).
- Khansaheb Improves Communication and Reduces Snagging Administration by 60%. Engineers spend less time following up on issues; previously, 10-15% of an engineer's time was spent following up with subcontractors for updates (AUTODESK Construction Cloud, 2022a).
- Windover Construction Reduces Quantity Takeoff Time by More Than 50%. The team experienced a time savings of more than 50% by replacing the traditional method with a faster way of completing a quantity take off by embedding the BIM data into Autodesk Take-off in Autodesk construction cloud (AUTODESK Construction Cloud, 2022c).
- Oahu Metal & Glazing Experiences 75% Time-savings in Project Kick-off (AUTODESK Construction Cloud, 2022b).
- Austin developed standardized operating procedures for data management to improve quality standards across projects, it can save them more than 30,000 hours annually (AUTODESK Construction Cloud, 2020).

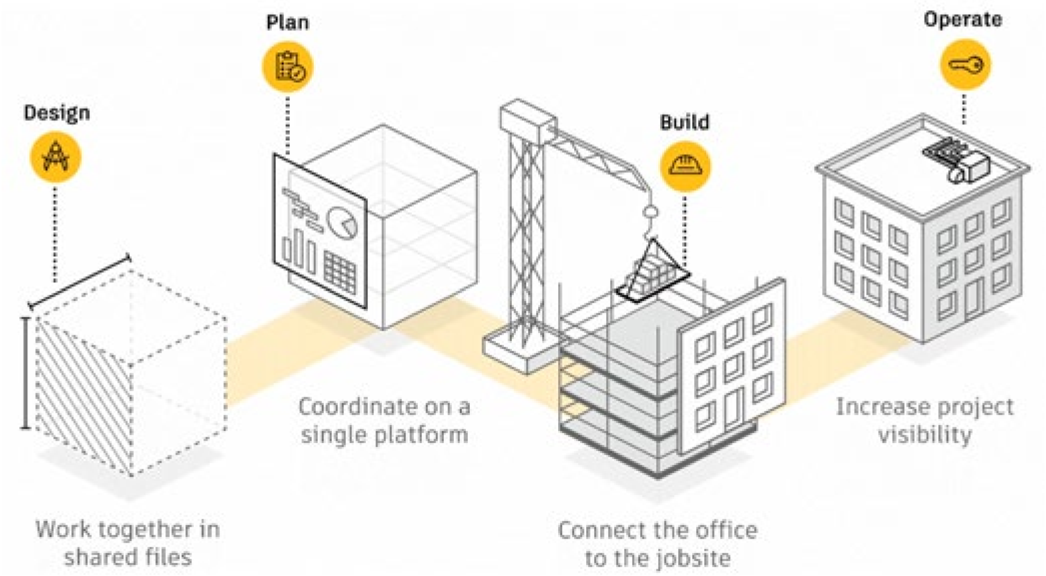


Figure 7. *Key features of Autodesk Construction Cloud CDE*
Source: AUTODESK Construction Cloud, 2023a.

Trimble Connect (Figure 8): Trimble Connect is a cloud-based CDE and collaboration platform designed specifically for the construction industry. It links data throughout each phase of the building life cycle to keep your project on schedule and on budget. Users can upload and share documents from over 60 industry tools or add their own source using the powerful Application Programming Interface (API). It provides access to information for all stakeholders, across all phases of construction, improves workflows, ensures on-time project delivery, and offers real-time access to job status and material costs.

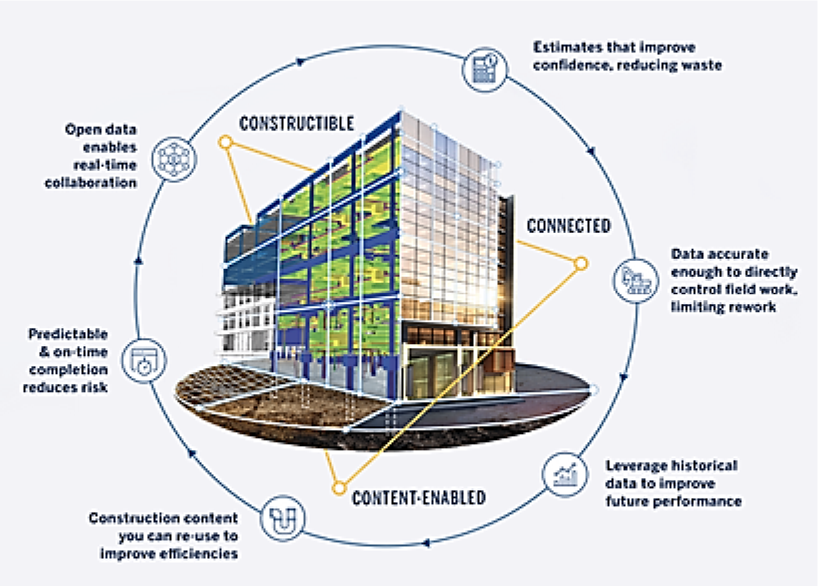


Figure 8. *Key features of Trimble Connect CDE*
BuildingPoint Australia Pty Ltd, 2021.

Bimsync: Bimsync is a cloud-based BIM collaboration tool developed by Catenda. It supports all buildingSMART standards (Industry Foundation Classes (IFC), building SMART Data Dictionary (bSDD), BIM Collaboration Format (BCF), Construction Operations Building Information Exchange

(COBie)) and comes with a range of APIs for easy implementation in the user's own software. Users can share and communicate issues, visualise BIM models in 2D/3D/4D and enrich models with documents and relevant information. It provides an easy overview of the latest updates and changes in a project.

Dalux Box: Dalux Box is a cloud-based BIM collaboration tool developed by Dalux. It intertwines the common data environment and BIM in one environment. Users can access information from their phone and online, synchronise their project files directly to the cloud from their desktop, link PDFs to plan, elevation or section drawings, and visualise the 3D model in the integrated BIM Viewer.

A comparison between the features of the abovementioned CDEs and their applicability to the VDAS stages are provided in Table 7.

Table 7*. Comparison between different CDE platforms*

	Autodesk Construction Cloud	Trimble Connect	Bimsync	Dalux Box
Source	construction.autodesk.com	connect.trimble.com	bimsync.com	www.dalux.com
Stage involved	Stage 4 Design	Stage 4 Design	Stage 4 Design	Stage 4 Design
	Stage 5 Build and commission	Stage 5 Build and commission	Stage 5 Build and commission	Stage 5 Build and commission
	Stage 6 Handover and close out	Stage 6 Handover and close out		
	Stage 7 Operation and maintenance	Stage 7 Operation and maintenance		
Highlight	Centralises project information for easy access and streamlined communication	Cloud-based construction collaboration tool	Coordinate with issue management system	Combine views of 2D drawings and 3D models
	Streamline multiple processes	Connects teams with data in real time	Visualise 2D and 3D models	Click anywhere on the drawing to create a markup
	Manage supply chain on the cloud	Supports document sharing from over 60 industry tools	Cloud-based Building Information Modelling (BIM) collaboration tool	Link PDFs to plan, elevation or section drawings and visualise the 3D model in the integrated BIM viewer
	Includes document sharing, real-time collaboration	Helps manage project schedules and costs	Supports all buildingSMART standards and offers API implementation	Combines common data environment and BIM in one place
	Offers advanced analytics and reporting capabilities	Real-time access to the job status and material costs	Enables sharing, communication, and visualisation of BIM models.	Supports the creation of markups on drawings

CDE offers significant benefits in construction projects by streamlining processes, enhancing collaboration and improving project outcomes. Figure 9 showcases the general utilisation and integration of CDE in a construction project:

- Initially, the project setup and collaboration stage establish the foundation by creating the project, assigning permissions, and inviting team members while establishing collaboration protocols.
- As the project progresses, design coordination and review capabilities facilitate seamless collaboration among stakeholders, ensuring clash-free designs and efficient issue resolution.
- Document control and management features enable centralised storage, version control and controlled sharing of project documents, ensuring easy access and collaboration.
- With construction project management tools, project scheduling, task tracking and communication become streamlined, contributing to improved efficiency and timely decision-making.
- Field collaboration and quality control functionalities enable on-site access, efficient issue tracking and quality control monitoring, ensuring a higher standard of workmanship.
- Finally, the reporting and analytical capabilities of CDE empower project teams to generate performance reports. By integrating CDE into construction projects, Australian construction professionals can leverage its comprehensive features to enhance collaboration, streamline workflows, and achieve successful project delivery.

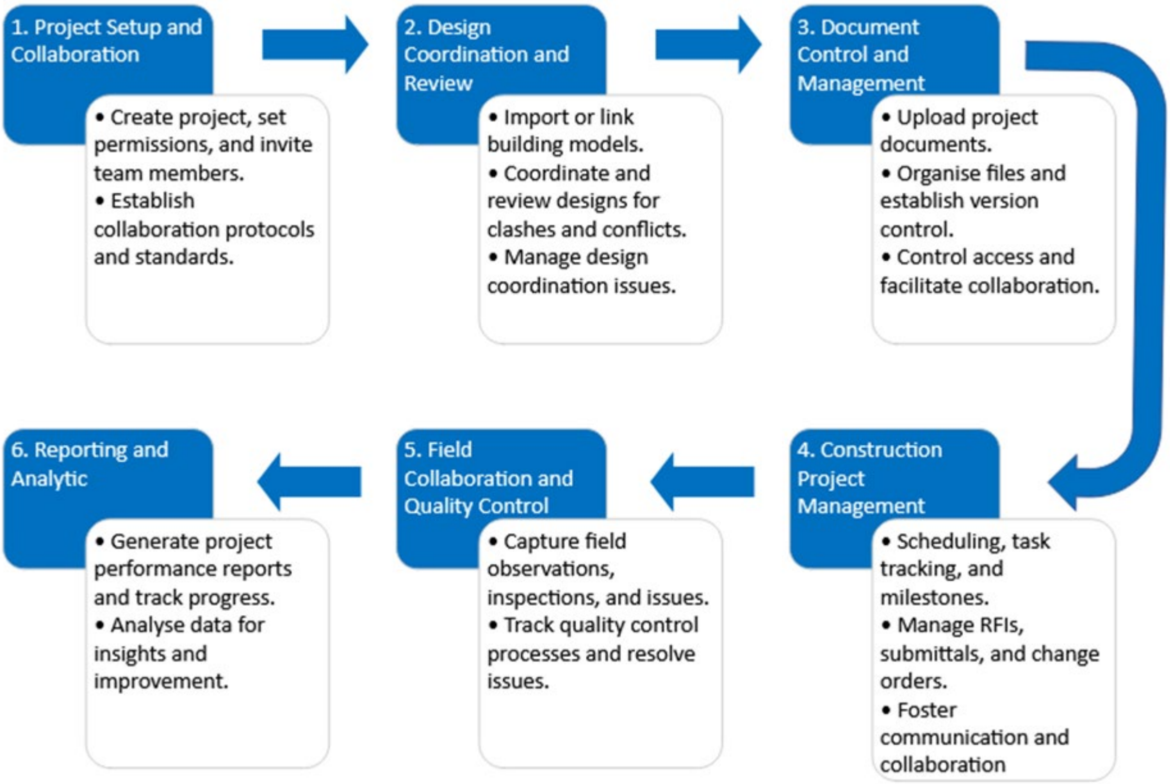


Figure 9. *Example workflow for integrating a CDE into a building project*

Woodside Building for Technology and Design

The Woodside Building for Technology and Design (WBTD) is claimed to be the largest educational building in the world to achieve Passive House (PH) verification (Aurecon, 2023). WBTD is thereby one of the most efficient and innovative teaching buildings in Australia and the largest PH project in the Southern Hemisphere. The building uses solar as one of its energy sources, and reflects international best practice in energy performance and thermal comfort. The project details, including budget, timeline (tender, design and build, and completion year), building geometry and stakeholders are tabulated below (Table 8).

Table 8. *Woodside Building for Technology and Design project details*

Project details	
Name and Client	Woodside Building for Technology and Design (WBTD) Monash University, Clayton Campus
Value	$176 million
Tender Design and Build Completion Year	August 2018 18 months (reduced by 4 months) Handover 2020
Building Height Gross Square Area	25.9m (5 storeys) 23,000 sqm
Architect/Interior Designer	Grimshaw
Structural / ESD / Civil / Fire / Mechanical / Lighting / Hydraulic / Acoustic / Façade Engineer	Aurecon
Landscape	ASPECT Studios
Environmental Analysis	Bollinger / Grohmann
Project Manager / General Contractor	Root Projects / Lendlease

PH is a voluntary, internationally recognised building standard for buildings that achieve higher standards compared with most commercial buildings in terms of thermal comfort, energy efficiency and lower energy costs. WBTD demonstrates the following sustainability benefits:

- Significantly reduced energy demands and subsequent operating costs
- High thermal comfort and quality of occupant experience
- High indoor air quality, health and well-being
- Balanced heat recovery ventilation
- Continuous insulation around the building envelope
- Building airtightness
- Designed to maximise daylight

As a living laboratory, WBTD provides visual access to the workings of the building, which enables students and researchers to learn from its physical design and building services. This is achieved as follows:

- Visual access to plant rooms through glazed windows provide insight into the role of different plant equipment components.
- Some areas of the raised floor are laminated glass with LED back lighting, which enables students to visualise how the mechanical, electrical and hydraulic services function.
- Structural steelwork and exposed piles include sensors for structural health monitoring, which read stresses and vibrations on structural elements and their changes under different thermal-mechanical loading conditions.

Roles and responsibilities of strategic actors

Strategic actors who determine long-term whole of government budgets, strategic infrastructure needs and approaches budgets and strategic infrastructure requirements for all significant Monash University projects, such as the WBTD project, are determined by the Vice Chancellor's Group, University senior executives and key committees of Council including the Resource and Finance Committee and The Environmental, Social and Governance and Estates Committee(Minagawa & Kusayanagi, 2015).

Project teams who develop, procure and deliver Victorian infrastructure

On the establishment of a business case, the spatialisation of the University needs and alignment of the project with the campus Masterplan is undertaken by the Monash University, Building Properties Division, Planning team. Faculty requirements are incorporated within the planning process. For the WBTD project, workshops were undertaken with stakeholders from the University to understand business strategies and priorities. Following this, the requirements were translated into the design documentation. The Monash University, Building Properties Division led the planning, design and construction of the new assets. Standard form contracts were administered. Asset managers and end users who impact on and/or are impacted by the operational and environmental performance of infrastructure assets

For the WBTD project, the teams who are impacted by the operational, environmental and community performance of infrastructure assets include teams in the Monash University, Building Properties Division such as Operations and Facilities Management (otherwise known as maintenance), Net Zero, Strategic Asset Management and end users comprising staff, students and industry collaborators largely from the Faculty of Engineering and the Faculty of Information Technology.

Challenges/Design Considerations

The critical challenges identified by the interviewed Project Managers are listed as follows:

- Designing a mechanical system to comply with Passive House (PH) Standards, first Australian building built to Passive House criteria (most significant)
- Rapid coordination of tender documentation to enable release to Tier 1 contractors – within 6 weeks
- Rapid coordination between complex ecosystem of stakeholders to resolve construction issues and deliver the design/construction of the project within 18 months
- Ensuring construction works stayed on track and within the forecast budget (semester 1)
- The construction industry is slow to embrace technology due to commercial and financial penalties
- An industry reputation as technology laggards due to fear of failure
- Technology can hamper process because of too much tinkering

- Dependence upon people for modelling "only as good as the person inputting the details"

The complex ecosystem of stakeholders (Figure 10) poses challenges with coordination, as quoted by the Project Managers:

- The Lendlease trade partners are Tier 1 level, and they are onboard with digital data systems "Don't think trades know about the cost because they derive so much benefit." (Senior Project Manager, Lendlease)
- "We were able to share a live model. We had the consultant team redo the design while having live input from the subcontractors indicating this couldn't work or look at this, which doesn't normally happen. It was a live process where we only got a third of the way through the process and subcontractor were able to commence producing the steel for the 30%. It was a very iterative process -- structural steel engineers and structural steel detailers working hand in hand. Worked bay by bay through the building. It was a rapid collaboration. It was bringing 2 buildings together. Beauty everyone had the model. It was an intense and good outcome." (Project Manager Services, Lendlease)
- "When you get consulting team, architects, engineers in the digital sandpit get some grating and toing and froing mostly from architects…. Generally, things need to be locked in. Audit trails make all the revisions visible now." (Senior Construction Manager, Lendlease)
- "Stakeholder included everyone from architects, builders, design consultants, user groups, students, faculties, and layer upon layer at Monash University, such as the Design Review Committee. Digital did help, for example, Virtual Reality sessions were conducted on user groups, and they could walk through the model and get their heads up to speed much faster to expedite the approval process. The Design Review Committee could visualise as they had walked through the model and could therefore make decisions on the spot."

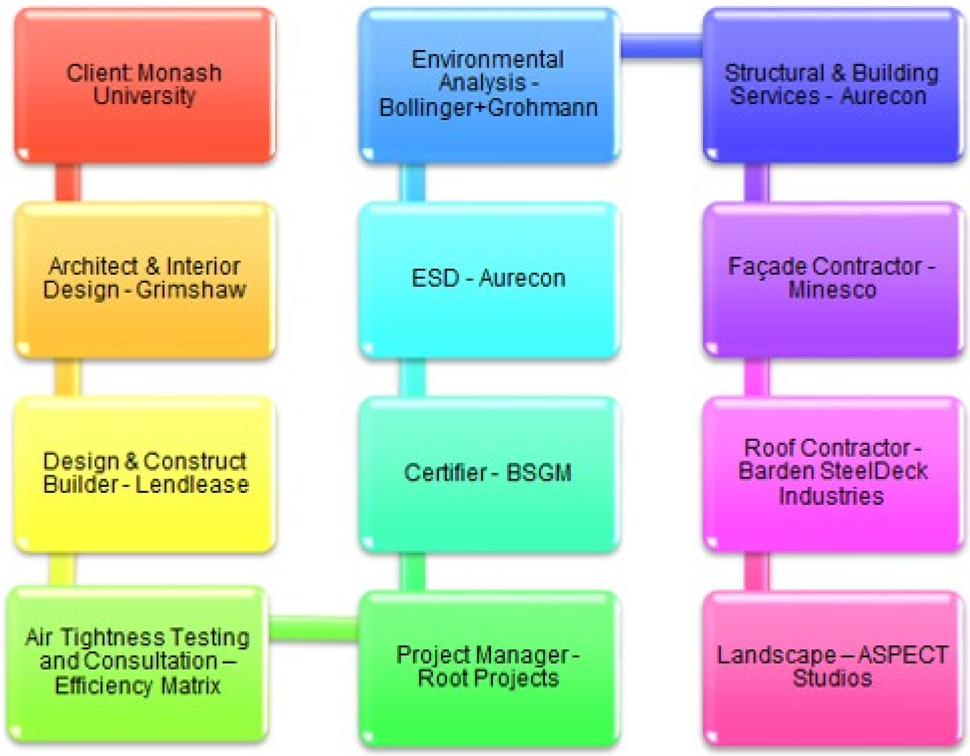


Figure 10. *Complex ecosystem of stakeholders for the Woodside Building for Technology and Design project*

The WBTD aims to achieve optimal energy efficiency and daylighting through a comprehensive design of its complex building mechanical system, and building fabric and shading elements (PassivHaus Institute, 2021):

- The building's mechanical system has been specifically designed and installed to minimise losses and optimise efficiency, which reduces the building's operational costs and GHG emissions. All mechanical equipment is selected from high efficiency products, which have an average Coefficient of Performance (COP) of 4.
- A dedicated outdoor air system comprises a heat recovery heat exchanger that recovers heat, which would normally be dissipated to the environment. The heat is converted into useful energy for the building.
- The building features a highly efficient Variable Refrigerant Flow (VRF) inverter air conditioning system, which offers a significant improvement over conventional air conditioning systems in terms of peak and part load energy efficiency.
- The building produces its own domestic hot water through high-efficiency R744 (CO_2) refrigerant heat pumps. All stormwater and pipework for the hydraulic systems have been specially designed, thermally treated and tested to minimise heat gain or losses.
- No natural gas or fossil fuel is used in the fully-electric building.
- The building has a range of features to improve thermal comfort for occupants, including adequate outdoor air for all spaces, and a mechanical system that can regulate and control humidity, carbon dioxide levels and temperature depending on the functional requirements of the given space.
- Fabric and shading elements were developed as an architectural requirement to optimise daylight while minimising unnecessary heat loads from the sun. The building thereby provides a barrier against external weather conditions.

Digital Build Methodology

In this project, several Building Information Models (BIM) were developed (site data, architectural, structural, and mechanical, electrical and plumbing), which were integrated into a central Revit model (Figure 11). This integration enables the different trades to work on a single BIM model. The central model was then exported into Navisworks Manage to manage clashes and issues between trades and thereby yield the as-built model to prevent these issues from occurring onsite (Figure 12). Navisworks Manage is also equipped with an Augmented Reality (AR) plugin that enables users to view the Navisworks file on a tablet or mobile device and thereby allow the construction team to raise issues, assign them to team members and take photos for office workers who are working remotely (Figure 13).

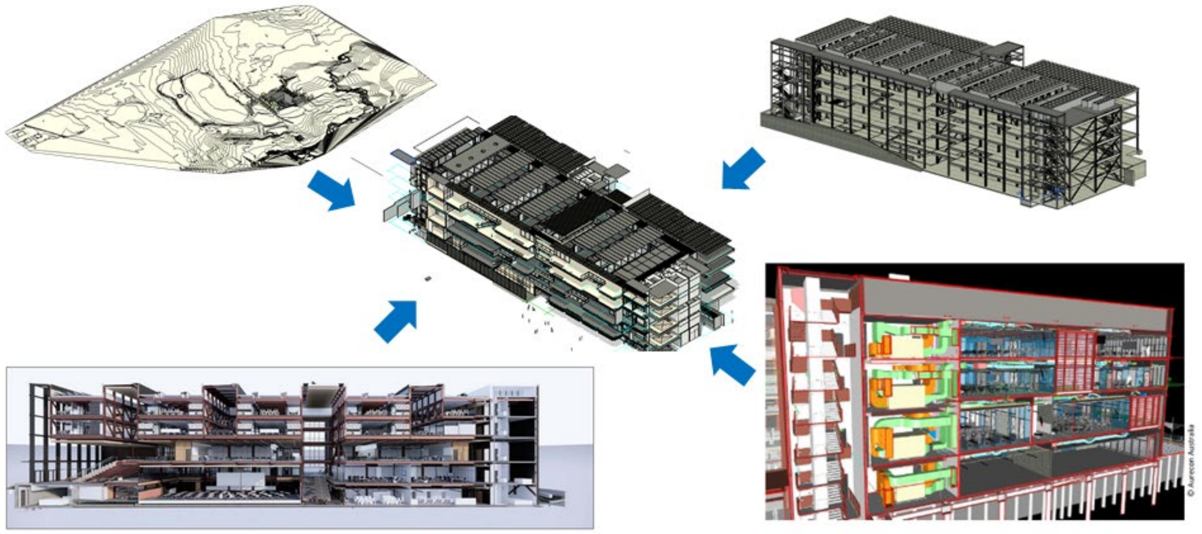


Figure 11. *Central Revit model comprising the site data, architectural, structural, and mechanical, electrical and plumbing models*

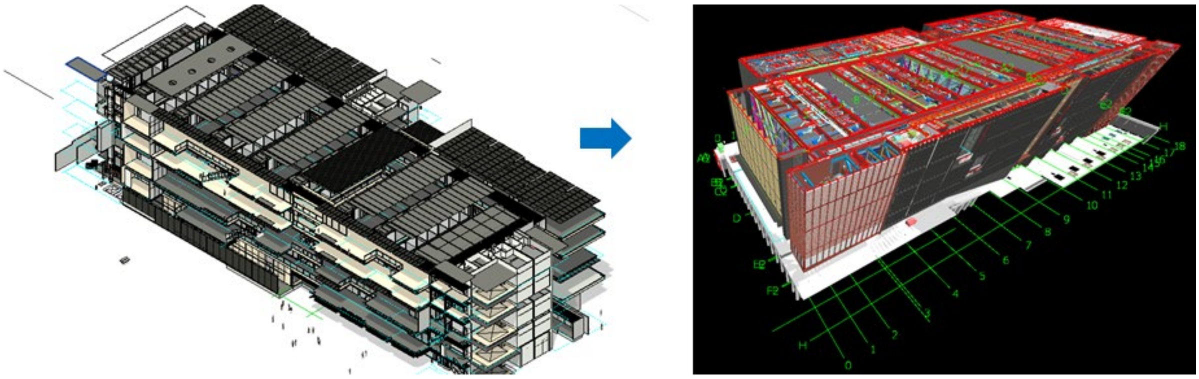


Figure 12. *Exported central Revit model into Navisworks Manage*

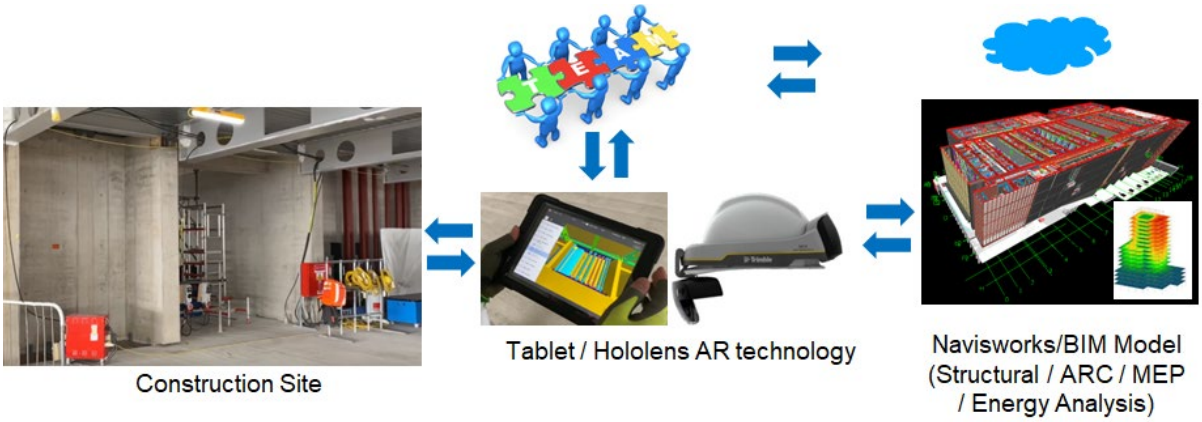


Figure 13. *Navisworks Manage to coordinate between the office and the construction site to resolve issues using augmented reality*

The BIM model for the complex components of the building’s mechanical system is critical to achieving Passive House (PH) verification. The detailed methodology for developing the BIM was not provided, and there are several ways this can be achieved. For example, the Mechanical, Electrical and Plumbing (MEP) components can be designed as modules and stored as a kit of parts via plugins in popular BIM software (e.g. Revit or Tekla Structures) for modelling and reuse as standardised components across projects. A cross-sectional view of the 3D mechanical plant room is shown below (Figure 14), as well as the floor plan (other plans for the upper levels and roof appear similar) to highlight the complexity of the mechanical services (Figure 15).

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Figure 14. *BIM model of the Woodside Building for Technology and Design's mechanical system*

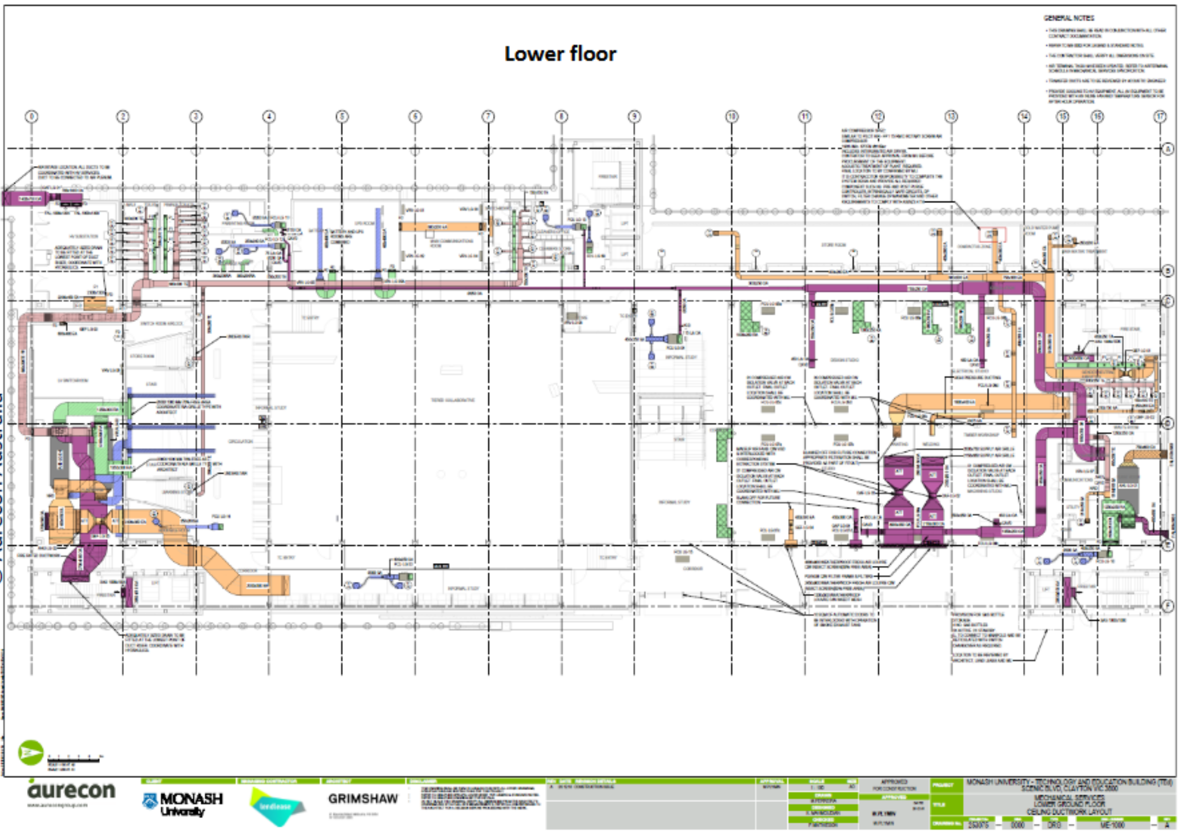

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Figure 15. *Plan view highlighting the complexity of the building's mechanical system*

The following model was provided for the installation of the air-cooled Variable Refrigerant Volume (VRV or VRF) condenser units on the elevated roof platform (Figure 16). This system is a packaged solution that uses refrigerants as the primary heat transfer medium. Different units can operate for heating and cooling simultaneously, which may increase the overall efficiency of the system, as the heat is removed from one area can be used for heating other parts of the building. While this solution is reasonably cost effective, it requires a reasonable area of roof space to accommodate the condenser units. System sizes are limited to reduce the potential hazards attributed to refrigerant leaks in the building.

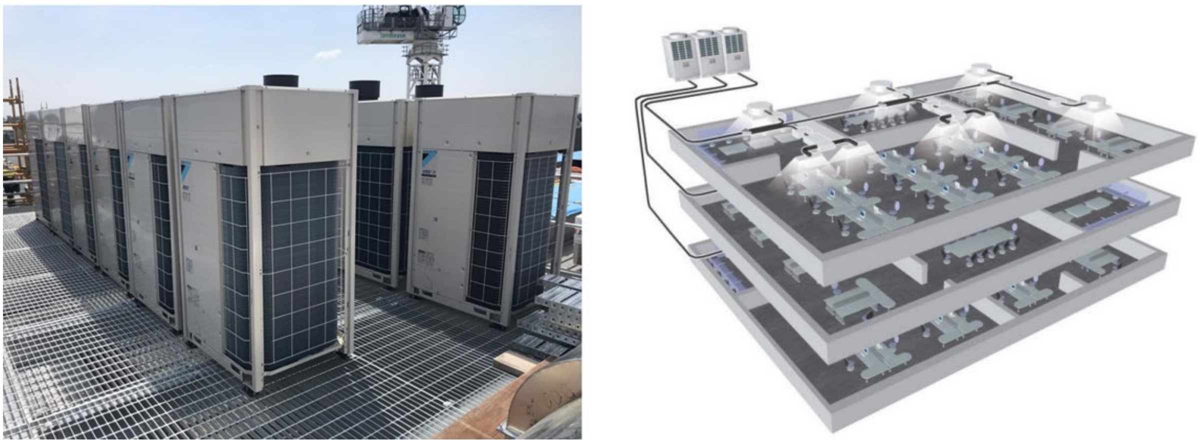


Figure 16. *Variable Refrigerant Volume (VRV) condenser units (left). The model is also shown (right).*

The internal insulated rigid and flexible ductworks are illustrated in Figure 17. These MEP components were captured in the BIM. The high efficiency CO_2 heat pump units for producing domestic hot water are also shown, with Coefficients of Performance (COPs) ranging from 5 to 7. PH recommends the incorporation of heat recovery into the ventilation system.

Figure 17. *Internal insulated rigid and flexible ductworks*

A cross flow plate heat exchanger heat recovery system was used as part of the ventilation strategy (Figure 18). The heat recovery units used in this project are all Eurovent certified (A+ grade), which generally have a thermally broken heat exchanger recovery rate between 81–83%. Effectively, this rate is required to recover sufficient heat from the exhaust air and transfer it to the building depending on ambient conditions. This enabled the building to be fully electric with no reliance on natural gas or any fossil fuels.

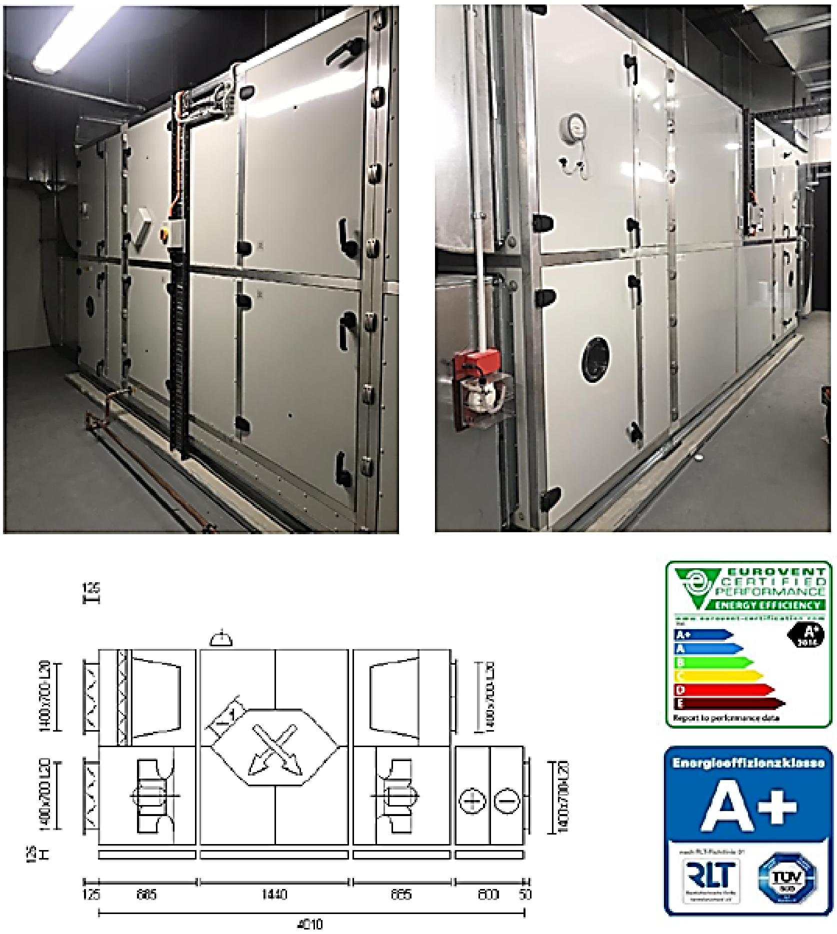


Figure 18. *Cross flow plate heat exchanger heat recovery system and schematic*

Discussion of Benefits of Digital Build

BIM-Driven Coordination between Stakeholders

The following benefits were realised from the digital model:

- *Figure 19* illustrates several issues resolved between stakeholders across different trades. An example is the request for the mechanical team to flatten a duct and move it closer to a wall, whereby a workshop was arranged to rectify this issue. Other examples include the review of penetrations between architectural components and mechanical ductwork, which can be highlighted in the Navisworks model directly such that all stakeholders are viewing the same inter-trade information on the building.
- The mechanical, electrical and hydraulic trades are the major sources of construction issues due to their complexity (Figure 20).
- In Figure 21, it is evident that the majority of closed issues were at the lower ground level of the building. This indicates that the learnings from the lower ground were incorporated in the upper levels, thereby reducing construction issues.
- It is also evident in Figure 22 that most of the issues were resolved during the first half of the design/construction phase. This is important because the different trades review the same model in a coordinated manner in Navisworks Manage, such that the BIM model represents the as-built structure as

closely as possible. Consequently, this minimised the issues being raised while the building was being constructed, and thereby mitigated this risk of delaying the project completion date.

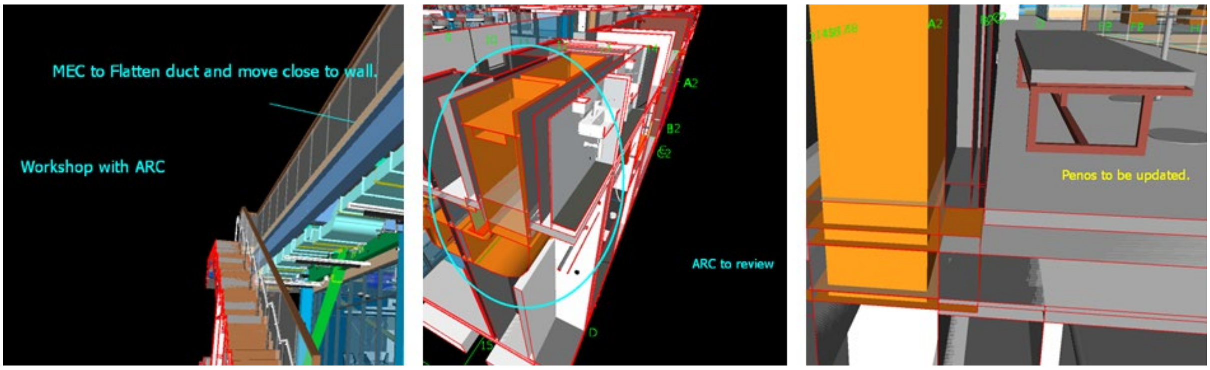


Figure 19. *Examples of issue resolution between stakeholders*

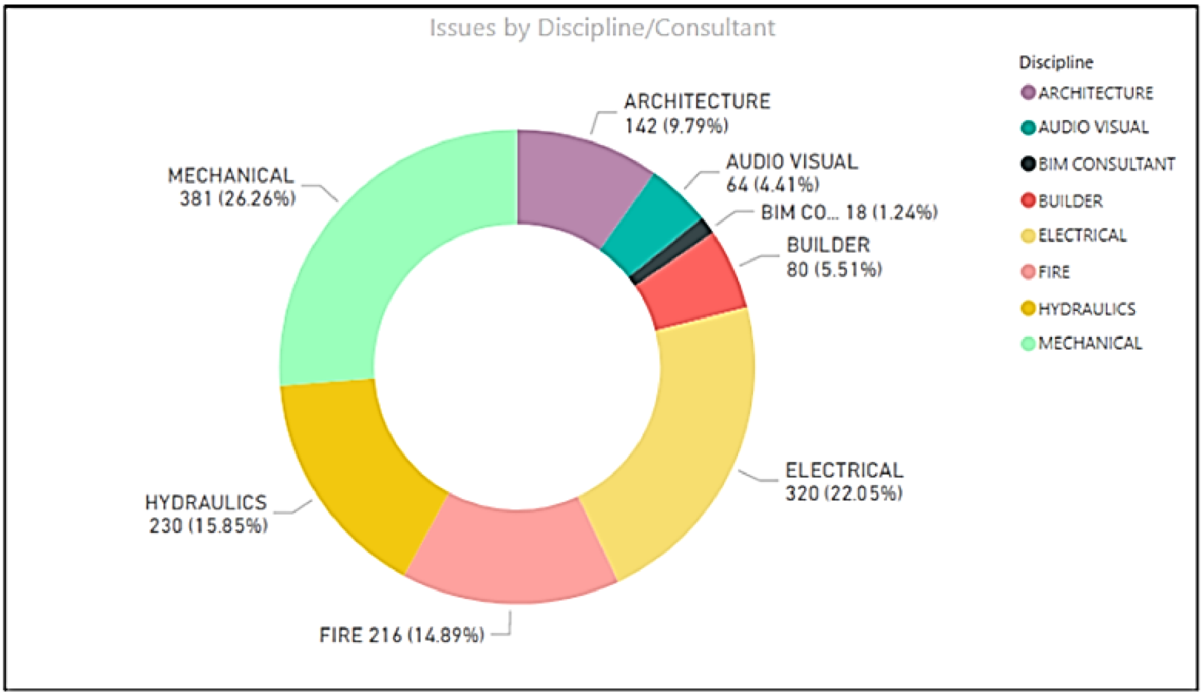


Figure 20. *Identification of issues by discipline/trade*

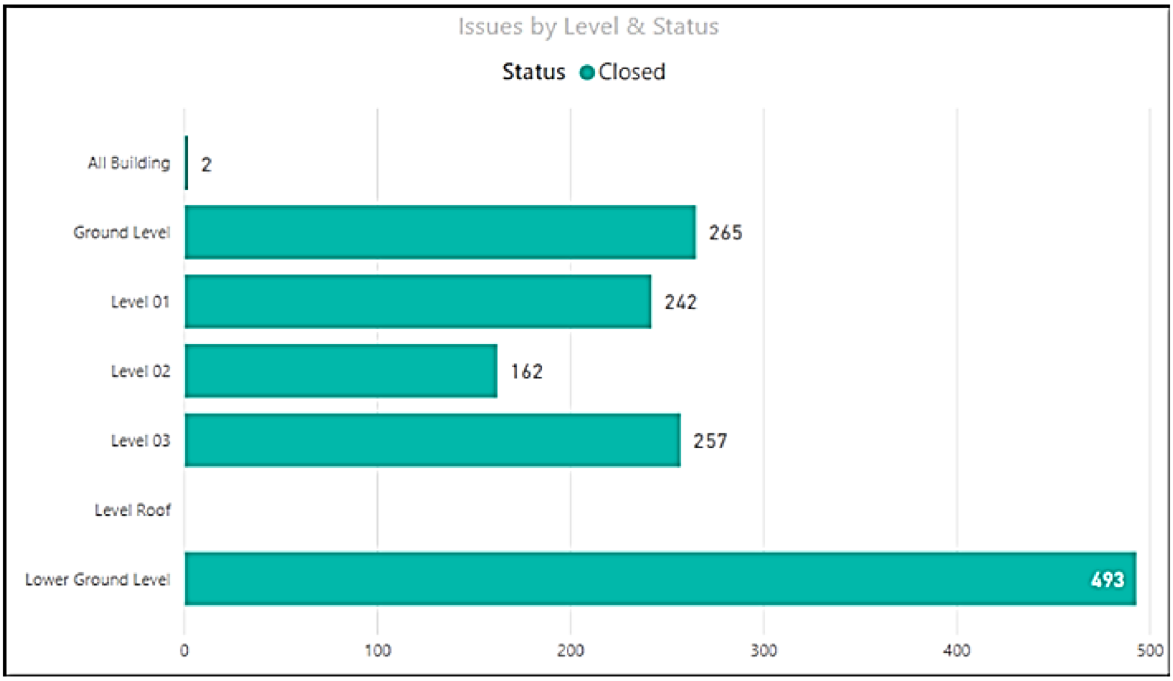


Figure 21. Closed issues on each level of the building

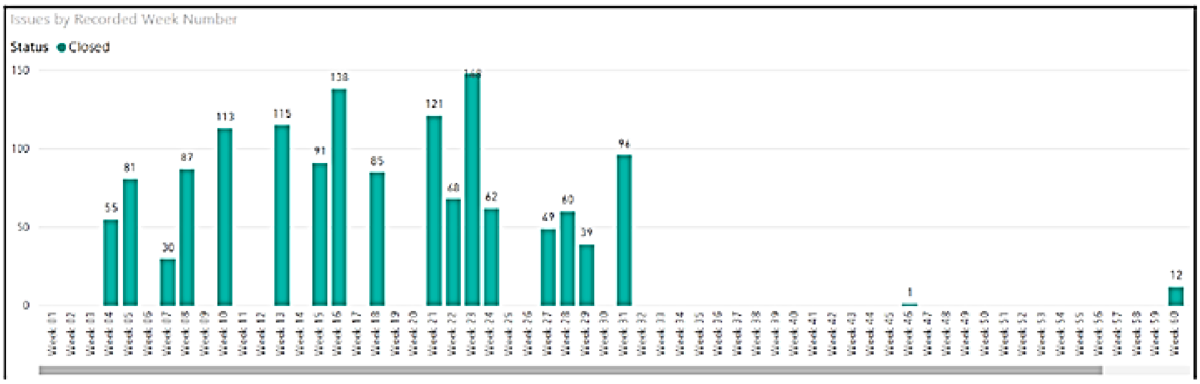


Figure 22. Timeline of closed issues

Passive House Verification

The most significant challenge in this project was designing a mechanical system that would comply with PH standards. There was no precedent to follow given that the WBTD is the first commercial building in Australia built according to PH criteria. Consequently, Aurecon needed to develop a solution that was tailormade for the building and delivered the functionality Monash University was seeking for the first time in an Australian context.

To this end, the BIM enabled 6 different simulations to be run to select the most efficient mechanical system. The material properties and geometries of the HVAC systems were input into dynamic energy simulation software to expedite the modelling of the energy performance and resulting thermal comfort of the building (e.g. EnergyPlus, DesignBuilder, TRNSYS, ESP-r), with the results shown in Figure 23. Aurecon then went through the design process to identify other factors that would impact the building’s energy consumption such air distribution systems and the overall efficiency of the thermal plant.

WBTD was designed for optimum efficiency, excellent Indoor Air Quality (IAQ) and maximum thermal comfort with a special focus on building physics principals. The mechanical system was specifically designed to minimise losses and optimise efficiency. The air distribution systems were designed to minimise inefficiencies and resistance. A dedicated outdoor air system was equipped with a heat exchanger for recovering heat. The air-conditioning system was tailormade for functional spaces of the building, which comprises an overhead supply, underfloor air distribution, and radiant in-slab heating and cooling systems connected to a modular heat recovery VRV system. This enables the system to serve spaces when needed without adversely impacting its efficiency. Figure 23 compares the energy consumption of different HVAC systems whereby VRV and CHW fan-coil unit systems were shown to be very good options to meet energy performance requirements. Internal heat loads such as lighting and equipment are the most dominant loads in the building that need to be managed well to reduce the overall impact on the mechanical system.

The perception of thermal comfort varies from person to person based on several variables, including activity level, clothing level, properties of the surrounding ambient environment, such as air temperature, radiant temperature, body surrounding air velocity and humidity of the air. According to ISO7730 (Ergonomics of the Thermal Environment), most of the building occupants would experience good thermal comfort if:

- the air is not too humid
- air speeds remain within the acceptable limits (for speeds under 0.08 m/s, less than 6% of people will feel a draft)
- the difference between radiant and air temperature remains small
- the difference of the radiant temperature in different directions remains small (less than 5°C; radiation temperature asymmetry)
- the room air temperature stratification is less than 2°C between the head and feet of a sitting person
- the perceived temperature varies less than 0.8°C.

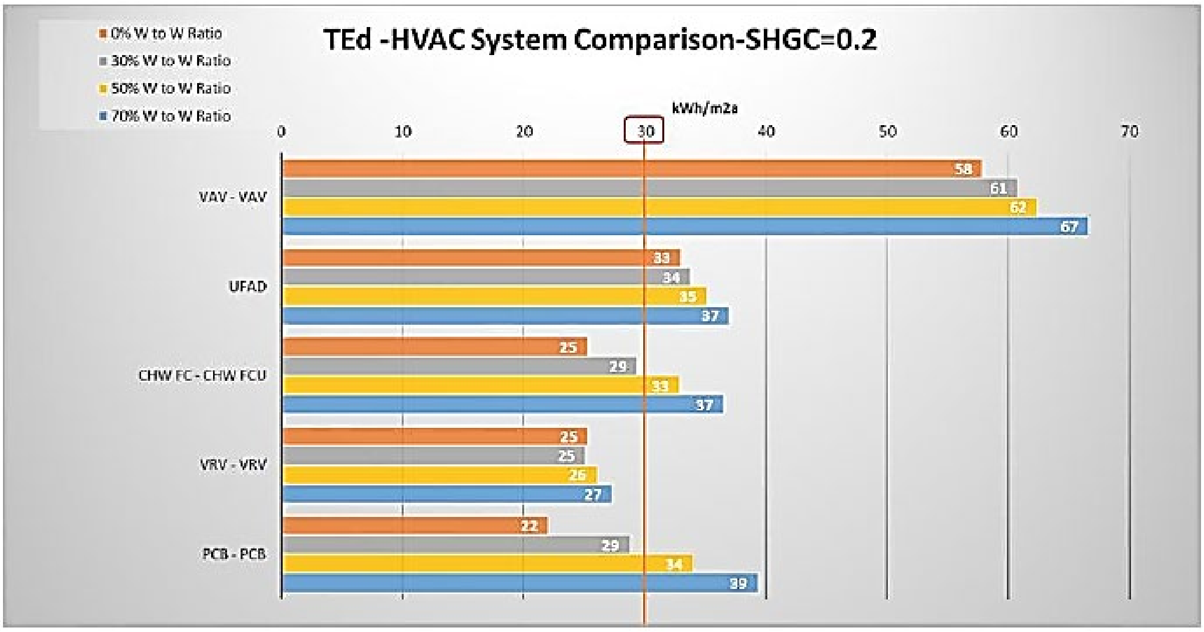
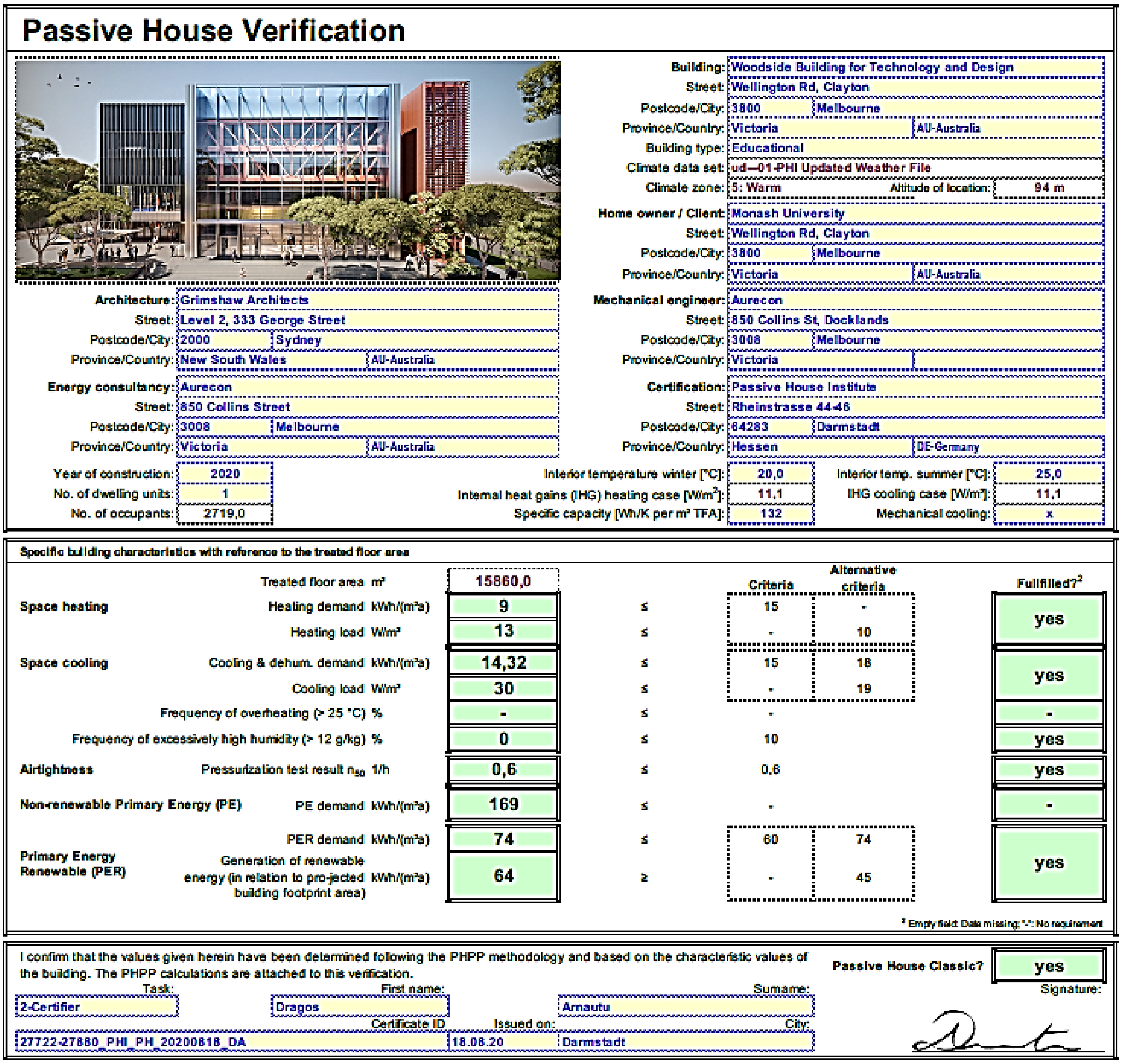


__Figure 23.__ Energy performance of the 6 different HVAC systems for satisfying Passive House verification criteria

By achieving PH verification (Figure 24), the building was designed for high occupant comfort. This was ensured through the following measures:

- The high-performance thermal envelope reduces the heat flow between the interior and exterior environment
- The thermal envelope reduces interior draughts as the interior surface temperatures vary only slightly from the surrounding temperature in the room, resulting in low radiant temperature differences between interior surfaces
- An airtight envelope reduces drafts and uncontrolled air movement
- Exterior shading reduces glare and non-useful solar heat gains in the summer
- Provision of 100% fresh air via heat recovery ventilation
- Occupant control of operable windows, internal blinds and ventilation systems

The PH verification results are presented in Figure 24. These include the fulfilment of several criteria, namely space heating and cooling demands, airtightness, and non-renewable and renewable primary energy.



Passive House Verification

Building: Woodside Building for Technology and Design
Street: Wellington Rd, Clayton
Postcode/City: 3800 Melbourne
Province/Country: Victoria AU-Australia
Building type: Educational
Climate data set: ud—01-PHI Updated Weather File
Climate zone: 5: Warm Altitude of location: 94 m

Home owner / Client: Monash University
Street: Wellington Rd, Clayton
Postcode/City: 3800 Melbourne
Province/Country: Victoria AU-Australia

Architecture: Grimshaw Architects
Street: Level 2, 333 George Street
Postcode/City: 2000 Sydney
Province/Country: New South Wales AU-Australia

Mechanical engineer: Aurecon
Street: 850 Collins St, Docklands
Postcode/City: 3008 Melbourne
Province/Country: Victoria

Energy consultancy: Aurecon
Street: 850 Collins Street
Postcode/City: 3008 Melbourne
Province/Country: Victoria AU-Australia

Certification: Passive House Institute
Street: Rheinstrasse 44-46
Postcode/City: 64283 Darmstadt
Province/Country: Hessen DE-Germany

Year of construction: 2020
No. of dwelling units: 1
No. of occupants: 2719,0
Interior temperature winter [°C]: 20,0
Internal heat gains (IHG) heating case [W/m^2]: 11,1
Specific capacity [Wh/K per m^2 TFA]: 132
Interior temp. summer [°C]: 25,0
IHG cooling case [W/m^2]: 11,1
Mechanical cooling: x

Specific building characteristics with reference to the treated floor area

					Criteria	Alternative criteria	Fullfilled?^{2}
	Treated floor area	m^2	15860,0				
Space heating	Heating demand	kWh/(m^{2}a)	9	≤	15	-	yes
	Heating load	W/m^2	13	≤	-	10	
Space cooling	Cooling & dehum. demand	kWh/(m^{2}a)	14,32	≤	15	18	yes
	Cooling load	W/m^2	30	≤	-	19	
	Frequency of overheating (> 25 °C)	%	-	≤	-		-
	Frequency of excessively high humidity (> 12 g/kg)	%	0	≤	10		yes
Airtightness	Pressurization test result n_{50}	1/h	0,6	≤	0,6		yes
Non-renewable Primary Energy (PE)	PE demand	kWh/(m^{2}a)	169	≤	-		-
Primary Energy Renewable (PER)	PER demand	kWh/(m^{2}a)	74	≤	60	74	yes
	Generation of renewable energy (in relation to pro-jected building footprint area)	kWh/(m^{2}a)	64	≥	-	45	

^{2} Empty field: Data missing; "-": No requirement

I confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The PHPP calculations are attached to this verification.

Passive House Classic? yes

Task: 2-Certifier
First name: Dragos
Surname: Arnautu
Certificate ID: 27722-27880_PHI_PH_20200818_DA
Issued on: 18.08.20
City: Darmstadt
Signature:

Figure 24. Passive House verification of the Woodside Building for Technology and Design

The PH standard requires that an air change rate (ACH) of 0.6 per hour be achieved at a pressure of 50 Pa. To this end, airtight barrier implementation was required to be continually examined while the project progressed. Attaining an airtight building is a function of several variables which include:

- Minimising service penetrations through the airtight barrier
- Designating the responsibility of airtight barrier execution during design and construction
- Testing of bespoke elements of the building prior to utilisation onsite to verify the performance of the product
- Testing of the envelope prior to fit out and paying close attention to junctions as this can have a significant impact on achieving an airtight building
- Where service penetrations were required, they are generally located in one accessible location where the airtight barrier or caulking can easily be applied
- All duct risers penetrating the airtight barrier were capped at the top or provided with proprietary products, such as dampers and collars

Benefits of Connected Data

People issues are significant throughout all Stages of a building project. For the WBTD, the vital importance of the team, the dependence on effective collaboration with a range of stakeholders and the reliance on an individual's expertise to achieve the precision and accuracy necessary for a complex build was evident from the Definition through to Handover and Closeout Stages. =

Further industry baseline metrics to demonstrate the benefits of digital build need to be established for modular and offsite construction. Even so, the WBTD case study found PH verification and some of the BIM data to support the benefits of a CDE. Research has also identified numerous benefits from using BIM in areas such as quality assurance, buildability (Sompolgrunk et al, 2022) and safety (Zhang et al, 2015).

The inherent nature of a 'project' that has timelines and strict contractual obligations, aligned with Design, Build and Commission through to Handover and Closeout Stages, can inhibit the innovation process. While participants indicated their standards, regulations and contractual compliance processes were in place for each Project, detailed awareness of the VDAS was not evident. The VDAS guidelines for managing data and information assets (*process*) is overwhelming for many in the industry. It was found that the work environment has a lack of connected data, differing workflows and time lags with federated data. The approach to managing (*content*) data and information is fragmented because data is stored in disconnected data sets.

Regarding the Operations and Maintenance Stage for the WBTD project, the 'data as part of the space' was a community benefit aligned with the *people* element, that resulted from the construction project. The sensors installed in the commissioned building for the WBTD has resulted in a living building, which enables significant teaching, learning and research opportunities for the users of the building including academics, students and their collaborators from wide ranging disciplines (Burbridge, 2017).

Current *technology* does not always have functionality to achieve ISO 19650 information management requirements. New systems have significant costs, that are often out of reach for Tier 3 and Small and Medium Enterprises (SMEs) (most traders in the construction sector); the Australian construction industry comprises SMEs (Australian Broadband Advisory Council, 2022; Hong et al, 2019). To facilitate digital transformation of SMEs, governing bodies need to lead the implementation and strengthen collaborative partnerships amongst stakeholders. Engaging contractors, as early as possible in the project, from the Design Stage of a project is recommended to achieve enhanced collaboration, integration of design and construction, along with improved fiscal and staff management (Hastie et al, 2017; Laryea & Watermeyer, 2016).

The VDAS is an aspirational blueprint and an essential part of the overarching governance principles that could assist in guiding the digital transformation of the construction industry in Victoria. A less complex version of the VDAS that can be part of the new skills training options for the construction industry by the Government is recommended.

The limitation of this research is only a small number of the Project stakeholders were available for interview. It is recommended that focus group sessions with representatives from each Project stakeholder group be conducted to develop prototype data and information approaches and prioritise the steps required to advance digital transformation for the industry.

The findings herein are summarised from interviews conducted for the WBTD case study. The benefits of connected data obtained from interviewing the Lendlease Project Managers are listed as follows and presented in Figure 25:

- Digital data and information systems enabled Lendlease to find millions worth of savings, without moving the end date of the project. Time savings are equivalent to cost savings
- Being able to share a live BIM enabled stakeholders to share connected data “we had the consultant team redoing design while having live input from the subcontractors to indicate what would work or look at this, which doesn’t normally happen” (Senior Project Manager, Lendlease)
- Less staff were required, it was possible to do things much faster, with much more abortive work and time frames were halved
- Allows staff to apply all the tools in the arsenal to get things done as fast as practical
- Claimed to eliminate clashes completely using Navisworks during the first half of the design/construction phase, which is consistent with the above findings from the digital build
- Construction issues (many) resolved quickly
- Navisworks/BIM integration enabled live input, and construction was completed ahead of schedule
- Remote monitoring of building performance
- Passive House (PH) verification achieved within a tight deadline.

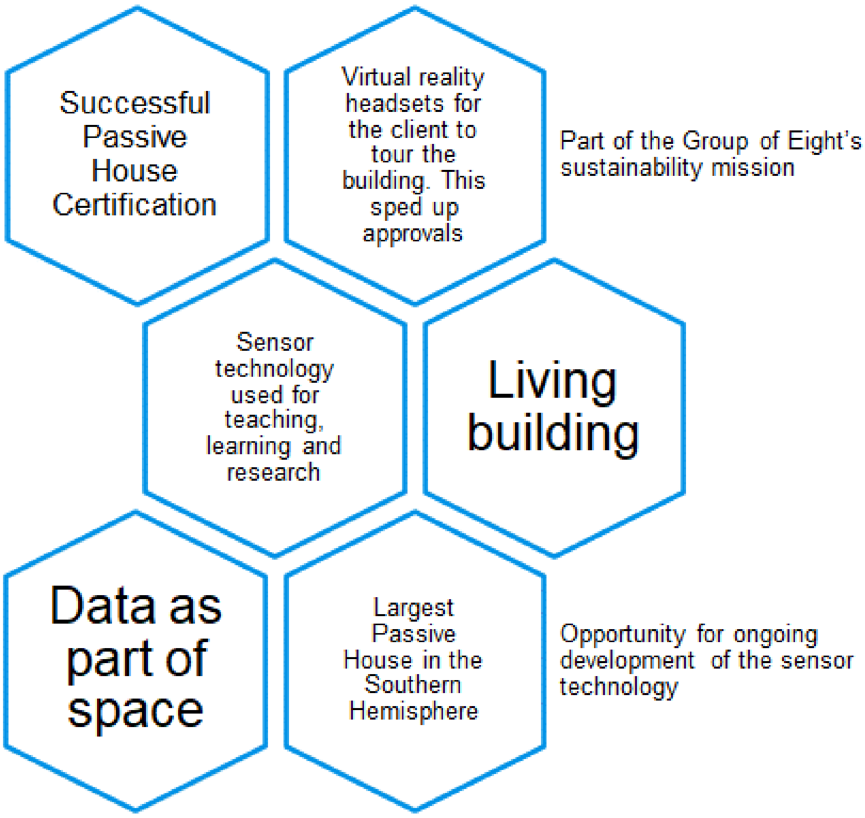


Figure 25. *Benefits of connected data in Woodside Building for Technology and Design project*

Reported Industry Benefits to Stakeholders

Numerous stakeholder benefits were reported in the interviews conducted for the WBTD project. Benefits such as a rapid collaboration from working with a live model, through to stakeholders transforming how they work with digital technologies because the gains are so obvious and plentiful. Working with a digital model underpinned successful PH verification that was achieved during the project. Digital technologies, such as virtual reality headsets, were used to enable university community stakeholders to explore the building model and expedite approval processes. The importance of digital build was highlighted for greater efficiencies with commissioning, and the ongoing maintenance and management of the building. The following quotes refer to the industry benefits from digital systems and connected data derived by WBTD stakeholders:

- “Benefit of the BIM was we were able to share the live model. We had the consultant team redoing design while having live input from the subcontractors indicating this wouldn’t work or look at this...… which doesn’t normally happen. It was a live process where we only got one-third of the way and the subcontractor was able to commence producing the steel for the 30% planning already done. It was a very iterative live process. Structural steel engineers and structural steel detailers work hand in hand. Worked bay by bay through the building and identified the holes for the structure. It was a rapid collaboration. It was bringing 2 buildings together.” [Lendlease, Senior Project Manager (Services)]
- “Ten to fifteen years ago, when we started to work in the 3D field it was not accepted by all. To make progress it must accepted by the whole industry not just the consultants. Must have the trade partners on board. A lot of our trade partners are Tier One level, and they understand. Don’t think trades know what the cost has been because they derive so much benefit. They need less staff, can do things much faster, much more abortive work, time frames to go through a process have been halved. When you see something in 3D the problems are halved.” [Lendlease Head of Conversion and Strategy]

- “For public stakeholders, the Woodside building is a landmark. It is an award-winning best in class, largest educational building in the world that has certified passive-house, and this puts Victoria on the world map.” [Lendlease, Head of Conversion and Strategy]

The below quotes are from a Lendlease Senior Construction Manager:

- “For the commissioning, we used the model and a heap of data to help us through the commissioning site. This comes back to the value of connected data; we had some issues and used the model in conjunction with the Building Management System (BMS). We had some control aspects the consultants had issues in relation to heating, cooling. Because it was a passive cooling it put on another level of complexity with outside air and control. We used the model and the data from the BMS to home in and found the cause. It took quite some effort.”
- “If you’ve got the central knowledge base – all the information and maintenance [details] are kept updated. Shows timeline of the building as it ages. A common source of knowledge. It is critical to managing a building.”
- “Stakeholder [the term is] widely encompassing. It includes everyone from architects, builders, design consultants, user groups, students, faculties and other layers at the University e.g. the Design Review Committee. Digital did help. Virtual Reality sessions were conducted with user groups, and they could walk through the model and get their heads up to speed much faster to expedite the approval process. The design and review committee could visualise as they had walked through the model and made decisions on the spot.”
- “A similar booking process and a digital platform enabled subcontractors to book deliveries.”
- “It was one of the best projects I've worked on from a stakeholder collaboration.”

Lessons Learned for Increasing Industry Adoption of the VDAS

The WBTD project was completed in 2020, coinciding with the publication of the VDAS. The VDAS (introduced in Section 2.2) is aligned with the lifecycle of key Victorian Government investment and ISO 55000 stages including the 7 Stages: 1. Brief, 2. Concept, 3. Definition, 4. Design, 5. Build and Commission, 6. Handover and Closeout, and 7. Operations and Maintenance. This research focused on the VDAS Stages 4–7.

Senior Project Lendlease staff that were interviewed explained that the WBTD project was not fully digital, though they were able to fulfil the objectives of the VDAS: “Everything is available at your fingertips such as the maintenance history for every piece of equipment. All the information that is critical to managing the building and the lifecycle of the equipment in the building.”

Of the 9 interviews undertaken for the WBTD project, it was found that there was limited familiarity with the VDAS. A Digital Engineer from the construction company that was interviewed described the VDAS approach as “academic and that their system does not work in a way that support it so much.”

The lessons learned are categorised and reported under the Knowledge Management System elements, namely *people, process, technology* and *content* (Table 9).

Table 9. *Adapted from Standards Australia (2005)*

Element	Definition
People	The ‘who’ such as digital engineers, asset managers, project sponsors, data custodians, architects, consultants, internal and external stakeholders.
Process	The ‘how’ and includes standards, regulations, technical guides, plans, checklists, codes, taxonomies, policies, procedures and other explicit sources.
Technology	The ‘tools’ such as software, hardware, storage, digital systems, platforms, databases and other expert systems.
Content	The ‘what’ such as research data, metadata, database records, graphics, maps, visualisations, reports and other digital objects.

People

- New roles, such as environmentally sustainable design and social procurement that are of most relevance to the Design Stage, in addition to the building information modelling manager, digital engineer and data champion, which are roles relevant to the VDAS Stages 1–6 that are being established.
- Managing architect and designer input, as they continue to tinker with digital models, was viewed as important in the Design Stage. Human effort to edit data to a high standard remains essential, for example “the amount of work and the human input that goes into the 3D model is vast, and we had a 3D modeller, who was engaged very early and I would have thought he would have been working 18 hours a day for 4 months, just in the models… Was it smooth? No. Was it beneficial? Yes.” (Senior Construction Manager)
- In Stages 2 and 3, it was raised that substantial commercial and financial penalties linked to failure to deliver on a project stifle innovation and technology transformation. Such penalties are a disincentive for adoption of knowledge management best practice.

Process

- Based on being “more efficient with the upfront process at the Definition Stage, the design processes are quicker” according to a Senior Construction Manager. Regarding process, the application of standards to achieve compliance with laws and regulations is applied throughout all Stages of the VDAS.
- “Each supply chain has their own internal processes that we don’t have access to them.” (Digital Engineer); related to Stages 4 (Design) and 5 (Build and Commission), and a reflection of the fragmented workflow experienced by team members.
- Legislative requirements of government and standards, such as ISO 19650, require the right people to apply the processes. According to a Project Lead Digital Engineer, “the Government enforces rules and many of us don’t understand why they are important. Articulating ‘why’ is the missing piece.”
- Aligned with Stage 5 (Build and Commission), offsite production processes to speed up construction were applied in the WBTD project and resulted in improved safety, less waste and improved communication.
- For final VDAS Stages 6 (Handover and Closeout) and 7 (Operations and Maintenance), audit and assurance processes were set in place for Operations and Maintenance to develop further. This was evident from the successful certification of Passive House (PH) status that was implemented and awarded.

Technology

- Stakeholders are challenged by “a sea of different technology systems that are not connected” (Digital Engineer). The *technology* does not always have the functionality required to achieve the digital asset management requirements set in the standards.
- The *technology* using BIM has enabled visualisation of the build prior to being on the site. Using the 3D technology makes it possible to build with confidence.

- To speed up project reporting an inhouse data warehouse *technology* system ingested data from numerous sources to generate reports was used by the Construction team.
- The *technology* and the connected data *content* underpinned the successful PH verification.
- Sensors were installed throughout the WBTD building to enable a living building infrastructure, for the teaching, learning and research stakeholder communities to optimise; this involved *technology, process* and *people* elements throughout VDAS Stages 3-7.

Content

- Diminished data (*content*) integrity was reported from transferring data around multiple *technology* systems using Application Programming Interfaces (APIs) during the Project Stages. For example, "when you take data out of one system and put it in another you lose the connections between the revisions and the versions. It is difficult to do what the ISO is trying to achieve. Difficult to apply in practice." (Digital Engineer)
- During Stages 4 (Design) and 5 (Build and Commission), a level of confidence is gained from working in 3D and knowing the building would look aesthetically good and that the design would work.
- For Stages 5 (Build and Commission) and 6 (Handover and Closeout) the model and a vast amount of data was used to commission the site. Significant challenges were resolved from troubleshooting using the data derived from the BIM in conjunction with the Building Management System to achieve the required heating and cooling (which provides automated control of the energy in the building for the PH verification).

Small School Project

Project Details

The Cowwarr Primary School (Figure 26), located at Church Street Cowwarr in Victoria, was significantly damaged by an electrical fault fire in January 2020. The main building, along with the library and the amenities, were destroyed. The Victorian School Building Authority provided relocatable buildings so students, who were temporarily relocated to Heyfield Primary School, could return to the school. Support services, including counselling, were made available to staff and students.

The Victorian Government committed to rebuilding the school. They consulted the community through an online survey from Tuesday 4 March 2020 until Wednesday 25 March 2020. They gave feedback from the survey to the architects so they could begin work on designing the rebuild. After close consultation with the principal and school, they released designs for the rebuild in December 2020. The new school includes office and administration spaces, a staff centre, gallery, practical activities area and 2 classroom spaces.

Figure 26. *Architectural model of the Cowwarr Primary School*

The project details, including budget, timeline (tender, design and build and completion year), building geometry and stakeholders are provided in Table 10. Generally, the team comprised Fleetwood and FSMA Architecture, who conducted the design process in close consultation with the community to ensure they best met their needs, including a new staff centre, gallery, practical activities area and 2 classroom spaces (Sensum, 2023). They incorporated red brick elements to coordinate with the town's historic buildings.

***Table 10.** Cowwarr primary school project details*

Project details	
Name / Client & Owner / Value	Cowwarr Primary School / Cowwarr Victoria / $1.9m
Tender / Design & Build / Completion Year	Burnt down in fire in 2020 / Rebuild commenced in 2021
Gross area	490 sqm
Architect/Interior Designer	FMSA Architecture
Prefab Design and Construction	Fleetwood

Challenges/Design Considerations

The key challenges of this modular building project are:

- early design completion
- access to consistent drawings to expedite off-site manufacturing/assembly and on-site assembly
- coordinated efforts between multiple trades in the factory
- the adoption of a Common Data Environment (CDE) in Fleetwood as a central source of information for a digital build project is in its infancy, and consequently, limited licensing is provided only for the design and steel departments.

Digital Build Methodology

BIM was developed to capture the modular design of the Cowwarr school, which involved the manufacturing of modules in a controlled factory environment with the modules being shipped and installed onsite. The detailed methodology for developing the BIM was not provided, and there are several ways this can be achieved. In the context of modular structures, the modules can be stored as a kit of parts via plugins in popular BIM software (e.g. Revit or Tekla Structures) for modelling and reuse as standardised components across projects.

Several components were extracted from the BIM model including the site and locality plans, central model details and ground module arrangement, elevations of the school, and the 3D structural model. The following details are lacking in the model:

- While the site and locality plans (Figure 27), architectural plans (Figure 28) and elevations (Figure 29), and structural models (Figure 30) can be extracted from the Revit model, they are generally missing connection details, and no properties are assigned to the modelled components (e.g. structural, thermal).

- BIM model is lacking integration with a CDE to the assess benefits of digital build in terms of coordination, conflict resolution and so on. This may be attributed to the standardised modular design, manufacturing and construction methods of the school, which do not require a collaborative environment as most of the build is completed in a controlled factory environment.

However, CDE may be integrated with the BIM to expedite offsite manufacturing and onsite assembly, by facilitating collaborations between contractors early in the design process, but this may be relevant for large projects with complex systems (e.g. complex mechanical and electrical systems that need to be assembled onsite and have the potential for clashes with structural components). In this project, the following advantages are provided by the BIM model alone:

- create assembly drawings and material take-offs
- generate an analytical model to assess the structural viability of the steel framed module during lifting and transportation
- conduct energy and daylighting optimisation from the building mass if the material properties are input into the system
- simulate the manufacturing process in the factory to reduce clashes between trades and thereby expedite the assembly process.

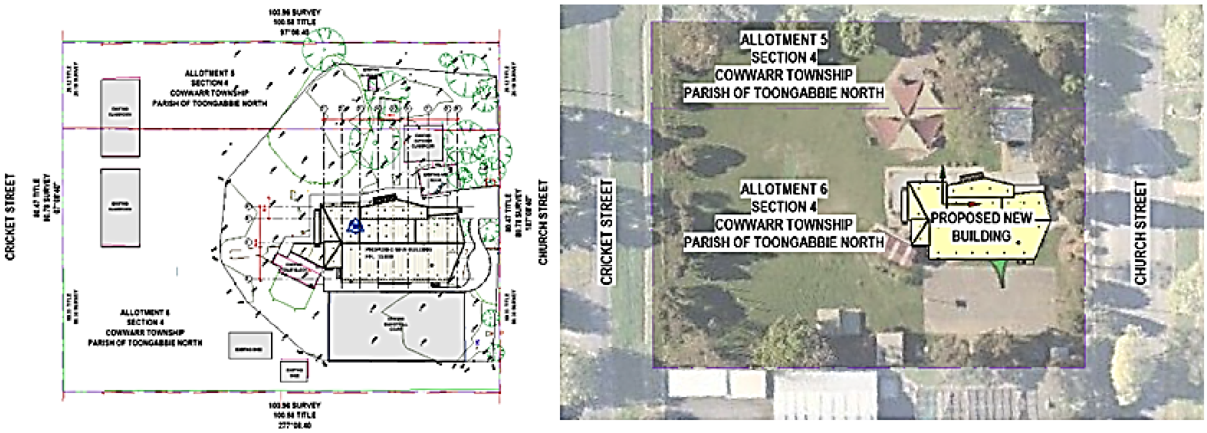


Figure 27. *Site plan (left) and locality plan (right) for the Cowwarr Primary School*

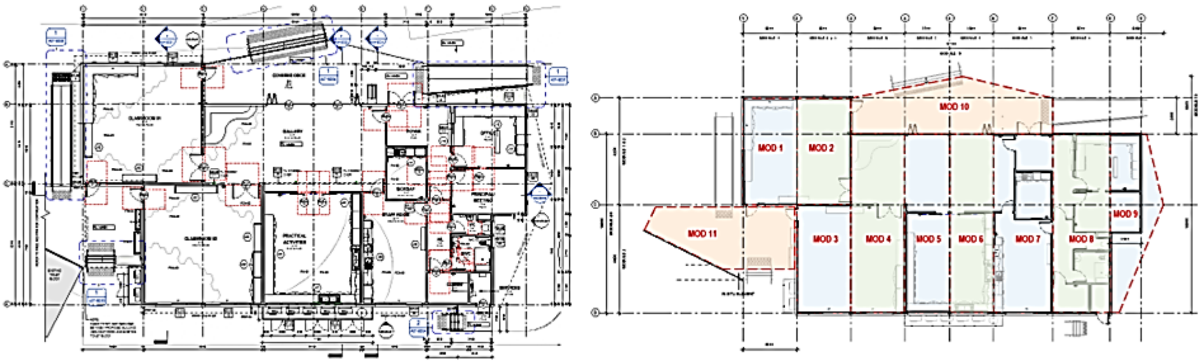


Figure 28. *Central model plan details (left) and ground module arrangement (right)*

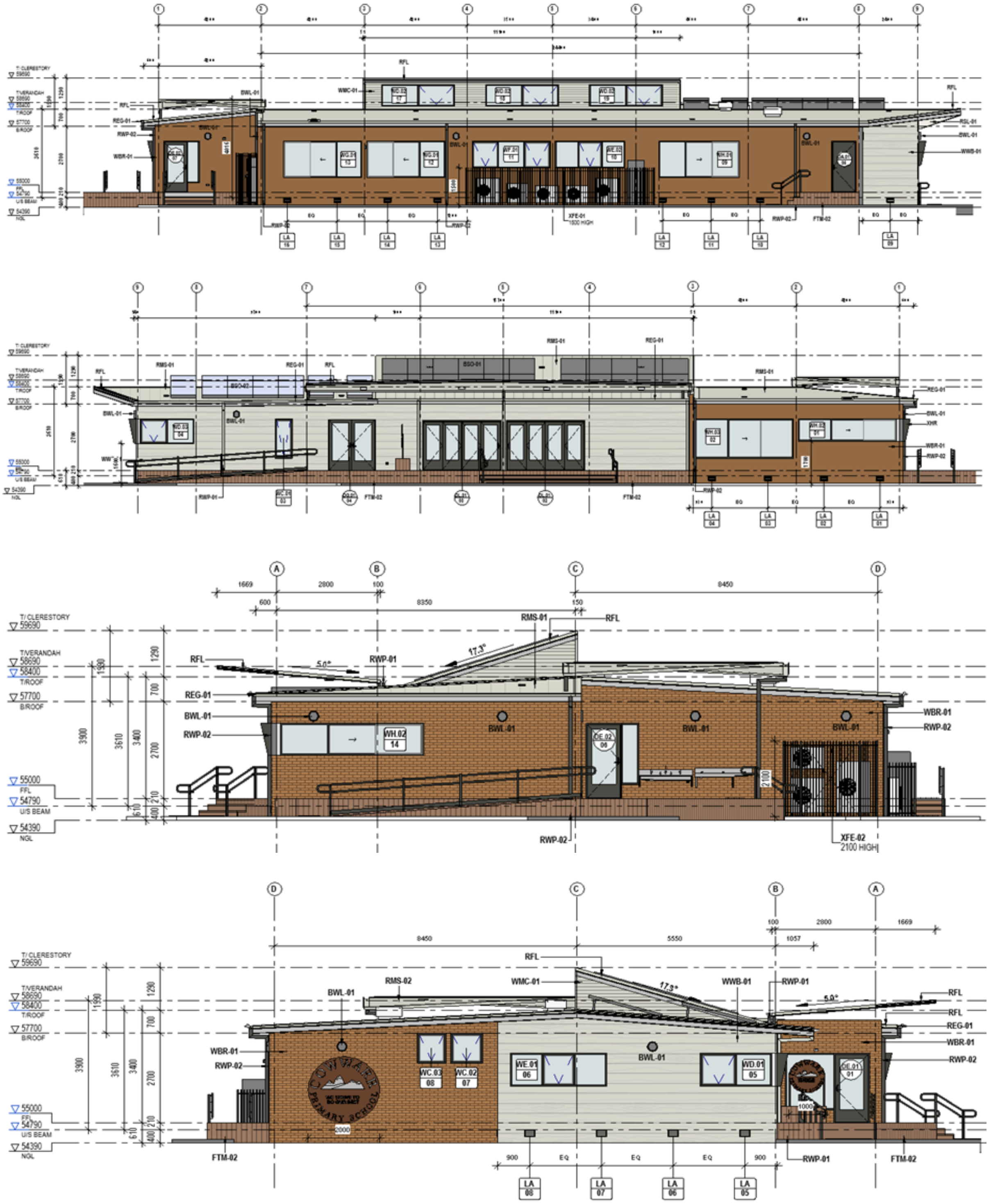


Figure 29. Elevations in order from top to bottom (North, South, West and East)

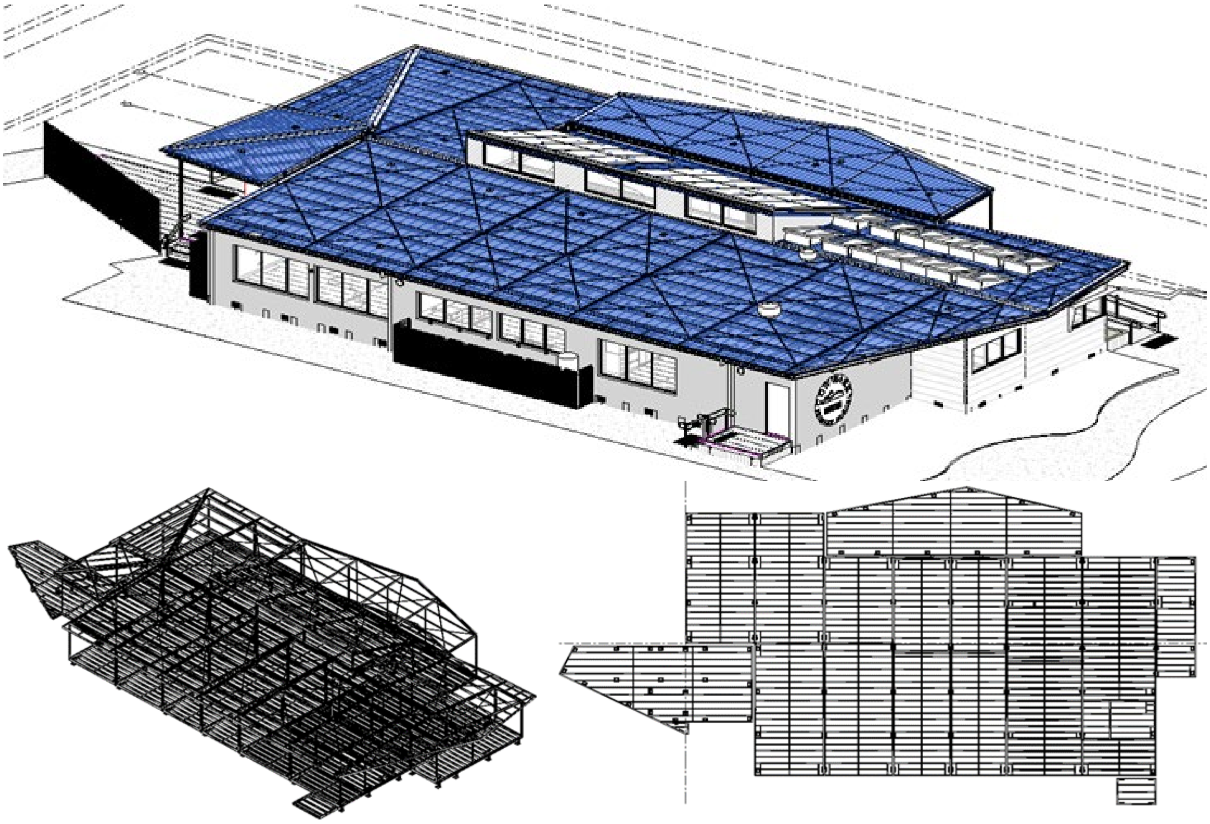


Figure 30. *Structural model attached to central model, and 3D and plan views of the structural model*

Discussion of Results/Benefits

Key stakeholder benefits from digital systems and connected data underpinning the Small School Project were identified during the 3 interviews conducted with senior Fleetwood staff, which were qualitative. Speeding up work significantly for clients was reported. The following quotes are from the Head of Design & Innovation, Fleetwood:

- "…Output of the standard documentation from the modelling exercise achieved automated dimensioning, sheets, formatting and outputs resolved in Advance Steel—speeding up work that would previously take days down to 8 minutes—*additional time* was still necessary if you were doing something slightly bespoke."
- "Computational design work in Advanced Steel to create a dialogue box designer for standard floor systems. For our design team rather than geometrically drafting, dialogue box parameters around the system—system elements were being utilised. System will automatically generate the geometry for the design work—think this is a 40% uplift in savings for steel design team. Drafting in CAD environment. Great deal of work and integration."

The Virtual Design and Construction Manager, Fleetwood, spoke of a reduction in clashes and the number of stakeholders involved from the use of 3D facilities and the importance of capturing data from the production floor:

- "By Providing an interface where Steel, Light Gauge Steel and Architecture can be overlayed utilising 3D facilities, we reduce clashes by increasing both visibility of those clashes on an integrated system and the number of stakeholders involved. The Mark-up tool we have enabled production to provide feedback – from the floor—regarding issues that only come to light once production has begun. This is information would have normally been lost as there was no "easy" way to send this feedback upstream."

To improve the workflow, the Virtual Design and Construction Manager recommended earlier engagement with key stakeholders:

- “We're coming from a space where people are siloed, the lessons learned have become siloed. How can we stop that from happening? Well, one of the ways that we can stop that from happening is earlier engagement with those manufacturing construction, estimating people sooner.”

Roles and responsibilities of strategic actors who determine long-term whole of government budgets, strategic infrastructure needs and approaches.

Interviews were limited to Fleetwood staff members. Interviews with personnel that are directly involved in the design and construction process are crucial to gain a detailed understanding of the digital build methodology and document the benefits.

Lessons learned for increasing industry adoption of VDAS

The lessons learned for increasing industry adoption of VDAS are sectioned under the *people, process, technology* and *content* criteria follow.

People

- Inhouse design expertise and embedded knowledge were highlighted as key to the Design Stage of the Project. Involving people in estimating for manufacturing is required at the project’s Design Stage. “We're coming from a space where people are siloed, the lessons learned have become siloed. We can stop that from happening from earlier engagement with those working in manufacturing construction and estimating sooner.” (Virtual Design Construction Manager).
- Having contractors involved as early as possible in the project (from the Design Stage through to Build and Commission) was viewed as essential to achieving efficient outcomes such as improved data and information management, for both Projects. In addition, the frustration from the lack of senior management support to lead the digital transformation required was raised by interview respondents.

Process

- For Project Two, the Design Stage, the sharing of information without a Common Data Environment takes “a huge amount of time” (Construction Company, Head of Design and Innovation). There was the appearance of being weighed down by an abundance of *processes*.
- The Virtual Design and Construction Manager, expressed that “we lack an understanding role of information management.” Even so, it was conveyed by the Construction company’s Head of Design and the Virtual Design and Construction Manager that standards are used as a guide when setting up systems.
- To support the Design, Build and Commission Stages a kit of BIM families is accessed to draw and build upon existing knowledge.
- Team integration has been achieved across the steel and design departments for the Design Stage *processes* to standardise the documentation for advanced steel from the modelling exercise, thereby speeding up work that would previously take days down to 8 minutes.

Technology

- Limited *technology* software licensing inhibits efficiencies for the Design and Build and Commission Stages; team members cannot always access building models.

- For the Design Stage improved workflow occurs when access, if possible, and the production team (*people*) can provide instant feedback to the design team. Numerous commercial *technology* systems that are costly and require a high level of expertise can inhibit further innovation and development.

Content

- It was not possible to generate reliable metrics because of system limitations. Diminished data (*content*) integrity from moving data in and out of systems, “Data integrity is lost as various functions in the business value different things, resulting in diminished integrity from a holistic perspective that would be addressed by the introduction of CDE integration across business functions” (Construction Company, Head of Innovation and Design).
- Lack of connected data to manage digital assets was reported, “While we aspire for a more connected and collaborative data environment, that is not the current reality. Without a CDE and rollout in the organisation we will be hard pressed to quantify accurately any likely improvements” (Construction Company, Head of Innovation and Design).

Shanghai Disaster Recovery Centre

Project Details

The Shanghai Disaster Recovery Centre (SDRC) (Li et al, 2014), which was constructed by the State Grid Corporation, is one of 3 centralised information system disaster recovery centres in China (Table 11). The SDRC has 5 floors, of which 4 are below ground. Three of these floors were designed as computer, ancillary equipment and precision air-conditioning rooms.

Table 11. *Project details for the Shanghai Disaster Recovery Centre (SDRC)*

Project details	
Name / Client & Owner	Centralised Information Data System Data Centre, Shanghai / State Grid Corporation
Tender / Design & Build / Completion Year	Construction commenced March, 2010 / completed and passed for acceptance by December, 2011
Gross Floor Area	28,214 sqm
Stakeholders	Details of stakeholders such as the BIM Expert, contractors, civil engineers, structural engineers, and MEP engineers were not provided

Challenges/Design Considerations

The main challenges encountered in the SDRC project are listed as follows:

- the involvement of professionals with diverse expertise
- complexity of the equipment and systems, including a total of 1,228 pieces (air-conditioning, electrical, water pumps)
- complex electro-mechanical systems, including 9 HVAC, 12 water supply and drainage, and 18 electrical engineering systems
- limited space, with an inter-storey height of 5.5m (bottom of the beam being 4.53m from the ground), 3m ceiling height in the corridor, 1.53m width to install the pipeline
- tight construction schedule (March, 2010 to December, 2011)
- given the challenging site conditions, including special soft ground in Shanghai, the construction duration was cut down to 7 months

- cost constraints for materials and labour.

The following challenges were associated with digital build in this project:

- The utilisation of BIM in real construction projects at the time was not fully investigated, where there was a lack of demonstration of its benefits in a comprehensive construction project. This affected the decision of stakeholders on its utilisation in the SDRC project.
- Recognition and enforcement by owners, as well as a balanced framework for implementation that accounts for both monetary and managerial outcomes, were stipulated as the most significant barriers to the implementation and acceptance of BIM across the building industry.

Digital Build Methodology

Given the lack of quantified cost benefits on how BIM can benefit real-world construction projects, a framework was formulated to measure the return from BIM through a completed project. Firstly, a survey was prepared for assessing the credibility of BIM in terms of comparing its workload with non-BIM methods, difficulty of learning BIM tools and the potential of its future adoption. The results obtained from BIM users across different implementations are summarised in Table 12. In the SDRC project, benchmarking was performed using BIM and non-BIM data, with the methodology detailed hereafter.

Table 12. *User interview questionnaire*

Categories	Conflict Resolution	Construction Scheduling
1. How do you evaluate the credibility of BIM?	Very credible: 63% Intermediate: 20% Low credibility: 17%	Very credible: 48% Intermediate: 32% Low credibility: 20%
2. Do you think BIM can reduce your workload compared with the traditional manners?	Very effective: 73% Intermediate: 20% Less effective: 7%	Very effective: 81% Intermediate: 15 % Less effective: 4%
3. Do you think it is very hard to learn BIM tools?	Hard: 28% Intermediate: 33% Not hard: 39%	Hard: 25% Intermediate: 45% Not hard: 30%
4. Will you embrace the opportunity of using BIM in future?	Willing: 72% Intermediate: 28% Not willing: 0%	Willing: 65% Intermediate: 30% Not willing: 5%

Establishing Non-BIM Data for the Case Study

The construction company involved in this project (details unknown) was stipulated to be one of the largest construction companies in China with many years of experience. The SDRC project was selected as a BIM pilot project by the Shanghai government. Consequently, the construction company was required to complete the design and planning using both traditional and BIM methods, while tentatively applying BIM in the construction phase. *The data from the case study was collected from numerous project meetings with stakeholders and through reports. Due to confidentiality, some of the cost information was not reported in this paper*. Instead, the company permitted comparisons of costs to derive percentage values. Interviews were also conducted with individuals (not documented) to gauge their experience in the BIM environment at the company.

The collected interview data was reported in a percentage format to assess the benefits of BIM. Conflict resolution and construction scheduling were the key implementations of BIM that were explored in this case study with quantifiable metrics.

BIM Applied in MEP Design Review/Conflict Resolution

MEP optimisation was identified as the main factor that can boost the profit margin of the construction industry, being the most complex system in a building. Figure 31 gives an example of how an MEP issue is identified and addressed, where a fan positioned in the refrigeration room conflicts with the thermal storage tank. The following sequence was noted:

- The design drawings indicate a fan elevation of 4.9m and a thermal storage tank elevation of 4.45m.
- While the design drawings showed a 100mm base elevation of the storage tank, this became 200mm after construction. Consequently, the actual elevation of the storage tank became 4.55m.
- The highest elevation permitted for the fan was 3.95m, when the fan reaches the bottom of the beam. The fan thereby conflicted with the storage tank.

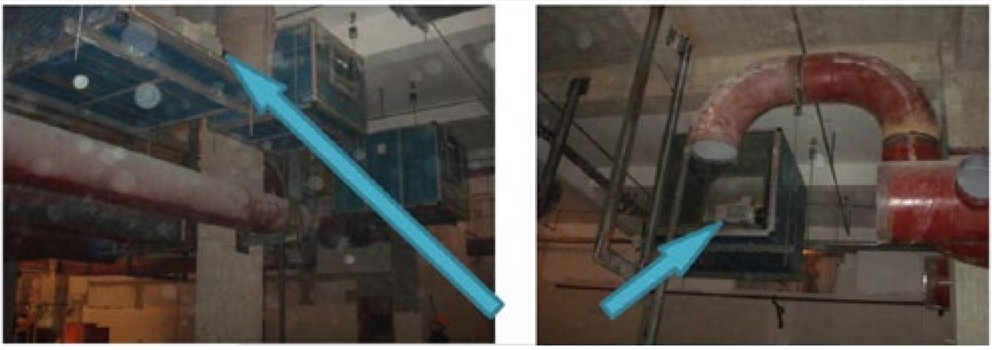


Figure 31. *Conflict between a fan positioned in the refrigeration room and the thermal storage tank*
Source: Li et al, 2014.

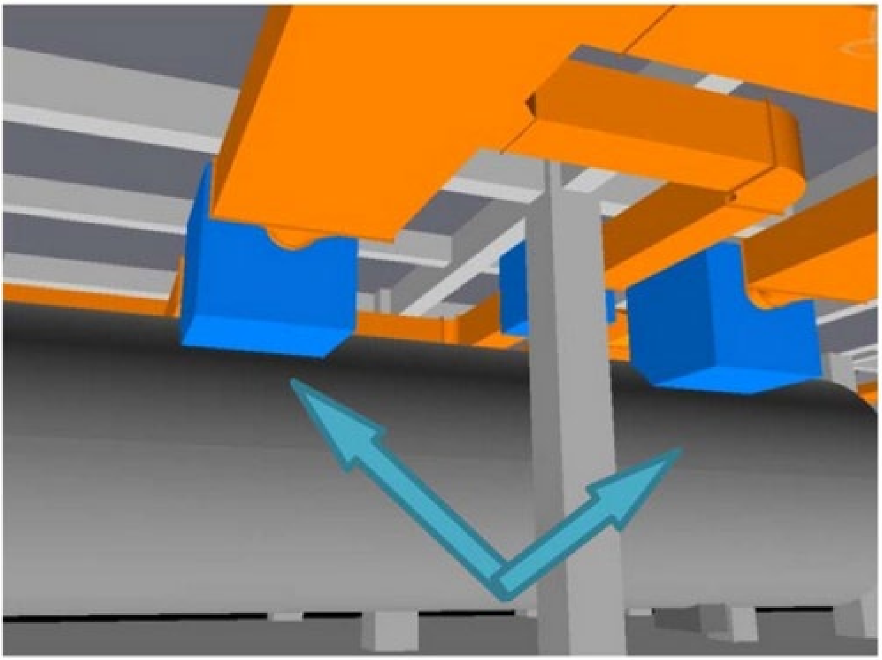


Figure 32. *Addressing the conflict in the 3D model, which is hidden in the 2D drawings*
Source: Li et al, 2014.

BIM was utilised prior to the installation, which enabled designers to identify and address this conflict, which was hidden within the 2D drawings (Figure 32). This can prevent the installation and removal of a conflicting fan, and thereby save costs and further work. This rework includes redesign of the fan and updating the drawings to enable the fan to be installed elsewhere. BIM can thereby integrate design information with the associated documentation, and is particularly useful for conflict resolution, reviewing designs, providing a walkthrough in the building, animating the construction sequence, and browsing component details.

4D Simulation of Construction Scheme

The 2 stages of the construction scheme are illustrated in Figure 33:

- The first stage illustrated in Figure 33a shows the construction order followed in the original construction scheme.
- As the second stage is completed, construction of the facility rooms in the original scheme remains ongoing (Figure 33b).

Consequently, neither the mechanical nor the electrical construction can be implemented in advance, nor can the construction duration be reduced. This is delayed by the construction progress of the facility rooms.

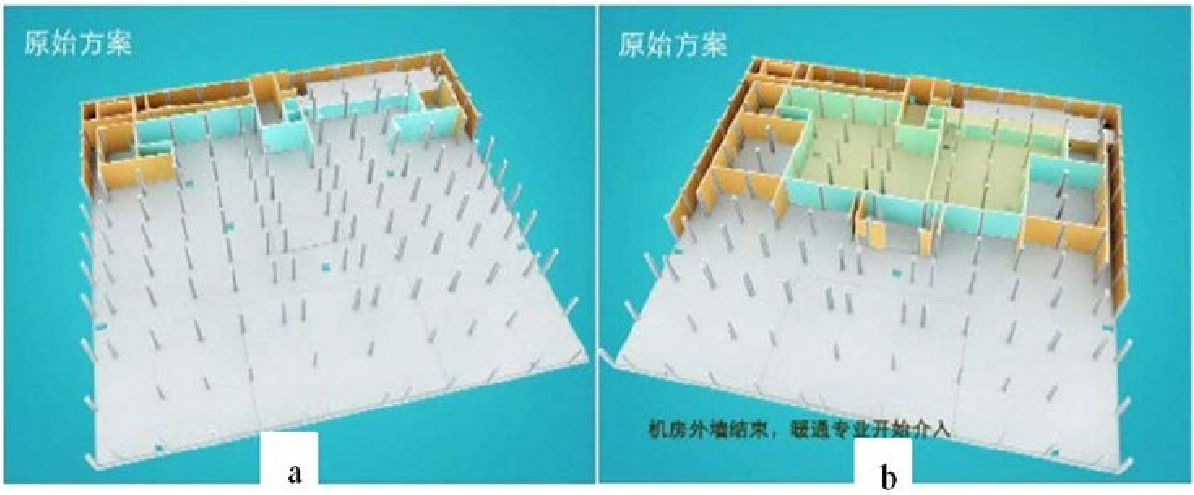


Figure 33. *Original construction scheme prior to optimisation: a) Stage 1; and b) Stage 2*
Source: Li et al, 2014.

The construction sequence was thereby optimised using a 4D-based construction progress simulation using BIM:

- During the first stage, the construction scheme was optimised and synchronised with the construction of the facility rooms (Figure 34a).
- When the second stage was completed, construction of the facility rooms had also been completed such that construction of the mechanical and electrical systems could commence (Figure 34b).

Due to BIM optimisation, the mechanical and electrical construction was conducted in advance, and the construction duration was not delayed. The advantage of BIM in this regard is highlighted by the following points:

- In a construction project, the required completion date can be fixed so as to not incur additional costs, which requires the construction manager to confirm that this date can be met based on the scope of the desired work.

- If this cannot be achieved, the owner may reduce the scope of work in the project or pay a premium to accelerate the schedule.
- The constructor analyses different delivery methods that may affect the completion date of a project within the desired budget.
- BIM analysis will thereby provide an early recommendation to the owner on the optimal project delivery method.

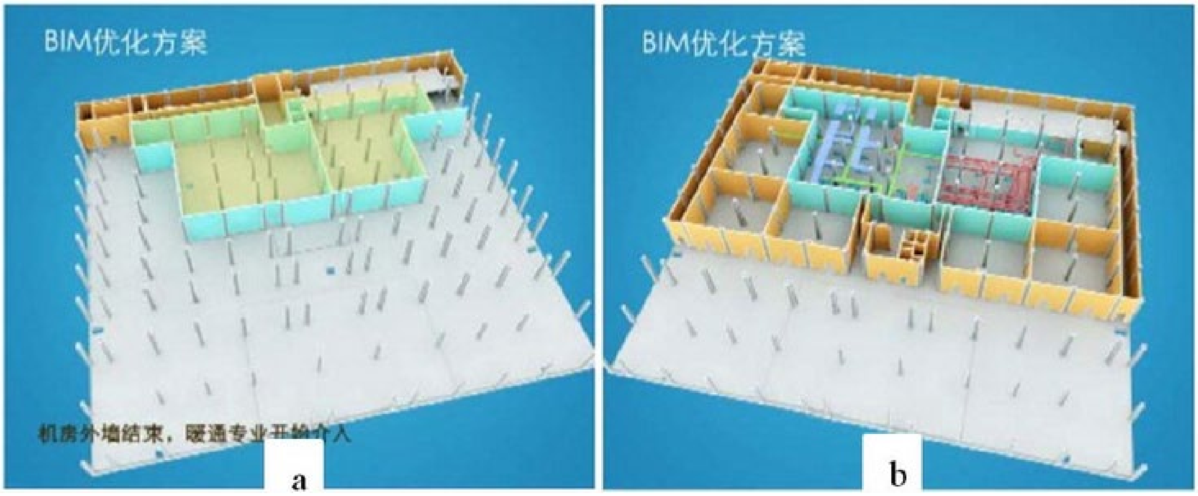


Figure 34. Optimised design of civil construction scheme: a) Stage 1; b) Stage 2

BIM can also provide a visual simulation of the construction schedule and construction system design as shown in Figure 35, and also improve links between construction activities and critical paths. Efficiency can thereby be significantly improved due to real-time coordination of the construction processes.

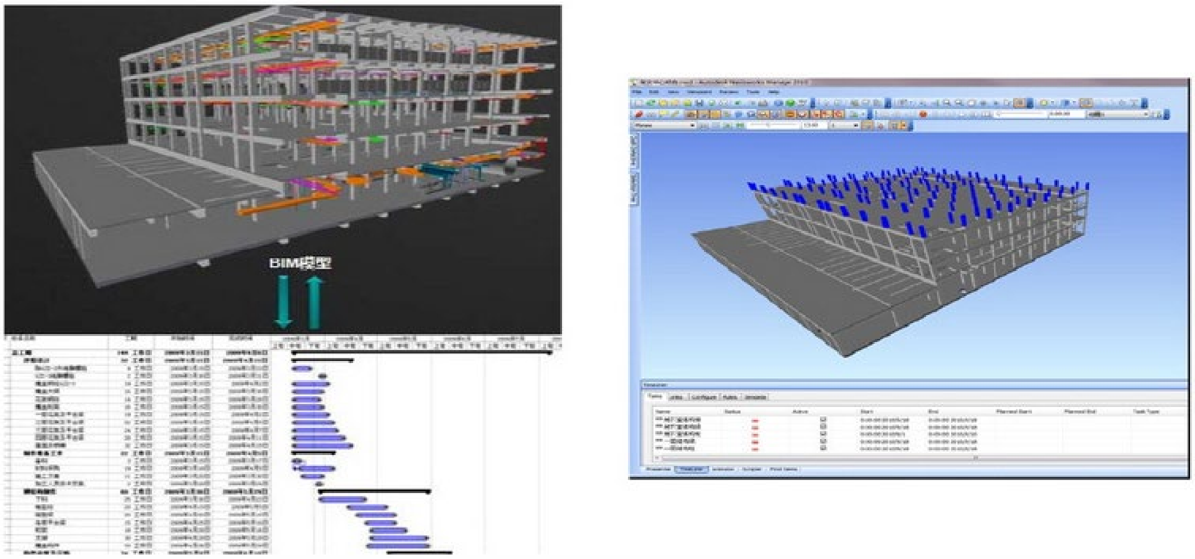


***Figure 35.** Construction scheme and simulation*
Source: Li et al, 2014.

Discussion of Results/Benefits

The SDRC project conducted a BIM-based optimisation by accounting for the large amount of information, and complexity and tight deadline of the construction schedule. The BIM model can replicate the actual building and provide the following key information:

- geometry of its components, including structural, mechanical, electrical and architectural
- material properties, including structural, energy/thermal and acoustic
- details on construction scheduling/rules
- possible states after the project design is modified.

The complexity of most modern buildings is typically multi-disciplinary. For example, constructors can encounter difficulties in working out key details from designers, who might overlook the difficulties of installation. It is thereby difficult for stakeholders to grasp all the necessary information without relying on technology. BIM can address this and thereby yield the following qualitative benefits, which ultimately enable the design team to identify the best design schemes that meet the owner's cost and functional requirements:

- Optimisation functionality facilitates the possibility of optimising the construction sequence of a complex project.
- BIM can integrate project design and cost analysis in the project planning phase, such that the impact of design changes on costs can be calculated in real-time.
- BIM can also optimise designs and simulate the construction sequence, which is particularly useful when difficult construction issues are encountered. Consequently, this can reduce the construction duration and costs.
- Early implementation of a 3D BIM model can reduce costs and waste, identify errors in the 2D design drawings, and avoid delays in the project schedule by enabling early coordination between the designer and constructor.
- BIM adoption during the early stages of a project enables the evaluation and balancing of all reasonable design options against functional objectives, and addressing urgent design decisions early in the design process.
- Reviewing, amending and addressing costs and budgetary issues, in accordance with operational considerations.

The following quantitative benefits were reported, in which the cost savings are tabulated in Table 13, and the time savings are presented in Table 14:

- BIM technology detected more than 2,000 errors in the original design.
- Error classification and conflict inspection reports resulted in the identification and elimination of 500 most important errors prior to the construction, which thereby reduced rework, labour and material waste.
- The construction schedule was reduced by 3 months mainly due to the reduced installation duration of the MEP systems and reduced construction duration of the structure.

Table 13. *MEP design issues, time and costs saving data based on a BIM design review (Cost-saving (%) = cost saving ($) / total MEP)*

Items	Issues identified			Time saving		Cost-saving ($)
Level 1 issues	198	67	265	0.05	13.25	0.265
Level 2 issues	132	32	164	0.1	16.4	0.820
Level 3 issues	95	26	121	0.15	18.15	0.968
Level 4 issues	58	6	64	0.2	12.8	0.832
Prefabrication	–	–	5	–	–	0.25
Total	483	131	614	–	65.6	2.91

Level 1 issues: Cannot be resolved onsite, no major impact on the actual construction process.
Level 2 issues: Shut down, waiting to be processed by technicians onsite.
Level 3 issues: Shut down, need to dismantle and reconstruct.

Table 14. *Construction scheme and simulation*

Task name	Original Duration (Day)	Optimised Duration (Day)	Timesaving (Day)
Civil structure	273	200	73
HVAC	81	58	23
Plumbing system	252	187	65
Electrical system	174	133	41
Fire protection system	88	60	28
Decoration	262	200	62

Lessons Learned and Recommendations

The lessons learned from the SDRC project provide evidence on how BIM can provide value for money through early conflict resolution and optimisation of the construction schedule. These lessons include:

- The proof-of-concept adoption of BIM in a real-world project provides insight into how it can be utilised to provide value for money.
- It was observed that BIM can provide effective coordination in the design and construction phases by involving various stakeholders in the construction process, including contractors, civil engineers, structural engineers and MEP engineers through the automated simulation of cost-activity information.
- Visualisation of the construction sequence of activities assists cost planning operators in identifying conflicts and communicating design alternatives that might be more cost-effective and time-saving. BIM tools continue to improve and can provide a feedback system that tracks the impact of design changes associated with costs.
- The survey indicated the increasing adoption of BIM.

The following conclusions were provided by the authors:

- There is a need to reinforce the benefits of BIM by conducting a thorough cost analysis.
- BIM should be rigorously undertaken, particularly in large scale projects, given that there are numerous factors affecting the efficient delivery of construction projects including rework, productivity and waste generation.
- The proof-of-concept BIM adoption in the SDRC project demonstrated how BIM can be potentially used in design review, error checking and design for constructability.
- Organisational and project management functions, including corporate strategy, management, and social and organisational context, may be affected by the implementation of BIM. These factors should be thoroughly studied.

Commercial Office Development in Perth CBD

This case study involves a commercial office development in Perth's CBD (Matthews et al, 2015) (Figure 36), which is part of the new Perth City Link project commissioned by the West Australian (WA) State Government. The building aimed to achieve a 5 Star Green—Office Design rating from the Green Building Council of Australia, and a 5 Star National Australian Built Environment Rating System (NABERS) energy rating. The project details are provided in Table 15, which was delivered using a design and construct procurement method.

Table 15. *Project details for the commercial office development in Perth's CBD*

Project Details	
Name / Client & Owner	Commercial office development, Perth CBD / WA State Government
Value	$54M AUD
Tender / Design & Build / Completion Year	Not provided
Height / Gross Floor Area	11 storeys / 13,000 sqm
Stakeholders	Details of stakeholders such as the planner, site manager, BIM Expert/4D modeller, contractors, structural engineers, and so on were not provided

Figure 36. *Commercial office development in Perth CBD*
Source: Matthews et al, 2015.

Challenges/Design Considerations

The reinforced concrete (RC) frame (including formwork, reinforcement and concrete) was selected as the element to be monitored in real-time to demonstrate the capabilities of BIM to the project team and contractor. The project scope was limited due to the lack of familiarity of the contractor's site team with BIM. The contractor’s existing process was compared against cloud-based BIM because a change in workflow may adversely influence their quality accreditation. The existing workflow for monitoring the progress of the RC frame is shown Figure 37, which involves setting the construction sequencing and flow, preparing and adjusting the construction schedule, reviewing the schedule, implementation of level 4-5 programmes, and commencing construction. Level 3 refers to the detailed schedule, while level 4-5 refers to the working schedule. The Level 3 schedule, which was implemented in Microsoft Excel, was an intermediate progress reporting schedule that was generated in parallel to ensure interoperability with any scheduling software package. The responsible personnel are also provided for each activity.

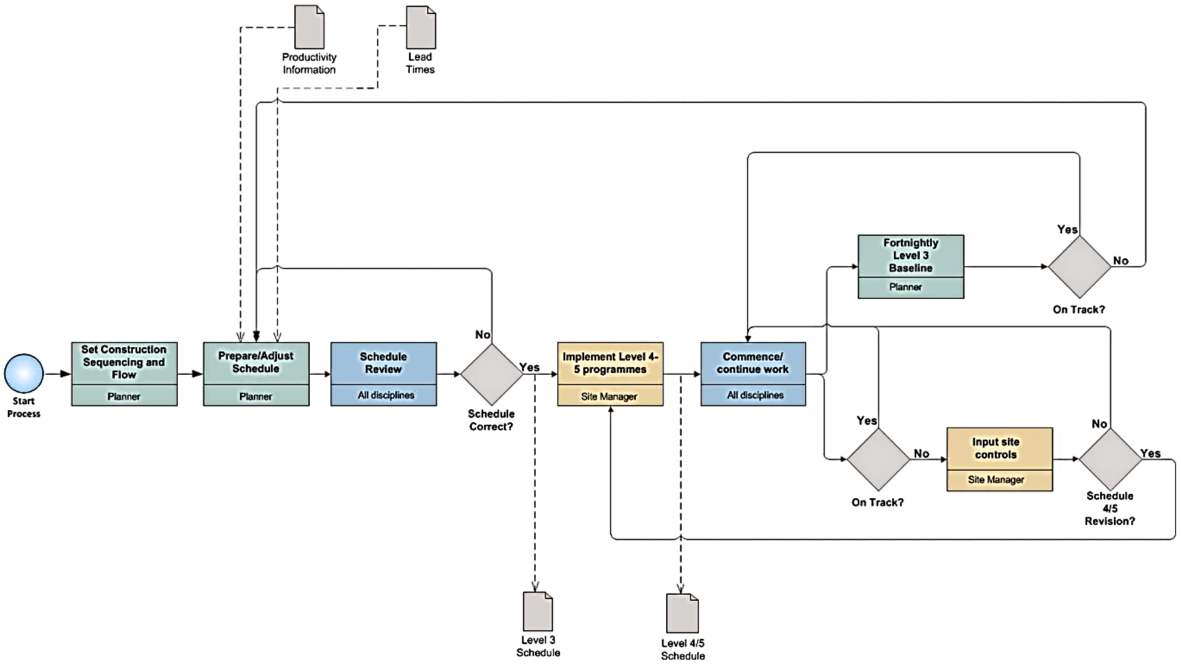
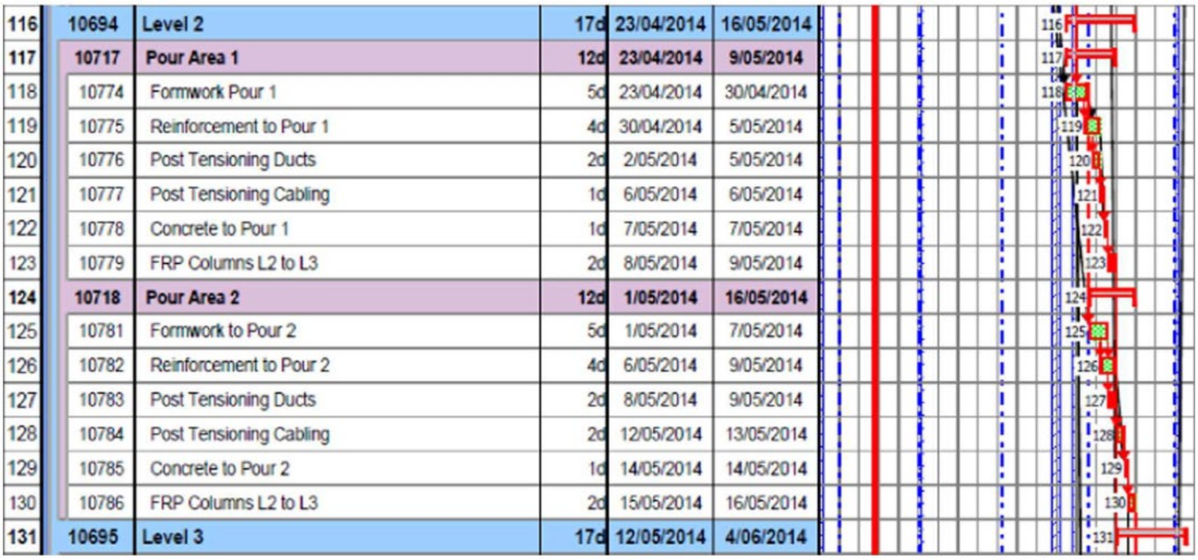


Figure 37. *Existing process for monitoring the process of the RC frame with responsible personnel*
Source: Matthews et al, 2015.

Digital Build Methodology

Modelling

The detailed design of the RC structure was modelled in Revit by the structural engineer. This model was imported into Navisworks and re-engineered using the iConstruct plug-in to align the tasks within the schedule with the breakdown of the model (Figure 38). The RC structure was to be constructed using 2 concrete pours per floor. Similarly, the columns were broken down into 2 groups per floor. The onsite engineer would decide the exact breakdown of the pours and grouping of the columns. Therefore, it was not yet possible to model an unknown breakdown in the BIM.



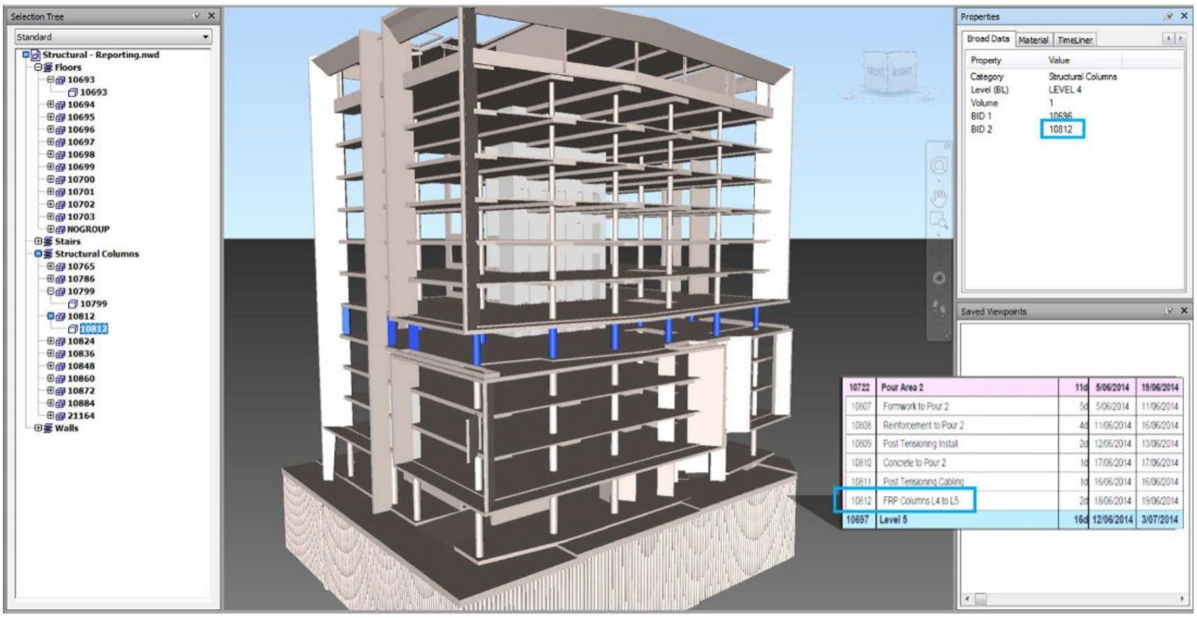
116	**10694**	**Level 2**	**17d**	**23/04/2014**	**16/05/2014**
117	**10717**	**Pour Area 1**	**12d**	**23/04/2014**	**9/05/2014**
118	10774	Formwork Pour 1	5d	23/04/2014	30/04/2014
119	10775	Reinforcement to Pour 1	4d	30/04/2014	5/05/2014
120	10776	Post Tensioning Ducts	2d	2/05/2014	5/05/2014
121	10777	Post Tensioning Cabling	1d	6/05/2014	6/05/2014
122	10778	Concrete to Pour 1	1d	7/05/2014	7/05/2014
123	10779	FRP Columns L2 to L3	2d	8/05/2014	9/05/2014
124	**10718**	**Pour Area 2**	**12d**	**1/05/2014**	**16/05/2014**
125	10781	Formwork to Pour 2	5d	1/05/2014	7/05/2014
126	10782	Reinforcement to Pour 2	4d	6/05/2014	9/05/2014
127	10783	Post Tensioning Ducts	2d	8/05/2014	9/05/2014
128	10784	Post Tensioning Cabling	2d	12/05/2014	13/05/2014
129	10785	Concrete to Pour 2	1d	14/05/2014	14/05/2014
130	10786	FRP Columns L2 to L3	2d	15/05/2014	16/05/2014
131	**10695**	**Level 3**	**17d**	**12/05/2014**	**4/06/2014**

Figure 38. Breakdown of model to tasks within the construction schedule in Navisworks
Source: Matthews et al, 2015.

The contractor and cost consultant aimed to simplify the process and decided that the BIM would be organised by storey. To this end, the elements in the model were grouped to represent either one floor per storey (beams, thickenings, and upstands included), one group of columns per storey, or a series of walls comprising the core. This re-engineering meant that one group within the model could be aligned with one task in the construction schedule. Furthermore, the integration of the contractor's Quality Assurance (QA) procedures was streamlined, which enabled reporting on tasks as they were completed (group of columns) rather than forcing reporting on each individual component (single column).

A new property was added to the object groups within the Navisworks model and used to embed the schedule task ID (Figure 39), which enabled the automation of the alignment of object groups with schedule tasks. In effect, this guarded against unnecessary digital rework in the event that either the schedule or the design subsequently changed. The following key points are highlighted in the automated workflow, which demonstrate time savings due to reduced rework in the modelling process:

- The schedule was created in Asta Powerproject and imported into the Autodesk Navisworks TimeLiner tool as a data source. A rule was established to automatically associate object groups with the correct schedule task based on schedule task ID.
- If the above rule was not established, linking the model objects to the tasks in the schedule would be a manual task, which would need to be done each time a change was made to the model or the schedule.
- Schedule task IDs were also pushed back into the Revit model as an additional safeguard against rework.
- The resulting Navisworks model was ready to be navigated via a browse structure that replicated the breakdown of the schedule tasks. This model was thereby suited to the needs of the onsite contractor.



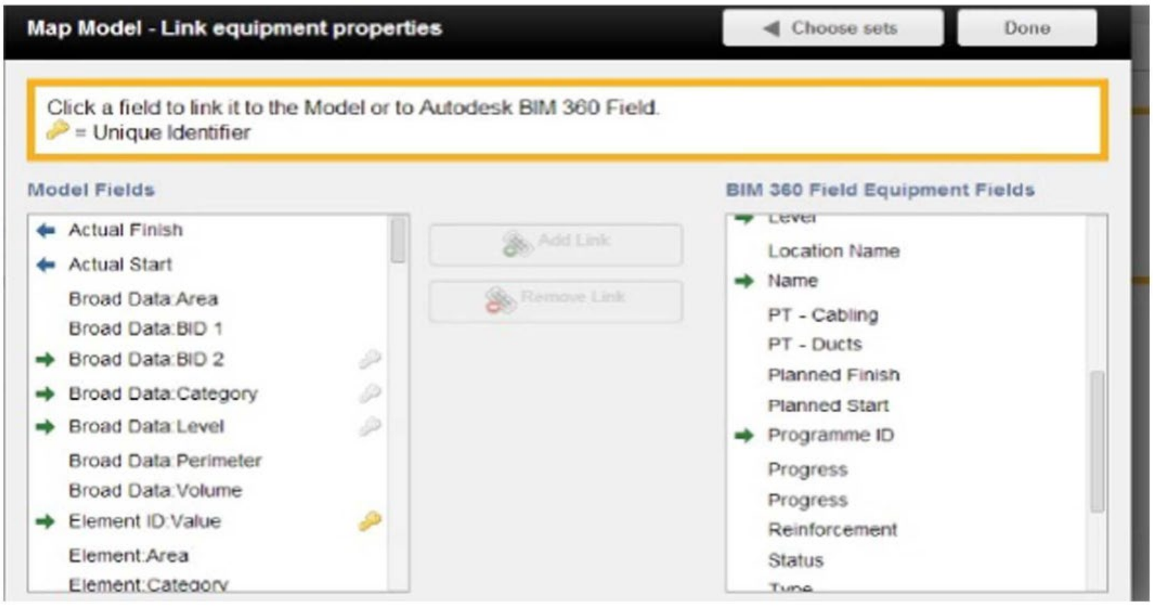
Property	Value
Category	Structural Columns
Level (BL)	LEVEL 4
Volume	1
BID 1	10696
BID 2	10812

10722	**Pour Area 2**	**11d**	**5/06/2014**	**19/06/2014**
10807	Formwork to Pour 2	5d	5/06/2014	11/06/2014
10808	Reinforcement to Pour 2	4d	11/06/2014	16/06/2014
10809	Post Tensioning Install	2d	12/06/2014	13/06/2014
10810	Concrete to Pour 2	1d	17/06/2014	17/06/2014
10811	Post Tensioning Cabling	1d	16/06/2014	16/06/2014
10812	FRP Columns L4 to L5	2d	18/06/2014	19/06/2014
10697	**Level 5**	**16d**	**12/06/2014**	**3/07/2014**

Figure 39. *RC structural model with the task ID within the construction schedule*
Source: Matthews et al, 2015.

The cloud-based BIM software Autodesk BIM 360 Field was customised to display the information that was required to monitor progress on the site remotely. The following points are noteworthy:

- As the site team became more familiar with the capabilities of mobile BIM, a request was made for all project data (drawings, specification and construction program) to be input into the BIM 360 Field application.
- Through the BIM 360 Field on an iPad, quality control checklists were implemented and completed after each concrete pour.
- Properties were created for all object groups in Navisworks, including planned and actual start and finish dates, and percentage completed.
- This model was then uploaded to BIM 360 Field where equipment objects were created and linked via a map model to the relevant object groups. Consequently, information collected on site (entered in BIM 360 Field via an iPad) was synchronised directly with the Navisworks model (Figure 40).



Click a field to link it to the Model or to Autodesk BIM 360 Field.
= Unique Identifier

Model Fields

- Actual Finish
- Actual Start
- Broad Data:Area
- Broad Data:BID 1
- Broad Data:BID 2
- Broad Data:Category
- Broad Data:Level
- Broad Data:Perimeter
- Broad Data:Volume
- Element ID:Value
- Element:Area
- Element:Category

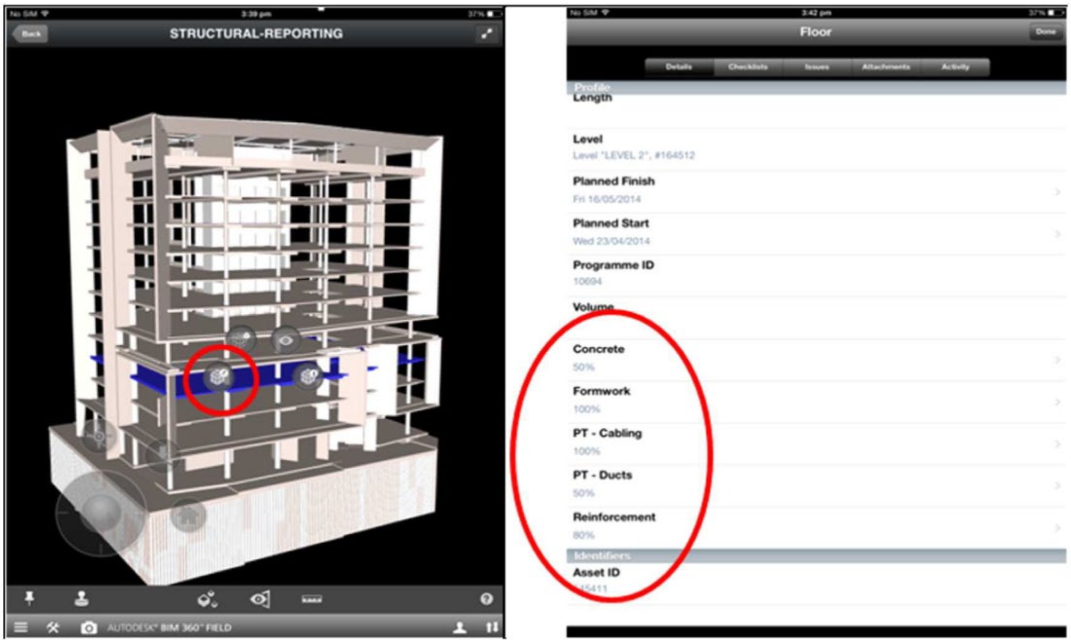
BIM 360 Field Equipment Fields

- Level
- Location Name
- Name
- PT - Cabling
- PT - Ducts
- Planned Finish
- Planned Start
- Programme ID
- Progress
- Progress
- Reinforcement
- Status
- Type

Figure 40. *Linking of object properties (in BIM) to equipment properties (in BIM 360 Field)*
Source: Matthews et al, 2015.

Real-time Site Data Collection

The contractor's site engineer was responsible for inputting the site data into the BIM 360 Field application. This involved inputting percentage complete information into each object group for the RC structure for progress monitoring. This reporting process was undertaken daily onsite using an iPad. The process is straightforward, which enables the engineer to visually select the object in the BIM and enter the relevant percent complete at the time. Figure 41 shows the iPad interface when inputting progress data into the model. The iPad input is then synchronised with the Navisworks model, which enables the reporting process to commence.



Length

Level
Level "LEVEL 2", #164512

Planned Finish
Fri 16/05/2014

Planned Start
Wed 23/04/2014

Programme ID
10694

Volume

Concrete
50%

Formwork
100%

PT - Cabling
100%

PT - Ducts
50%

Reinforcement
80%

Asset ID
5411

Figure 41. *Data input via iPad*
Source: Matthews et al, 2015.

The onsite construction progress was typically monitored daily by the site engineer (Level 4 and 5 being the working schedule), while the reporting of progress to the project planner and subsequent reporting and updating of the detailed schedule (Level 3) were conducted fortnightly. The following considerations are highlighted:

- The newly obtained data was integrated into existing processes given that the planner only required information for the detailed schedule (used for internal reporting).
- The contractor's processes had been certified according to ISO 9001 (Quality Management Systems). Consequently, any modification to their processes without formal approval by the certification body may jeopardise their insurance for the work they were undertaking in the event of a problem.
- To accommodate this crucial requirement while minimising disruption to existing Quality Assurance (QA) processes, the progress data collected onsite for individual tasks/objects of the working schedule were aggregated to produce a progress percentage for each floor in order to update the detailed schedule for the planner.

Figure 42 illustrates the flow of information between the site and office.

Figure 43 shows the re-engineered workflow to support the contractor's QA requirements, to highlight the complexity of the digital build compared with the original reporting process. The identification of differences through the schedule was simplified by having a planned and actual percentage complete for each floor. Pushing this data back in to the 4D model in Navisworks enabled a visual simulation of planned Vs actual work to be undertaken. A colour coded 4D progress report was also created from this data.

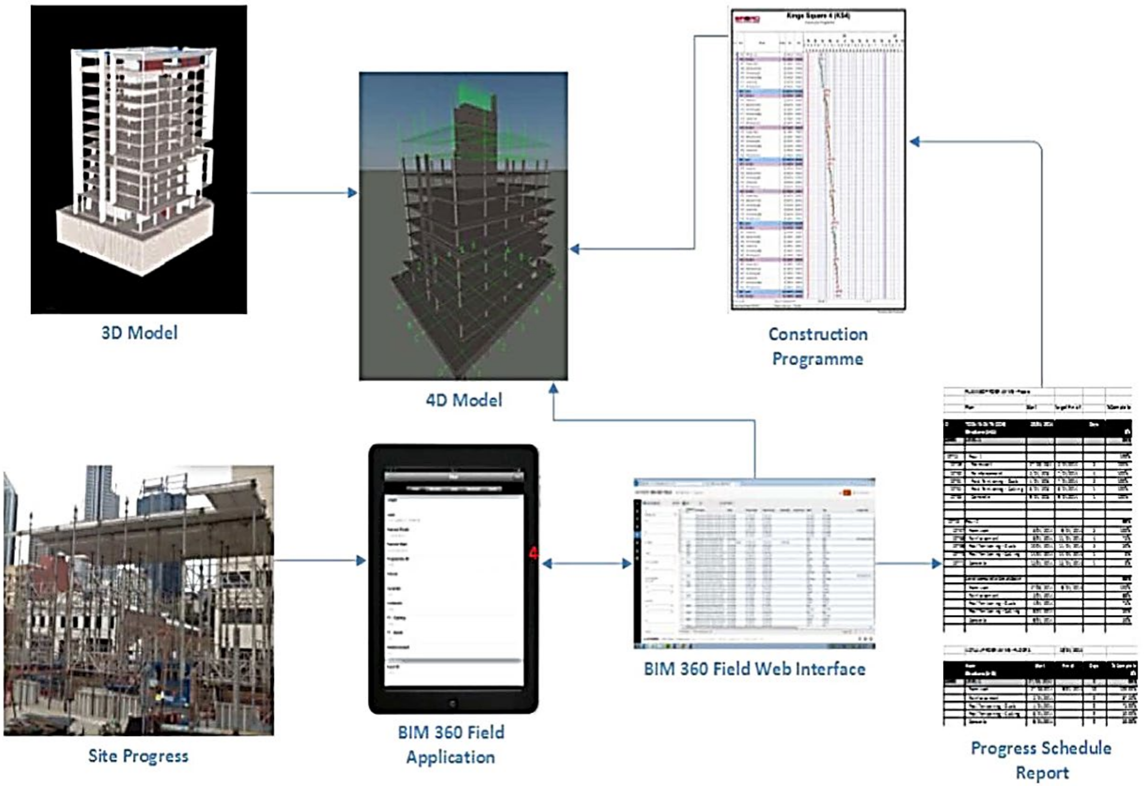


Figure 42. *Graphical flowchart demonstrating the flow of information between the site and office Source: Matthews et al, 2015.*

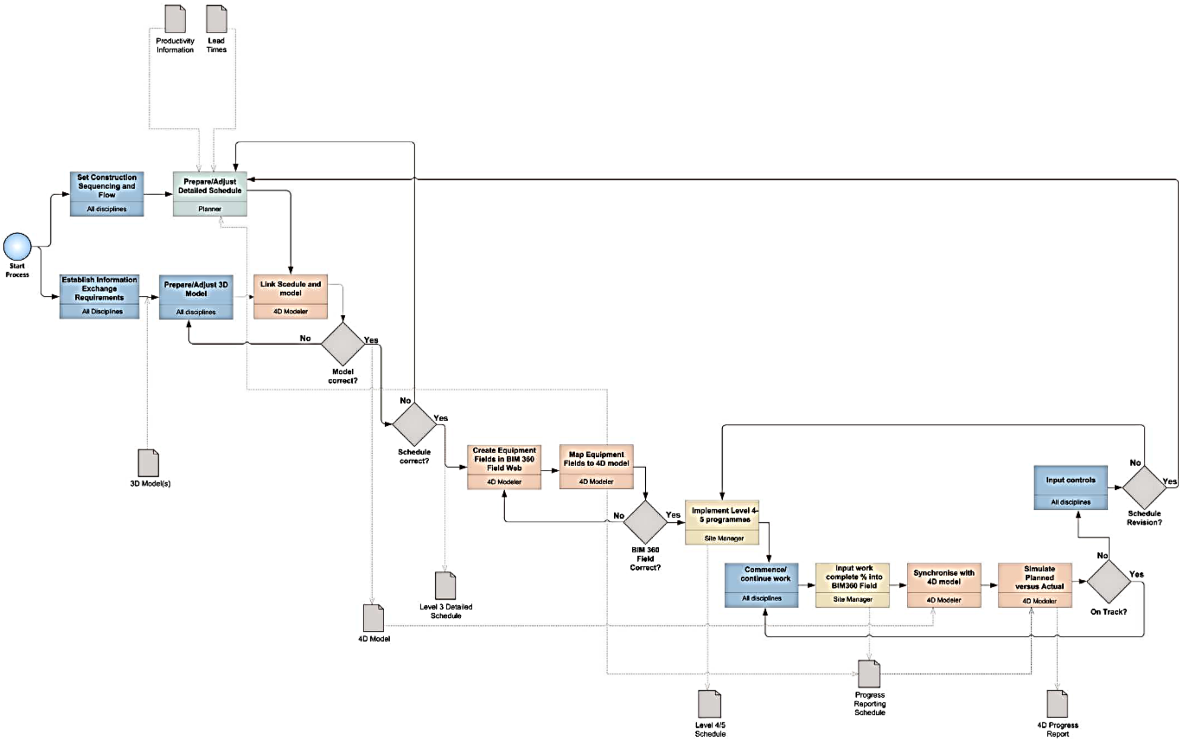
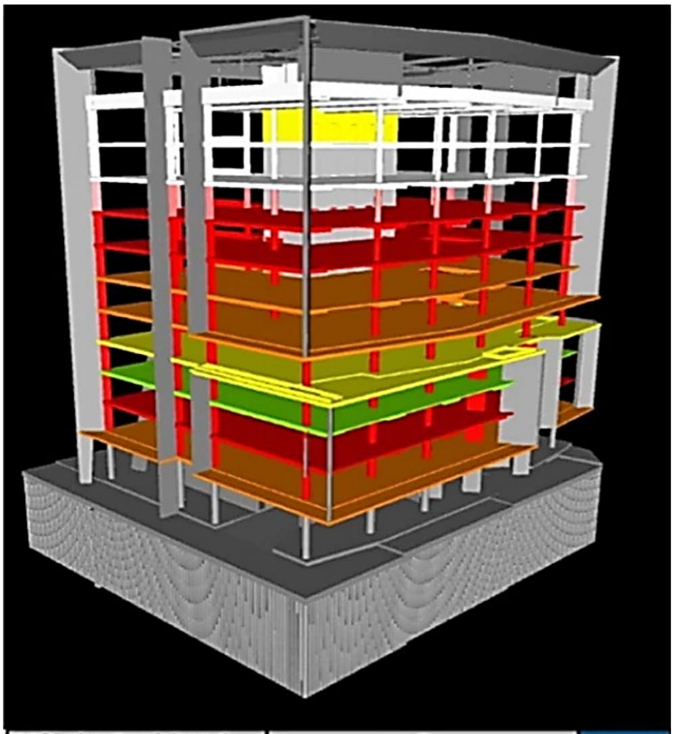


Figure 43. *Reengineered Process*
Source: Matthews et al, 2015.

Discussion of Results/Benefits

The resulting simulation shown in Figure 44 demonstrates how discrepancies between actual and planned progress can be visualised. This data is hypothetical in nature *as the real data made available to the researchers is commercially sensitive*. Initial feedback from both site and office-based users of the system indicated that *the integration of the progress data with the BIM offered little benefit to their everyday work,* even though the resulting imagery may be of benefit when communicating or negotiating with other stakeholders. In contrast, re-engineered processes to accommodate cloud-based, structured and searchable data entry offered the following benefits:

- Convenience due to having all information in one place.
- Efficiency of communication between onsite and office-based staff.
- Having real-time access to the latest data enables decision-making to be improved. This is exemplified by the planner being able to better determine what impact the progress of the RC frame would have on other subcontracted trades.
- The replacement of paper-based systems with cloud-based BIM enabled processes provides a mechanism for creating a fully auditable record of events, which can be searched or interrogated. Documents such as site diaries can thereby be accessed many years down the line.



30% shorter/ahead	A	🟦
20-30% shorter/ahead	B	🟦
10-20% shorter/ahead	C	🟩
0-10% shorter/ahead	D	🟩
On time	E	▨
0-10% longer/behind	F	🟨
10-20% longer/behind	G	🟧
20-30% longer/behind	H	🟥
30%+ longer/behind	I	🟥
Yet to commence	J	⬜

Figure 44. *Colour coded simulation of 'planned' vs. 'actual' progress*
Source: Matthews et al, 2015.

The use of cloud-based BIM on-site ignited interest amongst the site engineers and Foreman, especially due to the simplification of the non-conformance reporting process. The site-based team began to make requests to extend the scope of the cloud-based BIM once they were introduced to the technology, including:

- Uploading all existing documentation for the project (e.g. drawings, specification, construction program) to enable immediate access on site, including the ability to mark them with any issues found.
- Integration of checklists for quality assurance and quality control to enable completion on site with immediate access for office-based staff, including the cross-referencing of identified issues to the marked drawings.
- Attaching photographs to BIM objects to record and communicate progress.

Lessons Learned and Recommendations

The following lessons were learned in adopting cloud-based BIM:

- The newly re-engineered process was cumbersome to implement to reduce its impact on existing processes, including the contractor's QA procedure certified according to ISO 9001, and the reporting structure required by the planner.
- The data collected by the Foreman had to be transformed into a format useful for the project planner, and consequently, an intermediary progress reporting schedule had to be established in Microsoft Excel to enable it

to be interoperable with any existing scheduling software package. This process was semi-automated given that data needed to be manually copied from Excel and inserted into the planning software, which was to be automated in future work.

- The re-engineered process may not be generalised to other companies as they may have different Work Breakdown Structures (WBS) for their working schedule and detailed schedule.
- The visual 4D model had limited influence on improving the productivity of the RC frame's operations on-site.

The following recommendations were provided by the authors:

- Focus on how the generation of real-time quality and costing can be developed using cloud-based applications.
- While this case study provided the foundation for work to be undertaken particularly in the areas of real-time costing and quality management, research of this nature should be undertaken directly with industry to ensure that outcomes can contribute to improving performance and productivity within the construction industry.
- Only a limited number of studies have examined how BIM can be operationalised on-site during construction. To this end, explore how BIM could be realistically extended from detailed design to the construction site to specifically monitor real-life progress.

United School District in Los Angeles

The Los Angeles Unified School District (LAUSD) allocated $19.2B in funding for a large school construction and repair program in 2012 (Kuprenas & Mock, 2009), which involved the completion of more than 150 new schools for the students of Los Angeles. Due to funding deadlines, the second, larger phase of the program ($320M) was procured without a fully complete design. The contractor for this work was selected using a best value procurement and was also responsible for a limited, pre-construction design assist effort. One element of the design assist effort was the completion of a constructability review for the project.

Table 16. *Project details for the Public Sector Building Construction Project in Los Angeles*

Project Details	
Name / Client & Owner	Public Sector Building Construction Project / Los Angeles Unified School District (LAUSD)
Value	$320M AUD
Tender / Design & Build / Completion Year	Completed in 2012
Height / Gross Floor Area	Not provided
Stakeholders	Details of stakeholders such as the designer, contractor, subcontractors, construction manager and so on were not provided

Challenges/Design Considerations

The decision of the owner’s representative management team to include BIM as part of the constructability and coordination effort posed several design challenges. Several non-design team project participants, including the contractor, subcontractors, and construction manager, developed individual elements of the BIM and then collaborated to develop the complete model. The following key challenges were identified, which are associated with the coordination between stakeholders and project activities:

- Intra-trade coordination: Complexities arise from the placement of deck inserts, facilitating subcontractor prefabrication, work sequence visualisation and planning
- Inter-trade coordination: Conflict resolution between structural and MEP components.

Digital Build Methodology

The digital build process involved the assembly of a 3D BIM model, which involved the following steps:

- A consultant was hired to convert the completed design drawings for the architectural and structural concrete systems to a 3D model. To this end, the general contractor augmented the completion of the 3D models and shop drawing process.
- A subcontractor was assigned for modelling the mechanical, electrical, and plumbing (MEP), and the Fire Protection (FP) components.
- These models were then supplemented with the construction schedule, supplier details and assembly information for each drawing element.
- During construction, the BIM was used for intra-trade and inter-trade coordination, sequencing, conflict checking and visualisation.

Discussion of Results/Benefits

Intra-trade Coordination

The duration and fixed completion date of the project were fixed, despite the incomplete design in this project. Therefore, the main goal of BIM was to gain time in the construction process to maintain an aggressive construction pace of $500,000 worth of installations per day. The gain in construction field time was to be achieved via 3 dimensional MEP and FP intra-trade coordination prior to the commencement of onsite construction, which involved the following activities:

- placement of deck inserts
- increasing subcontractor prefabrication
- work sequence planning and visualisation.

Poorly located or omitted inserts pose a common coordination issue in large projects. Reducing the installation time of these components was critical to complete the project within the contracted duration. The level of coordination provided by 3D BIM enabled subcontractors to accurately insert the vertical and seismic supports by locating them visually ahead of onsite work. BIM thereby saved rework in the field and reduced installation durations. BIM also enabled prefabrication by the MEP and FP Trades. The following examples of prefabrication were identified:

- Rectangular ductwork (mechanical): The ductwork was detailed by the subcontractor in 3D and the geometry was sent straight to the computer for fabrication (Figure 45). Each component was labelled to match a callout on the shop drawing.
- Shower valves and domestic water piping (plumbing): The plumber created a 3D sketch of the plumbing assemblies as part of their submittal. These components were then shop fabricated, tested and labelled. On the site, the elevation was set, and the assembly was installed with screws (
- Figure *46*). The plumber also used the BIM model to identify quantities of cold water piping on each floor of the building. The pipe was bundled and labelled offsite, which was ready to deliver to the correct floor (Figure 47).

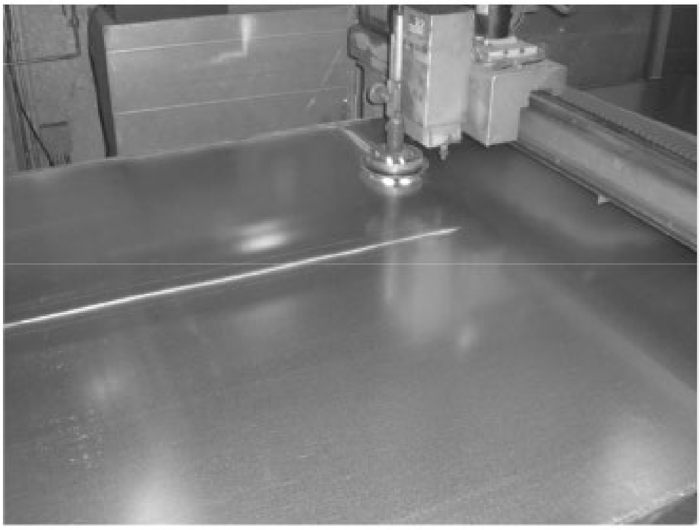


Figure 45. *Fabrication of ductwork via computer numerical control (CNC) machine*
Source: Kuprenas & Mock, 2009.

Figure 46. *Pre-assembled piping*
Source: Kuprenas & Mock, 2009.

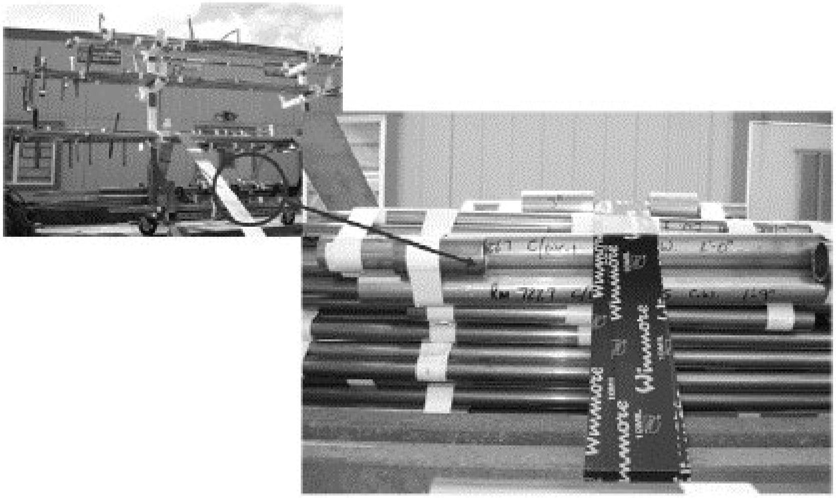


Figure 47. *Bundled pipe*
Source: Kuprenas & Mock, 2009.

The BIM model was also used for intra-trade work sequencing and planning for the underground electrical systems and waterproofing of the exterior skin. One dimensional electrical line drawings were converted to 2D plan drawings (Figure 48). The 2D plans were then converted to a 3D model (Figure 49) to help the field workers visualise material placement and sequence. The complexity of the onsite installation is highlighted by Figure 50. The intra-trade benefits and cost savings realised from the BIM model are listed in Table 17.

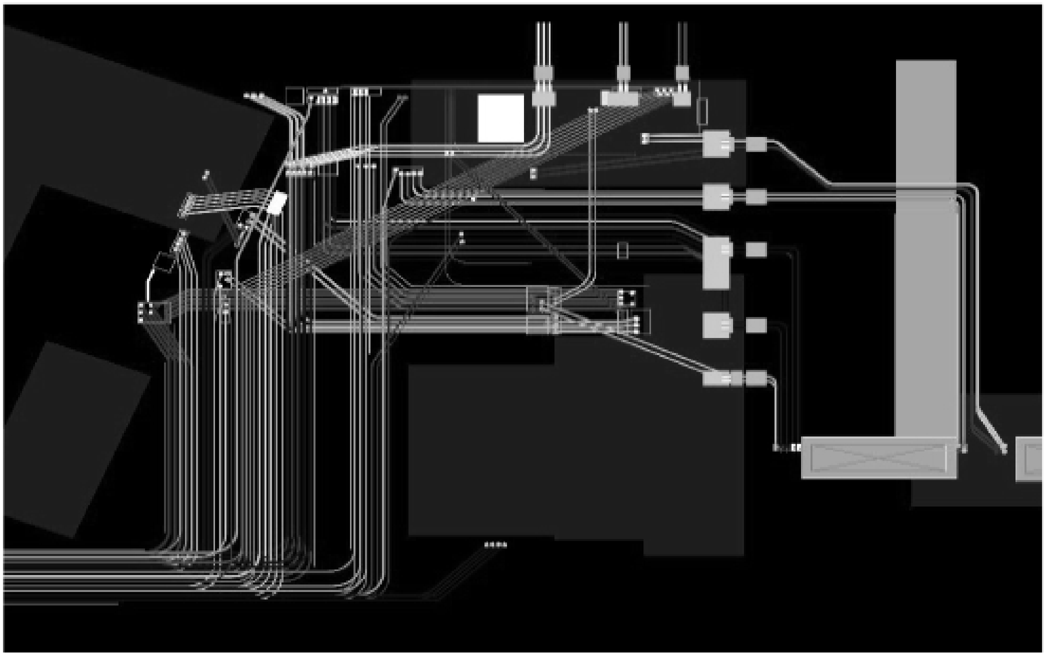


Figure 48. *Plan view of the main underground electrical room*
Source: Kuprenas & Mock, 2009.

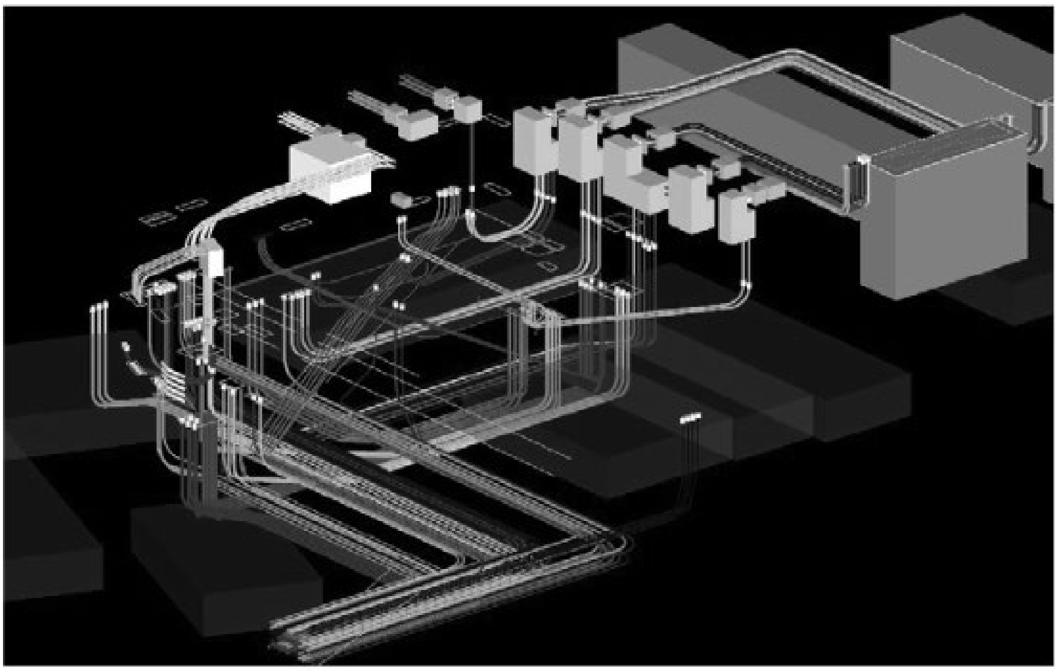


Figure 49. *3D model of the main underground electrical room*
Source: Kuprenas & Mock, 2009.

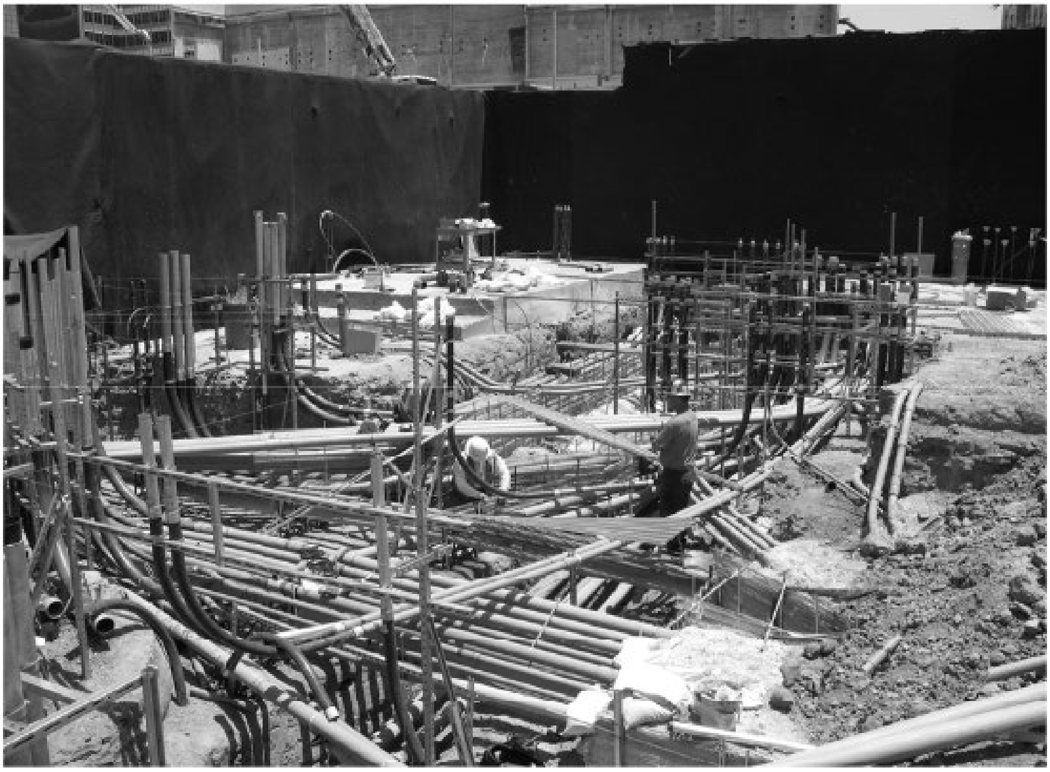


Figure 50. *Construction progress of underground electrical room*
Source: Kuprenas & Mock, 2009.

Table 17. *Intra-trade BIM model benefits and cost savings realised*

Coordination (inserts)	Visualisation (underground electrical)	Sequencing (MEP and FP systems)
Reduced rework $50,000	Sequencing $250,000	Preassembly $25,000
Shortened construction duration $10,000		Bundling $10,000
		Shop fabrication $25,000

Inter-trade Coordination

The BIM model facilitated clash detection between trades, which identified over 100,000 conflicts (examples shown in Figure 51 and Figure 52). A review of the 3D model found that 90% of the MEP systems did not fit in the provided ceiling space. Consequently, every floor of every building was affected and required redesign. The BIM model enabled these problems to be identified early in the project, which allowed adequate time for re-design and coordination with no impact on the construction schedule:

- The management team worked with the contractor to create a detailed MEP coordination schedule within the project schedule for completion.
- The team then created a schedule for resolving design conflicts based on that MEP coordination schedule. This schedule clearly identified the potential schedule impacts based on the current design.
- This led to the allocation of an onsite design team of fifteen architects and engineers to resolve these issues in a timely manner.

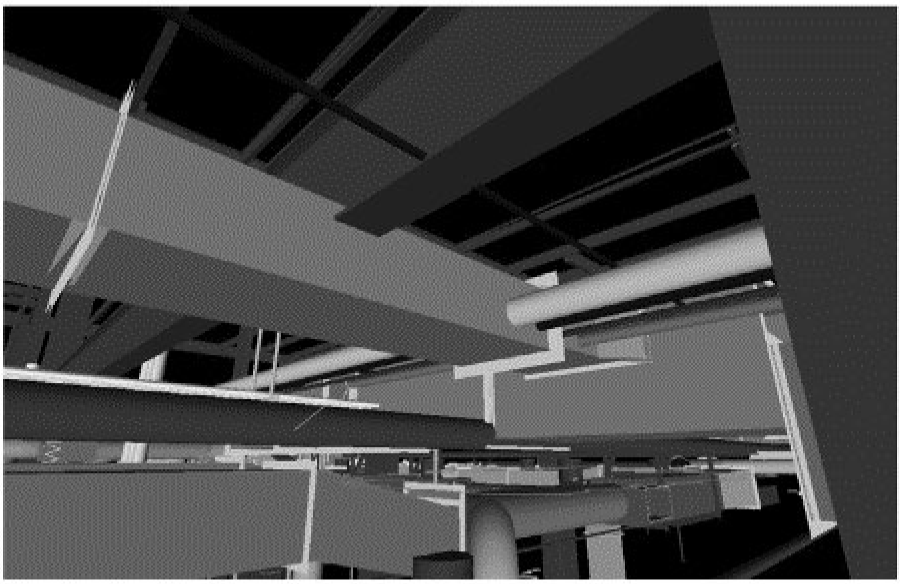


Figure 51. *Example of a conflict between a beam and duct*
Source: Kuprenas & Mock, 2009.

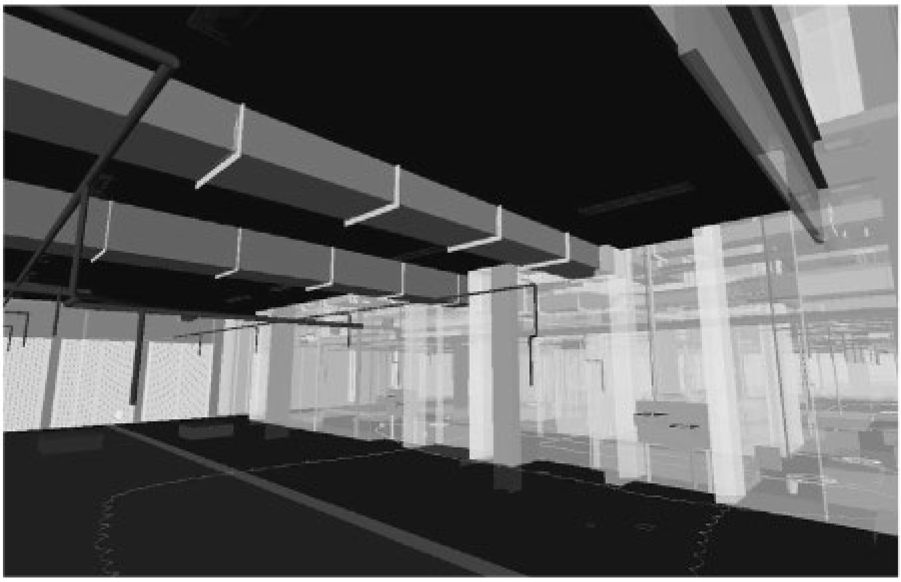


Figure 52. *Examples of ceiling height conflicts*
Source: Kuprenas & Mock, 2009.

The inter-trade BIM model benefits and cost savings realised are tabulated in Table 18.

Table 18. *Inter-trade BIM model benefits and cost savings realised*

Coordination	Visualisation (underground electrical)
Conflict checking (between trades) $4,000,000	Bulletins $250,000 Other changes $250,000

Lessons Learned

Three-dimensional BIM modelling was recommended for the following reasons:

- The process resulted in more accurate and complete contract documents, which reduced the number of contractor requests for information and change orders
- 3D visualisation resulting in reduced misinterpretations of the design intent and less rework onsite
- Minimal project delays resulted from prefabrication and the successful 3D coordination process, which included the resolution of conflicts and clashes.

The lessons learned from the adoption of BIM in both the design and construction phases are listed as follows:

- In the design phase, the mindset must be shifted from a 2D drawing mentality to create the foundation for 3D BIM modelling. The structure must be modelled in 3D, and MEP engineers must allocate 3D space for each system.
- Design consultants need to demonstrate to the architect that there is adequate space for the structure and MEP systems.
- It is advantageous to involve the general contractor and major subcontractors early for design input.
- During the construction phase, the general contractor and construction manager must take ownership of the BIM model and manage it according to onsite requirements.
- All major subcontractors (structural steel, MEP, FP and so on) must detail their components in 3D and combine their drawings into a single BIM model to be used during construction.
- Each trade must participate in BIM coordination meetings to resolve conflicts, and assist with visualisation and sequencing.

Lessons learned in terms of management and process timing were also provided:

- A centralised onsite BIM coordination room was recommended, with one fulltime BIM facilitator from each of the major subcontractors (MEP and FP) for the first 8 to 12 months of construction to maximise coordination and insulate them from the daily requests of their field staff.
- The coordination room is to be led by the general contractor’s coordination manager, who must have a strong technical background and the authority to make decisions during the entire project.
- All participants need to use compatible modelling software and should expect daily collaboration.
- The team should begin the modelling process when 80% to 90% of the contract documents are complete.

Healthcare Project in California, USA

This project involved the construction of a steel-framed Medical Office Building (MOB) in California (Khanzode et al, 2008). The MOB includes patient exam rooms, doctor offices, surgery and radiology rooms, public spaces, a cafeteria, numerous conference rooms, and so on. The project details are provided in Table 19.

Table 19. *Project details for the medical office building in California*

Project details	
Name / Client & Owner	Medical Office Building, California / Camino Medical Group
Value	$96.9M
Tender / Design & Build / Completion Year	Tender in 2005 / Completed in 2007
Height / Gross Floor Area	Three storeys and two-level parking garage / 250,000 square feet Floor to the underside of the metal deck is 4.26m Floor to ceiling height in most rooms is 2.9m
Stakeholders	Details of stakeholders are provided below

Roles and Responsibilities of Stakeholders

The project stakeholders and their roles are provided in Table 20 and described herein.

Table 20. *Stakeholders and their roles*

Stakeholder	Role
Sutter Health/Camino Medical Group	Owner
Hawley Peterson and Snyder Architects	Architects
DPR Construction, Inc.	General Contractor
Capital Engineering Consultants	MEP Design Engineers
Southland Industries	Mechanical Subcontractor
Cupertino Electric	Electrical Subcontractor
JW McClanahan	Plumbing Subcontractor
North Star Fire Protection	Fire Protection Subcontractor

Role of General Contractor (GC): GC enabled the MEP coordination process, which was supported by Building Information Modelling (BIM) and Virtual Design and Construction (VDC) VDC. The GC coordinated the hand-off of information from the architects and engineers to the subcontractors, and also the modelling and coordination work. Effectively GC developed a workable detailing schedule together with the architects and engineers, and subcontractors to support the construction schedule.

Role of the Specialty Contractors (SC): SCs were responsible for modelling their components using 3D technologies. For example, the HVAC contractor used BIM and VDC tools for MEP coordination, and had a leading role in the coordination process. Detailers of other trades (plumbing/electrical/fire sprinklers) were interested in the arrangement of HVAC equipment (e.g. fire smoke dampers, duct shafts, and low and medium pressure ducts), which occupied most of the above-ceiling space. They needed to know how the duct shafts and main ducts are routed because this has the most impact on how they will route their utilities. The SCs are also involved early in the process (between the conceptual and schematic design phases) so that they can relay their input into constructability and operations issues to the design team.

Challenges/Design Considerations

The main challenges identified in the project are listed as follows:

- Organisation of the MEP coordination process using BIM and VDC tools.
- Guidelines for the most efficient use of these tools for conflict resolution between the MEP subcontractors.
- Alignment of the contractual interests of the coordination team to meet the overall project schedule.

Based on the authors' experience in the US construction industry, the current MEP coordination process at the time was still followed on the majority of projects. This process involved the following steps:

- The specialty subcontractors or the engineers developing the detailed drawings for their own scope of work and overlaying the drawings on a quarter inch scale.
- A light table was used to identify potential conflicts that may occur in routing the MEP systems.
- The conflicts were then highlighted on the transparent drawing sheets and then addressed before the fabrication and installation process.

The process leads to several challenges, including the following:

- Difficulties in identifying conflicts due to the 2D representation of the designs.
- Delays in the construction process due to conflicts being identified onsite.
- Lack of trust in offsite fabrication due to uncertainties on how the systems fit together, which can lead to a lot of onsite fabrication.
- Required rework to rectify conflicts that were missed during design and coordination.
- Increased onsite supervision required to avoid conflicts between contractor trades.
- Increased administrative burden of more Requests for Information (RFI) and Change Orders (CO) due to the identification of conflicts in the field after budgets are approved.
- Overall reduced productivity for everyone involved in the process.

The owner, architect, engineers and contractor found that the team members had not worked previously on a similar project (in terms of size and scope), and have not collectively used the BIM and VDC tools for MEP coordination. This posed several important considerations to be addressed by the digital build methodology:

- How to best utilise the BIM and VDC tools for MEP coordination.
- The roles of each project team member in the coordination process.
- Addressing issues related to the technical setup, and sharing of models and drawings.
- The structure and management of the coordination process.

Modelling Process

The rendered Medical Office Building (MOB) and the site are illustrated in Figure 53. The project team adopted 3D and 4D VDC modelling tools for coordinating the design and installation of MEP systems. They decided to utilise these tools early in the project for visualisation and automated clash detection. The project team iteratively developed guidelines for the use of BIM and VDC tools, which were refined as they became more familiar with the coordination process using these tools. The guidelines include:

- Clarifying the role of the general contractor (GC) and specialty contractors in the coordination process.
- Developing the levels of detail in the architectural, structural and MEP models.
- Setting up the coordination process, including technical logistics, when to initiate the process, sequence of coordination, handoffs between designers and detailers, working in a collaborative room/space, 3D clash detection tools for conflict resolution, management of the process and final sign-off.
- Managing the coordination of the installation process.

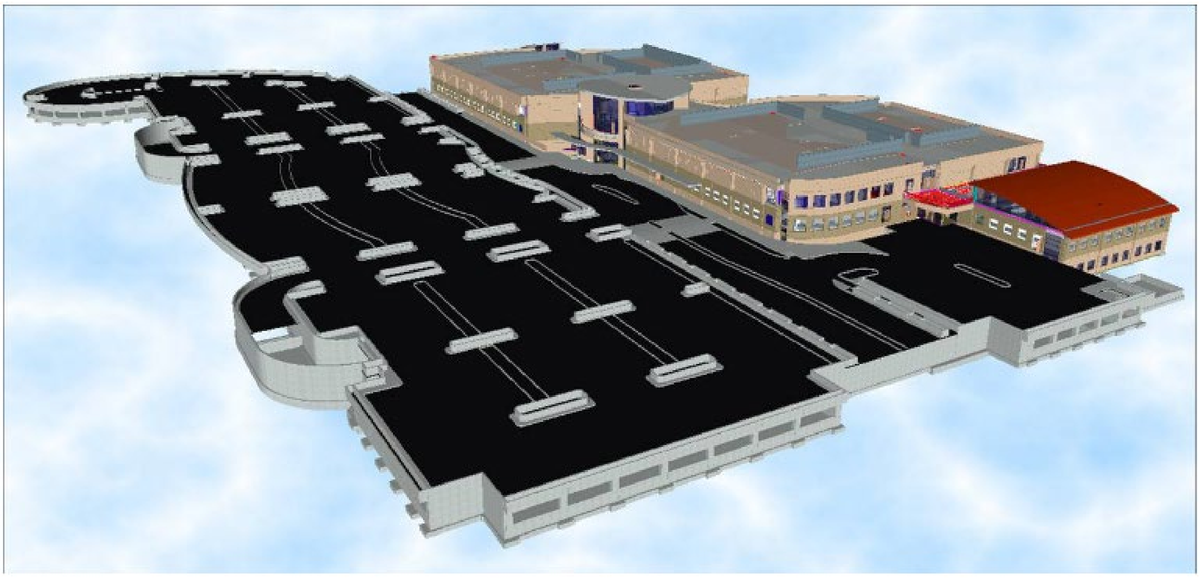


Figure 53. *3D model of the Medical Office Building (MOB) and site*
Source: Khanzode et al, 2008.

The team maintained a record of traditional metrics, including the number of Requests for Information (RFI) related to MEP coordination during the construction phase, number of Change Orders (COs) due to onsite conflicts, hours for rework, hours lost to injuries, productivity of field personnel and amount of prefabrication.

The goals set out by the entire project team from the coordination effort played a significant role in selecting the components that were to be modelled in 3D. Based on the authors' experience in prior projects, MEP/FP coordination can be divided into 2 distinct coordination efforts, namely: 1) the coordination of underground plumbing and electrical utilities; and 2) above-ceiling coordination of Mechanical, Electrical and Plumbing (MEP) and Fire protection (FP) utilities. The decision for implementing both of these coordination efforts using 3D tools implied that additional elements (e.g. foundation and framing) are required.

The level of detail to be provided in the digital build-driven coordination process is also a significant consideration. For example, details in the architectural model are required for determining the exact locations of the plumbing rough-ins in the walls but is not required for coordination and conflict detection with other systems like HVAC.

The project team decided to create the following 3D models for facilitating the coordination of MEP systems:

- Architectural elements: Interior walls and ceiling.
- Structural elements: Framing, slabs and foundations.
- MEP systems: Duct work, gravity lines, hot and cold water piping, major conduits and cable trays, FP systems with the mains and branches.
- Other specialty systems: Medical gases, depending on the project

The digital build tools adopted in this project and their functionalities are listed in Table 21.

Table 21. *Digital build tools and their functionalities*

Digital Build Tool	Functionality
Autodesk Architectural Desktop	Architecture
ETABS	Structural Analysis
Autodesk Revit Structure	BIM
QuickPen 3D Pipe Designer, CAD Duct, Fab Pro Mechanical Detailing, SprinkCAD Sprinkler Modelling	MEP
Navisworks JetStream	Coordination and Clash Detection

Coordination Process

The coordination process is grouped into technical logistics, kick-off of the coordination process, sequence of coordination, managing handoffs, working in the main collaboration room, and using clash detection to identify and resolve conflicts. These processes are summarised herein.

Technical Logistics: Team members need to agree to some basic rules at the outset of the project so that the sharing of electronic 3D models is efficient and benefits the entire team, given that many 3D models will be used in the project, and each subcontractor is likely to create their own model. The coordination complexity and interrelationships between the digital build tools across disciplines are illustrated in Figure 54. The project team should ensure that the following steps are adhered to:

- 3D models are accompanied by standard word documents describing revisions, and posted to a secure and accessible project website, ftp site, or a document collaboration site determined by the team (including GC, subcontractors, owner, architects and engineers).
- Organisation of the model files and other relevant documents on the server using a clear file structure.
- All personnel work from and post to the same server, which is backed up daily.
- Anything not intended to be seen in the 3D model is erased prior to file transfer.

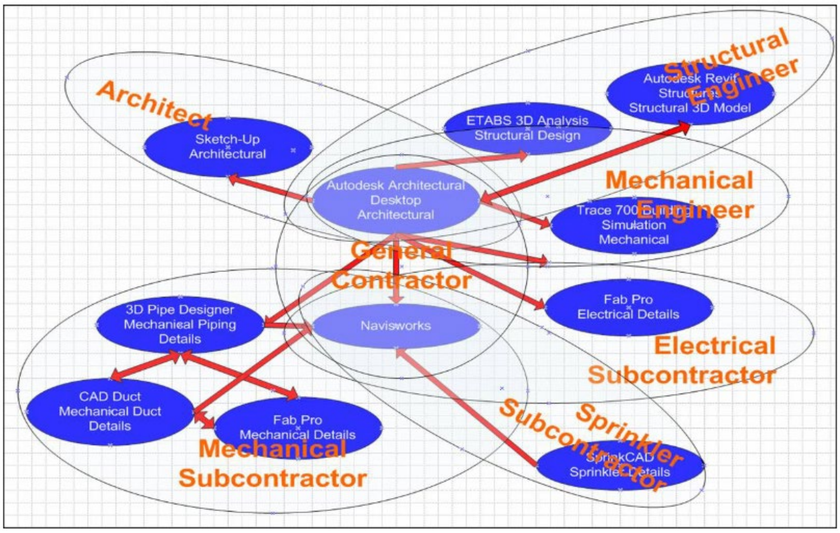


Figure 54. *Flow of information between trades, where Navisworks JetStream was used to combine the models and perform clash detection*
Source: Khanzode et al, 2008.

Kick-off coordination process: A kick-off meeting should be established, which involves all the project team members, and includes the following discussion items:

- Ensuring the technical logistics are correct.
- Performing the initial space allocation of the above-ceiling space, which involves the identification of the zones that each of the trade contractors will occupy (see
- Figure 55).
- Determine the breakup of floor plans such that they can be coordinated in smaller batches.

Coordination sequence: MEP and FP coordination 3D tools is most efficient using the following sequence:

- Start with the 3D structural and architectural model, and then add miscellaneous steel details.
- Perform preliminary space allocation, and then identify hard constraints (locations of access panels, lights, and so on).
- Draw the following components in order: 1) main medium pressure ducts from the shaft; 2) main graded plumbing lines and vents; 3) sprinkler mains and branches; 4) hot and cold water mains and branches; and 5) lighting and plumbing fixtures.
- Route the smaller and flexible ducts around the utilities, and then route the smaller hot and cold water piping, flexible ducts and so on.

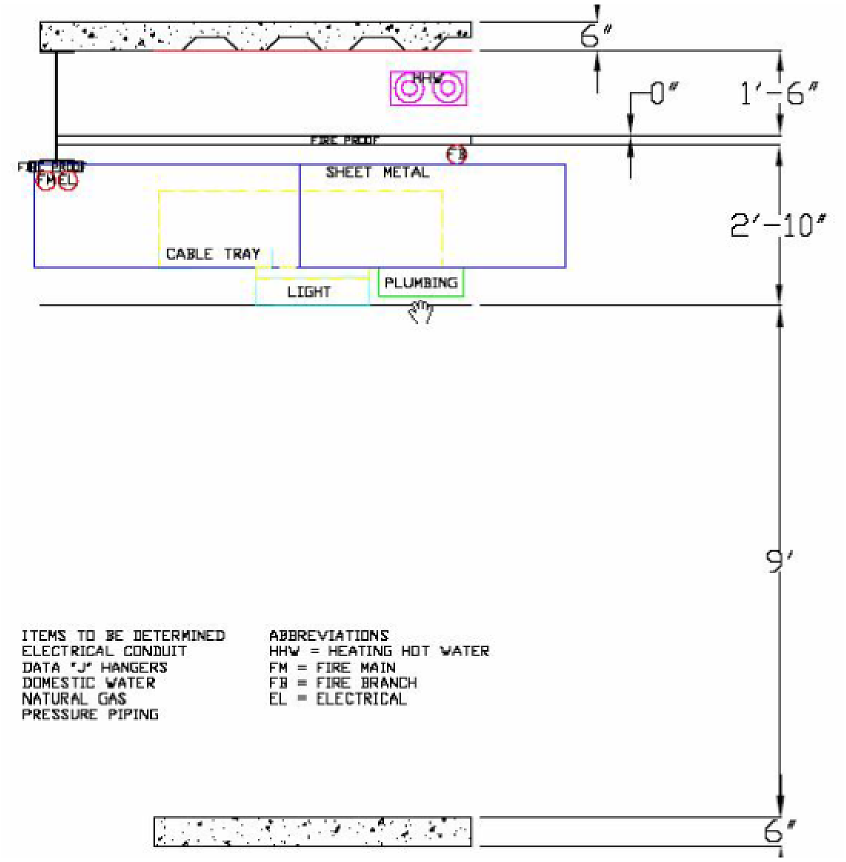


Figure 55. *Screenshot of the initial space allocation of the above-space utilities for the MEP systems*
Source: Khanzode et al, 2008.

Manage handoffs between designers and the subcontractors' detailers: In the US construction industry, the traditional build process (in both the design and construction phase) involves several specialty firms that focus on specialised, small portions of work. Managing the hand-off of information from designers (typically the engineers) to the subcontractors' detailers is extremely important, particularly in a fast-tracked project.

- During the design phase, architects work with several design consultants (structural engineers, acoustic consultants and mechanical engineers) to complete the design of the facilities.
- During the construction process, the general contractor typically coordinates the work of many specialty subcontractors.

Collaboratively, the design and construction teams should determine how the design will be broken down into small batch sizes that allow detailers to coordinate and complete an area so that fabrication can begin, which is an iterative process. An example of a process chart and document to determine the handoff between the design and the construction teams is provided in Figure 56 and Figure 57, respectively. This handoff is a result of honest negotiation between the design and construction teams, who determine how much information should be shared between the architects/engineers and the detailing team to meet the milestones for coordination and fabrication. The GC should attend these discussions with a clear understanding of the critical path.

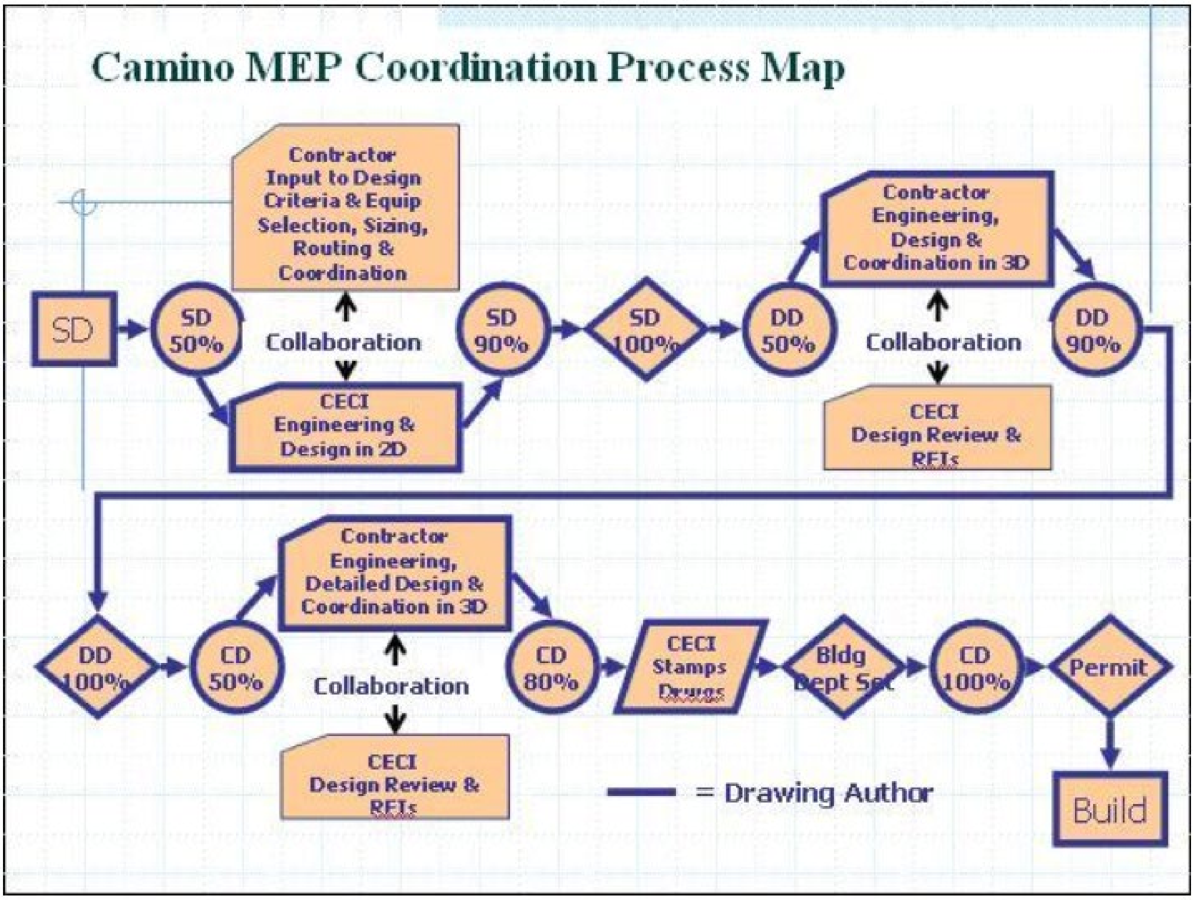
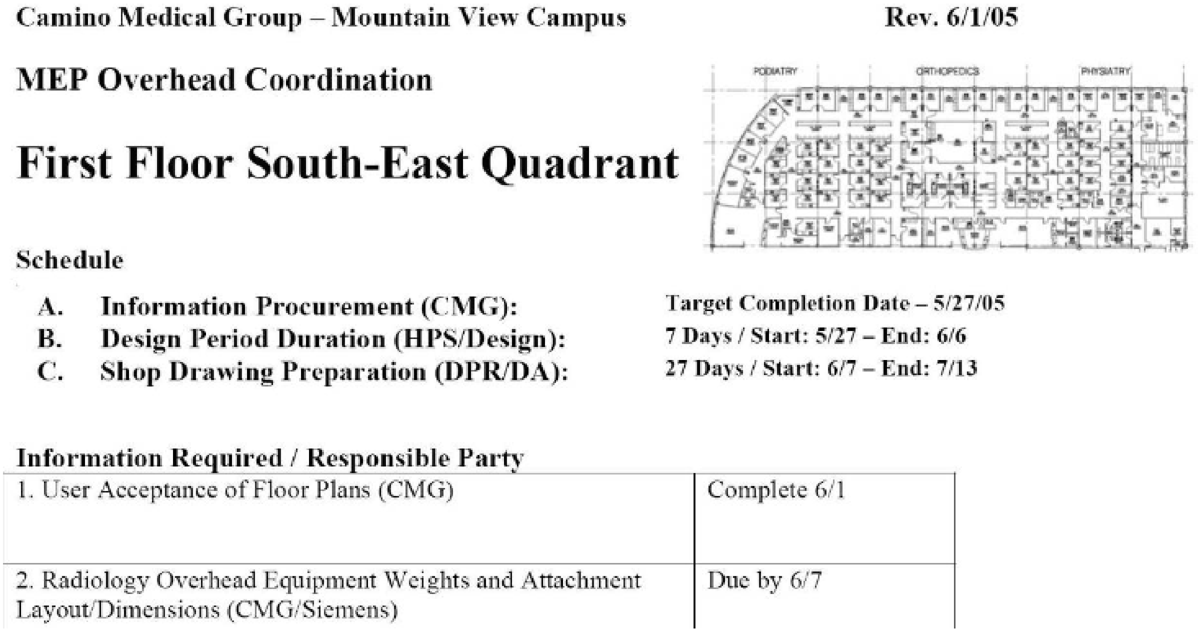


Figure 56. *Handoff process that was developed collaboratively by the design and construction teams*
Source: Khanzode et al, 2008.



Camino Medical Group – Mountain View Campus **Rev. 6/1/05**

MEP Overhead Coordination

First Floor South-East Quadrant

Schedule

A.	**Information Procurement (CMG):**	**Target Completion Date – 5/27/05**
B.	**Design Period Duration (HPS/Design):**	**7 Days / Start: 5/27 – End: 6/6**
C.	**Shop Drawing Preparation (DPR/DA):**	**27 Days / Start: 6/7 – End: 7/13**

Information Required / Responsible Party

1. User Acceptance of Floor Plans (CMG)	Complete 6/1
2. Radiology Overhead Equipment Weights and Attachment Layout/Dimensions (CMG/Siemens)	Due by 6/7

Figure 57. *The MEP coordination handoff document by the design and construction team to manage handoffs*
Source: Khanzode et al, 2008.

Working in the main collaborative room: To facilitate rapid decision making, detailers must work side-by-side to model and coordinate their designs to meet the coordination schedule. Effectively, detailers will not need to wait for posts to see the other members' tasks which significantly reduces wasted detailing efforts. In this project, detailers for the various specialty subcontractors shared a single room, with shared resources like servers, internet connection, printers and plotters, and coordinated the detailed design with each other and the design team.

Conflict resolution: NavisWorks JetStream is one of the commercial tools that enable project teams to combine 3D models from multiple CAD systems into a single model, and determine if they conflict with each other. This is facilitated through the clash detective module with an example shown in Figure 58. Conflict identification and resolution is an iterative process, which involves the following steps:

- The models from multiple disciplines (structural, architectural, MEP, FP and so on) are first combined into a single model.
- The clash detection module is run to identify clashes between these different systems.
- The clashes are then resolved in their native programs.
- Several iterations are performed until all clashes are resolved.

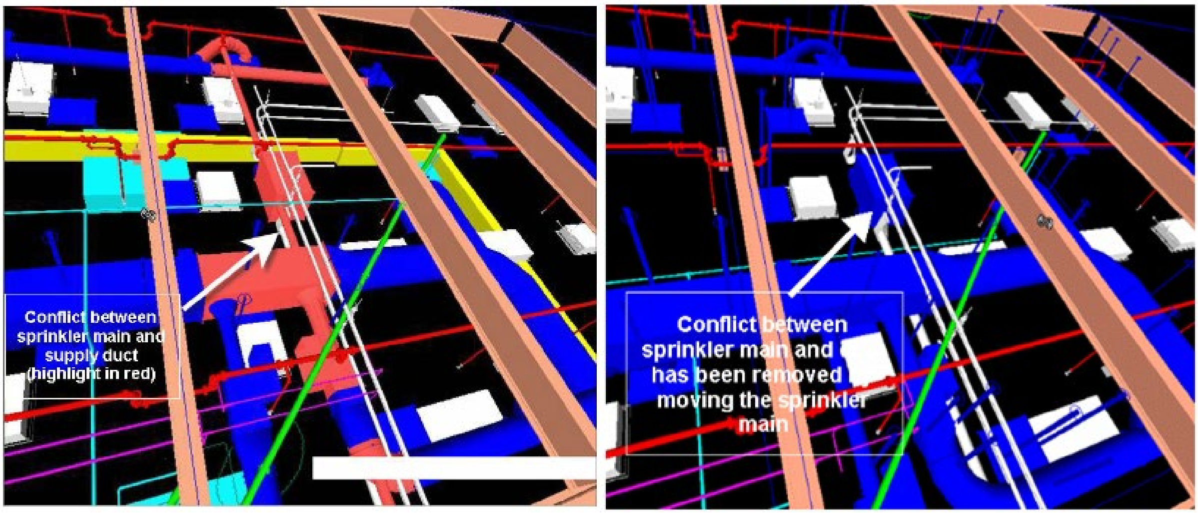


Figure 58. *Clash or conflict between a supply duct and a sprinkler main pipe (left), and the resolved clash by moving the sprinkler main to the right of the duct (right)*
Source: Khanzode et al, 2008.

Discussion of Results/Benefits

The above efforts resulted in the coordination schedule, which is established by the GC and MEP subcontractors. The coordination schedule (or work plan) is useful in terms of the following aspects:

- Ensures that clash-free drawings are used by installation crews in time for penetrations and hangers to be installed prior to the placement of reinforcement and concrete on the elevated decks.

- Sets dates for a final all-hands clash detection workshop for each area in time for pre-fabrication of assemblies to meet the master construction schedule.
- Minimises the potential for rework as much as possible and maximises information availability for all the team members.

The use of 3D/4D tools for MEP and FP coordination resulted in significant quantitative and qualitative benefits for the project team members. The benefits for the owner, general contractor, architects, engineers and subcontractors are listed in Table 22.

Table 22. *Benefits of digital build for the Healthcare project stakeholders.*

Stakeholder	Benefits
Owner	Less time spent on non-value adding activities (e.g. RFIs or COs due to MEP system conflicts) Only 2 of 233 RFIs were related to field conflict and construction related issues, and these 2 RFIs were for systems that were not modelled using BIM/VDC tools RFIs dealing with field conflicts on comparable projects are somewhere in the 200-300 range (no benchmarking was done with another similar-scale project) No COs due to a field related conflict (COs typically account for 1%-2% of cost of MEP systems), which is a significant saving for the owner The owner has an accurate as-built model, whereby information is a lot easier to find compared with traditional 2D drawings, which are normally sent to the owner at the end of the project This fast-tracked digital project delivery (compared with a traditional design-bid-build project delivery) yielded time and cost savings of 6 months and $9M, respectively, for the owner due to the use of the BIM/VDC tools and collaboration (Figure 59)
Architects/Engineers	Spending substantially less time during the construction phase of the project conducting construction administration No RFIs related to field conflicts or COs due to field conflict issues.
General Contractors	The GC's superintendents spent about 10-15 hours in the 8 months of the project dealing with field issues during MEP construction. They would typically need to spend 2-3 hours each day dealing with conflicts A total of 203,448 work hours have been spent during MEP coordination, and there has been only one recordable injury (versus a national average of about 8 recordable in for these many hours). This was attributed to more offsite pre-fabrication, just in time material deliveries, and efficient field coordination and installation Less equipment setup onsite and a cleaner site due to prefabrication
Speciality Contractors	A lot of reciprocal work that typically occurs during construction occurred during design, resulting in more efficient construction All the trades completed their work ahead of or on schedule More off-site prefabrication and more bolt-in-place assembly on site that required less labour than estimated at the beginning of the project resulted in improvements in productivity The mechanical contractor estimates that their field productivity has improved between 5 to 25% (Figure 60) based on comparing the estimated field productivity to the actual field productivity (related to field labour only) Guaranteed Maximum Price (GMP) project, where the mechanical contractor alone is giving back about $500k over his contract (valued at around $9.4M) due to savings on field labour All the plumbing, and medium and low-pressure ductwork was prefabricated, which was attributed to the use of 3D models for coordination. On comparable projects, none of the plumbing and at most 50% of the ducts would typically be prefabricated The mechanical contractor had to carry out less than 0.2% (only 40 out of 25,000 hours of field work) of rework in the field. They attributed this to accurate and coordinated 3D models that led to accurate fabrication and installation of almost all work the first time

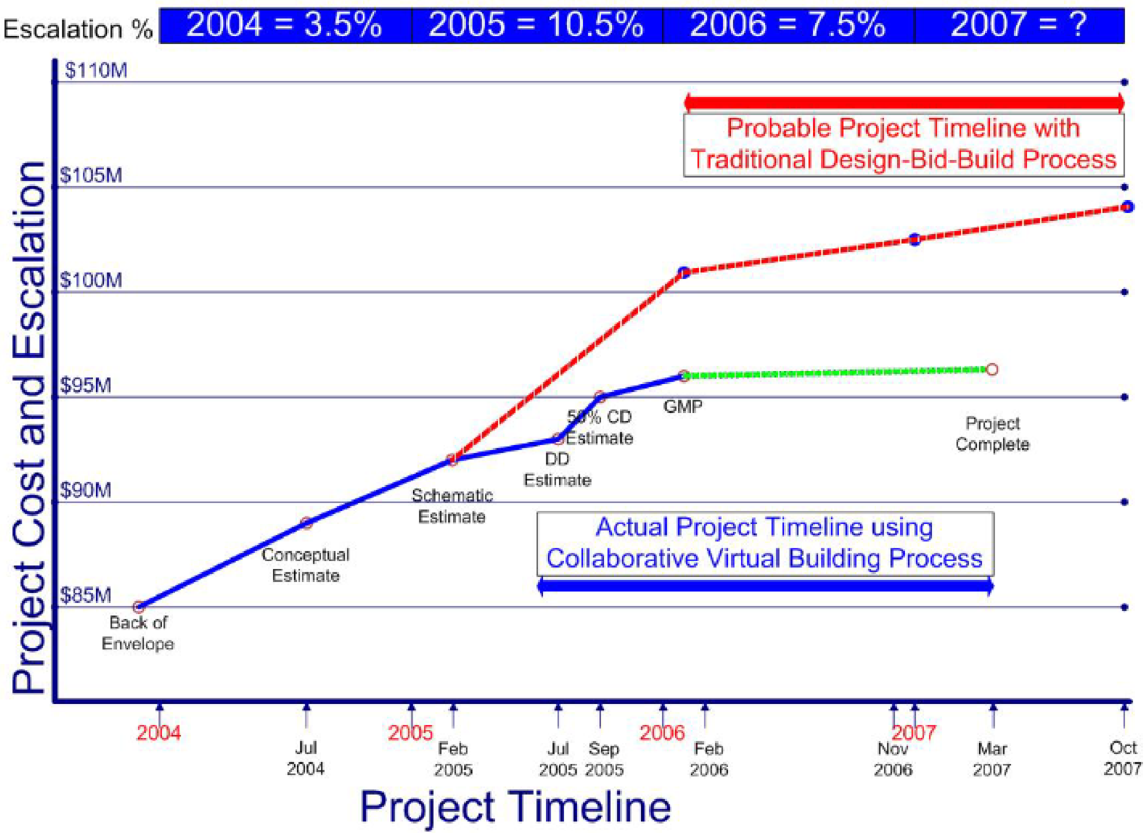


Figure 59. *Comparison between the collaborative digital build approach using VDC tools and the traditional design-bid-build method of project delivery*
Source: Khanzode et al, 2008.

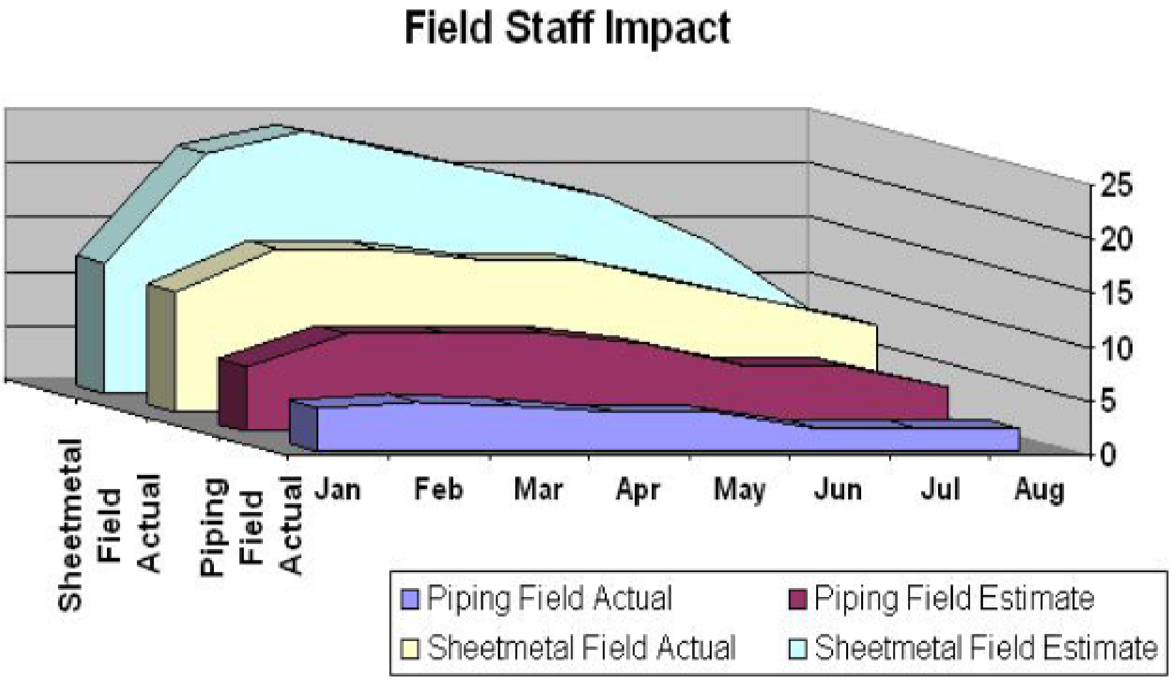


Figure 60. *Estimated versus actual hours spent by the mechanical contractor for the piping and sheet metal work*

Source: Khanzode et al, 2008.

Lessons Learned

The lessons learned and recommendations from the adoption of BIM/VDC for the MEP coordination process are summarised as follows:

- Although the organisation of subcontractors and their detailers on site were in the same collaborative room, working side by side during the coordination process, the FP subcontractor was not on site in this room with the other stakeholders. This resulted in many conflicts between the MEP and FP systems.
- At the beginning of the project, the architects and designers did not anticipate that they would spend much time in the collaborative room with the subcontractors when the coordination was ongoing but realised they had close to 2 days per week with the detailers so that most issues could be addressed.
- Towards the end of the project the electrical contractor had to relocate many electrical outlets in the patient exam rooms and doctors' offices. The end users requested some of these outlets to be moved after all the walls were roughed-in because the flexible conduit in some instances was shorter than the length required at the new locations and had to be re-installed in the field. On future projects, the team recommended that they would create a virtual mock-up of all the rooms in the facility to address these types of issues.
- The team also encountered a few instances where systems that were modelled interfered with systems that were not modelled. An example is the conflict between the supports for the exterior glass fibre reinforced concrete panels with the rainwater leaders (Figure 61). The lesson learned is that even miscellaneous steel supports should be modelled for a completely clash free installation with MEP systems.
- The architect modelled the Glass Fibre Reinforced Concrete (GFRC) wall panels in detail, which included the patterns of brick and the reveals, but did not model the supports where the panels were connected to the steel. For coordination of MEP systems, the team needed to have the exact locations of the steel connections to the GFRC panels, which shows that the level of detail should be decided collaboratively.
- The plumbing subcontractor needed the exact location of sinks in the casework to draw his graded plumbing lines from these sinks. The architect did not model these locations in 3D which resulted in the plumber having to refer back to 2D and interpret the locations before grading his lines in the 3D model. The general contractor initially did not include the scope of modelling for the seismic bracing and miscellaneous steel supports in any of the subcontractors' scope of modelling. Eventually, this was modelled by the mechanical contractor and is required for the accurate routing of pipes and ducts such that they not intersect with the seismic bracing.

Figure 61. *Conflict between the rainwater leaders and supports for the exterior glass fibre reinforced concrete panels Source: Khanzode et al, 2008.*

CONCLUSIONS

This section of the report summarises the outcomes of the mixed methods research activities and draws out key findings from the combined investigation of:

- The challenges and implications associated with the adoption of digital technologies in building projects identified through the literature review;
- Specific insights into the Victorian construction industry emerging from stakeholders' survey and focus groups providing; and
- The quantified benefits of digital build and connected data emerging from the detailed case studies, including documentation of the methodology used to achieve these benefits.

The integrative research outcomes show that BIM tools are increasingly employed for coordination, conflict resolution, and optimising the construction sequence. The Mechanical, Electrical and Plumbing (MEP) and Fire Protection (FP) systems are the most reported source of complexity, where digital tools and processes can achieve considerable time and cost benefits for individual building projects. However, the integration of BIM models with CDE is more limited. Broader benefits, such as effective knowledge-sharing between stakeholders, evaluation and ongoing innovation across projects, and supply chain integration requires greater take-up of digital build at organisational level, and greater levels of standardisation across the industry.

The benefits of digital build and connected data uncovered through the detailed case studies are listed in Table 23 overleaf. The comprehensive case study methodology quantifies key benefits achieved by each project and highlights the tools and processes adopted. Combined with the current state of international research on information management of a built asset from the literature review (Section 3), the research offers tangible strategies for the digital transformation of the construction industry. Stakeholder capacity and incentives to facilitate digital adoption, system standardisation and governance for operational consistency, industry-specific applications of digital asset management to optimise building and construction projects, and the Common Data Environments (CDEs) currently being adopted to streamline data sharing and collaboration. These focal points aim to provide a comprehensive understanding of the existing landscape and to identify avenues for effective implementation and scale-up of digital technologies in the construction sector.

The survey of project stakeholders provided insights on the uptake and experience of the VDAS, pointing to key opportunities to increase adoption across the Victorian building sector, including:

- Reduce the complexity of the VDAS to increase its adoption by a broader range of stakeholders, recognising the differing scale and capacity of actors in the building industry.
- Translate international project data to quantify the benefits of digital build for Victorian projects.
- Benchmark digital build against traditional design/construction processes to provide a strong case for investment.
- Consolidate the multiple and concurrent sources of construction information in a single source of truth to improve accountability, findability, accessibility, interoperability, transparency, reliability and reuse.
- Shift industry mindset towards digital practices to overcome major barriers to change, by
  - increasing leadership support and capacity building of staff
  - sourcing expertise, and allocating sufficient time and budgets for transitioning
  - demystifying the required technical skills, capabilities, and understanding of Industry 4.0
  - increasing system integration, platform interoperability and standardisation, including functionality with existing technology to replicate ISO 19650 information management tasks
  - addressing cybersecurity concerns.

Table 23. *Summary of the benefits of digital build obtained from the detailed case studies*

Case Study	Digital Build Tools Adopted and Purpose	Benefits of Digital Build and Connected Data
Woodside Building for Technology and Design (WBTD)	BIM modelling of separate building components (structural, architectural, MEP, FP and so on). Navisworks merged BIM models for coordination between trades and conflict resolution.	Improved coordination between different trades, including structural, architectural, MEP, FP. Most of the construction issues were resolved in the first half of the design/construction phase (total of 18 months). Fast-tracked project completion date (reduced by 4 months) Expedited the energy analysis of 5 different HVAC systems to achieve passive house verification Remote monitoring of thermal comfort conditions through the living lab sensors and data acquisition and reporting systems, which was otherwise not possible during lockdown
Small School Project	BIM for modelling the different school modules, which were assembled onsite	Access to a central BIM model as the single source of information Avoid carrying documents onsite, cloud-based access to BIM can be enabled through a tablet The Virtual Design and Construction Manager, Fleetwood, spoke of a reduction in clashes and the number of stakeholders involved from the use of 3D facilities and the importance of capturing data from the production floor
Shanghai Disaster Recovery Centre	BIM for clash detection and construction sequencing	Identified a total of 483 MEP issues prior to construction Vs 131 during construction Construction time savings of 65 days and 2.91% cost savings ($ / total MEP) Construction scheme optimisation resulted in a total of 292 days including reductions in the installation of the civil structure, MEP, FP and finishes
Commercial Office Development in Perth CBD	BIM for structural modelling (reinforced concrete floors). Navisworks with iConstruct plugin for construction sequencing BIM 360: cloud-based data access	Convenience due to having all information in one place Integration between the office and onsite personnel via tablet access to cloud-based data, improving communication efficiency. Real-time access to data enabled improved decision-making. BIM enabled processes provides a mechanism for creating a fully auditable record of events, which can be searched or interrogated.
Public Sector Construction Project in Los Angeles	BIM model for coordination and conflict resolution	Savings from the coordination of inserts: Reduced rework ($50k), shortened construction duration ($10k) Savings due to visualisation of underground electrical system: Sequencing ($250k), bulletins ($250k), other changes ($250k) Savings due to sequencing of MEP/FP systems: Preassembly ($15k), Bundling ($10k), shop fabrication ($25k) Savings due to conflict checking between trades ($4M)
Medical Office Building in California	BIM models (structural, MEP, FP and so on) Navisworks JetStream for virtual design and construction (VDC), combining multi-disciplinary BIM models into a single model for coordination and conflict resolution between trades	Only 2 RFIs dealing with field conflicts Vs 200-300 on comparable projects No COs due to a field conflict (typically account for 1-2% of cost of MEP systems) Fast-tracked project delivery (savings of 6 months and $9M) compared with traditional design-bid-build delivery method GC superintendents spent 10-15 hours (total within 8 months) dealing with field issues due to MEP Vs 2-3 hours per day in a traditional build Only 1 recordable injury in 203,448 hours of work (national average is about 8 in the amount of work hours)

A comparison of the Victorian case studies demonstrates the importance of understanding both project and organisational contexts when assessing the efficacy of digital build, and the extent to which has been adopted. For example, WBTD integrated the use of BIM and Navisworks to digitise the as-built structure in a single model, providing access to stakeholders across trades. Not only were significant time and delivery gains achieved (completed 4 months ahead of schedule, with design and construction issues resolved in the first half of the project), but the capacity to dynamically run and compare multiple simulations also optimised the project outcome in terms of energy efficiency, indoor air quality, and thermal comfort. It is important to note that WBTD was a flagship institutional project, with exemplary sustainability objectives supported by strategic investment in the ongoing monitoring of the building's use and operation.

By comparison, the BIM model of the Cowwarr Primary School included the site and locality plans and the 3D structural model. However, it was generally missing connection details, and no parameters were assigned to model properties (e.g. structural, thermal). The BIM model was not integrated with CDE, limiting the ability to fully assess benefits. This may be attributed to the standardised modular design, involving manufacturing and construction methods that required less collaboration than WBTD, as most of the work was done in a controlled factory environment. Furthermore, Fleetwood is a vertically integrated company and may not require a CDE for a specific project but rather to share information on projects between the departments within their organisation.

The project-specific objectives, funding, stakeholder groups and delivery approaches of each case study makes it challenging to quantify generalisable benefits of digital build. However, a number of key focus areas emerged from the mixed methods research highlighting where future government and industry investment might be directed.

Digital Leadership

- **Government Investment as a Catalyst**: The research indicates that government investment plays a pivotal role in promoting digital leadership within the construction industry. Examples from case studies, particularly in Victoria (VIC), showcase how government funding can drive digital transformation initiatives, noting it is incumbent on industry to present the value for money proposition and demonstrate the efficiencies to government.
- **Opportunity for Digital Leadership**: Despite government support, there is an opportunity for governments to further demonstrate digital leadership by directing funding towards projects that explicitly justify investments in digital build technologies.
- **Automated Clash Detection:** Return on Investment (ROI) of 10% to 20% can be expected by automating clash detection using BIM technology
- **Early Issue Identification:** Early identification of clashes can lead to an ROI of 5% to 15%, showcasing digital leadership in proactive problem-solving.

Integrated Data

- **Benefits of Connected Data**: The research highlights the significant benefits of integrated data, particularly through Building Information Modeling (BIM) and Common Data Environments (CDEs). Case studies demonstrate that connected data leads to improved coordination, conflict resolution, and efficiency across project teams and supply chains.
- **Early Engagement of Supply Chain**: The case studies, especially in VIC, underscore the value of early engagement with the supply chain through integrated data practices. This approach expedites project delivery and enhances collaboration among contractors, designers, and other stakeholders.
- **Information Management (IM) for Productivity:** IM practices can secure ROI ranges from 5.1:1 to 7.4:1, with direct labour productivity gains and cost savings (refer Table 5).

- **Asset Lifecycle Savings:** Cost savings at various asset lifecycle stages can translate into an additional £3.70 in annual GDP for every £1 of direct productivity gain (as discussed in the literature review, p 86, see Table 4).

Productivity Enhancement

- **Efficiency Gains through Digital Build**: The synthesis of literature, surveys, and case studies demonstrates that digital build leads to significant productivity enhancements. Digital tools, such as BIM and Navisworks, help in conflict resolution, coordination between trades, and improved construction sequencing.
- **Benchmarking for Productivity**: Case studies emphasise the importance of benchmarking digital build processes against traditional design-bid-build methods. Benchmarking data is vital for quantifying productivity gains, cost savings, and return on investment.
- **Virtual Roughing-In:** ROI between 8% and 18% can be achieved by virtually roughing-in systems before physical construction, addressing issues early, and improving productivity (see Figure 4).
- **Lifecycle Efficiency:** ROI of 6% to 12% can be realised by defining building lifecycle needs through digital models, reducing rework, and ensuring long-term facility effectiveness (see Figure 5).
- **Various Project Typologies:** Projects involving digital models (BIM) and digital management systems can achieve ROI between 1% and 25%, depending on the scale and complexity of the project and the extent of digital adoption (see Figure 4 and Figure 5).
- **Digital Twins for Infrastructure:** ROI in the range of 1% to 6% can be expected through accelerated risk assessment, predictive maintenance, remote monitoring, collaboration, and better financial decision-making (KPMG, 2021).
- **Common Data Environment (CDE):** ROI can vary from 32% productivity increase to 75%-time savings in project kick-off, showcasing productivity enhancements through digital tools (see Table 5).

Governments play a crucial role in driving digital adoption, while integrated data practices foster collaboration and efficiency across different industry actors. Digital build technologies contribute to sustainability goals and significantly enhance project productivity. However, benchmarking and data-driven assessments are essential to fully realise the benefits of digital transformation in construction. The above estimates are derived from the case study and literature reviews, presenting a broad overview that can be used as initial guidance. The actual ROI for a particular project will depend on numerous factors, including project objectives, technology implementation, and the specific challenges faced. These ROI ranges are not mutually exclusive and can overlap in certain projects, depending on the extent to which digital build practices are integrated. Considerations for better capturing the benefits of digital build include:

- Early access to case study data and stakeholders can enable a more comprehensive analysis to quantify the time and cost benefits of digital build.
- Availability of benchmarking data to make a quantifiable assessment of the benefits of digital build against the traditional design/construction process in a Victorian project.
- Utilisation of CDE to an adequate level in our selected case studies can provide stronger metrics compared with standalone BIM.
- Although not explicitly stated, addressing IP issues early on will enable businesses to share their data, technology, design, estimating and construction processes.

RECOMMENDATIONS

Based on the rigorous analyses of survey data, interviews, and multiple case studies, key areas for improvement and optimisation have been identified within the realms of digital leadership, integrated data management, decarbonisation strategies, and productivity enhancement. The following evidence-based recommendations are formulated to address these areas and drive a successful digital transition in the construction sector.

Table 24. *Summary of strategies for increasing adoption in digital build and connected data*

Themes	Recommended Strategies	Relevant Case Studies
Digital Leadership	**Digital Education and Training** Develop and sponsor training programs and certifications for construction professionals to enhance their digital skills. This can be done through partnerships with educational institutions and industry associations.	SDRC
	Government-Led Digital Pilot Projects Government agencies can initiate pilot projects that showcase the benefits of digital technologies in construction. These projects can serve as practical examples for the industry to follow.	LAUSD
	Digital Transformation Roadmaps Governments can work with industry stakeholders to develop clear digital transformation roadmaps and guidelines, outlining the steps and technologies needed for a successful transition.	Literature Survey results
Integrated Data	**Standardised Data Formats** Encourage the adoption of standardised data formats and protocols, such as Industry Foundation Classes (IFC) for BIM, to ensure interoperability among different software and data systems.	WBTD CODP
	Common Data Environments (CDEs) Promote the use of Common Data Environments (CDE) for project teams to collaborate and share data seamlessly. Establish best practices for CDE implementation and management.	WBTD CODP
	Data Sharing Agreements Facilitate the creation of data-sharing agreements and protocols among project stakeholders, ensuring that data is shared efficiently and securely throughout the project lifecycle.	WBTD CODP
	Invest in Data Analytics Invest in data analytics tools and platforms that can process and analyse integrated data to derive insights for better decision-making and performance optimisation.	MOBC

Themes	Recommended Strategies	Relevant Case Studies
Decarbonisation Strategies	**Sustainable Building Codes** Governments can update and strengthen building codes to promote sustainability and energy efficiency in construction. Encourage the use of eco-friendly materials and energy-efficient designs.	WBTD CODP
	Incentives for Green Building Certification Offer incentives and benefits to construction projects that achieve green building certifications, such as LEED (Leadership in Energy and Environmental Design) or BREEAM (Building Research Establishment Environmental Assessment Method).	CODP
	Research and Development Invest in research and development initiatives focused on innovative construction materials and technologies that reduce carbon emissions. Support collaboration between academia and industry for sustainable construction solutions.	WBTD
Productivity Enhancement	**Encourage Lean Construction Practices** Encourage the adoption of lean construction principles to streamline workflows and eliminate waste in construction processes. Provide training and resources to promote lean thinking.	WBTD
	Promote Digital Tools and Automation Technologies Promote the use of digital tools and automation technologies, such as robotics and AI, to enhance productivity. Offer incentives for companies that invest in and implement these technologies.	SDRC MOBC
	Implement Collaborative Project Management Implement collaborative project management platforms that facilitate communication and coordination among project stakeholders. Emphasise the importance of early involvement and collaboration to prevent delays and conflicts.	LAUSD
	Establish Performance Benchmarking and KPIs Establish industry-wide performance benchmarks and key performance indicators (KPIs) for construction projects. Encourage project teams to track and measure their performance against these benchmarks.	WBTD LAUSD

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APPENDICES

Appendix 1. Survey Instrument

Connected Data Survey

Question 1. Preserving the valuable data generated at each stage of an asset's lifecycle is critical and should be used for the public good. **Your response to this survey will increase the understanding of issues related to asset management and ultimately help to improve economic and social outcomes.** This survey is organised in 7 sections, to reflect the key stages of the Victorian Digital Asset Strategy (VDAS) released by the Victorian Government in 2020. The VDAS supports departments and agencies to plan, deliver, operate and maintain the assets they manage on behalf of the people of Victoria.

Question 2. Consent Form
Project ID: 32561
Project title: CRC#38 - Victorian Government Digital Build – Translating theory to practice

Associate Professor Gillian Oliver (Principal Investigator), Dr Misita Anwar, Dr Shijia Gao and Dr Lisa Kruesi, Department of Human-Centred Computing, Monash University, E: lisa.kruesi@monash.edu
Dr Jocelyn Cranefield, Wellington School of Business and Government, Victoria University of Wellington

You are invited to take part in this study. Please read our Explanatory Statement < *link to the statement*> in full before deciding whether to participate in this research. If you would like further information regarding any aspect of this project, you are encouraged to contact the researchers via email address listed above.
Your responses will be kept completely confidential.

Question 3. Please indicate your key role on a major current or previous construction project (internal roles unless specified):

○ Digital Engineer Project Champion (1)
○ VDAS Champion (2)
○ Asset Manager (3)
○ Facility Manager (4)
○ Head of Engineering (5)
○ Engineering Manager (6)
○ Maintenance Manager (7)
○ Project Director (8)
○ Legal Adviser (9)
○ Sponsor (10)
○ Data Custodian (11)
○ Data Steward (12)
○ External Consultant or Contractor (13)
○ External Builder or Construction Manager (14)
○ Other (please add your job title below) (15)
____

Question 4. Are you aware of the Victorian Digital Asset Strategy (VDAS) of 2020?

1. Yes (1)
2. No (2)
3. Uncertain (3)
4. Comment (4) ____

Question 5. How ready is your organisation to manage digital assets? *(Data and information are considered digital assets)* Please indicate your response to the following statements:

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
A. Governance processes are established	o	o	o	o	o
B. Suitable business processes and information needs are addressed	o	o	o	o	o
C. Required data standards and quality approaches are established	o	o	o	o	o
D. Suitable resourcing and support are established for effective training of new staff and other necessities	o	o	o	o	o
E. Required technology and systems are in place	o	o	o	o	o
F. Sustainable processes have been established to validate project(s) and the asset's data	o	o	o	o	o
G. Responsibility has been assigned to control and validate project(s) and asset's data	o	o	o	o	o
H. The approach to organisational readiness to apply the VDAS is repeatable	o	o	o	o	o

Question 6. What is the typical value of the construction projects with which you most commonly work?

- o Less than $10 million (1)
- o $10-20 million (2)
- o $21-50 million (3)
- o $51-100 million (4)
- o $101-500 million (5)
- o Greater than $500 million (6)

Question 7. This section focuses on the project's Brief and is Stage 1. The purpose of this stage is for the Appointing Party (the owner, State Government or those contracted on their behalf) to understand and clearly articulate the problem statement into a project opportunity statement and gather existing contextually relevant information to inform various concepts developed in Stage 2.

Please indicate your response to the below statements on the implications of establishing the exchange information requirements and the digital engineering strategy for a construction project:

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
Securing engagement and ongoing support of executives and sponsors has been possible (1)	o	o	o	o	o
There was a systematic approach to working with key stakeholders (2)	o	o	o	o	o
During Stage 1 (the Brief) and Stage 2 (the Concept) stakeholder roles, responsibilities and accountabilities were clearly defined (3)	o	o	o	o	o
To reduce claims on a project, access was provided to a platform with visualisation, sharing of data and information capabilities (5)	o	o	o	o	o
Intellectual property policy direction provided by the VDAS was easy to interpret and apply (6)	o	o	o	o	o
Post project licensing of information was agreed upon during either or throughout Stage 1 and Stage 2 of the project (7)	o	o	o	o	o
A review of the material and information being requested as part of the procurement process was undertaken by the Appointed Party (8)	o	o	o	o	o
Depending on the IP scope of the project, permitted uses of the Project Information Model was clearly defined during Stage 1 and/or Stage 2 (10)	o	o	o	o	o
The scope of the licences granted to the State were carefully defined to ensure that all desired future uses are permitted (in particular future uses in relation to separate projects) (11)	o	o	o	o	o
Commonwealth and State privacy law requirements in relation to the access of any personal details contained in the data, information and models were adhered within the project (12)	o	o	o	o	o
Data security and integrity obligations were adhered to throughout the project (14)	o	o	o	o	o
The project had a clear strategy on information liability on a stage-by-stage basis (15)	o	o	o	o	o
The Exchange Information Requirements synchronised with the Organisational Information Requirements and the Asset Information Requirements during Stage 1 (16)	o	o	o	o	o
A suitable Common Data Environment was established during Stage 1 (17)	o	o	o	o	o

Question 8. Please provide your comments on any of the above statements:

____

____

Question 9. This section focuses on Stage 2, the Concept of a project. During Stage 2 the Appointing Party engages designers, architects, and external consultants (the Delivery Team) to begin creating the best scope for the project to address business objectives. **Please provide your response to the following statements:**

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
In Stage 2 organisational-level Digital Engineering (DE) objectives were translated to project-level objectives and the DE Project Champion took ownership of these objectives (1)	o	o	o	o	o
Data custodians and/or data stewards identified in Stage 1, were onboarded in Stage 2 (2)	o	o	o	o	o
Asset and facilities managers were actively involved in Stage 2 and supported the DE Project Champion (3)	o	o	o	o	o
The Lead Appointed Party/Parties/Delivery Team contracted, successfully developed the DE and Building Information Modelling (BIM) data and information (4)	o	o	o	o	o
The Appointed Parties were engaged through a contract with a defined Appointing Party Exchange Information Requirements (5)	o	o	o	o	o
A Lead Consultant or Head Contractor was appointed to manage the inputs/outputs of all Appointed Parties (6)	o	o	o	o	o
A DE lead and/or information manager role(s) were appointed by the Delivery Team (7)	o	o	o	o	o
The DE Project Champion ensured that the Exchange Information Requirements were available, current and relevant to the project's context (8)	o	o	o	o	o
A draft Exchange Information Requirements / near-final Exchange Information Requirements were completed by the end of Stage 2 (9)	o	o	o	o	o
During Stage 2 the DE lead mapped the intended Delivery Team's systems and software for the project (10)	o	o	o	o	o
Project data schemes were determined in Stage 2, enabling project information to be accessed, analysed and maintained consistently (11)	o	o	o	o	o
The defined technology approach and a common data environment for the project was in place and communicated to the Delivery Team at Stage 2 (12)	o	o	o	o	o
The department or agency was able to view the project digital information developed by the Delivery Team (13)	o	o	o	o	o

Question 10. Please provide your comments on any of the above statements:

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____

____

Question 11. This section focuses on the project's Definition and Procurement and is Stage 3. The purpose of this stage is to develop the selected option from Stage 2 further. Development of this option informs a final business case. It is the stage where a large volume of information is gathered, and it is likely where the procurement of a head contractor or contractor (the Appointed Party) commences. **Please provide your response to the following statements:**

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
The tender was submitted as digital engineering information (1)	○	○	○	○	○
The tenderer limited the intended use of the information, model or data (2)	○	○	○	○	○
A compilation of information from Stages 1-2 was distilled into a package to underpin the decision to proceed with the project (3)	○	○	○	○	○
A Digital Engineering Execution Plan was developed (4)	○	○	○	○	○
A Digital Engineering Execution and Response was developed (5)	○	○	○	○	○
The appointed Delivery Team provided compliance/evidence that secure access and controls were in place for the digital engineering (6)	○	○	○	○	○
An organisational common data environment (CDE) was defined that internal stakeholders used on the project (7)	○	○	○	○	○
The CDE processes, procedures and responsibilities were established to validate the data gained at every gateway stage, including accuracy, compliance with standards, integrity, continuity and completeness (8)	○	○	○	○	○
The processes for transferring the relevant information containers of the Project Information Model to the Asset Information Model were agreed upon and documented in the Digital Engineering Execution Plan (9)	○	○	○	○	○

Question 12. Please provide your comments on any of the above statements:

____

____

Question 13. This section focuses on the project's Design and is Stage 4. The purpose of this Stage is to begin detailed design and engineering activities. This development occurs in step with community engagement, commercial reviews, onboarding, pre-works, and the development of a digital engineering execution plan. **Please provide your response to the following statements:**

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
The change management process to transition staff roles were effective during the project to embrace the digital engineering and VDAS processes (1)	o	o	o	o	o
The Appointed Party's digital engineering provided effective leadership on key information management areas (2)	o	o	o	o	o
Asset and Facilities Managers collaborated effectively between themselves and the Delivery Team (3)	o	o	o	o	o
Information management practices maximised existing design processes (4)	o	o	o	o	o
The technologies and systems that formed the common data environment were in place and operational by Stage 4 (5)	o	o	o	o	o
There was integration testing undertaken to ensure the smooth transfer of information from the Project Information Model to the Asset Information Model (6)	o	o	o	o	o

Question 14. Please provide your comments on any of the above statements:

____

Question 15. This section focuses on the Build and Commission and is Stage 5. The purpose of this stage is to translate the drawings, design and intent from Stage 4 and physically construct and commission the project. This occurs in line with the project's business case and objectives.

Please provide your response to the following statements:

	Strongly Agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
The Delivery Team (including subcontractors) maintained the digital engineering vision and the requirements detailed in the Exchange Information Requirements (1)	o	o	o	o	o
On completion of Stage 5 the contractor integrated the “as built” Project Information Model into the Asset Information Model as specified in the Exchange Information Requirements and Asset Information Requirements (2)	o	o	o	o	o
User access controls in line with security requirements were applied with the onboarding of subcontractors and other stakeholders (3)	o	o	o	o	o
Data information models that constitute the Project Information Model continued to be developed (4)	o	o	o	o	o
The Project Information Model was suitably developed to meet integration requirements of handover and close out (5)	o	o	o	o	o
The lead appointed party/contractor documented and communicated all changes that occurred on-site during Stage 5 (6)	o	o	o	o	o

Question 16. Please provide your comments on any of the above statements:

____

Question 17. This section focuses the project's Handover and Closeout and is Stage 6. The purpose of this stage is to complete the project in line with the project objectives and plan, and developing handover material to the Asset Owner. The handover includes all designs to as constructed or as built, transferring relevant and agreed information from Stages 1 to 6 of the project to the asset information model.

Please provide your response to the following statements:

	Strongly Agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
Effective communication between the Delivery Team and asset and facilities management stakeholders was well established by Stage 6 (1)	o	o	o	o	o
The Delivery Team and other relevant stakeholders finalised the Project Information Model (2)	o	o	o	o	o
The needs of the physical asset were reflected in the digital asset (3)	o	o	o	o	o
The digital asset complied with the scope, Asset Information Requirements /Exchange Information Requirements and the Building Code Australia requirements (4)	o	o	o	o	o
The final verified and approved information models were transferred as defined in the Exchange Information Requirements /Digital Engineering Execution Plan (5)	o	o	o	o	o
Information transfer was completed during Stage 6 as defined in the Exchange Information Requirements and Digital Engineering Execution Plan (6)	o	o	o	o	o
The Project Information Model data was handed over and stored as a record of development and the subset of the information was transferred to the Asset Information Model (7)	o	o	o	o	o
All of the information set out in the Exchange Information Requirements and the Master Information Delivery Plan was transferred to the Appointing Party –resulting in the Project Information Model sitting within the Asset Information Model and the Common Data Environment as an archive (8)	o	o	o	o	o
There was limited manual recoding to ensure no data loss, corruption or missed fields in setting up the Asset Information Model (9)	o	o	o	o	o
The data and information to be exchanged into Stage 7 was in a format that could be read by the asset management technologies and systems (10)	o	o	o	o	o

Question 18. Please provide your comments on any of the above statements:

____

Question 19. The final stage of the project is Operations and Maintenance and is Stage 7. The asset will have moved into an operational phase. The works delivered will be assigned ownership and put under the operational control of a government department, agency, operator or franchisee. It is important that the asset delivers benefits for Victorians.

Please provide your response to the following statements:

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
Sufficient resources were available to maintain the Asset Information Model (1)	o	o	o	o	o
Roles, responsibilities and authorities were established to maintain the Asset Information Model (2)	o	o	o	o	o
The organisation established, documented, implemented and maintained an information management process to cover the operational life cycle of the assets (3)	o	o	o	o	o
Document, graphical and spatial data was linked directly to the asset in the asset register (4)	o	o	o	o	o
After one year of operation, a detailed understanding of the asset's structures, operations and control management systems was achieved (5)	o	o	o	o	o
After 2 years a stable operation of the asset was achieved. This included a stable baseline on asset condition, asset performance, power and energy consumption and cost data (6)	o	o	o	o	o

Question 20. Please provide your comments on any of the above statements:

____

Question 21. Please provide comments on any lessons learnt based on your experience of construction projects during Stages 1 to 7:

____

____

____

Question 22. If you are willing to attend a focus group or an interview to elaborate on topics raised by this survey, please provide your contact details via this link.

The researchers wish to acknowledge the Office of Projects Victoria and the Master Builders Association Victoria for their help with this survey.

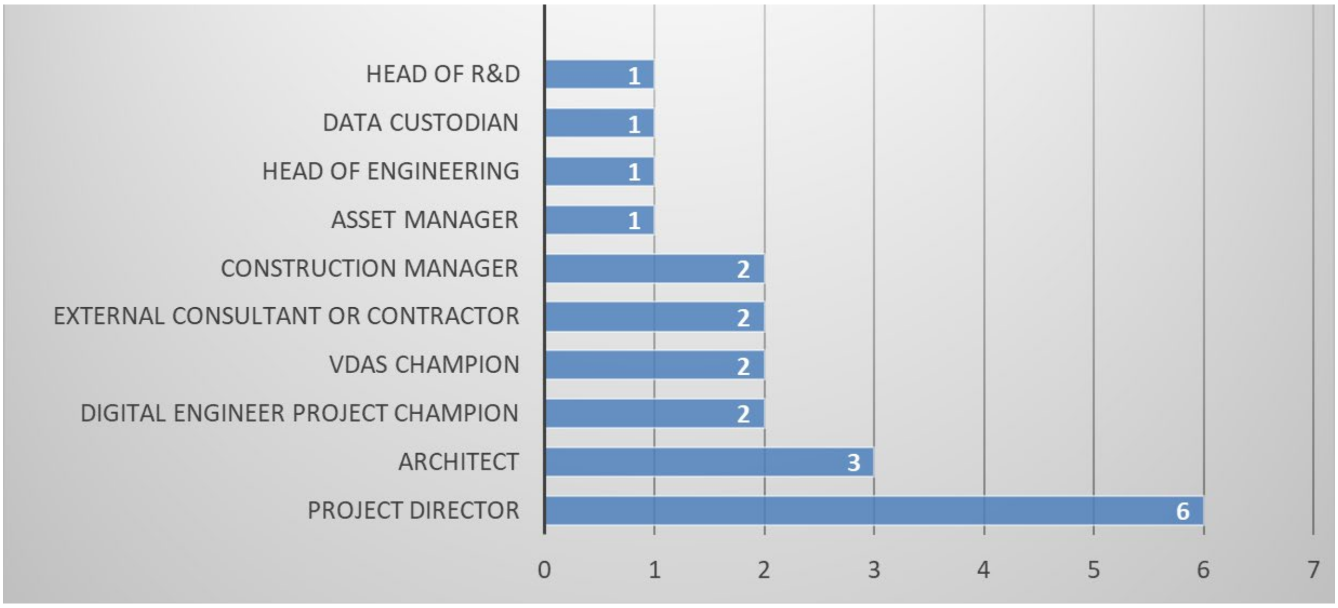
Appendix 2: Survey Results

Twenty-one respondents undertook the survey. **Question 1**. introduced the survey and **Question 2**. was the consent form, which all respondents agreed upon.

A breakdown of survey respondent's roles is in Table A2.1.

Question 3. A mix of construction stakeholders participated in the survey, including project directors and construction experts, such as architects and digital engineers along with managers.

Table A2.1. *Project role of survey respondents*



Responses to the survey questions decreased from question 7. For example, only 10 respondents continued and from question 9 and only 6 respondents continued, and responses progressively dropped off—with only 4 respondents completing the entire survey. It may be that the final stages were only relevant to a few respondents. Respondents have provided some useful feedback. It would appear from the results that the VDAS is overwhelming for many and there is minimal adoption of the VDAS approach.

The format was a typical 5-level Likert item, for example:

1. Strongly disagree
2. Somewhat disagree
3. Neither agree nor disagree
4. Somewhat Agree
5. Strongly Agree

measuring either positive or negative response to a statement. The neutral option can be seen as an easy option to take when a respondent is unsure.

Question 4. Awareness of the VDAS

When asked if they were aware of the VDAS of 2020, most respondents (15) indicated Yes, they were (71%), 5 (24%) indicated No and one respondent (5%) was Uncertain.

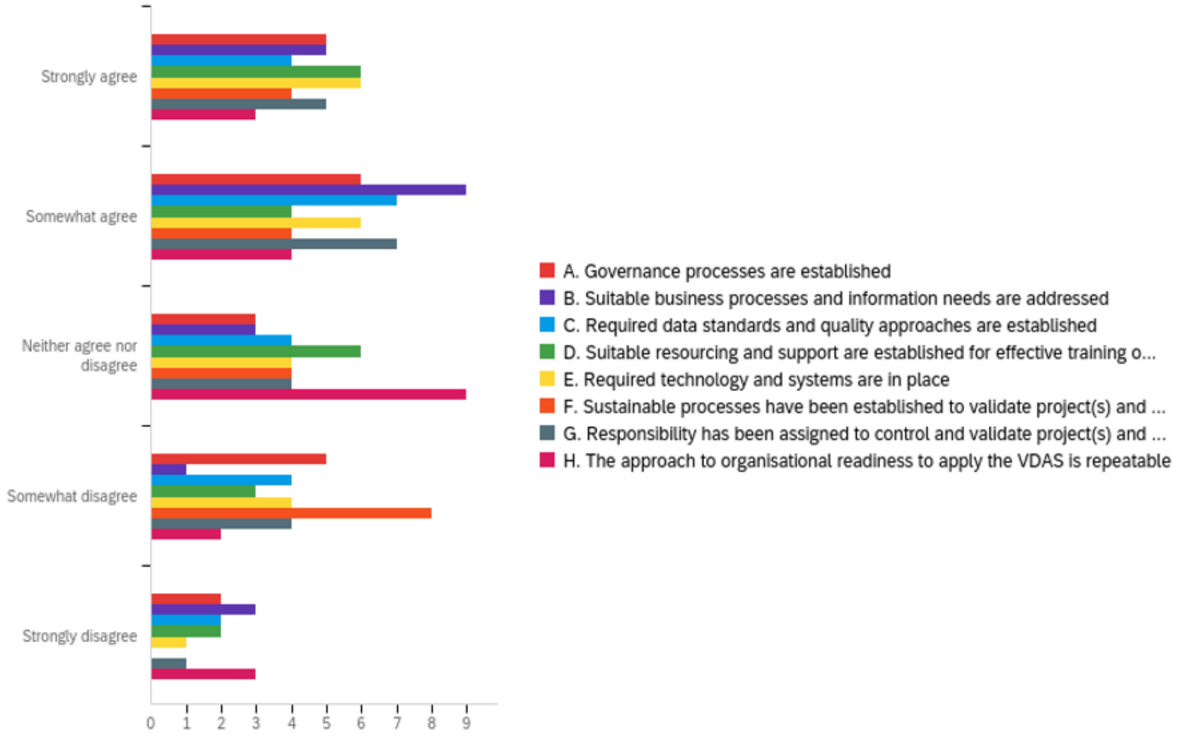
Question 5. VDAS and Organisational Readiness

In response to Question 5: **How ready is your organisation to manage digital assets?** (data and information are considered digital assets). The 21 respondents, 52% indicated they have governance processes established. Suitable business processes and information needs are addressed by 67%. While 52% of respondents indicated they have the required data standards and quality approaches established, 19% neither agreed or disagreed with this statement and 29% either somewhat disagreed or strongly disagreed with this statement; **this indicates a potential area for improvement**.

In response to the statement: Suitable resourcing and support are established for effective training of new staff and other necessities **is another area for improvement**, with 48%, less than half, indicating they strongly agree and somewhat agree and 29% neither agreeing or disagreeing and 24% somewhat disagreeing and strongly disagreeing. The majority, 57%, of respondents indicated that the required technology and systems are in place and 19% neither agreed or disagreed, 14% % somewhat disagreed and 10% strongly disagreed. The majority, 60%, of respondents disagree (20%) or somewhat disagree (40%) **that sustainable processes to validate project(s) and the asset's data exist**—with 20% strongly agreeing and 20% somewhat agreeing sustainable processes exist.

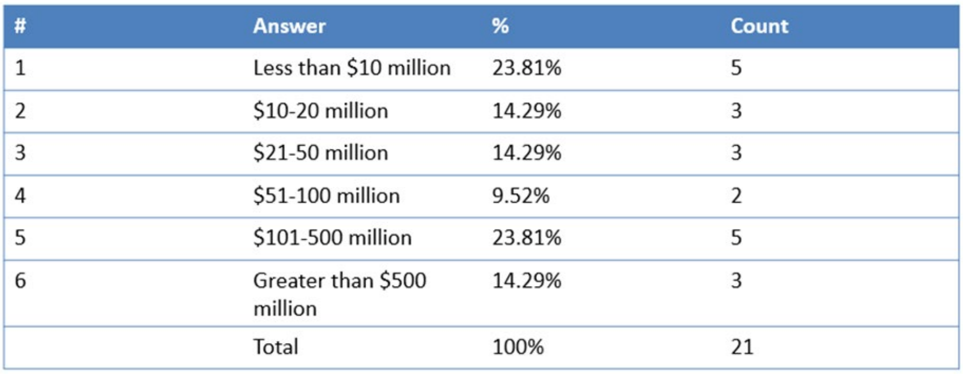
Lastly for this set of statements, the majority 57% either strongly agreed or somewhat agreed that responsibility has been assigned to control and validate project(s) and asset's data, with 19% neither agreeing or disagreeing and 24% somewhat disagreeing or strongly disagreeing. A summary of the 21 responses to the 8 statements (that follow the table) for question 5 of the survey are in Table A2.2.

Table A2.2. *Summary of the 21 responses to survey question 5*



Question 6.

Table A2.3. *Reponses to the typical value of the construction projects with which respondents most commonly work*



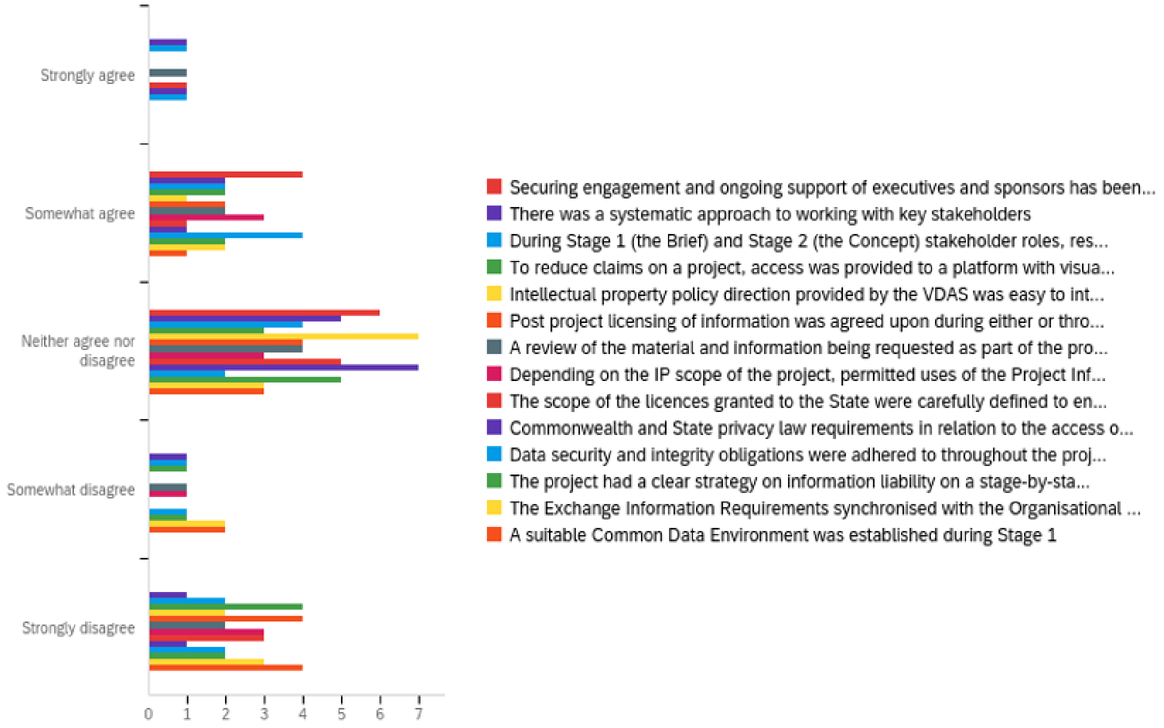
#	Answer	%	Count
1	Less than $10 million	23.81%	5
2	$10-20 million	14.29%	3
3	$21-50 million	14.29%	3
4	$51-100 million	9.52%	2
5	$101-500 million	23.81%	5
6	Greater than $500 million	14.29%	3
	Total	100%	21

The VDAS is applicable to any asset investment proposal with a total estimated investment of $10 million or more.

Question 7.

This question focused on the project's Brief (Stage 1.) for the Appointing Party (the owner, State Government, or those contracted on their behalf) to understand and clearly articulate the problem statement into a project opportunity statement and gather existing contextually relevant information to inform various concepts developed in Stage 2. A summary of the 10responses to the 14 statements (that follow the table) for question 7 of the survey are provided in Table A2.4. Responses are widely dispersed, with most either somewhat agreeing, neither agreeing or disagreeing, or strongly disagreeing.

Table A2.4. *Summary of the 10 responses to survey question 7*



A summary of 10 responses to the statements on the implications of establishing the exchange information requirements and the digital engineering strategy for a construction project follows:

1. Securing engagement and ongoing support of executives and sponsors has been possible

40% somewhat agreed and 60% neither agreed nor disagreed

2. There was a systematic approach to working with key stakeholders

10% strongly agreed, 20% somewhat agreed, 50% neither agreed nor disagreed, 10% somewhat disagreed and 10% strongly disagreed

3. During Stage 1 (the Brief) and Stage 2 (the Concept) stakeholder roles, responsibilities and accountabilities were clearly defined

10% strongly agreed, 20% somewhat agreed, 40% neither agreed nor disagreed, 10% somewhat disagreed and 20% strongly disagreed

4. To reduce claims on a project, access was provided to a platform with visualisation, sharing of data and information capabilities

20% somewhat agreed, 30% neither agreed nor disagreed, 10% somewhat disagreed and 40% strongly disagreed

5. Intellectual property policy direction provided by the VDAS was easy to interpret and apply

10% somewhat agreed, 70% neither agreed nor disagreed, 0.00% somewhat disagreed and 20% strongly disagreed

6. Post project licensing of information was agreed upon during either or throughout Stage 1 and Stage 2 of the project

10% strongly agreed 20% somewhat agreed, 40% neither agreed nor disagreed, 40% strongly disagreed

7. A review of the material and information being requested as part of the procurement process was undertaken by the Appointed Party

10% strongly agreed 20% somewhat agreed, 40% neither agreed nor disagreed, 10% somewhat disagreed, 20% strongly disagreed

8. Depending on the IP scope of the project, permitted uses of the Project Information Model was clearly defined during Stage 1 and/or Stage 2

30% somewhat agreed, 30% neither agreed nor disagreed, 10% somewhat disagreed, 30% strongly disagreed

9. The scope of the licences granted to the State were carefully defined to ensure that all desired future uses are permitted

10% strongly agreed, 10% somewhat agreed, 50% neither agreed nor disagreed, 30% strongly disagreed (either the respondent don’t know, or they strongly disagree)

10. Commonwealth and State privacy law requirements in relation to the access of any personal details contained in the data, information, and models were adhered to within the project

10% strongly agreed, 10% somewhat agreed, 70% neither agreed nor disagreed, 10% strongly disagreed

11. Data security and integrity obligations were adhered to throughout the project

10% strongly agreed, 40% somewhat agreed, 20% neither agreed nor disagreed, 10% somewhat disagreed and 20% strongly disagreed

12. The project had a clear strategy on information liability on a stage-by-stage basis

20% somewhat agreed, 50% neither agreed nor disagreed, 10% somewhat disagreed and 20% strongly disagreed

13. The Exchange Information Requirements synchronised with the Organisational Information Requirements and the Asset Information Requirements during Stage 1

20% somewhat agreed, 30% neither agreed nor disagreed, 20% somewhat disagreed and 30% strongly disagreed

14. A suitable Common Data Environment was established during Stage 1

10% somewhat agreed, 30% neither agreed nor disagreed, 20% somewhat disagreed and 40% strongly disagreed

Question 8.

Feedback received in relation to the statement:

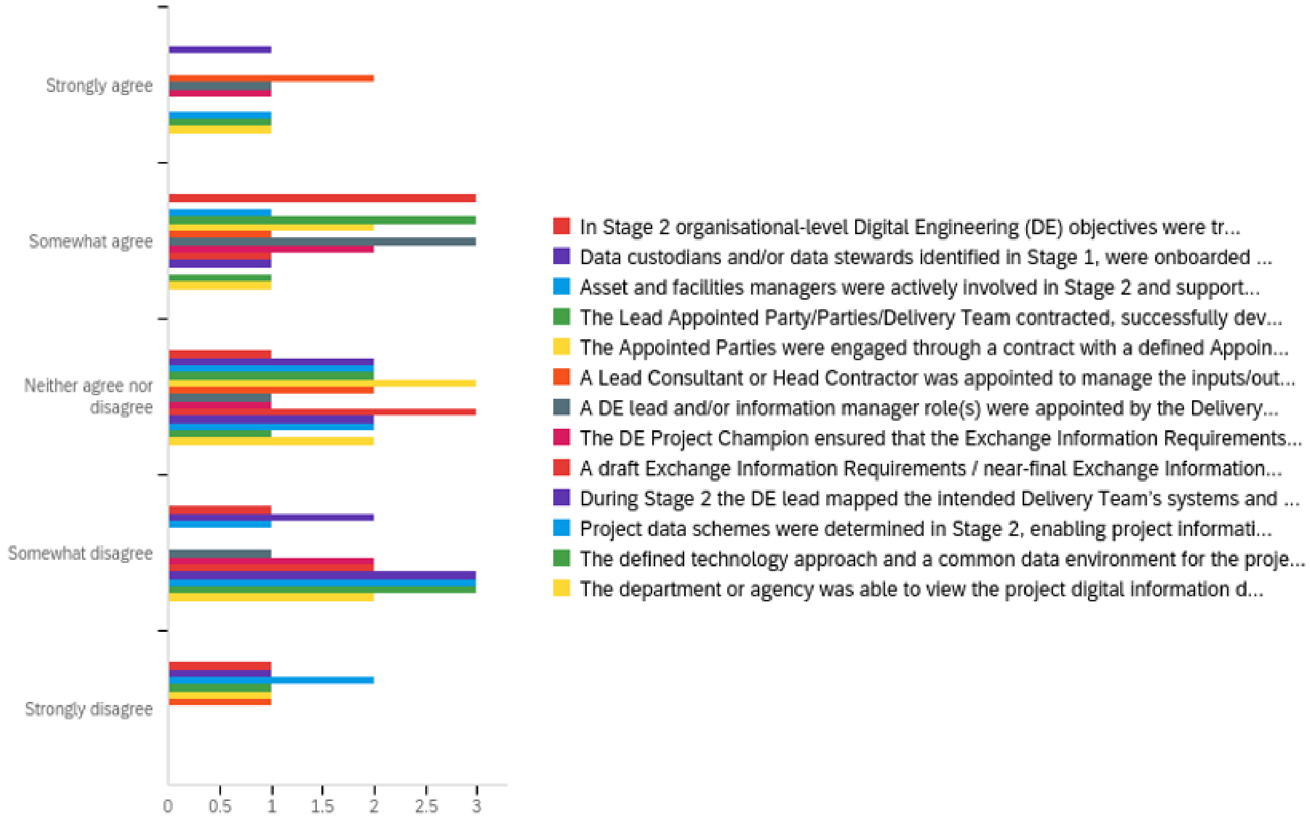
Have you experienced any changes in time, cost and/or effort because of the application of new information and data management processes related to Stage 1? Please help by providing the details:

- Additional time and cost
- As a contractor we are rarely involved at this stage
- The sharing of correct data is poor
- No
- None

Question 9.

Question 9 focused on Stage 2, the Concept of a project. During Stage 2 the Appointing Party engages designers, architects, and external consultants (the Delivery Team) to begin creating the best scope for the project to address business objectives. Six responses were received. A summary of the 6 responses to the 13 statements (detailed in Appendix 1) for question 9 of the survey are illustrated in Table A2.5. The responses suggest a diversity of situations.

Table A2.5. *Summary of the 6 responses to survey question 9*



Question 10.

Feedback received in relation to the statement:

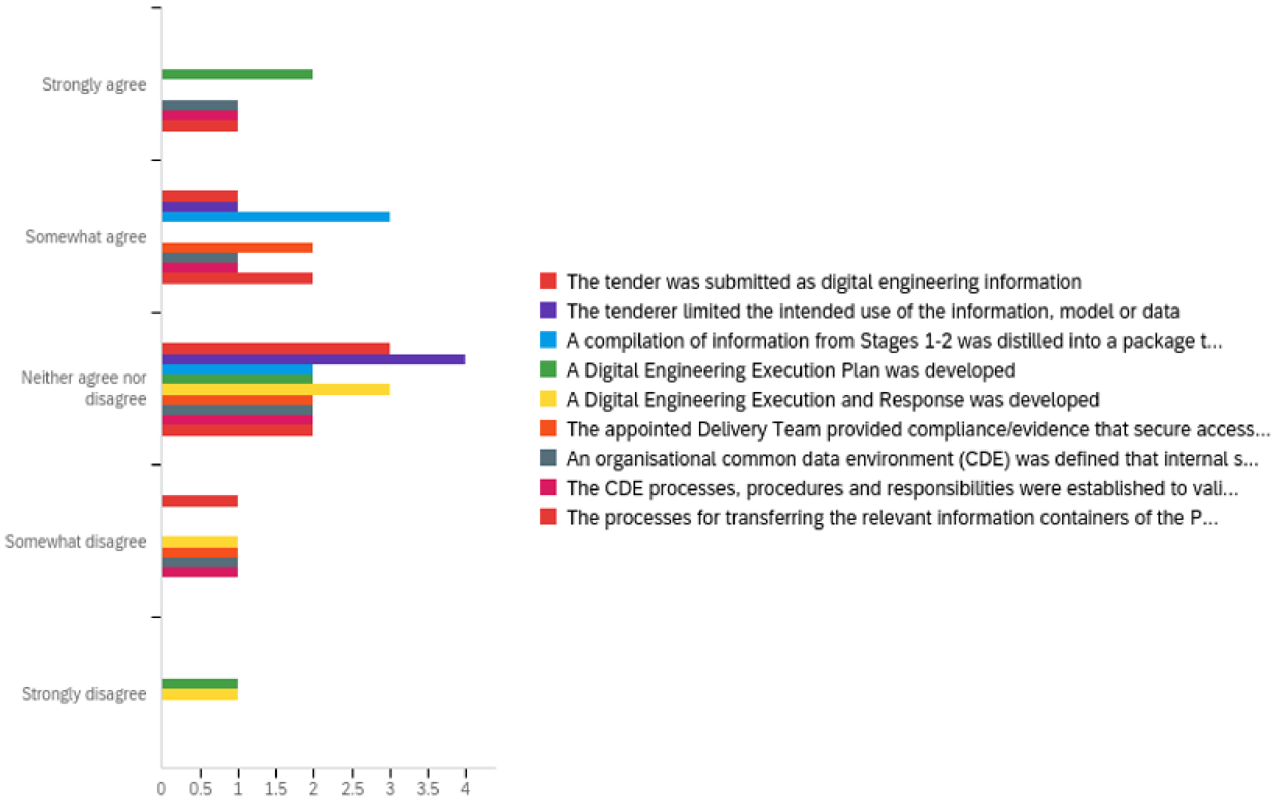
Have you experienced any changes in time, cost and/or effort because of the application of new information and data management processes related to Stage 1? Please help by providing the details:

- Additional time
- As a contractor we are rarely involved at this stage. Downstream, we do benefit if this is well established.
- None

Question 11.

This question focused on the project's Definition and Procurement and is Stage 3. The purpose of this stage is to develop the selected option from Stage 2 further. Development of this option informs a final business case. It is the stage where a large volume of information is gathered, and it is likely where the procurement of a head contractor or contractor (the Appointed Party) commences. The array of the 5 responses to 9 statements (detailed in Appendix 1) are illustrated in Table A2.6. Most respondents have indicated they *neither agree nor disagree* to many of the statements suggesting the statements may not be relevant to all the respondents. 60% agreed with the statement that "*A compilation of information from Stages 1–2 was distilled into a package to underpin the decision to proceed with the project*" (indicated by the light blue bar).

Table A2.6. *Summary of the 5 responses to survey question 11*



Question 12.

Feedback received in relation to the statement:

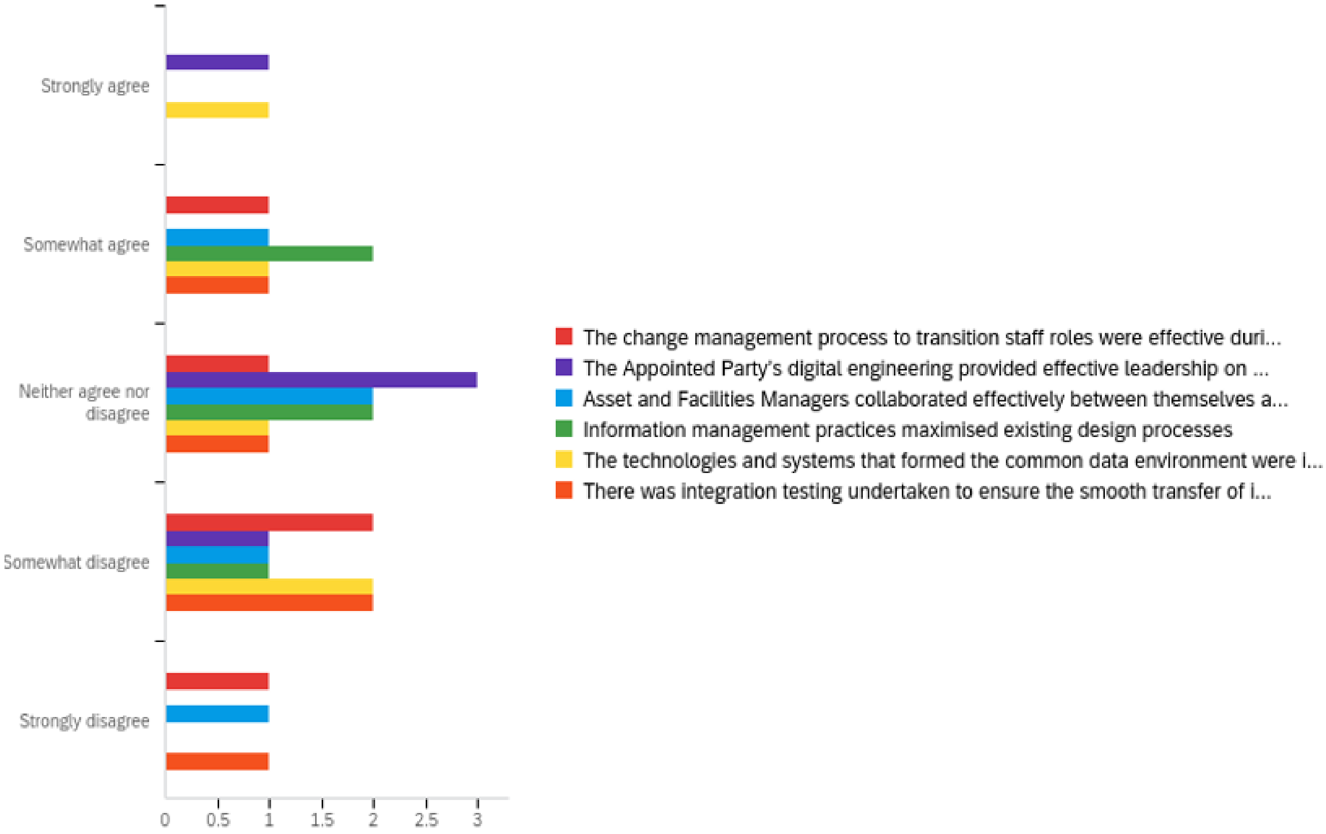
Have you experienced any changes in time, cost and/or effort because of the application of new information and data management processes related to Stage 3? Please help by providing the details:

- Additional time
- No
- Yes, when digital models are provided by the design team it enhances our ability to calculate cost & program. It also allows us to quickly determine if the design is resolved, and easily provide detailed information to tendering subcontractors.

Question 13.

This question focused on the project's Design and is Stage 4. The purpose of this Stage is to begin detailed design and engineering activities. This development occurs in step with community engagement, commercial reviews, onboarding, pre-works, and the development of a digital engineering execution plan. The 5 responses to the 6 statements (detailed in Appendix 1) are illustrated in Table A2.7. In response to the statement: The Appointed Party's digital engineering provided effective leadership in key information management areas, most respondents neither agree, disagree or somewhat disagree which is a noticeable trend. In response to the statement: The change management process to transition staff roles were effective during the project to embrace the digital engineering and VDAS processes, most of the responses indicated they somewhat disagree or strongly disagree with the statement. Otherwise, responses to the statements are widely dispersed.

***Table A2.7.** Summary of the 5 responses to survey question 13*



Question 14.

Feedback

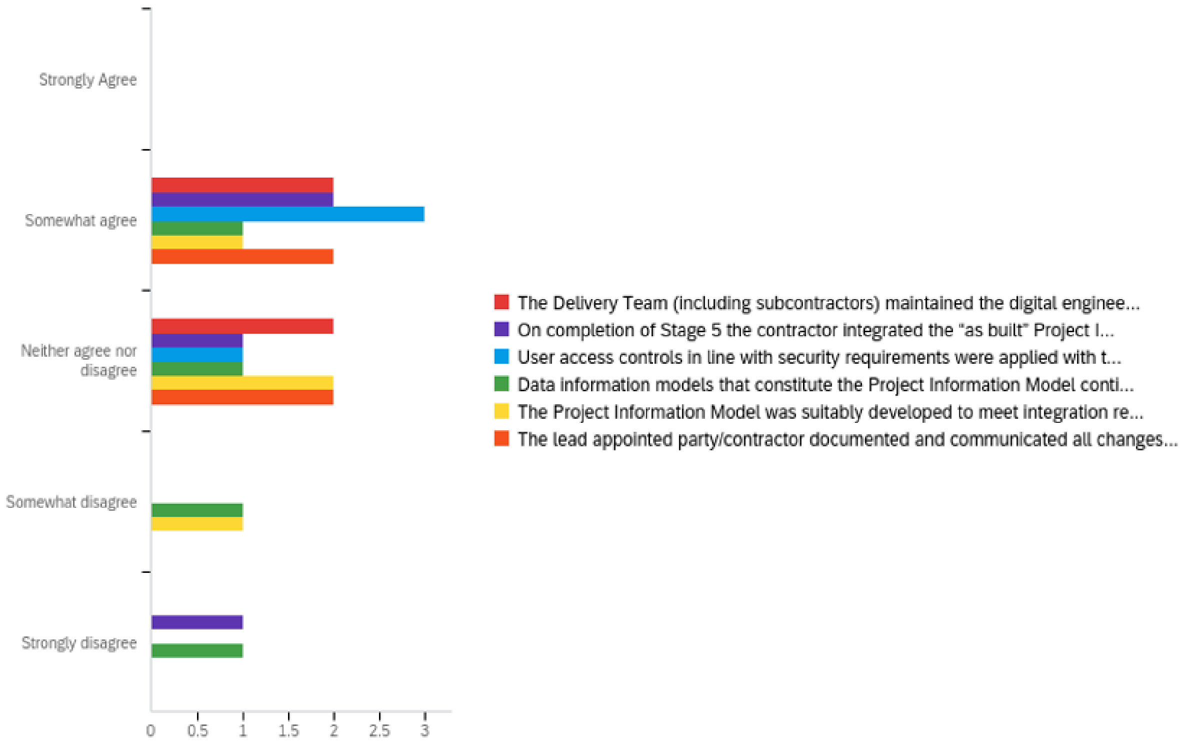
Have you experienced any changes in time, cost and/or effort because of the application of new information and data management processes related to Stage 4? Please help by providing the details:

- 3 responded either No or None
- In most cases there has been no requirements defined for handover of asset information.

Question 15.

This section focused on the Build and Commission and is Stage 5. The purpose of this stage is to translate the drawings, design and intent from Stage 4 and physically construct and commission the project. This occurs in line with the project's business case and objectives. The 4 responses to the 6 statements (detailed in Appendix 1) are illustrated in Table A2.8. Most responses fall within neither agree nor disagree or somewhat agree. With 75% somewhat agreeing with the statement: User access controls in line with security requirements were applied with the onboarding of subcontractors and other stakeholders.

Table A2.8. *Summary of 4 responses to survey question 15*



Question 16.

Feedback

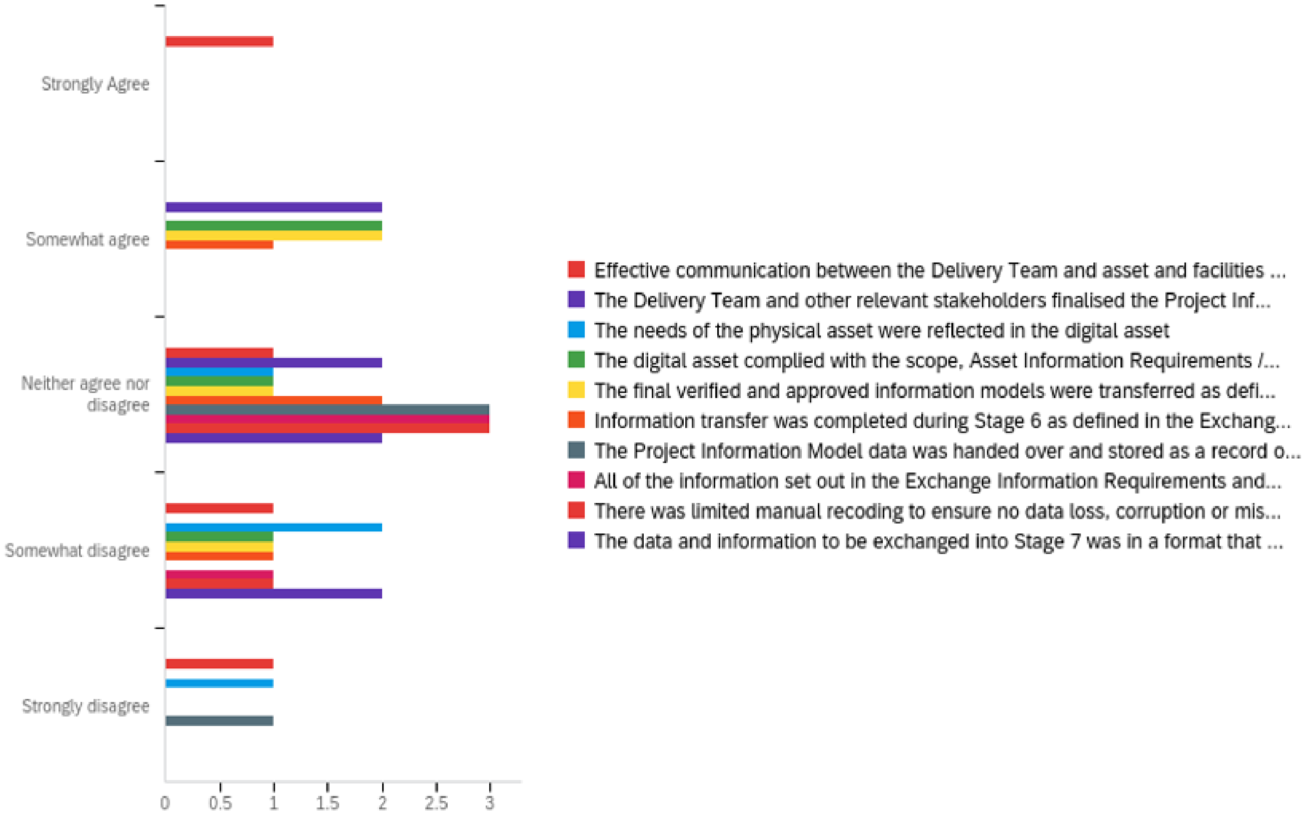
Have you experienced any changes in time, cost and/or effort because of the application of new information and data management processes related to Stage 5? Please help by providing the details:

- No
- The production of digital models by subcontractors helps reduce time for coordination and completion of as-constructed information.
- None

Question 17.

This section focuses the project's Handover and Closeout and is Stage 6. The purpose of this stage is to complete the project in line with the project objectives and plan and developing handover material to the Asset Owner. The handover includes all designs to as constructed or as built, transferring relevant and agreed information from Stages 1 to 6 of the project to the asset information model. The 4 responses to the 10 statements (detailed in Appendix 2) are illustrated in Table A2.9. Responses to the statements do not reveal any consensus. Most appear to neither agree not disagree with the statements potentially indicating the Stage might not be relevant or a lack of awareness of the process.

Table A2.9. *Summary of the 4 responses to survey question 17*



Question 18.

Feedback

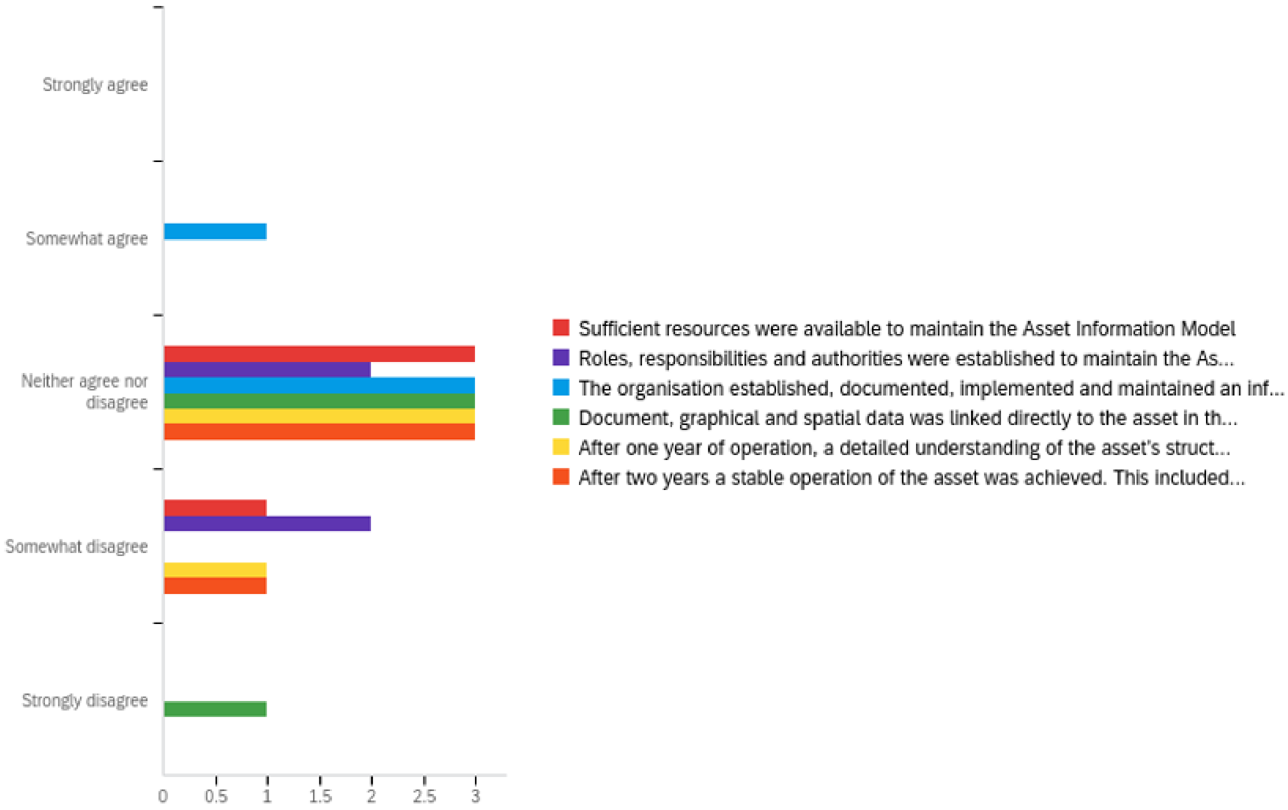
Have you experienced any changes in time, cost and/or effort because of the application of new information and data management processes related to Stage 6?

- No
- Although digital handover requirements are rarely defined, our digital construction process already provides the base for this, and theoretically would reduce the time required to handover as-built asset info.
- None

Questions 19.

The final stage of the project is Operations and Maintenance and is Stage 7. The asset will have moved into an operational phase. The works delivered will be assigned ownership and put under the operational control of a government department, agency, operator or franchisee. The 4 responses to the 6 statements (detailed in Appendix 1) are illustrated in Table A2.10. Responses to the statements do not reveal any consensus. Most responses appear to neither agree not disagree with the statements potentially indicating the Stage might not be relevant to the respondents.

Table A2.10. Summary of 4 responses to survey question 19



Questions 20.

Feedback

Have you experienced any changes in time, cost and/or effort because of the application of new information and data management processes related to Stage 7?

- No
- None

Please provide comments on any lessons learnt based on your experience of adopting improved information and data management processes within construction projects:

- Project scales average cost ranges from $3k to $4k. Several of the requirements listed above do not apply to projects of this size.
- Often the approach is too complex for most to organisations to comprehend or commit to without charging excessive fees to cover their lack of capability. While VDAS makes sense for Big Build infrastructure processes a scaled down version might be appropriate for medium scale/single buildings.
- There is an ongoing disconnect between B&C technologists and builders (and B&C consultants)

Appendix 3: Interview Questions

Industry User Group: Interview questions

1A. What is your role?

1B. How many years' experience in the field do you have?

1C. What level of projects are/have you worked on based on?

A. Less than $10 million
B. $10-20 million
C. $21-50 million
D. $51-100 million
E. $101-500 million
F. Greater than $500 million

1D. Based on VDAS stages 4–7 = which are relevant to your work?

2A. How has connected data changed the way you and your colleagues do your work? (what kind of adjustments are/were involved?)

2B. Please share any documented comparison of benefits with traditional design and construction processes? Please refer to the **Project 38.2 Template, Quantifying Project Benefits** (*available in the Methods section of this report*) sent with these questions.

2C. Please describe any digital build system(s) that you use or have used? Do you use a Common Data Environment (CDE)? Is the system interoperable with other systems e.g. HR, Finance systems?

Increased output

3A. Have you experienced any changes in time, cost and/or effort as a result of the application of new information and data management processes? Please explain by providing the details

3B. Have you experienced any technical efficiency gains or progress as a result of new information and data management processes?

3C. Have you experienced any asset performance improvements as a result of new information and data management processes?

3D. Has the organisational structure changed as a result of the introduction of new information and data management processes?

3E. How were information/data governance approaches followed in accordance with Victorian Digital Assets Strategy (VDAS)?

3F. Have you experienced any project changes in quality as a result of the introduction of new information and data management processes?

3G. Have you experienced any changes in risk-mitigation quality as a result of the introduction of new information and data management processes??

3H. Have you experienced any changes in risk-mitigation?

3I. Please can you share how these improvements have been measured?

Financial advantages

4A. Has your organisation experienced any financial advantages as a result of improvements with data and information management - such as (e.g. School building) in reducing the number of people required to run and maintain the facility?

5.Have any other benefits such as improved decision making, improved safety, waste reduction, improved communication and improved stakeholder engagement occurred? Please elaborate on each of these.

6. What information/data governance processes did you follow to achieve the benefits?

7. Do you have any other comments on the benefits of connected data from digital building?

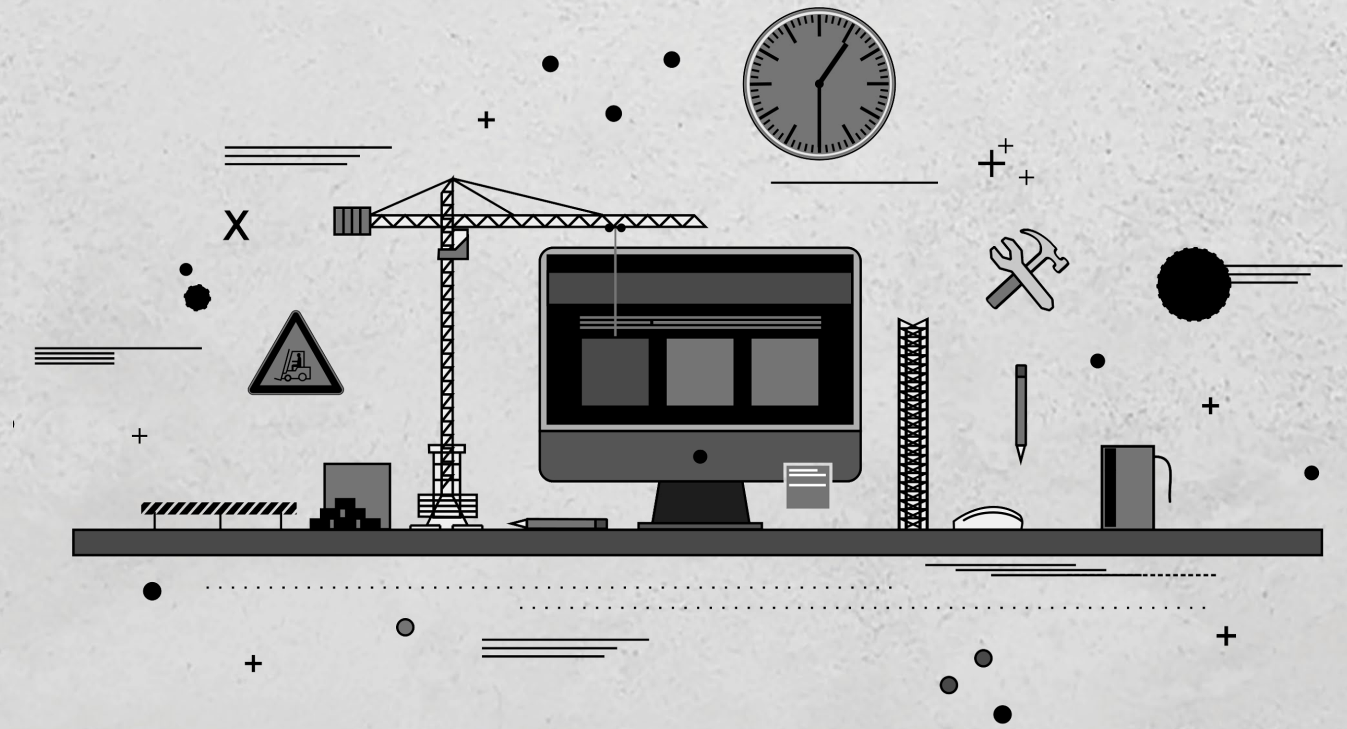
8. What has been the stakeholder challenges with this project? Can you provide details on your stakeholders (who they are?)

9. Can you outline any wider community benefits as a result of the project(s) e.g. professional communities, cross disciplinary project communities, citizen communities affected by projects.

building 4.0 crc

PROJECT #38.3
DECISION-MAKING SUPPORT FRAMEWORK FOR OFFSITE CONSTRUCTION IN VICTORIA

FINAL REPORT



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Australian Government
Department of Industry, Science and Resources

Cooperative Research Centres Program

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Author of this report:	Dr Siddhesh Godbole, Dr Omar Campos, Dr Echo Wang
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ABBREVIATIONS

ADDSS	Architecture Design Support System
ATO	assembly to order
BIM	Building Information Modelling
BOM	bill of materials
BoQ	bill of quantities
BREEAM	Building Research Establishment Environmental Assessment Method
C&D	construction and demolition
cDSP	Compromise Decision Support Problem
CLT	cross laminated timber
CM	construction management
CODP	Customer Order Decoupling Point
D&B	design and build
D&C	design and construct
DMSF	decision-making support framework
DSS	decision support systems
ECI	early contractor involvement
EPA	Environmental Protection Agency
ESG	environmental, social and governance
ETO	engineer to order
GBCA	Green Business Council Australia
GDP	gross domestic product
GHG	greenhouse gas
HIA	Housing Industry Association
HVAC	heating, ventilation, air conditioning
KPI	key performance index
LCA	lifecycle assessment
LCCA	lifecycle cost assessment
LCIA	life cycle impact assessment
MC	management contracting
MEP	mechanical, electrical and plumbing
MTO	make to order
MTS	make to stock
OCi	offsite category index
OPV	Office of Projects Victoria
OSC	offsite construction
OVGA	Office of Victorian Government Architect
PPP	public private partnership

RFP	request for proposal
SCCi	supply chain category index
SCORS	Structural Carbon Rating Scheme
SDG	Sustainable Development Goal
VBA	Victorian Building Authority
VDAS	Victorian Digital Asset Strategy
VE	Value Engineering

EXECUTIVE SUMMARY

Project #38.3 develops a decision-making framework that considers both qualitative and quantitative aspects of value creation in building projects.

Offsite construction, characterised by the fabrication of building components in controlled factory environments before on-site assembly, is increasingly recognised as a linchpin of sustainable construction practices. Its hallmark attributes encompass enhanced resource efficiency, minimised waste generation, and streamlined project timelines. By reducing the demand for raw materials and optimising processes, offsite construction substantially diminishes the carbon footprint associated with traditional construction methodologies. Furthermore, the controlled environment of offsite facilities enables stringent quality control, thereby fostering built environments that endure the test of time. The interplay between offsite construction and sustainable practices is undeniably pivotal, steering the industry towards more ecologically conscious horizons.

While the benefits of prefabrication in offsite construction are well-established, a persistent challenge revolves around the successful realisation of these benefits within hybrid projects. Offsite hybrid projects amalgamate on-site and offsite components, promising the advantages of both paradigms. However, a lack of comprehensive understanding often results in misaligned expectations and unrealised benefits. Achieving the touted efficiency gains and cost savings necessitates intricate orchestration, from project conceptualisation to execution. Effective coordination between on-site and offsite elements, synchronisation of timelines, and meticulous project management become paramount. Bridging the gap between potential and actual benefits requires a refined comprehension of hybrid project dynamics and a holistic approach to their implementation.

Key Findings

Project 38-3 was conceived on the backdrop of the Office of Projects Victoria (OPV's) offsite construction evaluation tool published in 2022. The project aimed to expand the scope of this decision-making framework to allow for a higher scrutiny of project attributes through the lenses of value creation. A thorough literature review of existing and preceding decision-making tools/frameworks was conducted to understand various approaches adopted in the world so far. The gap analysis from the literature review guided the development of the decision-making support framework in this project. The project benefited from weekly research meetings, monthly industry stakeholder meetings and bi-annual comprehensive brainstorming seminars. The project was limited to the development of a framework to pave the way for its adoption as a user-focused tool. In its current format, the framework offers a qualitative and quantitative assessment of the building project from multiple lenses.

The proposed decision-making support framework (DMSF) emphasises the following aspects of a building project;

1. **The Product typology framework** would help the user understand the impact of selecting different levels of productisation in a construction project. It is aimed to standardise the use of offsite index for a building project which could effectively capture the level of prefabrication in any construction project.
2. **The procurement framework** is aimed at informing the clients of the most aligned pathways of procurement based on specific project value expectations from a list of 18 value attributes.
3. **The sustainability framework** established a methodology to evaluate sustainability indicators of a building project based on available material quantity information. The framework highlighted different databases in use across the world and in Australia. Victorian Government sustainability targets are used to create a benchmarking scale that would aid the categorisation of future building projects based on their environmental

footprint. These metrics are expected to act as a control measure for new building developments in terms of steering them towards Australian net zero targets by 2030 and 2050.

4. **The circularity framework** established the 9Rs framework and highlighted available methods to increase the inherent circular economic value of a project. The framework used the National Waste Database, Australia 2022 and provided a quantitative assessment of the building project against the potential end-of-life circular economic value of the project.
5. **The supply chain framework** was aimed at quantifying a regional capacity to consistently deliver prefabricated building components of a certain typology. The supply chain category index (SCCi) was proposed as a metric to quantify a supplier product volume based offsite building category metric. This metric would notionally indicate the spread of suppliers on a product category scale. The importance of SCCi in quantifying the trends of supply chain capacities over the years was established. It was proposed that a project with ‘offsite category index’ or OCi and SCCi closely resembling, would find it increasingly easier to source required materials, have a competitive bidding process, and have larger control over price.
6. **The logistics framework** established a site evaluation approach based on its location, road access network, locality, regulatory permits, site storage, handling and craning friendliness and so on. The methodical approach is aimed at creating a logistics profile of the proposed construction project holistically.
7. **Constructability framework** encapsulates the physical interfacing of two or more building products on-site but is not limited to offsite building products. The evaluators, most likely those with construction management knowledge would be able to use this framework to analyse all component-level interactions in the construction phase of the project for all components from category 6 to category 1 (i.e., processed materials to fully fitted 3D volumetric building units). The interface being analysed is quantified for its ease (or conversely, complexity) of assembly on-site using a term coined here as ‘assembly score’. This assembly score would be used to estimate the complexity of the overall construction strategy for a given level of productisation and can be leveraged in estimating the potential schedule savings of the project.
8. **Schedule savings** are primarily based on the interface complexity of the construction phase of the project as evaluated previously. The interface complexity in each of the four construction phases of the project (viz., sub-structure, super-structure, exterior façade, interior fittings) is appropriately normalised based on the total amount of work done in each phase of construction. The amount of work done in each phase of construction is underpinned by the mass of materials/elements/components included in each phase.

Key recommendations towards framework deployment

The deployment of the proposed framework is expected to require developing a user-friendly tool that could ideally be hosted online through the OPV’s domain through an independent internet hosting service. Table 1 highlights the data collection requirements under each module of this framework towards its deployment. The implications of the level of data required are as follows:

1. Low: Requires minimal or no new data. Largely requires re-arranging and synthesising existing data available online following the steps outlined in this framework.
2. Medium: Requires collection of data generated from existing processes.
3. High: Requires establishing new processes for data collection.

Table 1. *Data required for deploying the decision-making framework.*

Evaluation	Level of New data required	Action required
Product typology	LOW	1. Categorisation of building products on the scale of Cat-6 to Cat-1 (from processed materials to finished volumetric building units). 2. Such a data table could be hosted on official Government web channels.
Procurement & contracts	MED	3. Lessons learned from Australian projects need to be collected to check the efficacy of procurement routes in delivering the said project objectives in Victoria.
Sustainability	HIGH	4. Sustainability indicators for Australian projects (recently built) should be tracked and included as a construction sector statistic on Australian Bureau of Statistics database. 5. This database can be leveraged to guide future developments based on per square metre footprint of sustainability indicators.
Circularity	MED	6. Codify 9R strategies for Victoria based on the project report to include expected steps required under each R strategy towards circularity. 7. Update construction waste recycling database to inform current and future developments for the avenues of the end-of-life stage of the materials.
Supply chain	HIGH	8. Initiate online survey to collect supplier information regarding supply capacity, type of material and product fabricated/supplier, location and other associated KPIs. 9. Put in place a mechanism to update this information every year or as required through a similar exercise.
Logistics	LOW	10. This exercise is largely user-focused and may not warrant the collection of any new data. However, the evaluation framework is required to be codified into an online tool platform.
Constructability and schedule savings	MED	11. Forward-looking exercise to involve a platform creation that would include supply chain products and their cross compatibilities. 12. Until such platforms are created, this exercise should be carried out by construction managers and 'offsite project integration' consultants who have domain knowledge of different construction systems and can assess their inter-compatibilities.

INTRODUCTION & BACKGROUND

The section introduces the project with its aims, objectives and key deliverables, and establishes the context of the work using OPV's prior development of the offsite construction tool 2022.

Introduction to B4.0 CRC project 38-3

Adopting offsite construction is a significant step towards more sustainable and efficient project delivery compared to the traditional methods of construction. Major projects are increasingly using offsite construction techniques throughout design and delivery. However, the decision about the compatibility of the offsite construction needs to be made early in the project establishment. Adoption and deployment of offsite construction technologies is a knowledge, expertise, and capital-intensive exercise for each project. Many project teams face difficulty in determining the extent and applicability, as well as design, planning, and delivery requirements of adopting offsite construction.

Currently, less mature Government departments struggle to make the critical decision of how much digital practice or offsite construction to adopt early in the project development or business case stage that the opportunity is missed. There is an need for a decision-making tool that can help stakeholders in assessing the applicability and efficiency of adopting offsite construction methods for construction projects. This is of essential importance for Government projects which often need to balance a complex range of constraints such as time, cost, quality, local content and sustainability outcomes.

The project was aimed at developing a DMSF designed to assist project teams in determining the applicability of on-site vs. offsite construction activities. The project explored the possibilities for enhancing the current offsite construction (OSC) evaluation tool while seeking opportunities for offsite construction based on the market/industry capacity and applicability. Given the unique nature of the offsite construction environment, an assessment of successful project tendering, fundamental processes, and regulations are required prior to deciding on the construction method. The project also identified the decision-making factors that could affect the adoption of offsite construction by conducting gap analysis and benchmarking with international examples, as well as performing a critical review of similar existing frameworks and tools.

Key deliverables set out at the beginning of the project were as follows:

- A development of an accessible decision-making framework which can be made publicly available to assist project teams in determining the suitable construction method considering:
    - Applicability of on-site vs offsite construction activities from design, construction, and regulatory point of view
    - Spaces in the project, functions of the spaces, standardisation of the processes, industry/market capacity, size of the project, cost per unit etc.
    - Asset classification – Uniclass 2015, repeatability of the components, size of the components
- Key recommendations for implementation of the decision-making framework.

OPV Offsite Construction Tool 2022

Offsite construction tool published by the OPV in 2022 was an Australian decision-making tool catering to Victorian Government departments. The tool indicated the alignment of Government project teams and the asset being developed towards one of the four construction methodologies viz., modular construction, volumetric prefab, non-volumetric prefab and traditional. The tool consisted of four sections:

1. Project information: Addressing client's familiarity to the asset building delivered, uniqueness of design and time urgency.
2. Project factors: Addressing repeatability, complexity, location of the site, and weather delay.
3. Construction factors: addressing constrained sites, risk of construction, site access, and traffic disruption.
4. Element design: Questions related to up to three repeatable items in the building.

With a weighted average of 36 questions in total, the tool delivered a chart showing the alignment of the four abovementioned construction methods to the client's answers about the project being delivered as shown in Figure 1.

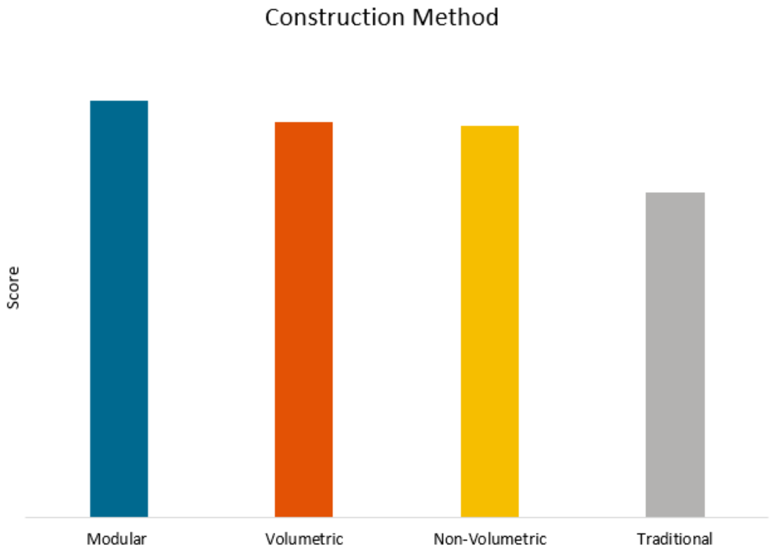


Figure 1. *Output of the OPV offsite construction tool 2022*

The OPV tool can be accessed at: https://www.vic.gov.au/offsite-construction

Stakeholder interaction on the critical evaluation of the tool revealed that:

1. The tool was high-level and had limited nuances of an individual project. The tool was designed to be simple to cater to clients with non-building engineering backgrounds.
2. The tool was geared towards offsite/volumetric building methods.
3. The tool contained rhetorical questions for the user the answers to which were feared to be always one than any other.

LITERATURE REVIEW

The section summarises the literature on the idea of decision-making in construction, and previous attempts at making a decision-making framework and tools in offsite construction.

Background: Decision-making

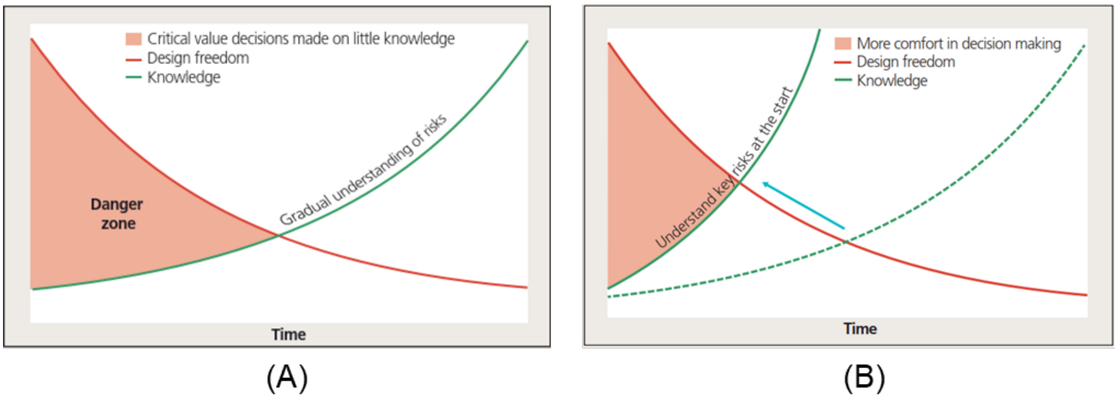


Figure 2. *Decision-making in construction and associated risks*

Decision support systems

- Decision Support Systems (DSSs): DSSs combine human judgements with computerised information to handle semi-structured or unstructured situations. They help decision-makers understand and solve problems more effectively.
- Applications of DSSs in Construction: DSSs have been developed in the construction industry to support decision-making in various phases of a project's life cycle. They are used for evaluating building, product, facility, service, and supply decisions.
- Examples of DSS Techniques: Several DSS techniques used in the construction sector include Decision Trees, Value Engineering (VE), and the Client's Value System. Decision Trees help with choices under certainty, while VE seeks the best functional balance between cost, reliability, and performance. The Client's Value System is a method for understanding client preferences.
- Sustainable Building Design: Sustainable performance in building construction has become a significant concern for professionals. DSS tools like Building Information Modelling (BIM) and the Building Research Establishment Environmental Assessment Method (BREEAM) are used to evaluate building performance and enhance sustainable design.
- Design Support Tools: Various DSS tools support building design decisions in the construction industry, such as Architecture Design Support System (ADDSS) Tool, Compromise Decision Support Problem technique (cDSP), and others that simulate energy performance analysis.
- Other Decision Support Tools: Apart from DSSs, the construction industry also uses cost/value modelling techniques, such as heuristic methods, empirical methods, simulation methods, and algorithmic methods (including regression analysis).

In broad terms, DSSs are used to structure the decision-making process and enhance the quality of decision-related information (Turban and Aronson, 2001). DSSs offer assistance across all management levels, granting decision-makers full control over each step. However, DSSs do not replace the tasks of the decision-maker (Turban, 1995). The most effective implementation of DSSs occurs during the **viability**, **feasibility**, and **conceptual design** stages of a project, providing practitioners with a clear understanding of the decision problem's boundaries and enabling better choices based on the decision knowledge base (Ammar et al., 2013).

Summary

The problem of decision-making, and the development of support tools have been addressed for over 3 decades and a review of 17 such frameworks and tools is presented.

	Authors	Year	Title	Parameters emphasis	Output	Jurisdiction	Target sector	Type
1	Construction Industry Institute (Force, 1992)	1992	MODEX: Automated decision support system	Factors supporting modularisation: Safety, construction time, labour availability, weather changes, quality, reducing interruptions Factors against modularisation: Transportation cost, transport size limitations, increased effort Factors influencing modularisation: plant location, labour considerations, plant characteristics, project risks, organisational factors	PC based software program pointing to project alignment	USA	Building construction	🖥
2	(Murtaza & Fisher, 1994)	1994	Neuromodex-neural network system for modular construction decision-making	Plant location, labour considerations, environmental and organisational, plant characteristics, project risks	Neural network model for project classification	USA	Building construction	💡
3	Construction Industry Institute (CII, 2002)	2002	Prefabrication, pre-assembly modularisation and offsite fabrication decision tool V1.1	Schedule, cost, labour, safety, site attributes, mechanical systems, project and contract type, design, supplier capability	PC based software program pointing to project alignment	USA	Residential/retail/commercial	🖥
4	(Blismas et al., 2003)	2003	IMMPREST Toolkit	Project cost, time, quality, health and safety, sustainability, site processes	PC based program toolkit for offsite selection	UK	Building construction	🖥
5	(Pan et al., 2008)	2008	Leading UK housebuilders utilisation of offsite construction methods	Typical drivers: cost, time, quality, on-site work, skill shortages, client influence, restricted site, health and safety risk Typical barriers: Complex interfaces, high capex, economies of scale, design freeze, transportation constraints, legal issues	Survey-backed weighted criteria	UK	Residential/Commercial	📋 👥
6	(Chen et al., 2010)	2010	Decision support for construction method selection in concrete buildings: Prefabrication adoption and optimisation	Project cost, time, quality, repeatability constraints Site conditions: Issues, weather conditions Supply chain availability, worker availability, Regulations, environmental pollution considerations, and logistics	Survey backed weighted criteria resulting in scored metrics	USA	Concrete structures	📋 👥
7	(Abdullah & Egbu, 2011)	2011	Application of analytic hierarchy process as a decision tool in choosing type of industrialised building systems	Cost, time and quality against precast panel, steel framing and formwork system	Analytic hierarchy decision tree with chosen parameters	UK	Steel, concrete building structure	📋
8	(Elnaas et al., 2014)	2014	Factors and Drivers Effecting the Decision of Using Offsite Manufacturing (OSM) Systems in House Building Industry	Drivers: Technical, economic, environmental, organisational, social Constraints: System, process, regulatory, logistics, resources, cost implications	Interviews, case studies based on weighted criteria	UK	Residential houses	📋
9	(Choi & O'Connor, 2015)	2015	Modularisation business case analysis tool: learning from industry practices	Cost comparison: Stick built costing, target % modular, technical feasibility, expected schedule savings, workhour cost savings, cost at assembly yard, modularisation benefits	Excel based tool comparing project costs	USA	Building construction	🖥
10	(Enshassi et al., 2019)	2019	Integrated Risk Management Framework for Tolerance-Based Mitigation Strategy Decision Support in Modular Construction Projects	Geometric tolerances, defects and damages, increased work hours to rectify damages	Risk of delay, risk of cost escalation for mitigation	Canada	Residential/retail/commercial	📋
11	Build and Construction Authority	2019	Code of practice on Buildability	Buildability score, constructability score based on preset criteria for prefabricated structural systems	Points-based framework for submission to obtain a building permit	Singapore	Residential/commercial	📋
12	(Mather & White, 2019)	2019	Designing with data: a systematic approach to offsite construction	Health and safety, sustainability, cost and supply chain, overall program risk, on-site program, construction and buildability, design and user performance	Interactive dashboard for users	UK	Building construction	🖥
13	(Goodier et al., 2019)	2019	Modularisation and offsite in engineering construction: an early decision support tool	Cost of project, schedule time, quality of plant, certainty and predictability, health and safety, sustainability	Excel based tool allowing users to evaluate offsite method alignment to decision drivers	UK, Italy	Building construction	🖥
14	(Cigolini & Castellano, 2002)	2022	Using Modularisation to ManageConstruction of Onshore ProcessPlants: A Theoretical Approach and a Case Study	Project cost of renting, mobilisation, demobilisation, facilities, consumption, module handling, man-hours, construction equipment, harbours, site and mod-yards	Theoretical framework with weighted cost comparison	Italy	Onshore plant structures	📋
15	(Khan et al., 2022)	2022	Drivers towards Adopting Modular Integrated Construction for Affordable Sustainable Housing: A Total Interpretive Structural Modelling (TISM) Method	Cost, productivity, environmental, policy, time, quality, social and market demand visibility	Conceptual framework based on cross dependencies of parameters	Australia	Building construction	📋

16	(Pickavance, 2021)	2022	Critical Reflections on 25 Years of Using Prefabrication and Modularisation in UK construction	Schedule time savings with precast concrete, steel decking, prefab slab and structural timber frame	Data comparison from case studies	UK	Building construction	📋
17	(Mofolasayo, 2023)	2023	Decision between on-site and offsite using life cycle assessment (LCA) concepts and system dynamics	Environmental impacts of on-site vs. offsite method, energy usage of on-site and offsite work, energy in transportation, handling, assembly,	System dynamics modelling of environmental impact parameters	Canada	Residential/commercial	💡

FRAMEWORK ESTABLISHMENT

This section highlights the learnings from the literature review, inputs received through partner interactions in this project and the structure of the proposed decision-making framework.

Learnings from literature

- Attempts to make a structured decision-making tool for offsite construction date back over three decades.
- Past decision-making tools and frameworks have been both generic and targeted in their scope. Generic frameworks tend to look out for a wide range of parameters that can drive the decision one way or the another. These factors included but not limited to cost, time, labour availability, health and safety, supply chain availability, client-contractor knowledge and awareness and so on (refer to literature review for more details)
- Targeted frameworks and tools have been developed aimed at answering specific questions such as total cost of build, life cycle cost assessment (LCCA), LCA for sustainability, risk profile of construction projects and so on (refer to literature review for more details).
- **Generic tools/frameworks** were those that were targeted to the briefing stage of the project where very limited information about the project would be available. These frameworks relied on the industry expert advice on the choice of prefabrication to suit the client expectations. Such tools and frameworks lacked the specificity in terms of the project at hands, and only provided a generic advice based on experience from past projects.
- **Targeted tools/frameworks** on the other hand were specifically aimed at evaluating the project at hand against a set criterion such as cost, embodied carbon, total life cycle costs, number of truck transports and so on. These frameworks required more information about the project at hand from the users to furnish relevant results and outputs. These frameworks were expected to be deployed during the concept and progressively detailed design stages of the project.
- Popular choice of framework creation has been a checkbox and input-output form hosted with excel sheet functionality remotely or on cloud. Several decision-making tools have resorted to online user interfaces for better user friendliness and to for commercialisation purposes.
- Most development of tools were seen centred in the UK, USA and Canada in the early days with other regions such as Singapore, Australia, Italy slowly contributing to this area in more recent times.

Stakeholder feedback

This project benefited from stakeholder insights and discussion over 1 year through:

1. 2 joint seminars (November 2022 and April 2023)
2. 12 monthly stakeholder meetings.

Stakeholder feedback was taken into consideration before finalising the structure of the decision-making framework in this project. Figure 3 shows the inputs gathered during the Q1 seminar in Nov 2022. The feedback highlighted the need for the decision-making framework to include:

1. Sustainability and circularity
2. High-level simplified assessment for upstream stakeholders of the project value chain
3. Need for consistent product typology
4. Preferred procurement routes.

Figure 3. *Stakeholder seminar feedback (November 2022)*

A decision-making framework was thus developed that touched upon the abovementioned aspects of building construction.

During the continual engagement with the stakeholders through project meetings, the following points were highlighted:

1. Early contractor involvement to be included for better awareness.
2. Design flexibility restrictions during increasing prefabrication to be addressed.
3. Recycling rates of the materials be incorporated in the sustainability/circularity assessment.
4. Government targets and mandates to be included for sustainability and circularity.
5. Design adaptability, durability and waste reduction to be linked to circularity.
6. Benefits of implementing circular economic principles should be duly considered from the client’s perspective.
7. The framework to indicate the consequences of user evaluation actions during each section.
8. Potential users of each section of the framework to be stated as multiple stakeholders may use the framework at different times during the project life cycle.
9. Framework to avoid guiding users towards any specific construction methodology.
10. Address the gaps in end-of-life supply chains towards a circular economy.
11. Provide a clear understanding of repeatability in design.
12. Benchmark sustainability indicators based on literature.
13. Explore the use case of generative Artificial Intelligence (AI) algorithm on top of the existing framework to make this into a tool.

Structure of Decision-Making Framework (DMF)

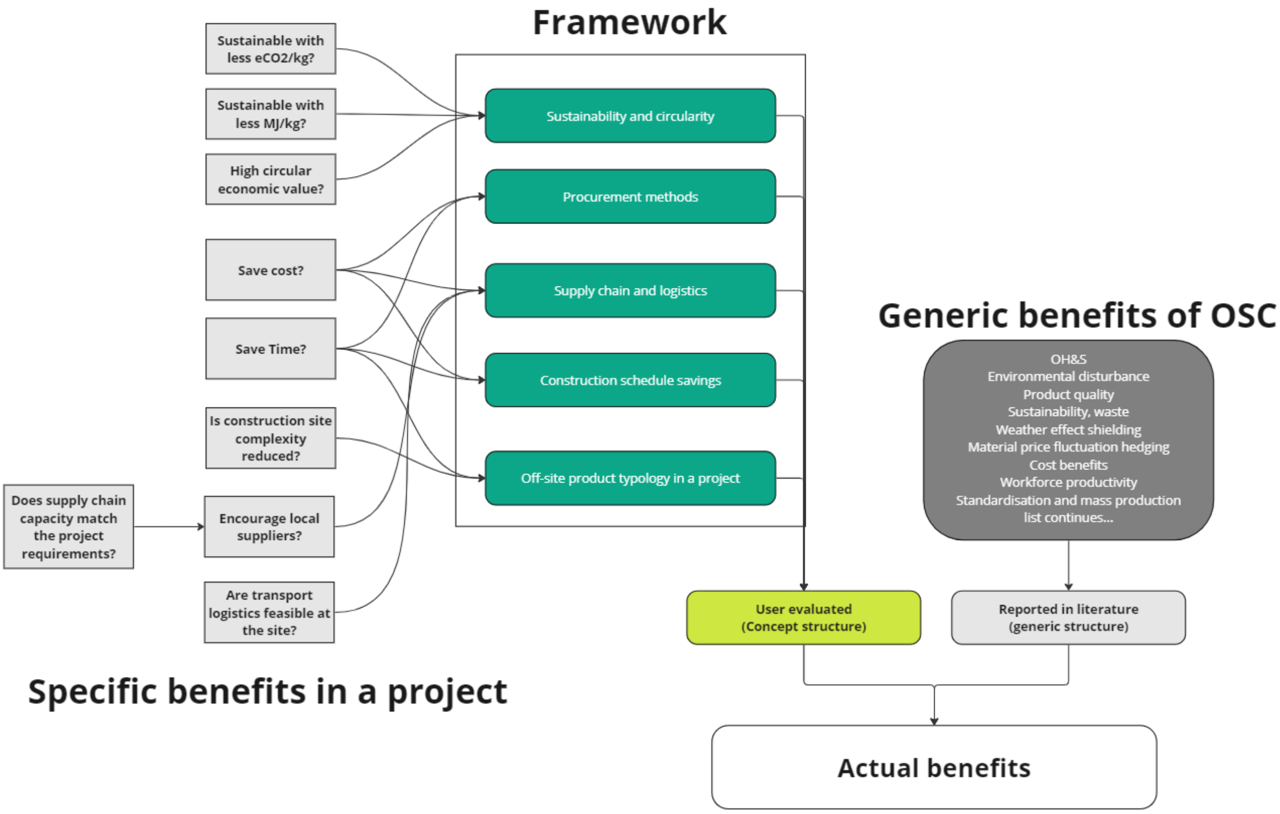


Figure 4. *Proposed decision-making framework structure*

The proposed DMSF was required to be tailored to a specific construction project under consideration based in Victoria, Australia. The five high-level modules as shown in Figure 4 are customised with the databases, data requirements and regulatory policies in Victoria. Together, they are aimed at demystifying the prospects of building an asset through different proportions of on-site and offsite methodologies.

The DMSF is placed at the early stages of the project value chain that is most influential to the overall project outcomes. However, each module of the DMSF illustrates the most applicable stage in the project value chain for that specific module. The structure of the DMSF reflects six key categories of decision-making criteria that were repeated in the literature as seen in the literature review and highlighted by the stakeholders. These broad categories or modules are dealt with separately in this report. Each module follows a similar structure in that it:

1. Introduces the context and relevance of this decision-making criteria to Victorian jurisdiction
2. Explores relevant project/construction parameters relevant for the decision-making
3. Builds the logic through either:
    a. Parameter weights
    b. Stakeholder feedback
    c. Data availability/ data collection
4. Demonstrates the nature and the usefulness of the framework
5. Recommends future actions based on the framework.

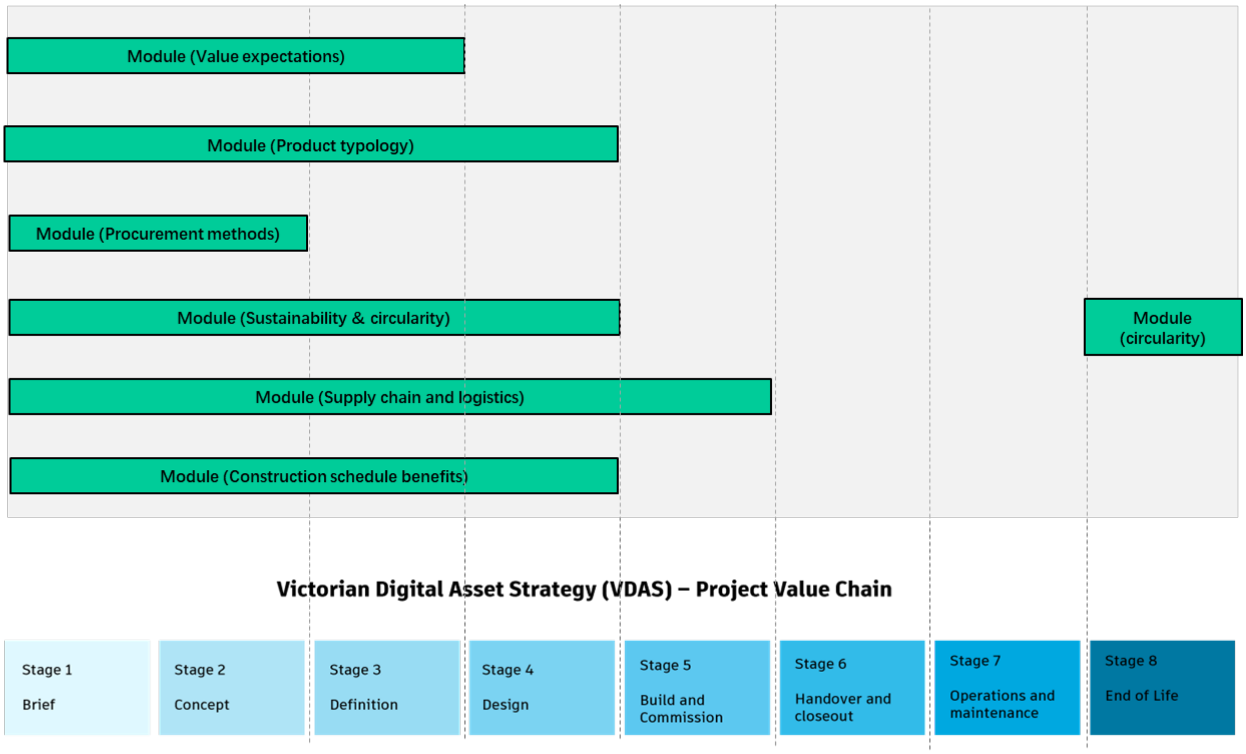


Figure 5. *Applicability of the decision-making framework to stages of the project value chain as per Victorian Digital Asset Strategy (VDAS)*

Figure 5 and Table 2 demarcate the positioning of the individual module with its intended users and project value chain as per the VDAS framework.

Table 2. *Applicability of the decision-making framework with VDAS stages and potential users*

Modules for evaluation	Potential users of the framework	Relevant project value chain stages (VDAS)
Product typology	Clients (private or Government), main contractor, architects	Brief, concept, definition and design
Procurement routes	Clients (private or Government), main contractor	Brief, concept, and definition
Sustainability	Main contractor, Architects, design engineers, clients	Brief, concept, definition, design operation and maintenance
Circularity	Client (private or Government), Architects, supply chain partners	Brief, concept, definition, design and operation and end-of-life
Supply chain and logistics	Client (private or Government), main contractor, architect	Brief, concept, definition, design-build and commission
Construction schedule benefits	Client (private or Government), main contractor, construction manager	Brief, concept, definition, and design

Framework scoping and limitations

- Several aspects of a building construction project were left out from this decision-making framework consciously such as financial viability, structural stability, architectural design based on functional requirements and regulatory approvals as per local council and the national construction code requirements. The argument provided in support of this decision is that a functional building asset should ideally be construction method agnostic. That means a fully functional and viable conventional building design should be indistinguishable from a prefabricated building design. This would allow rules pertaining to financial, structural, architectural and regulatory provisions to apply to conventionally built structures and offsite constructed structure equally. The prefabricated structure would need to be assessed only for those additional parameters that are brought in because of 'prefabrication'. Such parameters are grouped under high level modules introduced before in Figure 4 and laid out in Table 2.
- The scope of the proposed DMSF is limited to building structures comprising of residential detached dwellings, multi-unit apartment construction of medium to high rise, commercial buildings, hotels, schools, hospitals, prison cells and the like. Linear public infrastructure such as railways, roadways, waterways, offshore structures are not currently included in the scope of this DMSF.
- The decision-making framework is designed to guide the user into evaluating different aspects of the project being conceived. The users are encouraged to utilise various tools available in the market to evaluate the project against the criteria outlined in the framework. Some of the examples of this are illustrated in Table 3.

Table 3. *Information required in DMSF and potential sources of information*

Information required by the framework	Tools available in market
Bill of quantities/materials	BIM software (Autodesk, Bentley systems, ..)
Mass of the structure and associated materials	A digital model of the structure in BIM environment
Carbon factors, embodied energy factors for sustainability	EPiC database (hosted by University of Melbourne) or other third-party databases are provided in Table 8
Supplier attributes for supply chain evaluation	Supply chain data sourced from Government repositories or from third-party supply chain data providers
End-of-life fate of construction materials	Victorian database of construction waste recycling

MODULE: PRODUCT TYPOLOGY

A product typology refers to the classification of building products based on their commonalities and their state as they are received on-site. These commonalities are usually a set of parameters that could enable us to do further analysis on their constructability, supply, transport and logistics, handling and installation, procurement and so on. “as received on-site” indicates that the typologies are categorised based on the level of pre-assembly or prework done on them before transporting to the intended construction site for site assembly and installation. We could essentially categorise products on the basis of their: Primary materials, Level of pre-assembly, Structure in three dimensions, Procurement processes, Assembly processes, and Production processes among many others. Ginigaddara et al. (2021)) explored the literature published from 2000 onwards and observed the convergence of terminologies concerning prefabricated building products. They classified the OSC systems based on volumetric and non-volumetric components as shown in Figure 6.

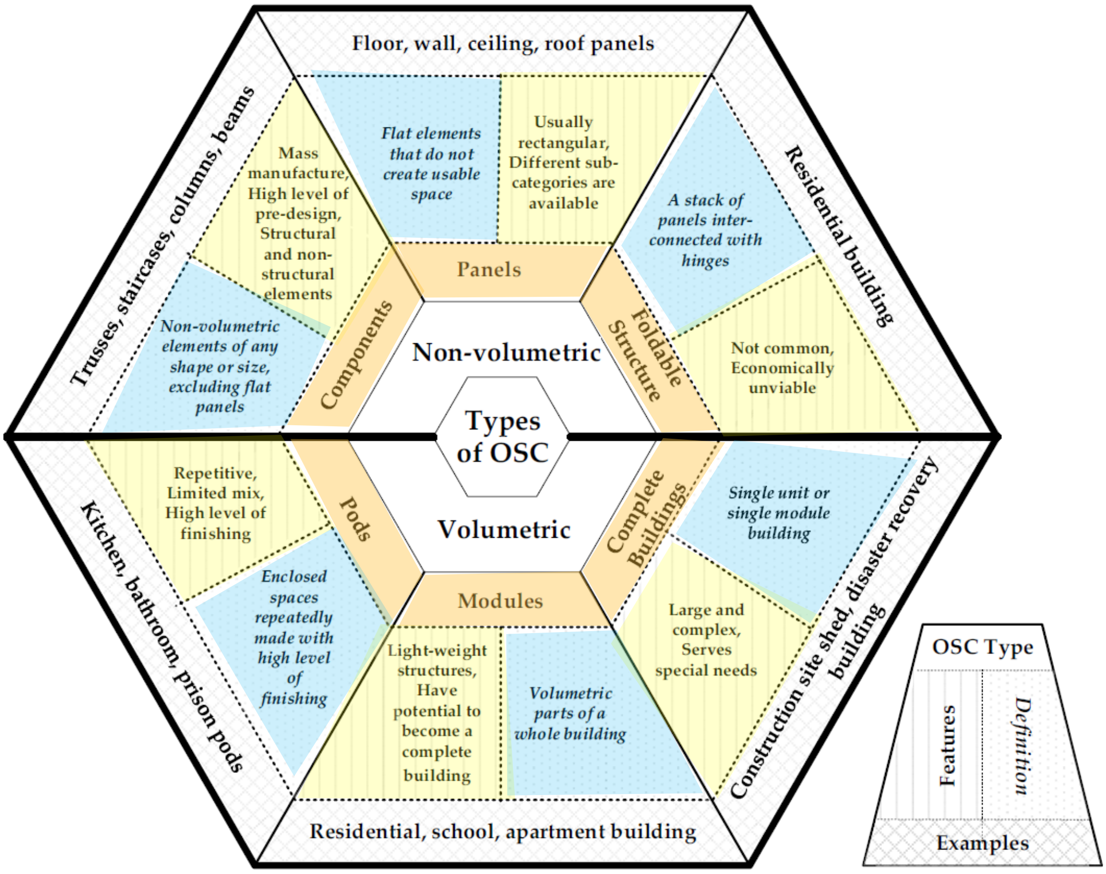


Figure 6. *Product typology by Ginigaddara et al, 2022*

Ayinla et al. (2020) proposed OSC classification based on the product type and their locations, geometric configuration, material, procurement processes, assembly processes, and production processes. Whereas the PhD thesis of Vibæk (2012) outlined a comprehensive framework for systems classification in OSC in a multi-tier map from T0 to T4. These tiers were further mapped with the preparation level, standardisation level, and service level as shown in Figure 7.

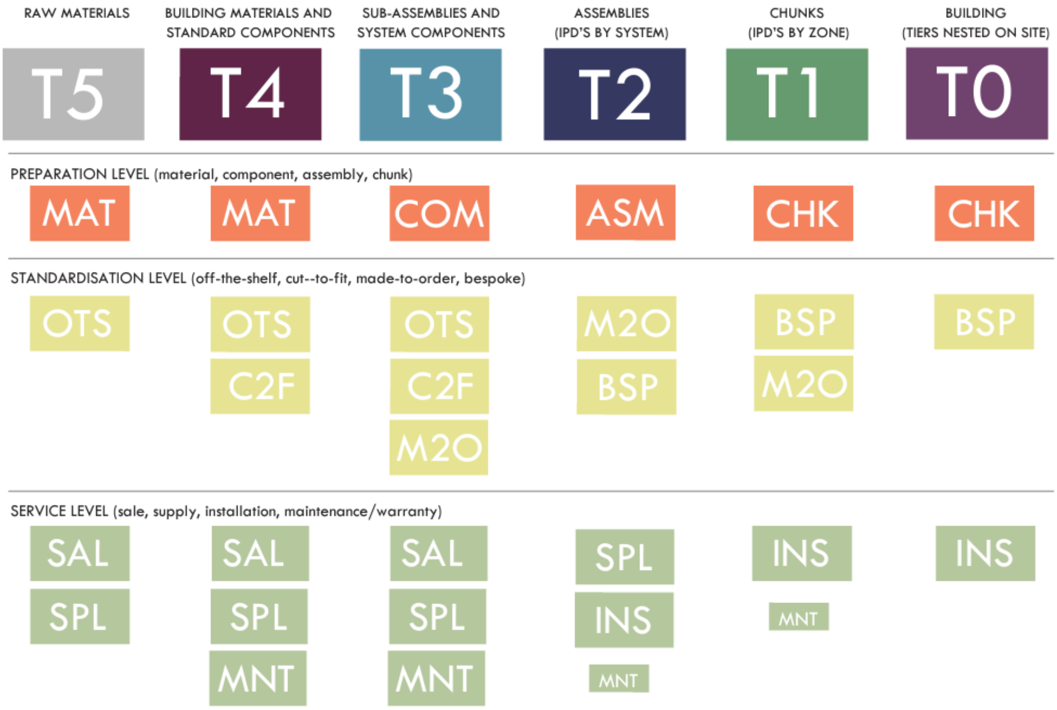


Figure 7. *Product typology mapping by K. Vlbaek (2011)*

We have seen a similar attempt at OSC classification from Bertram et al. (2019) in the McKinsey (2019) as shown in Figure 8:

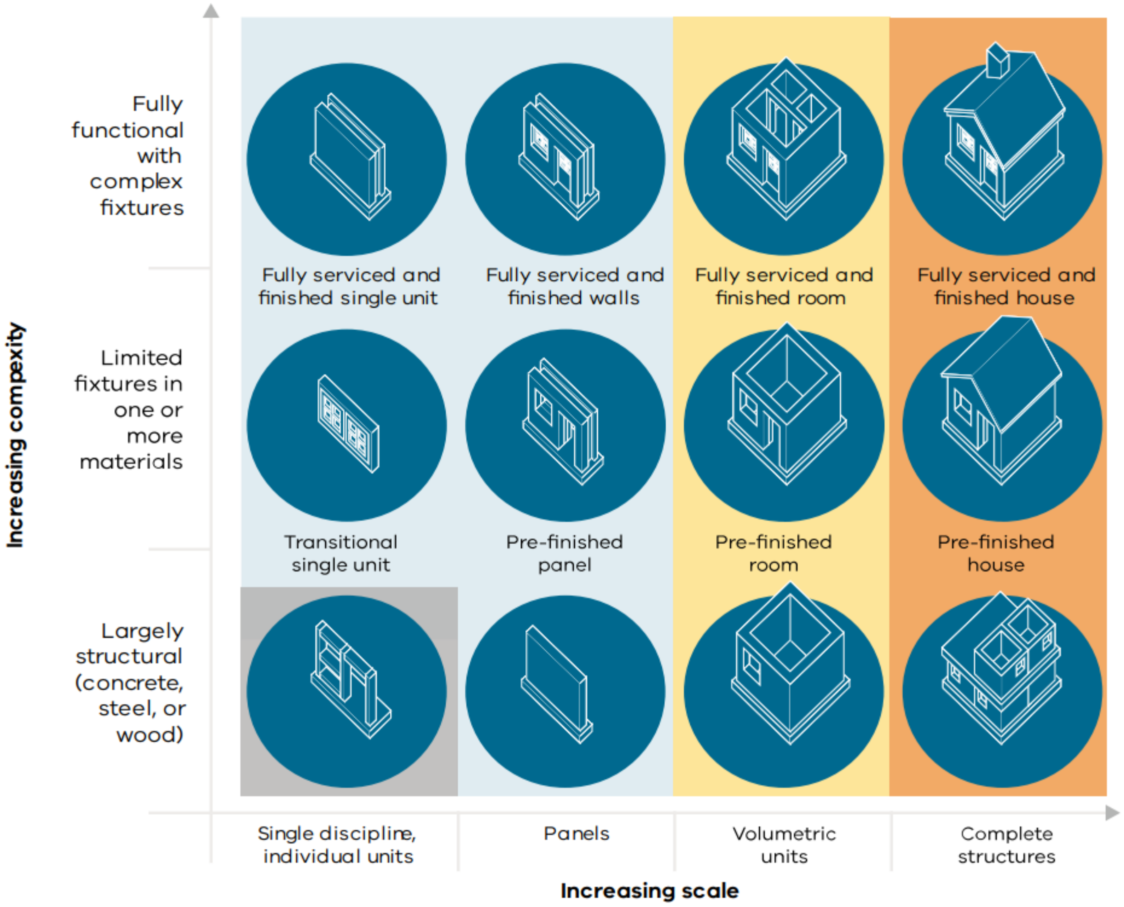


Figure 8. *Offsite product typology with complexity*
Source: McKinsey (2019).

The classification schema presented herewith is more or less consistent with their outcomes. Overlooking their semantic arbitrations, their commonalities were aggregated to build a scale suitable for the OSC project that enabled us further analysis in terms of supply chain mapping in Victoria and constructability analysis of Victorian projects.

In Figure 9, a product typology with six levels is presented.

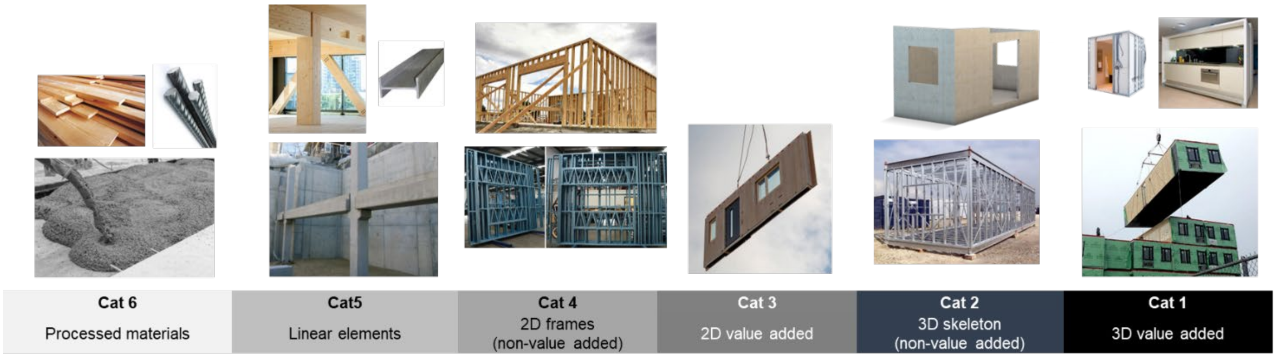


Figure 9. *Proposed offsite product category scale*

The six-level scale is set such that category 1 represents the state of the product that resembles the most with the building's "as built" condition during operation. Higher category numbers are incrementally attributed to the products and elements that are further away from the building's "as built" condition during operation. Following this logic, the categories are described as follows:

- Category 6 – are the processed materials that are shipped to the construction site where most of the works takes place. These processed materials would require moulding, cutting, shaping, joining and temporary structures to support them while they gain the required shape and strength. A significant portion of work is done on-site to create a functional space as per "as built" condition. Examples include Timber planks, elements, ready mix concrete, reinforcing steel bars, screws, nuts, and so on.
- Category 5 – would include linear products that are precut to size. Examples include Structural steel elements, Cross Laminated Timber (CLT)/GLULAM timber beams and columns, precast concrete beams and columns and so on.
- Category 4 – are 2D panels that provide structural envelop similar to Cat – 2 products. Generally, these panelised (2D) products would not include other subsystems and would require the site -work to make them functional from the building perspective. Examples include CLT panels, concrete wall panels, concrete floor slab, light gauge steel wall frames, timber wall frames and so on.
- Category 3 – are 2D panelised modules that incorporate one or more subsystems such as insulation, plastering, exterior skin façade, wiring, doors, windows and so on.
- Category 2 – are 3D volumetric skeleton systems that provide a structural envelope on-site. These products primarily serve a single purpose of providing structural integrity and envelop and require site work to add other subsystems as mentioned above to make them operational from a functional perspective. Examples include steel, timber, concrete modular unit.
- Category 1 – are 3D volumetric building modules or buildings as a whole that incorporate one or more subsystems pre-assembled such as insulation, internal plastering, fixtures, MEP, HVAC ducting etc.

System mapping framework

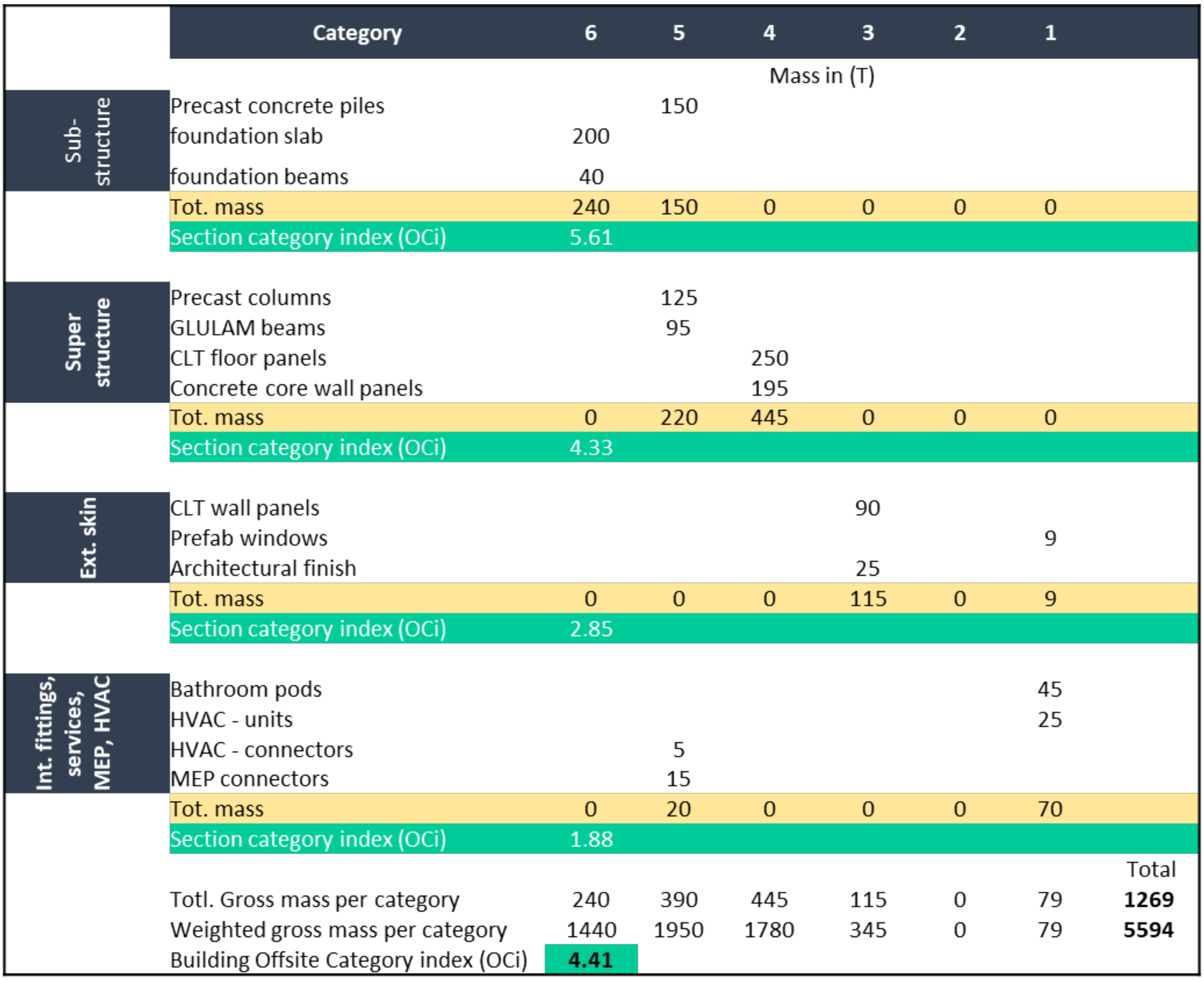
The abovementioned scale can be used to represent the overall proportion of offsite building categories in a construction project. The current Australian offsite building market is 3–5% of the total construction market (JOHANSON) which is set to increase in percentage. The quantification of such numbers could be inaccurate without a methodical approach to quantify the level of productisation in a building project. Many aspects of every building project are prefabricated even from a conventional construction perspective such as HVAC equipment, timber frames, plaster walls, white goods, furniture, windows, doors and so on. Whereas such buildings are not considered to be “prefabricated” as per the norms of the day. On the other hand, a fully 3D volumetric building structure is counted as equal to a structure that may involve prefabricated bathroom pods as the element of productisation. It is clear that the former represents a highly productised building construction, and the latter represents a case with small utilisation of productisation. The development of a metric that would help address this issue can help in organising projects based on their ‘level’ of prefabrication. Such hierarchical organisation of projects can bring out nuances in the data previously not seen. Towards that, Table 4, shows the building sections in rows and offsite product categories in columns. It is worthwhile to collect and segregate the information on building products arriving at the site and their product typologies this way.

Table 4. *Offsite product category evaluation of building construction project*

	Category	6	5	4	3	2	1
Sub-structure	Precast concrete piles		●				
	foundation slab	●					
	foundation beams	●					
Super-structure	Precast columns		●				
	GLULAM beams		●				
	CLT floor panels			●			
	Concrete core wall panels			●			
Ext. skin	CLT wall panels				●		
	Prefab windows						●
	Architectural finish				●		
Int. fittings, services, MEP, HVAC	Bathroom pods						●
	HVAC - units						●
	HVAC - connectors		●				
	MEP connectors		●				

The list of building sections is shown for illustration only and can be appended from the bill of quantities (BoQ) and Bill of Materials (BOM) data either available through previous estimates or by early modelling of structure in the design software of choice. To extend this framework further, a third dimension could be added to this matrix representation of product data in a project. This third dimension could represent any chosen metric such as number of suppliers available for supply chain evaluation, embodied energy/carbon/water for sustainability evaluation, mass in kgs for structural evaluation and so on. One such example shown below represents the mass of the structure as the third dimension.

Table 5. *Offsite category index (OCi) evaluation of a project (illustration)*



	Category	6	5	4	3	2	1	
				Mass in (T)				
Sub-structure	Precast concrete piles		150					
	foundation slab	200						
	foundation beams	40						
	Tot. mass	240	150	0	0	0	0	
	Section category index (OCi)	5.61						
Super structure	Precast columns		125					
	GLULAM beams		95					
	CLT floor panels			250				
	Concrete core wall panels			195				
	Tot. mass	0	220	445	0	0	0	
	Section category index (OCi)	4.33						
Ext. skin	CLT wall panels				90			
	Prefab windows						9	
	Architectural finish				25			
	Tot. mass	0	0	0	115	0	9	
	Section category index (OCi)	2.85						
Int. fittings, services, MEP, HVAC	Bathroom pods						45	
	HVAC - units						25	
	HVAC - connectors		5					
	MEP connectors		15					
	Tot. mass	0	20	0	0	0	70	
	Section category index (OCi)	1.88						
								Total
	Totl. Gross mass per category	240	390	445	115	0	79	**1269**
	Weighted gross mass per category	1440	1950	1780	345	0	79	**5594**
	Building Offsite Category index (OCi)	**4.41**						

In this example, a 7-storey semi-prefabricated building construction is hypothesised to prefill the data matrix in Table 5. The component mass (in tons) is for illustration purposes only. The mass is chosen as the quantification parameter as many other parameters are directly linked with how much mass a building has, such as foundation depth, foundation size, structural member sizes, sustainability indicators and so on. The mass of the structure is added along the rows and columns as shown in the last row and column. The column totals are weighted with the category numbers. (For example, the total mass of category 6 products is multiplied by 6 and so on.) The 'mass weighted average' of the category number is shown as the offsite category index (OCi) for this building project equal to 4.41, as per the following equation.

$$\frac{\sum_1^6 (Cat_i \times M_{cat})}{\sum_1^6 M_{cat}}$$

Figure 10 shows the placement of the building project on the scale of 1 to 6 based on its mass, 1 being completely prefabricated and 6 being constructed on-site from just processed materials, both of which are unlikely. This provides an opportunity for the Government to create regulations and code provisions for the buildings based on their OCis which would be a number between 1 to 6 similar to the likes of the existing NatHERS energy rating system.

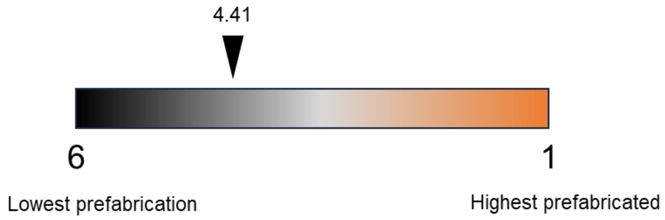


Figure 10. *OCi for the entire building expressed on the product category scale*

Recommendation

The product OCi is inspired by a comprehensive literature review and stakeholder interactions about offsite product categorisation and its potential use in benchmarking the extent of prefabrication.

1. The OCi could help monitor the progress of the construction industry in Australia in a more meaningful way than the current metrics of quantifying the market penetration of prefab construction systems.
2. Steps required to implement an OCi framework are:
    a. Nominating available building construction materials and products into product categories based on their level of pre-assembly (referenced in this module). This exercise could be conducted by:
        i. The Government internally and results made public.
        ii. Non-governmental organisations such as PrefabAUS.
        iii. Third-party partner construction technology industry partner.
    b. Endorsing the OCi for each building project at the planning approval stage. (Ex., Hospitals: OCi > 4, Residential apartments: OCi > 4.35, and so on)
    c. The OCi could support higher levels of prefabrication without actually favouring one method of prefabrication over another, but this would need to be subjected to the appropriate assessments to understand the impact of any additional regulatory requirements.

MODULE: PROCUREMENT AND CONTRACTS

The definition of procurement has been evolving due to the increasing significance of procurement-related activities to enterprise success (Nissen, 2009). Within the Department of Treasury and Finance, procurement is defined as the process of involving a supplier to deliver capital asset investments, such as buildings, civil infrastructure, and information and communications infrastructure. Construction procurement refers to the overall management and responsibility for constructing a building or infrastructure (Government as Smart Client, 2021). There are various forms of procurement methods/routes introduced to the construction industry over the years, which play a significant role in sourcing material and labour, assigning responsibilities, and sharing risk among project participants to execute a project. Selecting the most appropriate procurement method is crucial to ultimately enhance the likelihood of project success and client satisfaction. This module outlines an overview of the most widely used procurement methods within the Australian construction industry, followed by evaluation criteria for the selection of procurement methods. In addition, the new procurement approach, early contractor involvement (ECI), and new evaluation criteria are discussed in the context of offsite construction. In the end, recommendations are presented based on an extensive literature review and experts' opinions.

Overview of Popular Procurement Methods

Procurement methods have grown more adaptable over time, and the interchange between them has emphasised the need to differentiate distinct procurement systems from one another (Love et al., 2012). OVGA (Office of Victorian Government Architect) broadly categorised procurement methods into direct procurement and indirect procurement, depending on the client who has direct control of the design process (Government as Smart Client, 2021). In the literature, procurement methods can be classified into 4 main categories namely separated procurement methods, integrated procurement methods, management-oriented procurement systems and relationship-based procurement methods (Masterman, 2003; Rahmani et al., 2017). Figure 11 illustrates the most widely used project procurement methods in the Australian context discussed in this section. The following presents their key feature, contractual and working relationship, conditions for use, potential benefits and risks based on OVGA (Government as Smart Client, 2021).

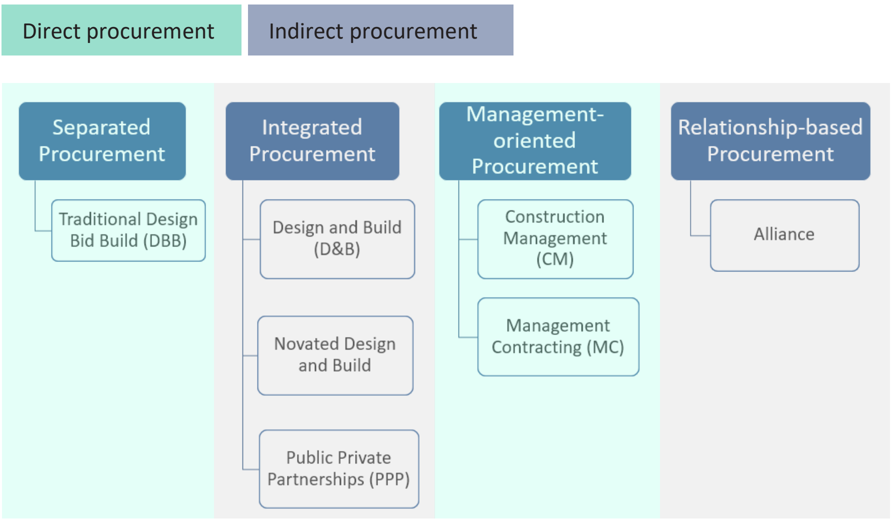


Figure 11. *Most widely used project procurement methods in the Australian context*

Separated Procurement-Traditional Design Bid Build (DBB)

Key features

- Architect is engaged directly by the client to undertake all stages of the design process.
- The client engages the builder independently of the architect to build the works.

Conditions for use

- Well-defined scope of work.
- Limited variations to the contract price due to client-instigated changes.
- High-quality design is critical from the outset of the project.
- The client is requiring expert advice independent of the builder during building construction.

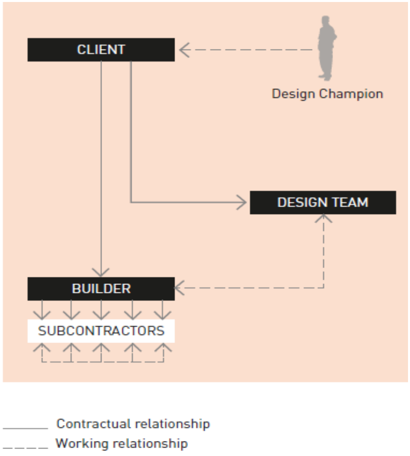


Figure 12. *Separated procurement model*

Potential benefits

- Enables client to control scope, design, and vision and allows adequate time to develop design fully.
- Opportunity for clear design intent from the outset of the project.
- Responsibility remains with the builder and reduces the risk of additional claims by the builder.
- Established processes clearly understood by designers, contractors, and clients.
- A high-quality built outcome is likely and maximises design innovation.
- Relatively low tender and tender evaluation costs; Construction delays can be kept low.

Potential risks

- Removes the opportunity for collaboration with the contractor during the design phase.
- Potential lack of consideration of whole-of-life cost. Relies on a completed design.
- The client must outlay almost all the consultant fee costs before proceeding with construction.
- Potential insufficient consideration of constructability issues during the design development.
- Minimal opportunity for innovation by the contractor.
- Documentation of insufficiently high quality for a client to maintain the tendered cost.

Integrated Procurement Design and Build (D&B)

Key features

- The client enters a single contract with a construction company that provides both the design, documentation, and construction.
- Design services may be subcontracted to a team of designers.

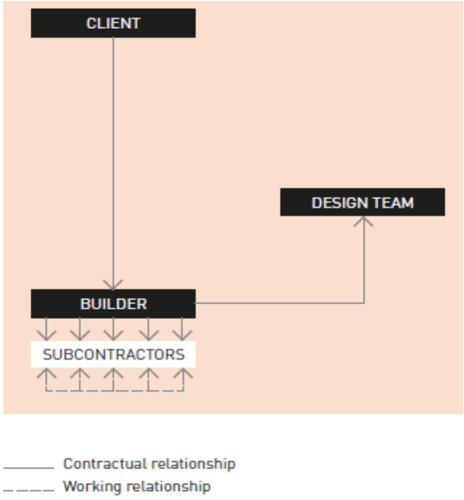


Figure 13. *Integrated procurement model*

Conditions for use

- An early commencement on-site is required.
- The client can prepare clear, concise, and well-documented performance and technical criteria.
- The client requires a total commitment for time and cost at a fixed price.
- The client's control over design quality is not a priority.
- Design requirements are clearly specified and understood.

Potential benefits

- Faster and less exposure to risk of variations for trivial or design-related issues.
- More 'open' design scope, greater variety of design choices.
- Possible higher degree of innovation regarding buildability advice.
- Suitable for projects of basic infrastructure, and low complexity.
- Contractor has control over design details and timing of work.

Potential risks

- Qualitative interpretation of documentation is totally with the contractor.
- Indirect relationship between client and designers. Lack of option to select a preferred design expertise.
- Changes to the design brief after early design phases can be costly. Price may be exceeded.
- Complex tender evaluation potentially increases costs and delays contract award.
- Loss of control of design outcome and limited direct management of design issues.
- Few opportunities for stakeholder and end-user consultation to influence the design.
- Building contractors capture all benefits.
- Limited connection to the client compromises the design intent. Potentially compromising desired outcomes.
- Insufficient time allowed for tenderers to prepare quality designs. The design quality is not protected.

Integrated Procurement-Novated D&B (Novation)

Key features

- Transfer the architect's contract with the client to the builder/head contractor after the design has reached an agreed stage.
- The builder is appointed after the submission of tenders based on a brief and preliminary design development document.

Conditions for use

- The client requires more extended control of the design than D&B allows, but with minimum risk.
- The builder is considered skilled enough for design documentation and construction.
- The client requires competitive, comparable prices through tendering.
- The extent of work needs to be fixed limiting any variations to the construction contract, post novation.

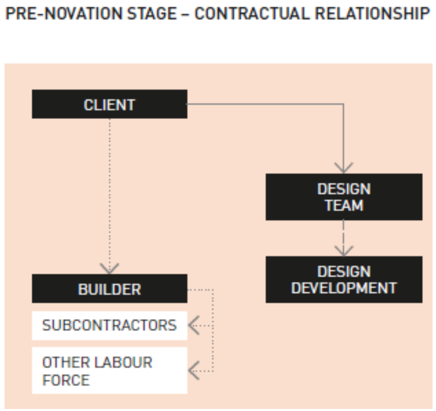


Figure 14. *Pre-novation contractual relationship*

Potential benefits

- Compared with Design and Construct (D&C), the client maintains greater control during the preliminary design phase.
- Design teams' initial contracts with clients can develop designs to achieve the desired outcomes.
- The design team continues as Design Champion and carries the history of strategic decisions prior to contractor engagement.
- Head Contractor takes on responsibility at novation for the design documentation and construction.
- Collaboration opportunities between the design team and the Head Contractor.
- Detailed construction methods are tailored to the preferred systems of the contractor.

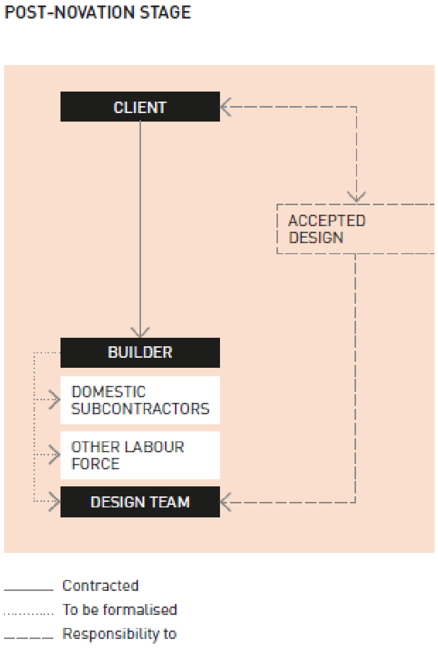


Figure 15. *Post novation contractual relationship*

Potential risks

- Potential compromise of the desired outcomes.
- Potentially compromised design quality by the Head Contractor to save cost.
- Potential lack of focus on whole-of-life cost.
- Does not provide for measurement or assessment of design outcome.
- Unforeseen variations are required after novation.
- Post contract the level of risk to the Government/user can be high.
- Limited opportunity for innovation by the contractor.
- Tenderers may include a contingency price.
- Potential lack of design team fees allocated to the post novation phase.
- Limited connection to the client compromises the design intent.
- Price may be exceeded; design quality is not protected.
- Insufficient time allowed for tenderers to prepare quality designs.

Integrated Procurement Public Private Partnerships (PPP)

Key features

- Involves a contract between the public and private sectors, where the Government pays the private sector to deliver infrastructure and related services over a specified period (typically 20–25 years).
- The design team is part of a private bidding consortium that combines design, construction, finance, and operational services into a single contract with the Government.

Conditions for use

- Project is of sufficient scale. Outputs are measurable.
- A competitive environment is necessary to promote innovative solutions.
- Collaborative relationship is desirable between the design team, the builder, the operator, and the facilities manager.
- Design is valued in the evaluation process.
- The private sector is more suitable for managing project risks.
- The private sector partner is responsible for considering the whole-of-life costs.

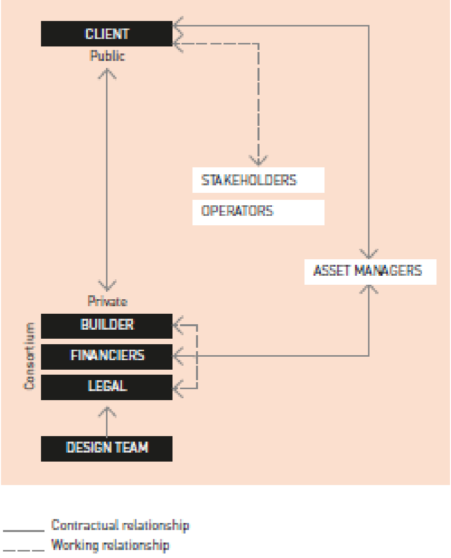


Figure 16. *PPP contracts*

Potential benefits

- Design proposals integrated into the assessment process with the early involvement of an integrated supply team.
- Interactive Tender Process during the Request for Proposal (RFP) phase to minimise misinterpretation risks and gather feedback.
- Alignment of Government and bidders' interests, including design optimisation.
- The client is given the choice between different design approaches of respective consortia.
- Emphasis on whole-of-life costs with penalties in PPP contracts for commercial performance.
- Private party assumes design risk, including Fitness for Purpose risk.
- Potential for better value for money. Capital costs reduced.
- Encourages innovative solutions in service delivery and adopts tested best practices.
- Focus on commercial and operational efficiency, delivering facilities as planned, on time, and within budget.
- Clearly defined operation and maintenance responsibilities through contracts.

Potential risks

- Commercial preferences may hinder the State from acquiring the best design team.
- Caution is needed to ensure design brief consistency with the proposed quality in the Reference Design.
- Lack of lifecycle and handback clauses protecting quality, such as warranties nearing expiration.
- Inadequate specification detail from the State’s design team or time during the Interactive Tender Process.
- Time and cost constraints may limit the pool of design teams capable of bidding.
- The client lacks the expertise to effectively monitor design quality throughout the process.
- Establishing cost transparency can be challenging.
- Effective partnerships require strong relationships between Government agencies and consortium parties.

Management-oriented Procurement-Construction Management (CM)

Key features

- The ‘traditional builder’ is replaced by a Construction Management organisation, working directly for the client in managing the construction phase.
- Works are completed by a series of trade contracts between the client and each contractor.

Conditions for use

- The client needs to begin construction early while finalising the design and documentation for later trade packages.
- The client requires direct control over work in operational settings.
- For complex projects where the design of certain elements cannot begin before work is initiated on others.
- If a contractor faces financial collapse mid-project, completing the project through CM may be more efficient.

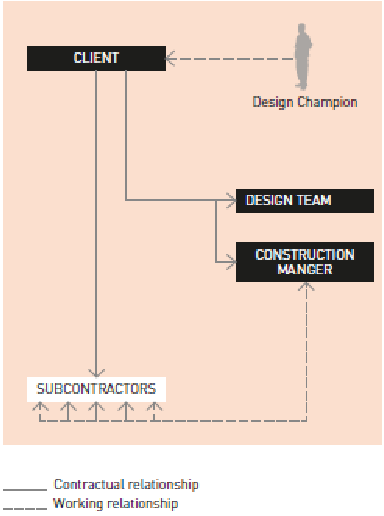


Figure 17. *Management-oriented procurement*

Potential benefits

- The direct payment by the client to the trade contractors provides a better working relationship on-site and removes the typical delay associated with a payment.
- Claims for variations and time extensions are directly related to trade contract claims as opposed to a builder’s claim under a lump sum contract that may or may not relate to any trade contract delays on-site.
- Input of construction advice into the design is readily enabled.
- Construction may commence before completing the design, allowing for project time compression.
- Allows for competitive tendering as packages of work are developed.
- The client selects the architect and design consultants.

Potential risks

- The construction manager doesn't bear cost or design risks but may assist the client with cost control and design advice.
- The final project cost remains unknown until the last package is contracted during construction.
- The construction manager acts as the client's agent and takes responsibility for their own services, while the client bears the risk of the trade contractors who are contracted directly with them.

Management-oriented Procurement-Management Contracting (MC)

Key features

- Involves the client in appointing a head contractor (the Managing Contractor) who may deliver or engage subcontractors to deliver the works.
- Once the Managing Contractor is appointed, the design team continues to develop the documentation so that the Managing Contractor can let each specialist package.

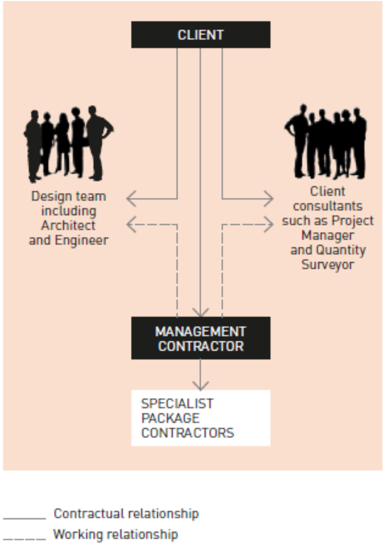


Figure 18: *Management-oriented contracting*

Conditions for use

- Complex or high-risk projects with uncertain scope, risks, or technology.
- Available high degree of expert Government input.
- Where ECI is beneficial.
- Where the managerial skills of the parties involved can best be utilised.
- Desirable industry input and innovation during the design stage.

Potential benefits

- The client may appoint the design team before the Managing Contractor.
- Potential for shorter project duration and improved working relationships among parties.
- Single point of responsibility for design, construction, and fitness for purpose.
- The client retains a higher level of project management control. Design changes are easier to accommodate.
- Collaboration between clients and suppliers is essential for optimal project outcomes.
- Early involvement of the contractor addresses buildability issues and considers whole-life considerations during the design phase.
- Collaboration between the client and the Managing Contractor through the design and construction phases of the project.
- The client can provide input into design development and influences the design and construction processes.

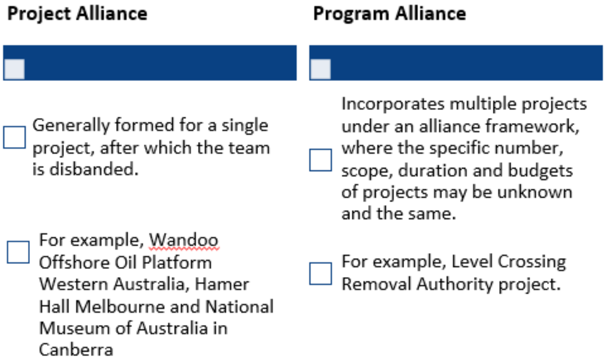
Potential risks

- Insufficient time to establish the scope and develop the tender documents.
- When payment does not include quality of design as a key performance parameter.
- Difficulty setting cost targets with limited design details.
- Contract lacks clarity regarding design ambitions and the architect's role.
- Managing Contractor takes risks of on-time completion and trade contractor performance, limiting the number of interested tenderers.

Management-oriented Procurement Alliance

Key features

- A state agency (‘Client’) works collaboratively with private sector parties (‘non-owner participants’).
- Two Alliance models:



Project Alliance	**Program Alliance**
☐ Generally formed for a single project, after which the team is disbanded.	☐ Incorporates multiple projects under an alliance framework, where the specific number, scope, duration and budgets of projects may be unknown and the same.
☐ For example, Wandoo Offshore Oil Platform Western Australia, Hamer Hall Melbourne and National Museum of Australia in Canberra	☐ For example, Level Crossing Removal Authority project.

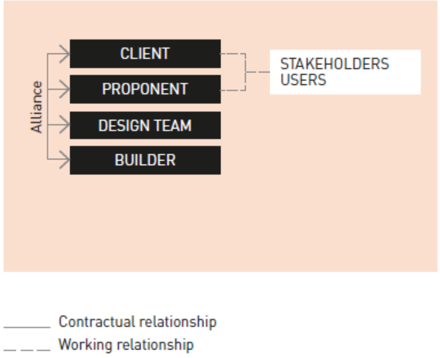


Figure 19: *Management-Oriented Procurement Alliance*

Project Alliance-Conditions for use

- Complex and high-risk high-value infrastructure projects.
- Owner possesses knowledge, skills, preferences, and capacity to influence or participate in project development and delivery.
- Urgent project start required with an unclear solution. Require a high level of innovation.
- Unpredictable risks that are best managed collectively or are too costly to transfer.
- The client can appoint senior executives to represent and manage its interests in the alliance contract.
- Client's close involvement, sufficient internal resources, and ability to add value.
- Projects involving a diverse and demanding range of stakeholders.

Project Alliance-Potential benefits

- Promotes a collaborative culture for achieving exceptional design results.
- Minimises disputes among designers, contractors, and the Principal/Client.
- Offers flexibility to modify design and incorporate ongoing changes during construction.

Project Alliance-Potential risks

- Success relies on securing the best-skilled consultants and contractor, and clear project objectives.
- Over emphasis on commercial incentives at the expense of design quality.
- Client struggles to clearly articulate project design objectives and requirements aligned with the approved business case.
- Limited incentives to perform often result in cost overruns once incentives diminish.
- Failure to fully consider lifecycle or long-term servicing costs.
- Failure to include design quality as a key performance index (KPI) and to correctly weight.

Program Alliance-Conditions for use

- Complex and high-risk high-value infrastructure projects.
- Owner possesses knowledge, skills, preferences, and capacity to influence or participate in project development and delivery.
- The project owner requires additional skills and resources to address project risks.
- There is a pipeline of works. Urgent project start.
- Requires a high level of innovation.
- Unpredictable risks that are best managed collectively or are too costly to transfer.
- Projects involving a diverse and demanding range of stakeholders.
- Commitment to capturing innovations and continuous improvements across projects.

Program Alliance-Potential benefits

- Promotes a collaborative culture for achieving outstanding design results.
- Minimises disputes among designers, contractors, and the Principal/Client.
- Continuous improvement through project delivery.
- Offers flexibility to modify designs and incorporate ongoing changes during construction.
- Opportunity to create a strong multidisciplinary and collaborative design environment.
- Flexibility to explore design options, advance risk mitigations, and engage with stakeholders and the community before committing to the project.

Program Alliance-Potential risks

- Success relies on securing the best-skilled consultants and contractors, clear project objectives, and defined lines of responsibility in the Program Alliance Agreement (PAA) and subsequent Annexures.
- Failure to consider designated KRAs for urban design and correctly weight design quality.
- Limited opportunity to influence a short list of preferred urban designers, architects, and landscape architects.
- Active engagement with designers is required to maintain design quality and address on-site design changes during construction.
- Inadequate time for designers to develop a robust reference design during the Transfer of Care (TOC) period.
- Limited ability to improve design quality post contract award.
- Failure to fully consider lifecycle or long-term servicing costs.
- Lack of commitment to integrated consideration of urban renewal opportunities.

Early Contractor Involvement (ECI)

The seventh edition of Civil Engineering Procedure suggests that ECI denotes '… a non-traditional procurement route, where a contractor's skills are introduced early into a project to bring design 'buildability' and cost efficiencies to the pre-construction phase' (Engineers), 2016). The term 'ECI' may be used as a concept to describe any procurement method that involves the contractor during the design phase or as its own procurement route (Finnie et al., 2018). as shown in Figure 20. Contractors can't contribute much to the design and planning in a separate procurement method (traditional DBB) as the level of detailed design specification is generally very high at the time of calling for bids by project delivery organisations. Integrated procurement methods involve either contractual or physical integration. In D&B, the design is typically outlined in functional performance and often derived from conceptual design drawings. While the contractor's construction knowledge and experience do influence the project design, the absence of the contractor at the project definition and conceptual design stage impedes the client to fully benefit from the contractor's expertise when the project is defined and scoped. Management –oriented procurement methods enable the client to benefit from extensive advice on buildability or constructability from the management contractor during the design phase. Nevertheless, the management construction team may exhibit less proactive behaviour in Construction Management, primarily because of a lack of contractual connections with the design and delivery parties. Similarly, Management Contracting might suffer from inadequate management fees, which can also contribute to a lack of proactivity on the part of the management construction team. Relationship-based procurement methods have been shown to foster collaborative relationships between the parties involved, enabling the highest extent of ECI. Alliancing's fundamental aspect involves sharing information, knowledge, and expertise within a trust-based, non-adversarial environment. In such a setting, contractors willingly contribute their knowledge and experience, leading to cost and time savings for the project, which ultimately benefits them.

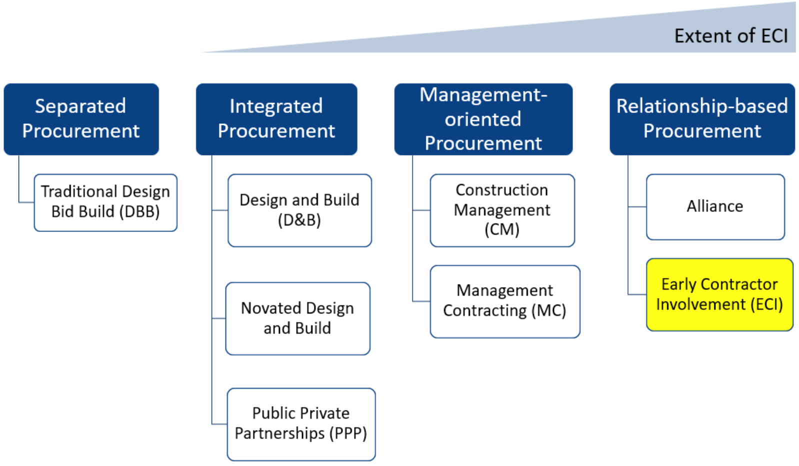


Figure 20. *Extent of contractor involvement at the early stage of the project in different delivery systems Source: Rahmani et al. (2014).*

As can be seen from Figure 20, ECI is classified as a relationship-based procurement method when has its own procurement route, typically referred to as a two-stage procurement process. According to Alliancing Association of Australasia (Australasia, 2008), the designer and constructor work together in a contractual relationship with the client, firstly to scope and price a project (Stage 1) and then to D&B a project (Stage 2). Several documents have been published by the South Australia’s Department for Transport Energy and Infrastructure, and the Queensland’s Department of Transport and Main Roads in an attempt to standardise the ECI contract as practised in Australia (Edwards, 2009). Its conditions for use, potential benefits and risks are identified below from an extensive literature review.

ECI-Conditions for use

- Complex and high-risk high-value infrastructure projects but smaller than a typical alliance project (Whitehead, 2009).
- A high degree of uncertainty in time, cost, and scope (Australasia, 2010).
- Demonstrating value for money for clients is a fundamental objective compared to Alliance (Rahmani et al., 2022).
- Innovation is a key requirement (Blayse & Manley, 2004; Rahmani et al., 2016a).
- Pivotal concern about constructability requiring methods, techniques, and technologies (Song et al., 2009).
- Clients require complete interaction and control over the design (Rahmani et al., 2022).
- Requires sufficient funding for regular payments to the contractor (Li et al., 2005).

ECI-Potential benefits

- Improves working relationship during the delivery phase, enhance trust and reliability and reduce mindreading and inaccurate assumptions (Marinelli & Salopek, 2020; Rahmani, 2021; Rahmani et al., 2016a).
- Enhances communication and working relationships between the client and contractor, reducing the risk of opportunism (Rahmani, 2021).
- Enhance constructability in design therefore reducing the waste of design efforts and risk of delay (Rahmani, 2021; Rahmani et al., 2016a).
- Increases opportunities for innovative solutions (Rahmani, 2021; Rahmani et al., 2016a).
- Higher certainty in the price and scope (Song et al., 2009).
- Reduces rework during the delivery stage and achieves better value outcomes through value engineering and constructor oversight of design (Rahmani, 2021).

Program Alliance-Potential risks

- Raises treasury's concerns for demonstrating value for money (Rahmani, 2021).
- Lack of client experience and resources in using ECI (ED Love et al., 2014; Rahmani, 2021).
- Contractor misinterpretation affects client-contractor relationships and commitments (Rahmani, 2021; Rahmani et al., 2016b).
- Failure to cover design and tendering costs due to problematic remuneration mechanisms (Rahmani, 2021).
- Lack of guidance during relationship transition and prevailing industry cynicism (Rahmani, 2021).
- Imbalanced leadership leads to a position of supremacy and advantage (Rahmani, 2021).
- Potential loss of innovation as the contractor prioritises constructability and cost savings (Whitehead, 2009).
- Contractor's reduced motivation to provide the best staff due to early appointment (Whitehead, 2009).
- Higher risk-adjusted price due to the absence of competitive tension (Whitehead, 2009).

Most of the constraints, including difficulties for designers to incorporate offsite construction technology, connectivity and potential mismatch between design and manufacturing and issues with transportation and site restrictions, may be summarised as design buildability issues (Finnie et al., 2018). Through ECI, works can be collaboratively planned, harnessing the contractor’s buildability knowledge to foresee risks and maximise value when using offsite construction technologies (Marinelli & Salopek, 2020; Rahmani, 2021; Rahmani et al., 2016a). Even though it is widely accepted that ECI can enhance offsite construction, there are co-existing opportunities and challenges from the client’s perspective in the Australian context as identified by Rahmani (2021). The future adoption of ECI relies heavily on the results and outcomes of more completed projects that have implemented ECI schemes. As more projects utilise ECI, the industry will gain a better understanding of its benefits and effectiveness, leading to increased confidence and potential for wider application in future projects.

Evaluation criteria

The most comprehensive and up-to-date evaluation criteria for selecting the appropriate procurement method were generalised by Naoum and Egbu (2016) from an extensive literature review (134 journal articles and reports from 1980 to 2015). These 20 criteria not only include classic criteria such as time, cost, and quality, etc., but also include modern criteria such as buildability, sustainability, innovation, etc. A utility value for each procurement route against these criteria was identified based on the information from the literature and adjusted based on the survey results from 57 construction engineers. Each procurement route and client criteria were scored on a scale of 10 to 110 to avoid any possible imbalances due to the occurrence of zero. Table 6 presents the identified evaluation criteria and their corresponding utility value for each procurement method. It is worthwhile noting that only the most widely used procurement methods were assessed. Users can provide relative importance to each criterion based on their own projects to obtain a final score for each procurement method.

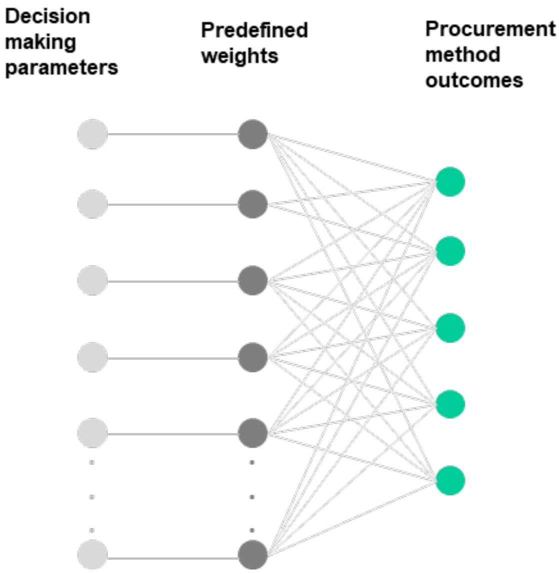


Figure 21. *Decision mapping tree for procurement methods*

The working of evaluation criteria are presented in Figure 21. The decision-making parameters are proposed as questions to the user of the framework. The user inputs to these questions are rated on a scale of 0 to 100. These inputs are derived from the self-evaluation of the project by the user. The user inputs create the 'decision-making layer' from the mapping shown in Figure 21. The predefined weights as shown in Table 6 are used to map user inputs onto five procurement methods as specified below.

Table 6. *Evaluation criteria and their utility value*

Client criteria	Separated	Integrated	Management-Oriented		Relationship-Based
	Traditional Design Bid Build	Design and Build	Management Contracting	Construction Management	Alliancing
Speed of construction	*20*	*90*	*110*	*100*	*80*
Price certainty	*90*	*100*	*40*	*40*	*90*
Time certainty	*80*	*110*	*50*	*40*	*100*
Importance of quality level	*100*	*50*	*90*	*100*	*110*
Complexity	*30*	*80*	*90*	*90*	*100*
Project size	*30*	*90*	*80*	*80*	*90*
Safety	*70*	*110*	*90*	*90*	*100*
Price competition	*110*	*50*	*70*	*80*	*80*
Flexibility and variations	*70*	*40*	*100*	*100*	*110*
Risk	*90*	*100*	*70*	*30*	*50*
Buildability	*10*	*90*	*80*	*80*	*90*
Innovation	*20*	*100*	*70*	*80*	*110*
Supply chain	*50*	*90*	*90*	*90*	*100*
Lean construction	*50*	*100*	*90*	*90*	*90*
Sustainability	*30*	*100*	*70*	*70*	*90*
Value engineering	*20*	*90*	*100*	*100*	*110*
Maintenance cost	*30*	*100*	*60*	*70*	*110*
Roles and responsibilities	*90*	*110*	*60*	*60*	*70*
BIM	*20*	*100*	*70*	*70*	*60*
E-procurement	*110*	*40*	*60*	*50*	*30*

Even though the modern criteria mentioned above can reflect the characteristics of offsite construction, especially the buildability and lean construction, a couple of new criteria need to be emphasised for better decision-making (Assaf et al., 2023), as shown in Table 7. The utility value for these new criteria may require further study.

Table 7. *Other criteria in Selecting Procurement Methods in OSC Projects*

New Criteria	**Comments**
Accurate allocation of transportation costs	One major concern of the OSC projects is the rising cost of transferring the components from the manufacturer to the site, including renting trailers and wrapping the prefabricated components (Salama et al., 2020).
Flexibility in the transportation processes	The flexibility of highway agency regulation could impact the OSC project's schedule and hinder its success (Schoenborn, 2012).
On-site contractor/manufacturer's abilities to obtain early funding & client's flexibility in providing advance payments	The cash flow issues for OSC project participants result from the significant upfront needed capital (Wuni & Shen, 2020). Based on three case studies of Australian OSC projects, the on-site contractors of all the cases experienced a remarkably negative cash flow in the early stages of the projects (Sutrisna et al., 2019).
Banks' familiarity with the OSC projects	Financing OSC projects is challenging as the banks (lenders) are not yet familiar with the OSC arrangements. In New Zealand, lenders only offer funding when the prefabricated modules arrive on-site (Mills, 2018), which might risk the manufacturer's financial stability, who will have to pay for materials and labour for around six months before the first module arrives on the site.
Clear ownership of modules in the manufacturing stage	There is unclear ownership of the modules between the manufacturer and the client (Salama et al., 2020), which may complicate the financing structure of modular construction projects, as lenders seek collateral to agree on financing the projects (Cameron & Di Carlo, 2007)

Outcome and Recommendation

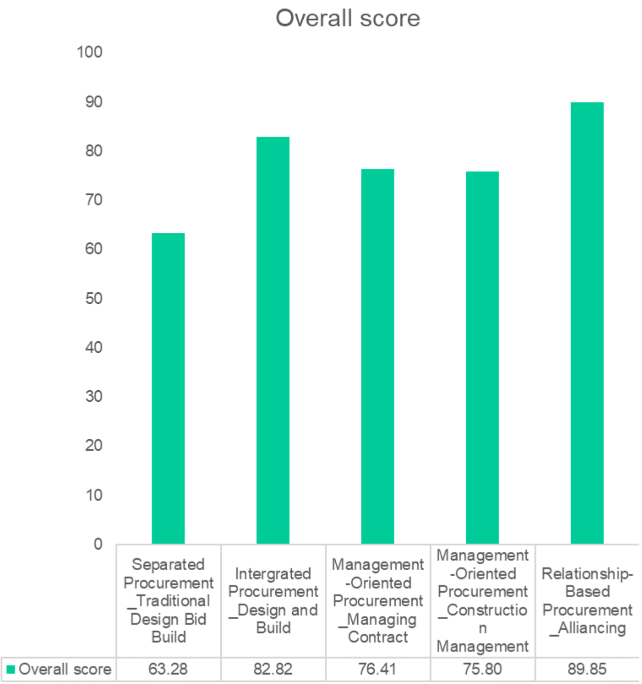


Figure 22. *Alignment of procurement methods based on user evaluation of project value expectations.*

The scoring system developed through an extensive literature review delivers a scoring bar chart shown in Figure 22, showing the relevance of five broad procurement routes for the success of the project based on the user definition of success.

This module outlines an overview of the most widely used procurement methods within the Australian construction industry, followed by decision-making criteria for the selection of the most appropriate procurement method. By providing the relative importance for each criterion based on individual projects, a final score can be used as a guide for the users to select procurement methods. In addition, the new procurement approach, ECI, and additional evaluation criteria are discussed in the context of offsite construction. The following recommendations are given based on an extensive literature review and experts' opinions:

- For the construction industry to meet the managerial, technical, and social challenges, both the industry and its participants must welcome "change" and allow innovative procurement methods to grow, which is a client-driven process supported by the rest of the building team.
- The future adoption of ECI relies heavily on the results and outcomes of more completed projects that have implemented ECI schemes. As more projects utilise ECI, the industry will gain a better understanding of its benefits and effectiveness, leading to increased confidence and potential for wider application in future projects.
- Further efforts are needed to adapt the decision-making process to the Australian context, by including more data sources such as lessons learned from previous case studies, and questionnaire surveys from experts in the industry.

MODULE: SUSTAINABILITY & CIRCULARITY

Sustainability

Introduction

The construction and demolition (C&D) sector is a major contributor to waste generation and resource consumption worldwide. In fact, construction creates an estimated third of the world's overall waste, and at least 40% of the world's carbon dioxide emissions (Bilsen et al., 2018). In addition to waste generation, the construction industry consumes about 50% of global steel production and 3 billion tonnes of raw materials are used each year to manufacture building products worldwide (Rodrigues de Almeida & Zafra Solas, 2016). This high level of resource consumption has far-reaching environmental consequences, making it essential for the industry to adopt more sustainable practices.

In Australia, the C&D sector is a significant contributor to the nation's economy, generating over $360 billion in revenue and sharing 9% of the total gross domestic product (GDP) (Shooshtarian et al., 2022). However, the C&D sector produces 44% of the country's total waste or about 27 million tonnes per year. This represents a significant increase from the 20.4 megatonnes of waste generated in 2016-2017, which accounted for 29.6% of the total waste generated or imported by the Australian economy during that time (ABS, 2019). As Australia's population grows, even more building and construction will be needed, making it essential for the industry to take practical steps towards reducing its environmental footprint. In order to address these challenges, there has been a growing interest in the adoption of sustainability and circular economy strategies in this sector.

In general, sustainability refers to the practice of using natural resources responsibly today, so they are available for future generations tomorrow (Kuhlman & Farrington, 2010). It is the ability to be maintained at a certain rate or level and the avoidance of the depletion of natural resources in order to maintain an ecological balance (Maine). In the context of the C&D sector, the Environmental Protection Agency (EPA) defines sustainable construction as "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's lifecycle from siting to design, construction, operation, maintenance, renovation and deconstruction" (EPA, 2023). Sustainable construction means building with renewable and recyclable resources and materials. During construction projects, care must be taken to reduce waste and energy consumption where possible and protect the natural environment around the site.

A circular economy is an economic system that aims to minimise waste and make the most of resources. It is based on three key principles, driven by design: eliminate waste and pollution, keep products and materials in use, and regenerate natural systems (Ellen MacArthur Foundation, 2013a). These principles provide a framework for transitioning towards a circular economy that is more sustainable, resilient, and equitable.

The first principle, eliminating waste and pollution, involves designing products and processes to minimise the generation of waste and pollution. This can be achieved through strategies such as designing for disassembly, using fewer resources, and implementing waste reduction measures. The second principle, keeping products and materials in use, involves extending the life of products and materials through strategies such as reuse, repair, refurbish, remanufacture, and recycle. This can help to reduce the demand for virgin materials and minimise waste generation. The third principle, regenerating natural systems, involves restoring and regenerating natural systems to improve the environment (Ellen MacArthur Foundation, 2013b). This can be achieved through strategies such as using renewable energy sources, promoting biodiversity, and implementing regenerative agriculture practices.

Sustainability and circular economy are closely related concepts that aim to promote responsible use of resources and minimise negative impacts on the environment. Sustainability focuses on meeting the needs of the present without compromising the ability of future generations to meet their own needs, while circular economy aims to keep resources in use for as long as possible, extract the maximum value from them while in use, then recover and regenerate products and materials at the end of their life. By implementing circular economy practices in a holistic manner, we can promote sustainable development and ensure a better future for ourselves and future generations. Thus, circular economy is considered in this study as a subset of sustainability: Circular economy is considered as a means to achieving sustainable development in the C&D sector (see Figure 23).

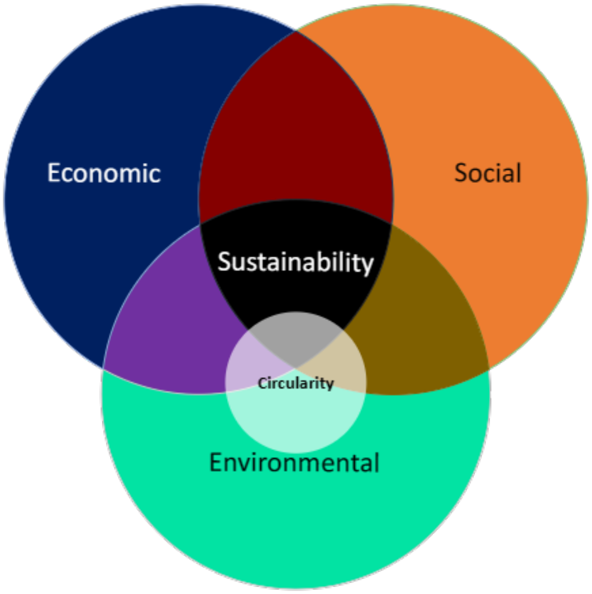


Figure 23. *Relationship between sustainability and circularity – circularity as a subset of sustainability*

Several strategies can be implemented to promote sustainability and circular economy, including refuse, rethink, reduce, repurpose, reuse, recycle, remanufacture, repair, refurbish, and recover (Morseletto, 2020). These strategies involve minimising waste generation and resource consumption through efficient design, production, and consumption practices; finding new uses for existing materials, products, and buildings; reusing and recycling waste materials; remanufacturing existing materials and products; repairing and refurbishing existing buildings; and recovering energy and materials from waste (Ghaffar et al., 2020).

Implementing these strategies requires a holistic approach that involves collaboration between different stakeholders, including governments, businesses, and consumers. Governments can promote sustainability and circular economy by implementing policies and regulations that encourage responsible resource use and waste management. Businesses can adopt sustainable practices by implementing circular economy strategies in their operations and supply chains.

If decision-makers, such as property owners, designers, and project managers, have comprehensive information about the environmental impact and resource requirements of materials, they can make better choices about which materials to use to enhance the environmental sustainability of a project (Rosen & Kishawy, 2012). Although some information is available to help make these important decisions, it is often based on limited sources and can be hard or expensive to obtain. As a result, a more comprehensive decision-making framework is required to provide relevant information for making choices in the Australian C&D industry.

In Australia, there are several initiatives aimed at promoting sustainability and circularity in the C&D sector. For example, the Federal Government has pledged to achieve net zero emissions by 2050 and has recognised the importance of decarbonising Australia's building industry in achieving this goal (DCCEEW, 2021). The Green Building Council Australia (GBCA) has also published a report on embodied carbon and embodied energy in Australia's buildings (GBCA & thinkstep-anz., 2021).

The adoption of sustainable and circular economy strategies in the C&D sector is aligned with the United Nations Sustainable Development Goals (SDGs), which are a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity (UN, 2022). The 17 SDGs are integrated—they recognise that action in one area will affect outcomes in others, and that development must balance social, economic, and environmental sustainability. In particular, SDG 12: Responsible Consumption and Production aims to promote resource and energy efficiency, and sustainable infrastructure, and provide access to basic services, green and decent jobs, and a better quality of life for all (UN).

Evaluation criteria

Sustainability in the C&D sector is measured using a variety of indicators. A study by Danso (Danso, 2018) identified key indicators for measuring sustainable construction materials. These indicators are divided into three dimensions: environmental, social, and economic.

Environmental indicators focus on measuring the environmental impact of the built environment sector, including resource consumption, waste generation, greenhouse gas emissions, and biodiversity. Economic indicators focus on measuring the economic performance of the built environment sector about sustainability and circular economy. Examples of economic indicators include the value-added of the circular economy, public investment in circular economy projects, and the economic benefits of circular economy practices. Social indicators focus on measuring the social impact of sustainability and circular economy practices in the built environment sector. Examples of social indicators include job creation, community engagement, and access to sustainable housing and infrastructure.

The key indicators covered within this study include energy (megajoules), water (litres) and greenhouse gas emissions (kilograms of carbon dioxide equivalent). These indicators can be used to assess progress towards sustainability and circular economy in the built environment sector. By regularly monitoring these indicators, stakeholders can identify areas for improvement and implement strategies to promote sustainable development.

Method

The process analysis approach is commonly used to determine environmental flows. It starts with creating a diagram that shows all the individual processes involved in the project being evaluated, which can range from a simple structure to an entire city. The data collected depends on the focus of the analysis and can vary from a single environmental flow for one life cycle stage, such as energy used during construction, to a full LCA that takes into account a wide range of flows throughout the project's entire life cycle, including raw material extraction and eventual demolition and disposal of materials (Huang et al., 2020).

In our research, we used a hybrid method called Path Exchange hybrid that combines process and environmentally extended input-output approaches. This method integrates available process data into an input-output model of the national economy, ensuring that the entire supply chain of a material is covered across the economy while utilising as much detailed and relevant process data as possible (Albino et al., 2002). Figure 24 outlines the general steps followed to estimate the key indicators for sustainability and circularity in this module.

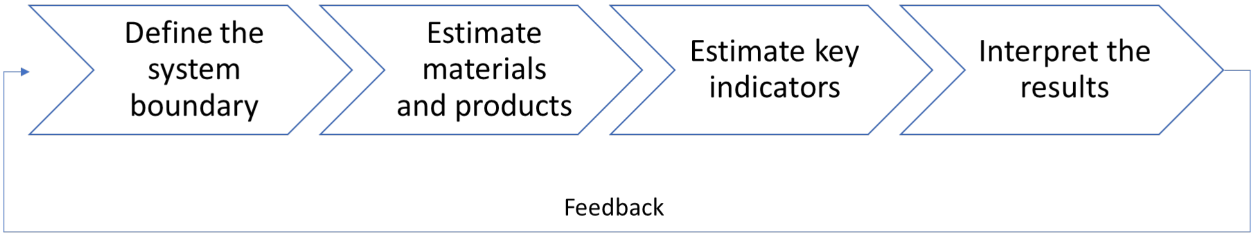


Figure 24. *Method used to estimate sustainability and circularity indicators.*

Define the system boundary

According to the European standards EN 15978 and EN 15804, the building life cycle is divided into several stages (see Figure 25). These stages are used to assess the environmental performance of buildings and building products. The life cycle stages according to the EN standards are as follows:

- Product stage: This stage includes extraction and processing of materials, energy and water consumption used by the factory or in constructing the product or building, and transport of materials and products to the site.
- Construction process stage: This stage includes the transport of materials/products to the site, the energy usage due to activities on-site (machinery use, etc.), and the carbon emissions associated with the production, transportation, and end-of-life processing of materials wasted on-site.
- Use stage: This stage includes the use, maintenance, repair, replacement, and refurbishment of the building and its components. In addition, it includes operational energy and water.
- End-of-life stage: This stage includes the deconstruction or demolition of the building, as well as the transportation, processing, and disposal of its waste materials.
- Benefits and loads beyond the system boundary: This stage includes any potential benefits or loads that occur beyond the system boundary of the building, such as recycling or reuse of its materials, which is relevant for evaluating circular economy practices.

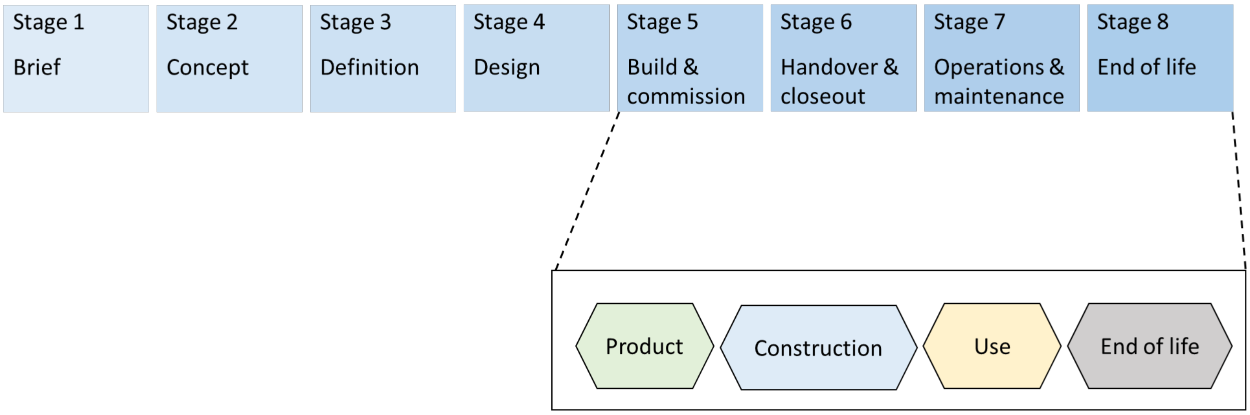


Figure 25. *Building lifecycle stages and their relationship to VDAS lifecycle*

Operational, embodied, and lifecycle analysis are all important tools for assessing the environmental impact of buildings.

Operational analysis is used to evaluate the energy consumption of a building during its use (see Figure 26). This includes heating, cooling, lighting, and other energy-consuming services such as the operation of fridges, washing machines, TVs, computers, lifts, and cooking appliances. This type of analysis is useful for identifying ways to improve the energy efficiency of a building and reduce its operational carbon footprint.

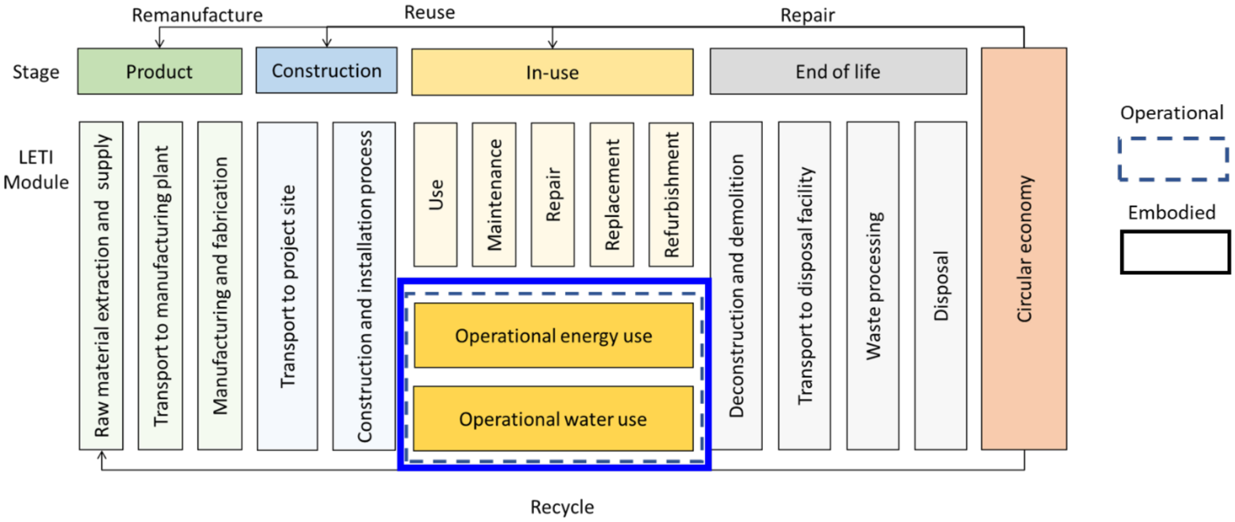


Figure 26. *System boundary within the building lifecycle using the operational approach*

Embodied analysis focuses on the energy and resources used to produce the materials and construct the building itself (see Figure 27). This includes the extraction of raw materials, manufacturing, transportation, and construction processes. Embodied analysis is useful for identifying ways to reduce the environmental impact of a building's construction, such as by using more sustainable materials or construction methods.

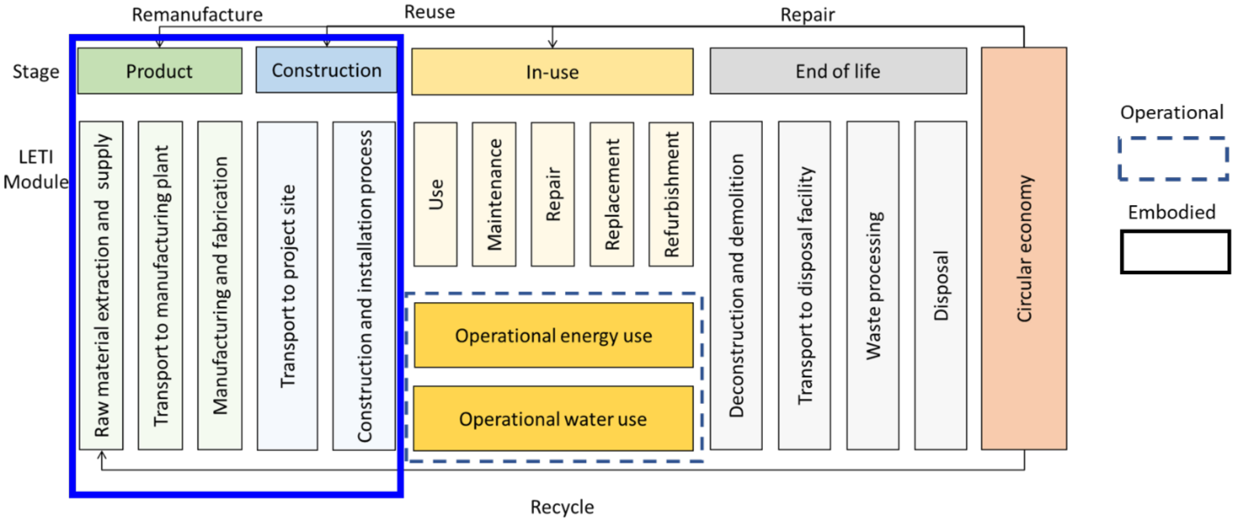


Figure 27. *System boundary within the building lifecycle using the embodied carbon approach.*

Lifecycle analysis takes into account both operational and embodied energy, as well as end-of-life energy, to assess the overall environmental impact of a building throughout its entire life cycle. This type of analysis is useful for evaluating the long-term sustainability of a building and identifying ways to reduce its overall carbon footprint.

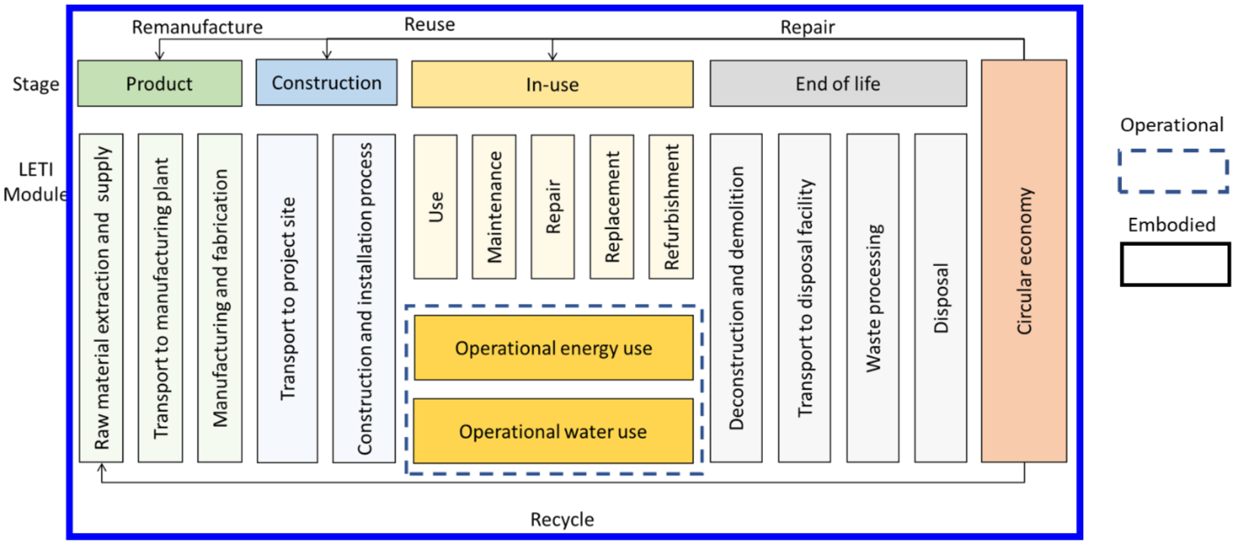


Figure 28. *System boundary within the building lifecycle using the lifecycle assessment approach*

In general, lifecycle analysis provides the most comprehensive view of a building's environmental impact, as it takes into account all stages of its life cycle. However, operational and embodied analysis can also be useful for focusing on specific aspects of a building's environmental impact.

Estimate materials and products

This step provides a systematic approach to estimating the quantities of materials and products used in the construction of a building based on previous information collected from the product typology module.

- Establish the functional unit: For example, the total floor area of the building.
- Develop a list of the main materials contained within the project: This information can usually be extracted from construction documentation, such as drawings, specifications, and schedules (see Figure 29). If a BoQ is available, this can significantly streamline the process.
- Determine the quantity of each material: Based on the previous information provided in other modules, identify the main materials to be used for the structure of the building. For example, if concrete and steel are identified as the main structural materials, determine the quantity of each that will be required for the project.
- Estimate the total quantities of materials and products: Once the quantities of each material have been determined, calculate the total quantities of materials and products that will be required for the construction of the building.

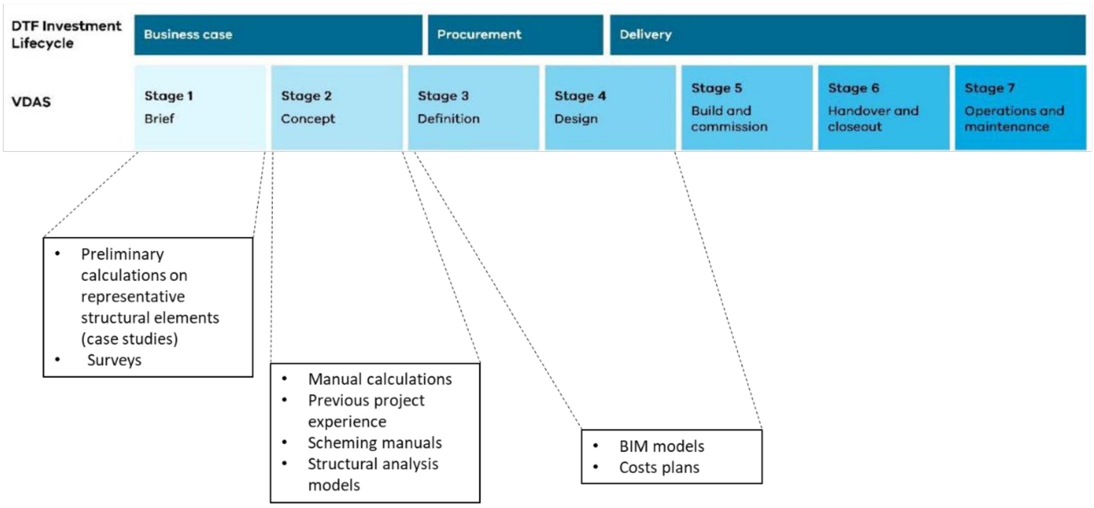


Figure 29. *How to obtain materials data over the project lifecycle*

Estimate key indicators

To estimate the key indicators selected for this study (i.e. water, energy, and emissions) the quantities of materials and products are multiplied by environmental flow coefficients obtained from an LCA of buildings database. There are several tools available today for conducting LCA of buildings. These tools may vary in their user processes or interfaces, as well as in their Life Cycle Impact Assessment (LCIA) methodologies, data sources, standards followed, and certifications with which they comply. Some of the most common LCA databases are presented in Table 8.

Table 8. *LCA material/product carbon factor databases*

Region	Database	Notes	Link
Europe			
UK	Built Environment Carbon Database (product-level database)	Free online database developed by a consortium of built environment institutions to collect UK EPD data. Beta version launching 2022	www.becd.co.uk
UK	ICE database	Wide-ranging material database covering Modules A1–A3	https://carbon.tips/ice3
UK	BRE Verified BS EN 15804 EPD	EPDs for specific products, with a range of modules	https://carbon.tips/breEPD
UK	BRE IMPACT	350 BS EN 15804-compliant datasets modelled in SimaPro	https://carbon.tips/umx
Europe	European Aluminium EPD Program	EPDs for specific aluminium products, with a range of modules	https://carbon.tips/lca8
France	Environmental and health reference data for building construction products	EPDs for a range of building construction products, in French	https://carbon.tips/lca33
Germany	Oekobaudat	EPDs for a range of building products	https://carbon.tips/lca15
Germany	IBU	EPDs for specific products, in German. Requires registration	https://carbon.tips/lca17
Ireland	Irish Green Building Council	Generic data for 15 building materials on the Irish market	https://carbon.tips/igbc
Italy	EPD Italy	EPDs for specific products	https://carbon.tips/lca19
Norway	EPD Norge	EPDs for specific products	https://carbon.tips/lca18
Spain	DAP construcción	EPDs for specific products	https://carbon.tips/lca21
Sweden	International EPD	EPDs for specific products	https://carbon.tips/lca22
Switzerland	Ecoinvent	Paid database	https://carbon.tips/lca23
North America			
Canada	CSA EPD	EPDs for specific products, some not available for immediate download	https://carbon.tips/lca2
Canada	CRMD	Requires registration. Small number of carbon emission data points	https://carbon.tips/lca3
USA	ASTM EPD	EPDs for specific products	https://carbon.tips/lca4
USA	EC3	EPDs for specific products	https://carbon.tips/4hv
Asia			
Turkey	EPD Turkey	EPDs for specific products	https://carbon.tips/lca27
Australia/Oceania			
Australia	EPiC database	Wide-ranging material database	https://carbon.tips/epic
Australia, NZ	Australasian EPD	EPDs for specific products	https://carbon.tips/lca29
New Zealand	Branz CO2NSTRUCT	Calculation sheet, using data from specific EPDs along with general databases	https://carbon.tips/lca34
South America			
Latin America	EPD Latin America	EPDs for specific products	https://carbon.tips/lca31

For this study, we have used the EPiC database developed by The University of Melbourne and commonly used in Australia. The EPiC database is a comprehensive and consistent open-access Life Cycle Inventory of environmental flow coefficients for construction materials. The database contains over 850 coefficients that can be incorporated into existing LCA workflows and processes (Crawford et al., 2019).

Results and interpretations

It is crucial to consider the impact of various structural design solutions on a building's carbon emissions, energy consumption, and water use over its lifetime. Calculations of these key indicators should inform design decisions aimed at reducing these environmental impacts, to achieve net zero emissions, energy efficiency, and water use reduction for all assets. This requires coordination among the design team and an understanding of how different building elements are interdependent. By taking this approach, the entire design team can work together to minimise the building's carbon emissions, energy consumption, and water use over its lifecycle and avoid unintended consequences of reducing structural embodied carbon.

To further enhance the decision-making framework, a rating scheme for key sustainability indicators (i.e. energy use, water consumption, and carbon emissions) is proposed. This rating scheme could be similar to the Structural Carbon Rating Scheme (SCORS) and use visual tools to display the ratings (see Figure 30). The SCORS is a proposed rating system for structures that can be used to compare high-carbon and low-carbon design decisions and options, informed by a review of embodied carbon estimates per gross internal area (GIA) from 326 projects shared by Arup, Price & Myers, and Thornton Tomasetti (Arnold et al., 2020). Within the SCORS scheme, an 'A' rating means that the estimated carbon emissions of the primary super-structure plus sub-structure are in the range of 100 – 150 $kgCO_2e/m^2$ GIA. On the other hand, a 'G' rating means that the estimated carbon emissions are above 400 $kgCO_2e/m^2$ GIA.

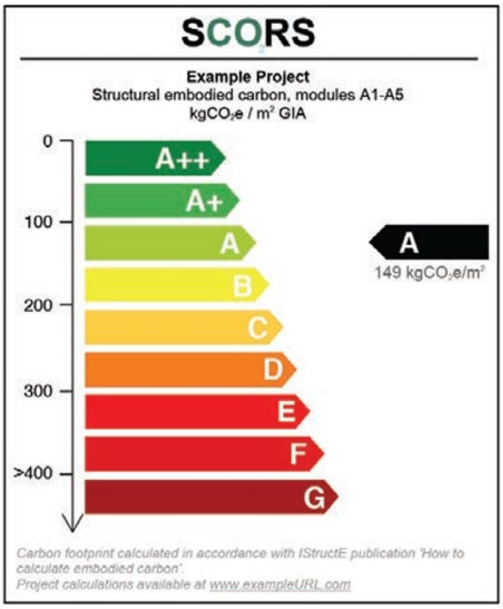


Figure 30. *The SCORS*
Source: Arnold et al., 2020.

To extend its applicability, the ratings could be based on the average energy, water, and emissions from similar building typologies in Australia (e.g. rooted in case studies), allowing for easy comparison and identification of high-performing buildings. In addition, carbon intensity could be presented by building component and material type as proposed in (Drewniok et al., 2023) (see Figure 31). By incorporating this rating scheme into the decision-making process, design teams can make informed choices about the sustainability of their designs and strive to achieve high ratings in these key sustainability indicators. This can help to drive innovation and encourage the adoption of best practices in sustainable design.

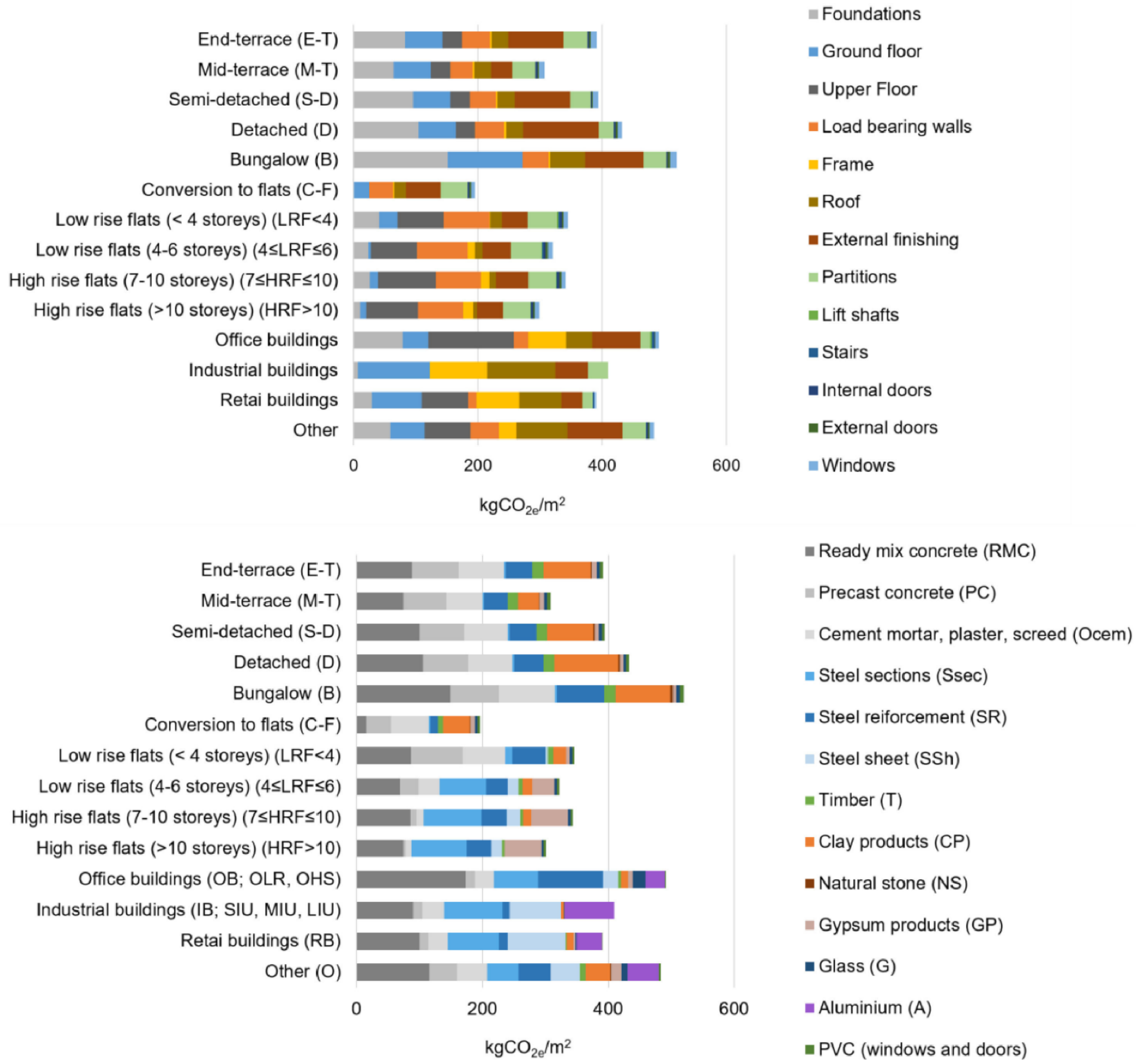


Figure 31. *Upfront embodied carbon intensity: (top) by building component; (bottom) by material type*
Source: Drewniok et al., 2023.

One of the key principles in achieving net zero is a commitment to openly sharing data and best practices that can help us achieve zero carbon emissions. By using the proposed decision-making framework, various scenarios can be explored to identify strategies for reducing resource consumption and carbon emissions. These scenarios can help to establish best practices, refine targets, and identify opportunities for significant reductions in material consumption.

Circularity

To explore in more detail the characteristics of the materials (to be) used throughout the lifecycle of the building, circularity is evaluated at this stage. For this purpose, we adopted the 10R framework inspired by (Potting et al., 2017).

The 10R framework is an approach that focuses on every stage of the product life cycle. It is widely applied to various systems, including the construction sector, to support the transition towards a circular economy. The 10R framework includes the following strategies: Refuse, Rethink, Reduce, Repurpose, Reuse, Recycle, Remanufacture, Repair, Refurbish, and Recover. These strategies aim to minimise waste and maximise resource efficiency by promoting the use of sustainable materials and practices throughout the entire life cycle of a building or construction project.

The circularity framework is designed to provide users with key strategies and best practices for the built environment, taking into account the life cycles of both the project and the building (see Figure 32). This helps ensure sustainable and responsible decision-making throughout the entire process.

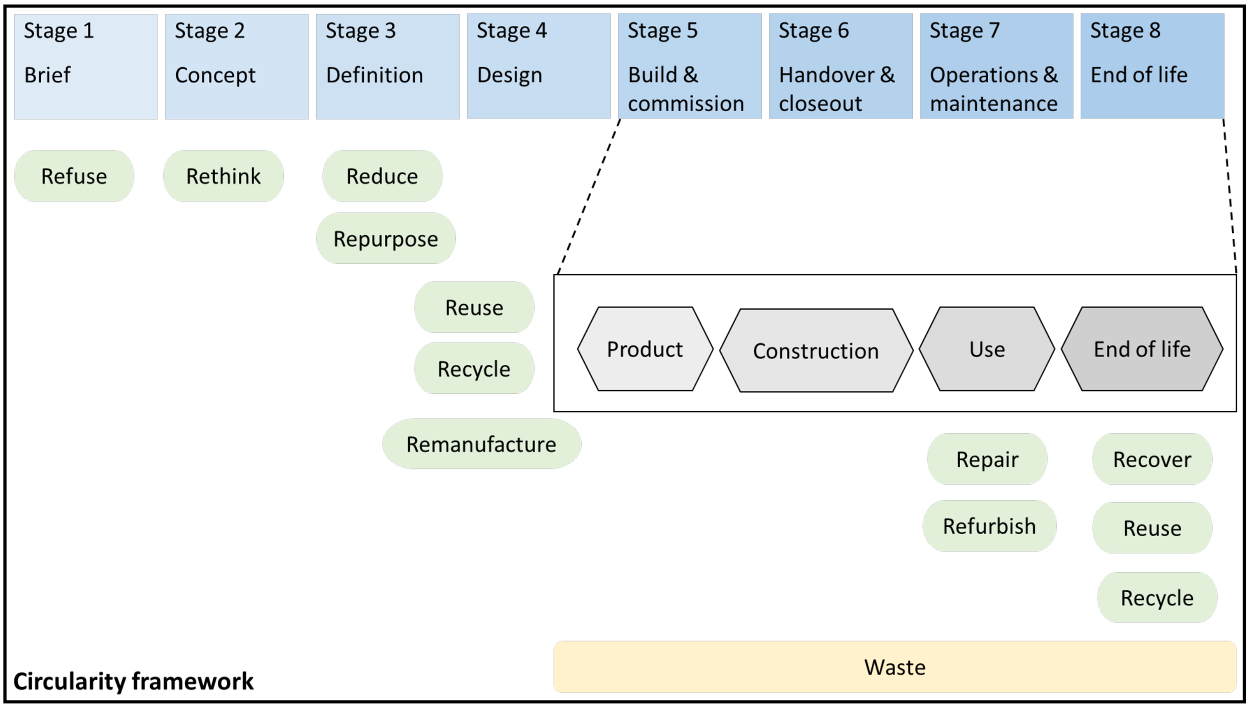


Figure 32. *Circularity framework for decision-making in the C&D sector*

Method

Refuse to use materials or products that are harmful to the environment or cannot be reused or recycled. It involves depreciating materials or products with direct impacts and proposing a different one with identical or better functions and fewer impacts.

Best practices include:

- Investigate low-carbon options such as timber piles (used in maritime applications), rubble trenches or dry-stack masonry (often suitable for smaller-scale projects where materials are available locally).
- Use concrete alternatives such as Limecrete or Hempcrete where performance requirements allow, such as in ground floor slabs.
- Use as high a cement replacement mix as possible below ground (this could be possible if the need for early strength gain is managed).

Rethink the design and construction process to minimise waste and maximise resource efficiency. It involves rethinking the way we design, produce, and consume goods and services to minimise waste and pollution, keep products and materials in use, and regenerate natural systems.

Best practices include:

- Designing for disassembly: Designing buildings and infrastructure in a way that allows for easy disassembly and reuse of materials at the end of their lifecycle.
- Redesigning products and systems: Rethinking the way products and systems are designed to consume fewer raw materials, extend their lifecycle, and generate less waste.
- Designing for efficiency: Designing buildings and infrastructure to be energy-efficient, water-efficient, and resource-efficient to minimise waste generation and resource consumption.
- Reducing reliance on virgin resources: Using fewer raw materials by incorporating recycled or repurposed materials into the design process.
- Innovating business models: Developing new business models that prioritise the circular economy principles of using fewer resources, using resources for longer, recycling resources, and regenerating resources.
- Collaborating across industries: Collaborating with partners across industries to develop circular solutions that minimise waste and pollution while maximising resource efficiency.
- Select low-carbon materials such as concrete, steel, and aluminium.
- Design and construct (or renovate) buildings to handle severe storms, flooding, wildfire, and other impacts that are expected to result from a warming climate.
- Locate critical systems to withstand flooding and extreme weather events.
- Model design solutions based on future climatic conditions as much as possible, rather than relying on past data.

Reduce the amount of resources used in the construction and operation of buildings. It involves reducing the amount of waste generated and resources consumed through efficient design, production, and consumption practices.

Best practices include:

- Implementing measures to reduce waste generation during construction, such as using prefabricated components, minimising packaging waste, and recycling construction waste.
- Reduce the building weight where possible, taking into account the whole-life carbon impacts of any thermal mass benefits (review live-load requirements with the client and seek to optimise these).
- Reduce the amount of retaining required in basement designs by landscaping surrounding ground levels rather than creating retaining structures.
- Encouraging sustainable consumption practices among building occupants, such as reducing energy and water use, minimising waste generation and recycling.
- Using renewable energy sources such as solar or wind power, to reduce reliance on non-renewable energy sources and minimise greenhouse gas emissions.
- Use building lifecycle analysis to reduce embodied carbon in the built environment.
- Implement low-carbon procurement policies to reduce embodied carbon in the built environment.
- Reduce the life cycle of material use, energy use, and waste generation through source reduction.

Repurpose materials and products for new uses, extending their lifespan. It involves finding new uses for existing materials, products, and buildings to extend their lifecycle and minimise waste generation.

Best practices include:

- Transforming existing spaces into multipurpose areas, such as using office canteens as restaurants in the evening, reduces the need for new space in new buildings, avoiding the corresponding resources needed.
- Retrofitting: Adapting the use of a building when demand for a building type decreases.
- Choosing long-lasting building materials and products: Select materials and products that are durable and can be repurposed at the end of their lifecycle.

- Develop an adaptation or disassembly plan with key information (e.g., as-built drawings, materials, key components, structural properties and repair access and contact information).
- Use simple open-span structural systems and standard-size, modular building components and assemblies.
- Modular design: consider separating structural elements from functions that could be changed or moved as part of future adaptation, for example not enclosing lifts, stairs and toilets within shear walls, restricting where these could move in future Fit-outs.
- Redeveloped to accommodate different needs and/or uses (e.g. from industrial use to mixed-use) but exceeding current regulations and standards through significant changes and replacement of shorter-life parts.
- Use durable materials that are worth recovering for reuse and/or recycling.

Reuse materials and products, either in their original form or with minimal alterations. It involves reusing a discarded material, product or building that keeps the same functions by another user.

Best practices include:

- At the beginning of life:
  - Reusing building materials, such as bricks, timber, and steel, in new construction projects to reduce the demand for virgin materials.
  - Promoting the reuse of materials through initiatives such as material exchanges, where surplus materials from one project can be used in another.
  - Divert and reuse raw C&D debris as a resource.
- At the end-of-life:
  - Implementing deconstruction practices, rather than demolition, to carefully dismantle buildings and recover reusable materials.
  - Develop an adaptation or disassembly plan with key information (e.g., as built drawings, materials, key components, structural properties and repair access and contact information).
  - Use simple open-span structural systems and standard-size, modular building components and assemblies.
  - Use durable materials that are worth recovering for reuse and/or recycling.

Recycle materials to create new products, reducing the need for virgin resources. It involves including, in the manufacturing process of a product, materials that reached their end-of-life use to make materials with the same, higher (upcycle), or lower (downcycle) qualities.

Best practices include:

- **Beginning of life:**
  - Using recycled materials such as recycled concrete aggregate or recycled steel, in new construction projects to reduce the demand for virgin materials. Some resources to consider are:
  - Recycling Victoria Datahub: https://www.vic.gov.au/recycling-victoria-data-hub.
  - Buy Recycled Directory: https://directories.sustainability.vic.gov.au/buy-recycled/
  - Use recycled aggregate where possible for groundwork. This may sometimes be available on-site.
  - If using steel, prioritise high recycled content and shorter transport distances to the site.
  - Use 100% recycled reinforcing steel (this should be standard practice).
  - Reducing the amount of resources used in construction by using recycled or repurposed materials, designing for efficiency, and minimising waste during construction.
- **End-of-life:**
- Recycle materials that can be diverted, including concrete, wood, asphalt, gypsum, metals, bricks, glass, plastics, and salvaged building components such as doors, windows, and plumbing fixtures.
- If the building is likely to have a short lifespan, consider screw piles, which can be reused/ recycled at end-of-life.
- Investing in infrastructure to support the recycling of building materials, such as concrete, steel, and wood.
- Implementing recycling programs on construction sites to collect and recycle waste materials, such as concrete, steel, and wood.

- Promoting the recycling of materials through initiatives such as material exchanges, where surplus materials from one project can be recycled and used in another.

Remanufacture products to extend their lifespan and reduce waste. It involves remanufacturing existing materials, products, and buildings to extend their lifecycle and minimise waste generation.

Best practices include:

- Use remanufactured building materials such as steel, glass, and timber, to create new products with a reduced environmental impact.
- Implementing design for remanufacturing practices to facilitate the remanufacturing of building materials and products at the end of their life cycle.
- Promoting the remanufacturing of materials through initiatives such as material exchanges, where surplus materials from one project can be remanufactured and used in another.
- Investing in infrastructure to support the remanufacturing of building materials, such as steel mills or glass recycling plants.

Repair products to extend their lifespan and reduce waste. It involves fixing a damaged product to give back its initial performance.

Best practices include:

- Implementing maintenance programs to regularly inspect and repair building systems, such as HVAC, plumbing, and electrical systems, to extend their lifecycle and reduce the need for replacement.
- Promoting a culture of repair among building occupants, encouraging them to repair rather than replace broken or damaged items.
- Providing repair services, such as handyman or appliance repair services, to facilitate the repair of building materials and products.
- Using durable materials that can be easily repaired, rather than disposable materials that need to be replaced when damaged.
- Green renovation: Upgrading existing buildings to improve their energy efficiency and reduce their environmental impact.

Refurbish buildings and products to extend their lifespan and reduce waste. It involves renovating an outdated product to make it a new one.

Best practices include:

- Redeveloped for similar needs and uses but meeting or exceeding current regulations and standards through restoring, refinishing and future proofing while minimising changes and avoiding replacement of any parts.
- Implementing refurbishment programs to upgrade existing buildings, such as improving energy efficiency, replacing outdated systems, and modernising interiors.
- Promoting a culture of refurbishment among building owners and occupants, encouraging them to refurbish rather than demolish and rebuild.
- Providing refurbishment services, such as interior design or renovation services, to facilitate the refurbishment of existing buildings.
- Using sustainable materials that have a reduced environmental impact during the refurbishment process.

Recover energy from waste materials through processes such as incineration or anaerobic digestion. It involves the process of retrieving heat, electricity, or fuel from non-recyclable materials by incineration.

Best practices include:

- Implementing waste-to-energy programs to recover energy from waste materials, such as incinerating non-recyclable waste to generate electricity.
- Using recovered materials, such as recycled concrete aggregate or recovered metals, in new construction projects to reduce the demand for virgin materials.

- Promoting the recovery of materials through initiatives such as material exchanges, where surplus materials from one project can be recovered and used in another.
- Investing in infrastructure to support the recovery of energy and materials from waste, such as waste-to-energy plants or material recovery facilities.
- Reduce the life cycle of material use, energy use, and waste generation through source reduction.
- Recycle materials that can be diverted, including concrete, wood, asphalt, gypsum, metals, bricks, glass, plastics, and salvaged building components such as doors, windows, and plumbing fixtures.

These strategies can help reduce waste generation and resource consumption in the built environment sector while promoting a circular economy approach. They align with the principles of the circular economy, which include using fewer resources, using resources for longer, recycling resources, and regenerating resources. By implementing these strategies in a holistic manner, the built environment sector can move towards a more sustainable future.

Although some of the previous strategies may be applied, some waste may be generated throughout the different stages of the building lifecycle, including excavated material such as rock and soil, waste asphalt, bricks, concrete, plasterboard, timber and vegetation, and asbestos and contaminated soil. In addition to the circular economy strategies proposed above, some best practices on waste management include:

- Consider how to coordinate design development to avoid over design, especially in structural elements.
- On-site waste can be effectively reduced by moving more of the construction activities offsite, so that on-site work becomes mainly assembling components rather than cutting and shaping materials.
- Provide adequate supervision to ensure waste management plans are implemented and complied with, and regularly audit everyone who manages waste on your behalf.

In order to understand the economic, social, and environmental aspects of waste, the diversion rate per main material is provided to the user. In the context of C&D, the diversion rate refers to the percentage of waste materials that are diverted from the waste stream through recycling, reuse, long-term storage, and energy recovery. The goal is to redirect as much waste as possible away from landfills and into more sustainable disposal methods, such as recycling or reuse. The diversion rate can vary based on material types and across different regions. In this study, the National Waste Database 2022 (DCCEEW, 2022) is used to provide data and information on Australia’s waste generation, recycling, recovery and fate for all waste streams and various material categories (see Figure 33).

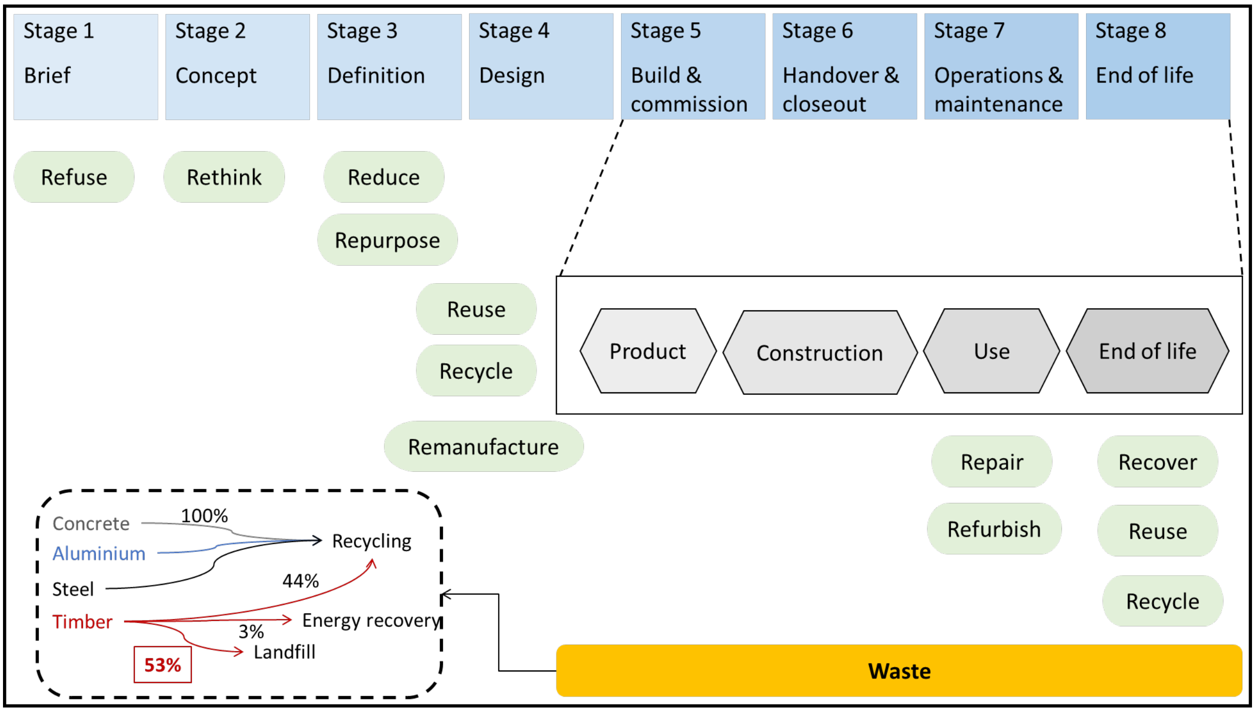


Figure 33. Diversion rate for different materials used in construction

Summary

The environmental sustainability profile of a project can be accurately predicted as more detailed information about the materials and products becomes available. The sustainability framework outlined in this chapter highlights the concepts of sustainability indicators evaluation. The evaluation of sustainability indicators is facilitated by the EPiC database of construction materials. The results of the framework shed light on the following aspects of the project;

1. Sustainability indicator (embodied energy)
2. Sustainability indicator (embodied water)
3. Sustainability indicator (embodied carbon)
4. Sustainability benchmarking using the UK construction database.
5. Percentage of total materials going in the landfill, recycled, or sent for energy recovery as per the Victorian database.

Recommendations

1. The accuracy of the sustainability indicators is underpinned by the accuracy of the emission and embodied energy factors in the relevant databases. As outlined in this module, there are plenty of environmental sustainability databases available in Australia. For a consistent and standardised evaluation across the building sector in Victoria, it is advisable to follow a standardised suite of emission factors approved by the Government.
2. Figure 34, illustrates the positioning of the project at hand with respect to SCORS scale of sustainability footprint post-evaluation. Although sustainability evaluation of projects is a relatively new phenomenon in Australia, there is a scope to track the building footprint of each building asset category as a statistic in the Australian Bureau of Statistics.
   The metric can be leveraged to create a sustainability scale to benchmark projects based on Australian/statewide standards.
3. Circularity is a multi-pronged approach. Industry feedback indicated a strong agreement on the lack of end-of-life supply chain infrastructure in Victoria and Australia. Multiple strategies such as recycling, repurposing, upcycling, downcycling, reusing and remanufacturing require significant capacity building. Government incentivisation for end-of-life logistics, transport, and processing can significantly impact the methods of project evaluation against circular economic values.

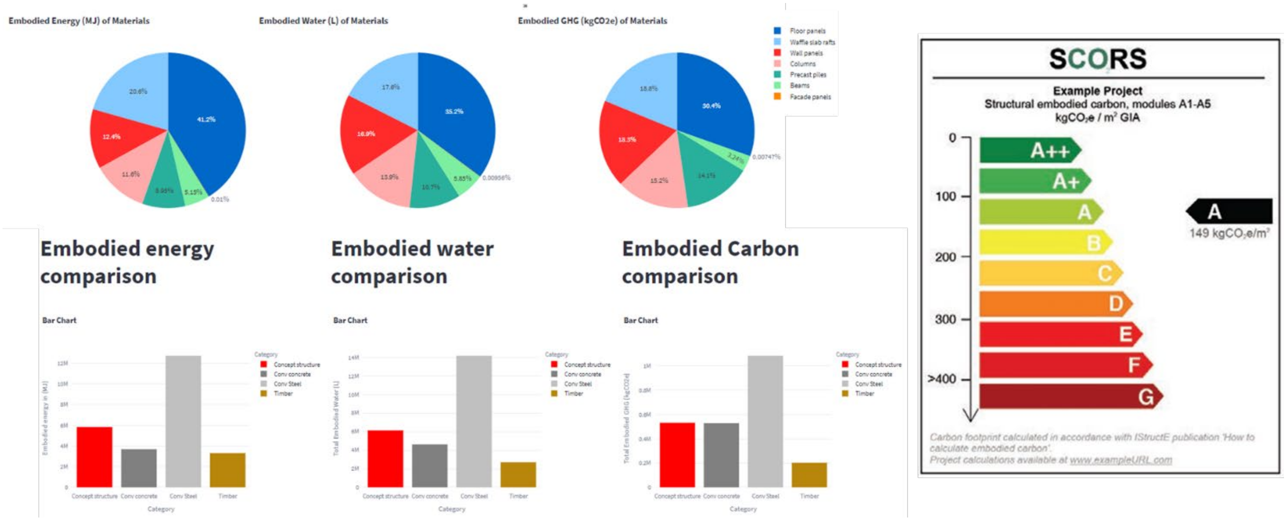
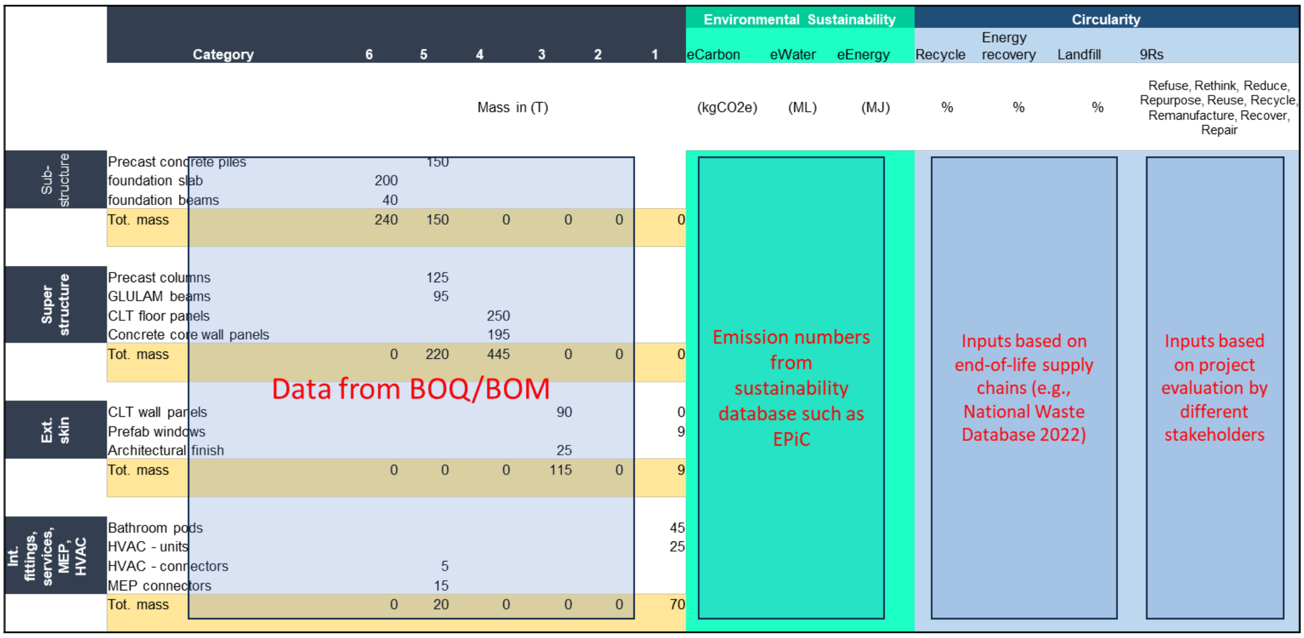


Figure 34. *Sustainability indicators of the project (for illustration purposes only) and benchmarking*



	Category	6	5	4	3	2	1	Environmental Sustainability eCarbon	eWater	eEnergy	Circularity Recycle	Energy recovery	Landfill	9Rs
		Mass in (T)						(kgCO2e)	(ML)	(MJ)	%	%	%	Refuse, Rethink, Reduce, Repurpose, Reuse, Recycle, Remanufacture, Recover, Repair
Sub-structure	Precast concrete piles		150											
	foundation slab	200												
	foundation beams	40												
	Tot. mass	240	150	0	0	0	0							
Super structure	Precast columns		125											
	GLULAM beams		95											
	CLT floor panels			250										
	Concrete core wall panels			195										
	Tot. mass	0	220	445	0	0	0							
Ext. skin	CLT wall panels				90		0							
	Prefab windows						9							
	Architectural finish				25									
	Tot. mass	0	0	0	115	0	9							
Int. fittings, services, MEP, HVAC	Bathroom pods						45							
	HVAC - units						25							
	HVAC - connectors		5											
	MEP connectors		15											
	Tot. mass	0	20	0	0	0	70							

Data from BOQ/BOM

Emission numbers from sustainability database such as EPiC

Inputs based on end-of-life supply chains (e.g., National Waste Database 2022)

Inputs based on project evaluation by different stakeholders

Figure 35. *Analysis of the project from the standpoint of sustainability and circularity principles*

MODULE: SUPPLY CHAIN AND LOGISTICS

Victorian supply chain challenges

In June 2021, the Minister for Regulatory Reform requested that the Commissioner for Better Regulation identify any regulatory barriers in the supply chain for timber as Victorian building and construction businesses continue to experience significant delays. The Government received the Commissioner's final report in October 2021, which made 10 recommendations (Regulation, 2021). The focus of the report was on supply constraints related to steel and timber products, which have been severely affected by increased demand and various external factors such as bushfires and COVID-19. The report suggested that while the current peak of supply chain challenges may be near, prices and disruptions were likely to continue into 2022. In June 2021, its survey showed increases in timber prices of between 10% and 36% over the 12 months to June 2021. MBV's members reported that timber had increased by as much as 50% so far in 2021. The report forecasted a surge in demand for skills, labour and materials due to the rapid increase in public infrastructure investment. It proclaimed that shortfalls in jobs were likely to exceed 105,000 across Australia and that there would be a growth in demand for materials of 120%. In the 10 years to 2018-19, Victoria's softwood plantation area had increased by 2%, and its production of soft sawn wood by 4%. In the same time period, Victoria's estimated population had increased by 22%.

MBV's consultation with its members indicates that 98% of its members have experienced delays in access to timber and over 80% have had delays in access to windows and steel products. Over the 10 years to 2019, Victoria has managed to slightly increase its plantation area by 2%. Increased maritime freight prices have reportedly risen by over 300% in some cases. In the 12 months to August 2021, 69,715 approvals were granted – 12% more than in the year to August 2020 (and 19% more compared to August 2019)

According to data from the Victorian Building Authority (VBA), the population shift away from Melbourne is reflected strongly in the building activity numbers with a 33% increase in permit activity in regional areas and a 44% increase in the value of works for those permits (Authority, 2021). The Gippsland region showed the strongest growth recording an almost 40% increase in permit numbers and an almost 45% increase in the value of works. Rights for consumers to terminate a contract where there are delays of more than 1.5 times the agreed time for completion, or where the overall price has increased by 15% or more.

Offsite Supply chain performance evaluation

Supply chain capacity is critical for OSC project success. Information flow has been cited as one of the most important aspects in managing OSC supply chains (Sutrisna et al., 2019). The authors proposed a framework to analyse supply chain information that compartmentalised information as internal and external. Client requirements and project requirements are classified as internal information and social and regulatory information are classified as external.

Internal		External	
Client requirement	Project requirements	Social	Regulations

Figure 36. *Information categorisation crucial for supply chain capacity*

(Zhang et al., 2021) conducted a systematic literature review of OSC supply chain literature from 2000 to 2021 and collated the top 65 KPIs for analysing OSC supply chain performance. The authors advised the organisations to choose relevant KPIs from a list of 35 economic, 19 social and 11 environmental KPIs as shown in the radial chart below (Figure 37).

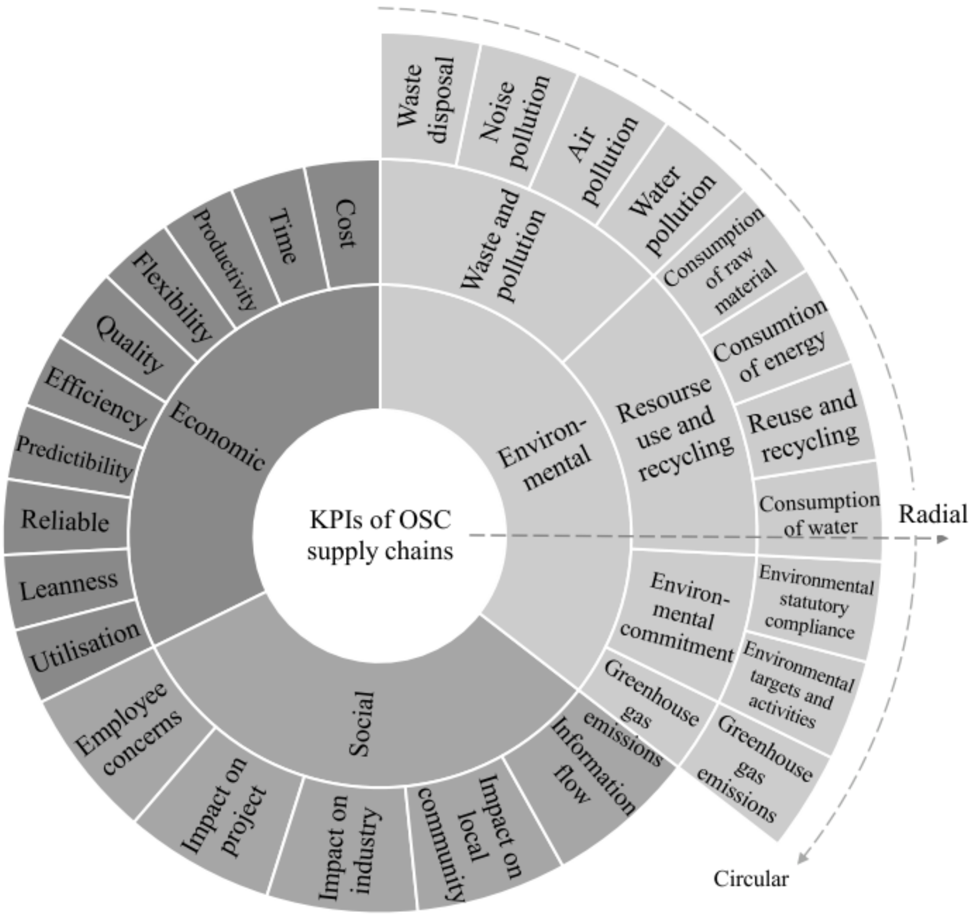


Figure 37. *Supply chain assessment KPIs*

It quickly becomes apparent that to measure the supply chain capacity, appropriate and real-time data must be collected. Supply chain information in the construction sector of Victoria, Australia, can be explored through official Government websites, industry associations like the Master Builders Association (MBA) and the Housing Industry Association (HIA), and trade publications focused on the Australian market. Valuable insights can be gathered from business directories, research reports, and attendance at industry events. Local contractors, builders, and experts in offsite construction can be connected with, and participation in online forums and communities is recommended for networking. Additionally, suppliers and manufacturers can be directly contacted to inquire about their capabilities. The credibility of sources should be verified, and the gathered information should be validated for accuracy and relevance to specific needs.

In Victoria, the Department of Treasury and Finance maintains a construction supplier register that can be found at: https://www.dtf.vic.gov.au/construction-supplier-register/access-construction-supplier-register. A similar platform could be leveraged to collect real-time information on construction supplier data.

Framework for OSC supply chain mapping

It is essential to not only have the appropriate supply chain data but also to analyse it, identifying patterns relevant to the specific construction project in question. The capacity of a region's supply chain is contingent upon the requirements of the project and what the region can provide. In this context, the suggested framework examines the supply chain's capacity by consolidating supplier data along with its various attributes. This process presupposes that current supplier information is accessible either through Government channels or via a third-party survey. The figures presented in the tables are hypothetical and don't correspond to actual data from Victoria. Readers should treat this methodology as a guide only.

Assuming the existence of a supplier's database, the framework correlates the data with the subsequent attributes:

1. Supplier distance by category and selected construction site location
2. Supplier annual volume by product category building material, and services.
3. Number of suppliers by category and Customer Order Decoupling Point (CODP)
4. Number of suppliers by chosen KPIs (economic, social, environmental).

Supplier distance by category of product and selected construction site location

This assessment provides an initial evaluation of the availability of supply chain participants within a specified radius of a construction project site. With the radius as the defining parameter, the supply chain data can be refined based on the intended construction site's location. All further analyses in this chapter will proceed under the assumption that the location filter has been correctly set.

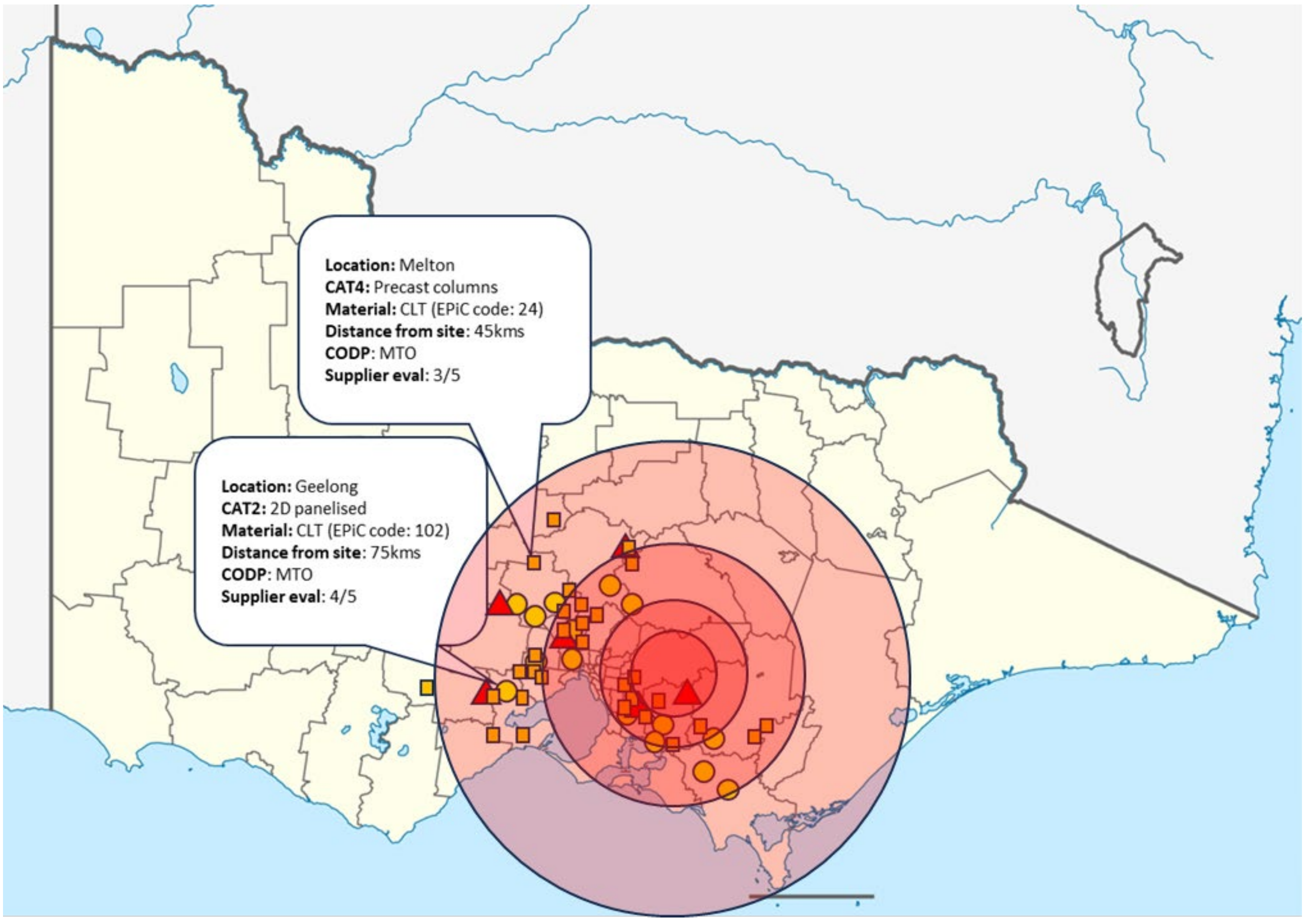


Figure 38. *Illustrated mapping of suppliers based on project location*

Suppliers with product categories and building materials.

Mapping suppliers with construction product categories and types of construction materials are sought for the following reasons:

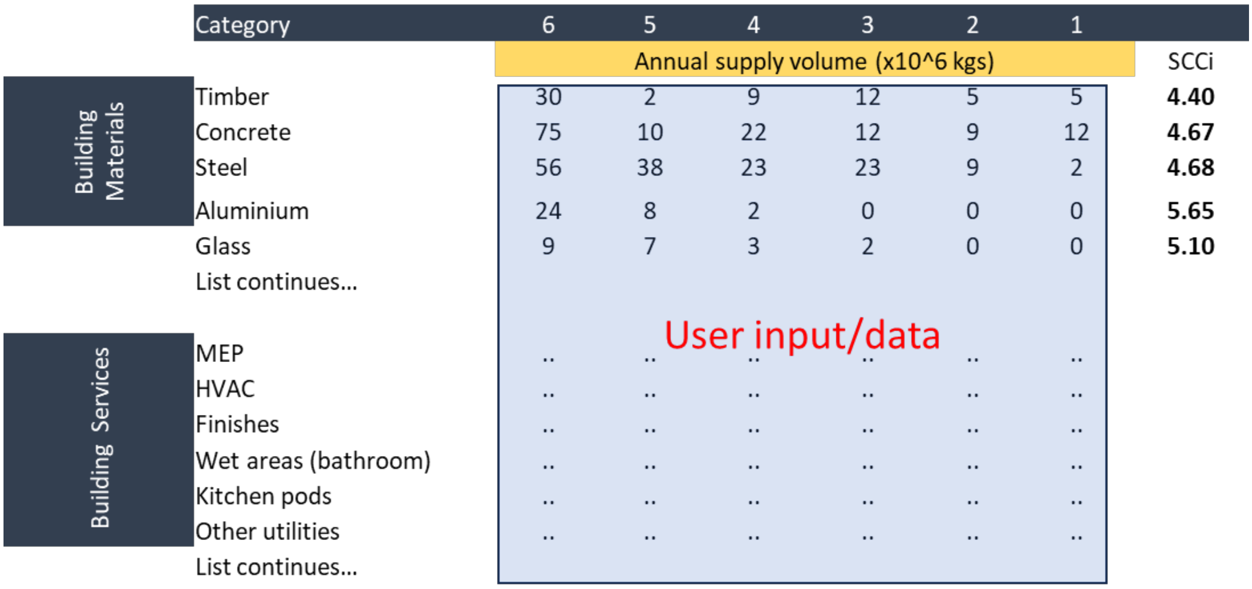
1. **To indicate the “productisation capacity” of the suppliers in the region.**

   The productisation capacity is conceptualised as the ability of the supply chain to manufacture, distribute, and supply pre-assembled building products as indicated in “product categories” in the previous chapter. This is demonstrated by higher supply output in category numbers 4, 3, 2, and 1 that demarcate 2D panelised and 3D volumetric building units.

   The ‘Supply chain category index’ (SCCi) is the weighted average of product category numbers with the volume of material supplied in each category, where category number is used as weights as shown in the following equation:

$$\frac{\sum_1^6 (Cat_i \times N_{supp_i})}{\sum_1^6 N_{supp_i}}$$

Table 9. *Supply chain capacity index (SCCi) evaluation based on suppliers in chosen region*



	Category	6	5	4	3	2	1	
		Annual supply volume (x10^6 kgs)						SCCi
Building Materials	Timber	30	2	9	12	5	5	**4.40**
	Concrete	75	10	22	12	9	12	**4.67**
	Steel	56	38	23	23	9	2	**4.68**
	Aluminium	24	8	2	0	0	0	**5.65**
	Glass	9	7	3	2	0	0	**5.10**
	List continues...							
Building Services	MEP	..	..	..	..	..	..	
	HVAC	..	..	..	..	..	..	
	Finishes	..	..	..	..	..	..	
	Wet areas (bathroom)	..	..	..	..	..	..	
	Kitchen pods	..	..	..	..	..	..	
	Other utilities	..	..	..	..	..	..	
	List continues...							

User input/data

The supply volume is expressed in kgs of product supplied in the market as shown in Table 9. Supplier product volume can be estimated by adding the individual supplier annual throughput in kgs (of a product) for each category of product. It is acknowledged that the mass of the product may not accurately capture the supplier’s throughput as many products may be measured in number of units, length in linear metres, area in square metres etc. However, for the sake of finding a common ground between all the materials and products for comparison, the mass attribute was chosen. The mass may be considered as a proxy to the supplier throughput as production efforts, production and transportation logistics, energy and cost are all positively correlated with the mass of the product.

The SCCi produced thus, would indicate a weighted average supplier capacity in each geographic location to supply/manufacture building products on the product category spectrum (see Figure 39).

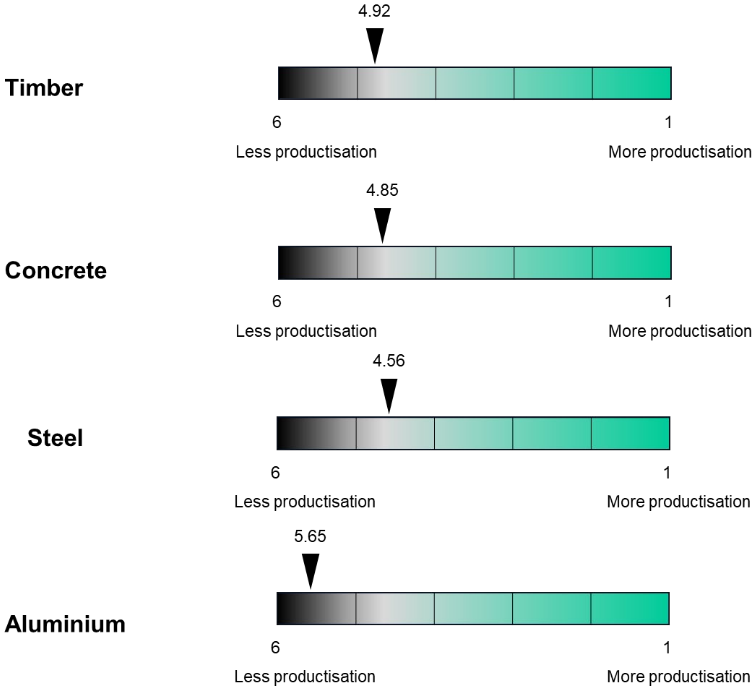


Figure 39. *Supply chain capacity index (SCCi) for basic construction materials*

2. To indicate the supply chain category index (SCCi) for each material in the market

The SCCi can be plotted for different materials and building services to indicate the number of suppliers producing products on the spectrum of categories 1 to 6. A higher SCCi (close to 6) would indicate that the supply chain is predominantly producing/supplying less pre-assembled products. Whereas the lower SCCi (close to 1) would indicate that a particular geographic location has an increasingly higher number of suppliers producing/supplying highly pre-assembled products.

It is expected that as the market penetration of prefabricated buildings increases, the supply chain will start skewing towards producing highly premanufactured products which could be tracked through SCCi for different kinds of materials (see Figure 40).

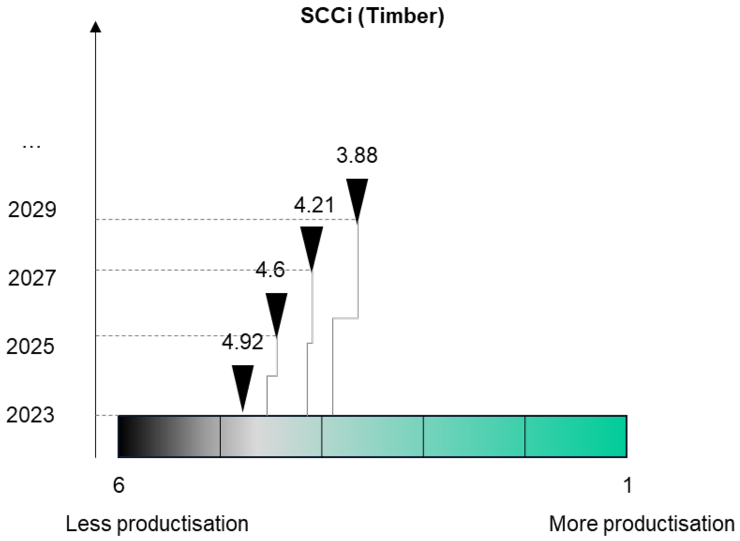


Figure 40. *Tracking SCCi through time for concerned construction materials*

Suppliers with COPD and product categories

From the perspective of the prefabricated construction market, the CODP represents the point in the production process where prefabricated building components transition from being standardised and produced in advance to being customised based on actual customer orders (Mostafa et al., 2014). Up to the CODP, the manufacturer produces prefabricated components based on forecasts and market demand. Beyond the CODP, the production becomes customer-specific, and tailored to individual project requirements. Understanding the CODP helps prefabricated construction companies optimise their production and inventory management, ensuring efficient and timely delivery of customised modules to meet customer demands.

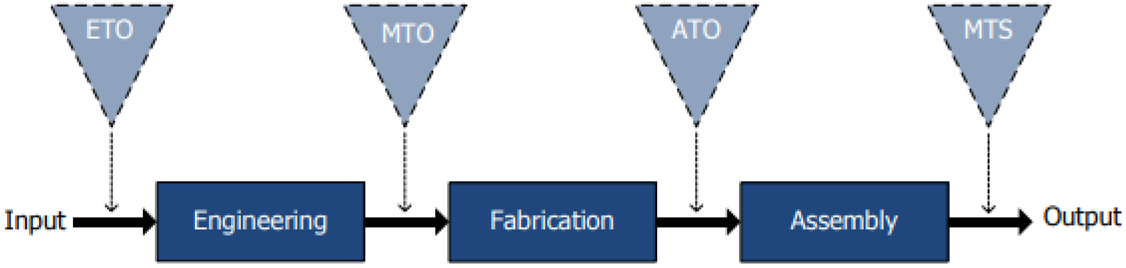
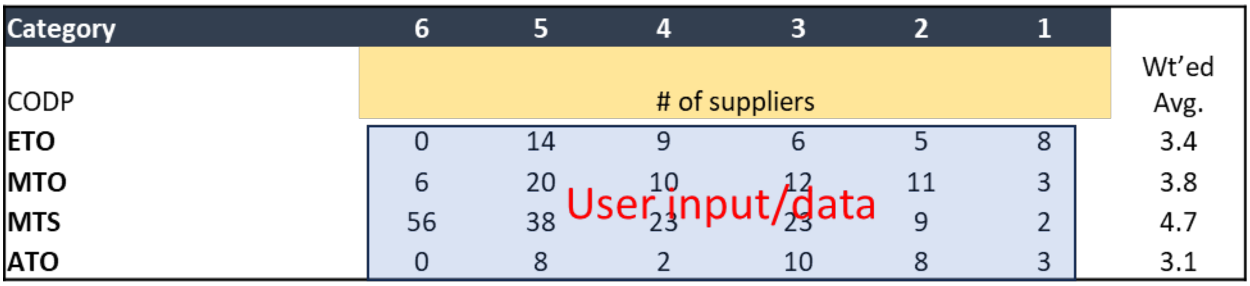


Figure 41. *Positioning of CODP on product value chain*

In the prefabricated construction market, companies adopt different manufacturing strategies: ATO (Assemble to Order), ETO (Engineer to Order), MTO (Make-to-Order), and MTS (Make to Stock). ATO involves customising standardised components during assembly, ETO designs unique products for each customer, MTO manufactures based on specific customer orders, and MTS produces standardised components in advance for quick delivery. The choice depends on customer demands, production complexity, and the balance between standardisation and customisation.

Mapping the number of suppliers with CODP and product category can give useful insights into the readiness of the supply chain in fulfilling the required product order in a building construction.

Table 10. *Analysis of supply chain data based on COPD strategies of participating suppliers*



Category	**6**	**5**	**4**	**3**	**2**	**1**	
CODP	# of suppliers						Wt'ed Avg.
ETO	0	14	9	6	5	8	3.4
MTO	6	20	10	12	11	3	3.8
MTS	56	38	23	23	9	2	4.7
ATO	0	8	2	10	8	3	3.1

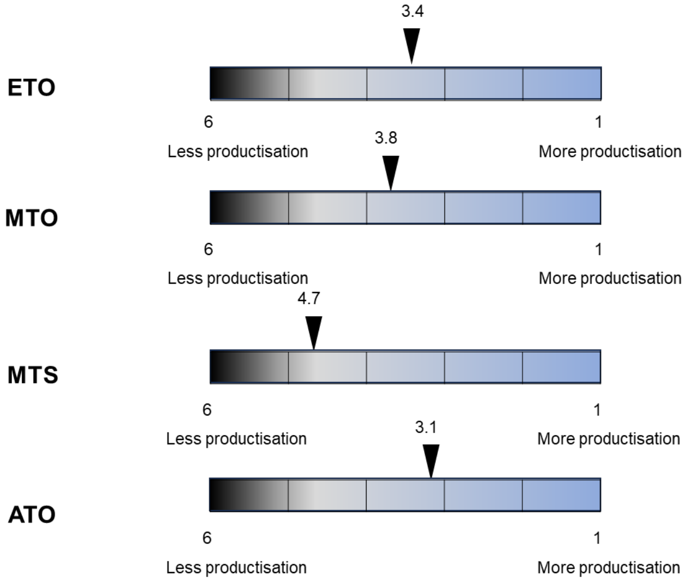


Figure 42. *SCCi based on CODP of suppliers in the given geographic region.*

Inference:

Because of the nature of the production strategies and the positioning of CODP, the lead time for production changes in approximately this order:

ETO>MTO>ATO>MTS (Bortolini et al., 2019)

Building projects that are required to be built quickly may need to assess the supply chain capacity that is able to deliver MTS, and ATO products that closely match with the offsite construction index (OCi) of the project.

Suppliers with user-defined KPIs

Using a similar framework as defined in the previous two examples, the supply chain assessment can be continued for user-defined KPIs listed in Figure 37. The selection of KPIs would depend on the client's value expectations from the project and the availability of data.

Examples of client value expectations influencing the choice of suppliers in the project supply chain could be as follows:

1. Sustainable supply chain: KPIs: waste and pollution, GHG emissions, ESG commitments
2. Social impacts: KPIs: Local community impact, job creation, inclusivity, employee ratings
3. Economic: KPIs: Cost, time, quality, flexibility, leanness, utilisation.

Outcome

For a given distance from the construction site, filtered SCCi and OCi could be compared. For a building project with the OCi = 4.41 (from the previous example) the SCCi for different material categories could be compared as shown in Figure 43.

1. The SCCi (supply chain capacity index) could be used to quantify a region's capacity to cater to similar kinds of projects quantified in terms of OCi (offsite category index).
2. OCi, expresses the project demand and SCCi expresses the supply capacity. OCi, is dynamic and changes with each iteration of the design whereas SCCi, is reasonably static and changes only with the change in suppliers in a region.

3. The decision maker would be required to analyse the SCCi vs. OCi, for different distances from the construction site, and for required KPIs for the suppliers from the data to find the best-suited construction method and the associated materials.
4. The user or the decision maker would have to analyse the trends in SCCi for a given region to assess the regional capacity to fulfil the requirements of a hybrid construction project.
5. It is noted that a large gap between the SCCi and the OCi of a project in a given location would not necessarily mean the unviability of a project in the given region. An individual small-scale offsite building project may require only a few supply chain players in the region that satisfy the building project requirements. However, a higher gap between the SCCi and the OCi would point towards a smaller availability of required supply chain players required by the project which would increase the risk of the project in case the available suppliers default.

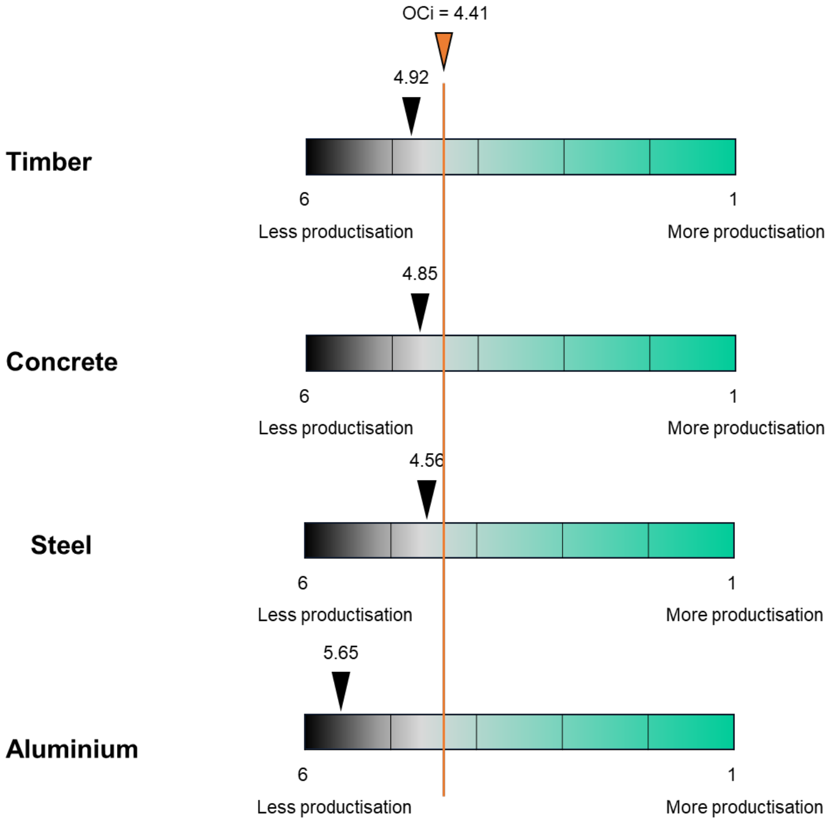


***Figure 43.** Making sense of offsite category index (OCi) and supply chain capacity index (SCCi) for different materials*

Site logistics and transportation

In this section, the focus is directed towards the site logistics, specifically with regard to its efficacy in meeting the requisites of offsite construction projects. This perspective entails a comprehensive evaluation of the construction site's capabilities, akin to a thorough capacity analysis. The analysis of the site's demand aspect encompasses the strategic scheduling of project deliveries, encompassing the timely arrival of materials and products at the site. Subsequently, this involves their temporary storage, adept handling, and proficient erection into designated positions. It is noteworthy that the orchestration of site logistics and transportation is intrinsically intertwined; the available modes of transportation to the designated construction site wield substantial influence over the site selection, transportation choices, and potentially, the structural possibilities.

The assessment of a site's suitability for either prefabricated or conventional construction projects encompasses a multifaceted evaluation. Certain attributes of the site are unaffected by the envisaged building that is intended for that locale. In contrast, other parameters are inherently linked to the specific structural design planned for that particular site. Illustratively, attributes such as the site's geographical location, the navigational challenges posed by the prevailing road network, and the ecological sensitivity of the environs represent characteristics that exist independently of the building's concept. Within Figure 44, a depiction is presented, demarcating the array of predetermined site attributes that necessitate consideration during the design phase of the building. Additionally, a separate group of site attributes emerges, which are contingent upon the intricate design particulars of the project.

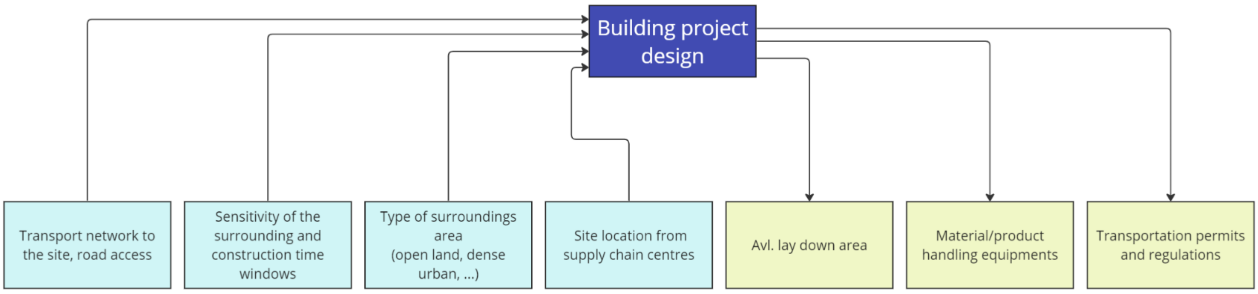


Figure 44. *Site logistics parameters*

Important information pertaining to the site could be grouped into the following sub-points inspired by the research by (Yang et al., 2021) and (Guerlain et al., 2019).

1. **Site location from the major supplier centre**

   It is observed that distant and remote construction sites pose challenges in supplying labour, equipment, materials and other essential site utilities during construction. As the site distance from the supplier locations grows, a prefabricated building solution might emerge as a favourable alternative where most parts of the building can be manufactured in the nearby construction yard and then transported to the site for minimal work on-site. Although this may incur an increased risk of component damage during transportation, increased transport emissions and increased costs.

2. **Type of surrounding area**

   The construction site may be classified into one of the many categories such as; dense urban, urban, suburban, rural, industrial, commercial, and residential. The higher the density of the built-up area around the site, the more are challenges in transporting larger prefabricated chunks of the building. Developed areas may also pose additional challenges in terms of local council regulations for road access and disturbance to the surrounding areas and the time window for construction.

3. **Site connectivity with major roads**

   The flow of materials and products from and to the construction site is heavily affected by the road access to the construction site. Urban and heavily populated areas may have to navigate through the local guidelines for construction time permits for transportation, craning operations, construction noise and other specific requirements. Generally, these requirements are expected to be more stringent as the construction site gets highly dense.

4. **Site laydown area or warehouse proximity**

   As the projects start to include higher category products (towards Cat 1, finished 3D volumetric) the shipment deliveries start to get bigger and specific. That is, the size of each high-category product arriving on-site is typically very large and is non-interchangeable. This puts the sequencing and scheduling under the spotlight where any errors in delivery sequencing of such products can have a detrimental impact on the construction activities on-site. Typically, the contractors may choose to utilise the existing lay-down area if available on-site or hire a storage yard in the vicinity of the construction site to hedge against the risk of improper sequencing and unforeseen scheduling delays.

5. Site handling and erection of product deliveries

Once arrives on-site, the product and deliveries need to be lifted into place. For different types of products, the strategies for handling may be different. The larger building products towards category 1, are lifted off the transport vehicle directly into their intended place in the building using cranes. The smaller products towards category 6, may be offloaded from the truck and transported using forklifts to the material transport lifts on the site or to the laydown area waiting for the availability of a crane to deliver them on the appropriate level.

6. Transportation route assessment for the proposed building project

The maximum size of prefabricated building components and parts is limited by the transportation requirements and the capacity of the road network. The transportation feasibility framework can be described in a series of 8 steps as shown in Figure 45.

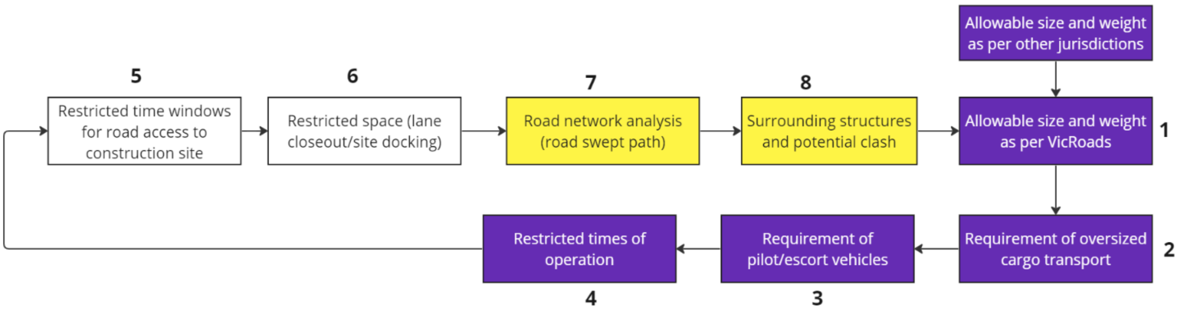


Figure 45. *Transportation capacity checks*

Overall, a structure similar to the one used before (OCi and SCCi) may be invoked in analysing the site logistics and transportation feasibility of a project for a given construction site.

Table 11. *Site logistics and transportation evaluation rubric*

Criteria	Highly suitable (Score 2)	Suitable (Score 1)	Neutral (Score 0)	Challenging (score -1)	Highly challenging (score -2)
Site					
Site Accessibility	Direct access from main roads or highways.	Direct access from main roads or highways.	Moderate access.	Access through narrow routes.	Very tight turns or low bridges.
Site size and layout	Extremely limited space	Some space constraints	Ample space for main operations	-	-
Neighbouring structures	Very dense with risk of disruption.	Moderate neighbouring structures.	Few neighbouring structures.	-	-
Site terrain	Flat and stable.	Mostly flat with minor unevenness.	Moderate unevenness.	Uneven or sloped.	Steep slopes or challenging terrain.
Road infrastructure	Wide, well-maintained roads suitable for heavy loads.	Good roads with minor challenges.	Average road conditions.	Under-developed roads.	Poor roads, unsuitable for transport.
Distance from regional centres/supply chains	> 200 km.	100 – 200 km.	< 100 km.	-	-

Loading and unloading zones	Dedicated, spacious zones with proper infrastructure.	Good zones with minor constraints.	Available, but not ideal.	Undesignated, direct from the street.	Extremely constrained zones.
Transportation					
Distance from the manufacturing facility	Within 20 km.	20-50 km.	50-100 km.	100-200 km.	> 200 km.
Obstacles and restrictions	Clear routes with no obstructions.	Few obstructions, easily manageable.	Some obstacles; are manageable with planning.	Multiple obstacles; require careful planning.	Many challenges; extensive rerouting required.
Traffic patterns	Low traffic, easy transport scheduling.	Moderate traffic, manageable scheduling.	Busy roads; scheduling requires planning.	High traffic; requires off-peak scheduling.	Extremely busy; significant disruptions.
Permit and regulations challenges	Streamlined permits, and highly supportive regulations.	Clear permit paths, minor hurdles.	Moderate regulatory challenges.	Significant permit hurdles.	Heavy restrictions; significant opposition.

Interpretation:

The rubric presented outlines a way to quantify the site and transportation logistics capacity of the building project being considered. The rubric can be used to score site suitability and transport suitability for offsite construction separately. Some parameter values in the rubric are left blank after ‘neutral’ signalling that any more change in such parameters beyond has no bearing of that parameter on the applicability of offsite construction.

Scale:

Site applicability: -6 to 14

-6 to -1	-1 to 4	4 to 9	9 to 14
Highly challenging	Neutral	Moderately applicable	Highly applicable

Transportation applicability: -8 to 8

-8 to -4	-4 to 0	0 to 4	4 to 8
Highly challenging	Neutral	Moderately applicable	Highly applicable

This rubric provides a structured framework to evaluate the suitability of a construction site for offsite construction. It's essential to customise the rubric based on specific project needs, local conditions, and other contextual factors to ensure accurate evaluations.

MODULE: CONSTRUCTION SCHEDULE BENEFITS

The module set out to quantify potential savings in the construction duration of a project on account of different levels of offsite productisation inclusions in the project. The module sets out the quantifiable parameters of a project and proposes a methodology to objectively compare two or more hybrid construction projects for their relative performance on construction schedule savings with each other.

The construction schedule gains notable advantages through the implementation of a heightened level of productisation across various segments of the building process. This is manifested in the diminished intricacy and the progressively enhanced compatibility of prefabricated systems, resulting in an expedited assembly process on-site. The acceleration of on-site assembly, particularly pertaining to extensively pre-assembled components, exhibits a positive correlation with the reduction of the overall construction timeline for a given project (Abdul Nabi & El-adaway, 2021).

However, it is essential to acknowledge that several challenges may impede the alignment of the construction schedule with these efficiencies. Factors such as geometric tolerances, quality assurance, rework, potential damage during transportation, site congestion, crane and rigging limitations, requisites for temporary structures, and the coordination of transport deliveries, could potentially contribute to schedule discrepancies. Nevertheless, a robust risk analysis framework can serve as a means to effectively manage these aspects.

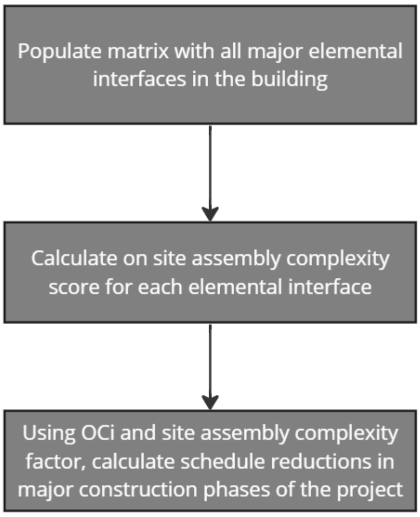
It can be posited that a heightened degree of prefabrication corresponds to an augmented potential for time savings during the construction phase of a project. The gains in time achieved during the construction stage are counterbalanced by an extended duration in the design phase. The integration of extensively prefabricated building elements within a construction project necessitates the early finalisation of intricate construction product designs. As the degree of prefabrication advances, the production strategy is inclined towards ETO or MTO methodologies. Such approaches mandate the timely fixation of designs, accompanied by an adequate lead time for the fabrication of the requisite building components.

Strategically positioned inventory facilities, either situated on-site or in close proximity, can serve as a safeguard by offering a buffer against unforeseen schedule alterations without disrupting the production continuum. The employment of these buffer time hedging strategies has demonstrated their efficacy in mitigating potential schedule delays.

Project information and mapping

There are multiple levels of scheduling of the construction activities starting from master schedule, phase schedule, look ahead planning and weekly planning in broad terms (Mostafa et al., 2014).The hierarchy of these scheduling activities is determined by the time scale at which they operate. The master schedule defines the work to be carried out over the entire duration of a project. It identifies major milestone dates and incorporates critical path method logic to determine the overall project duration. Phase scheduling generates a detailed schedule covering each project phase such as foundations, structural frame, and finishing. The phase employs reverse phase scheduling and identifies handoffs between the different specialty organisations to find the best way to meet milestones stated in the master schedule. LAP indicates the first step of production planning with a time frame ranging from two to six weeks. At this phase, activities are broken down into the level of processes, constraints are identified, responsibilities are assigned, and assignments are made ready (Hamzeh et al., 2012).

The framework presented below builds upon the product typology category spectrum introduced before (Cat 1 – 6). The framework follows the steps outlined below:

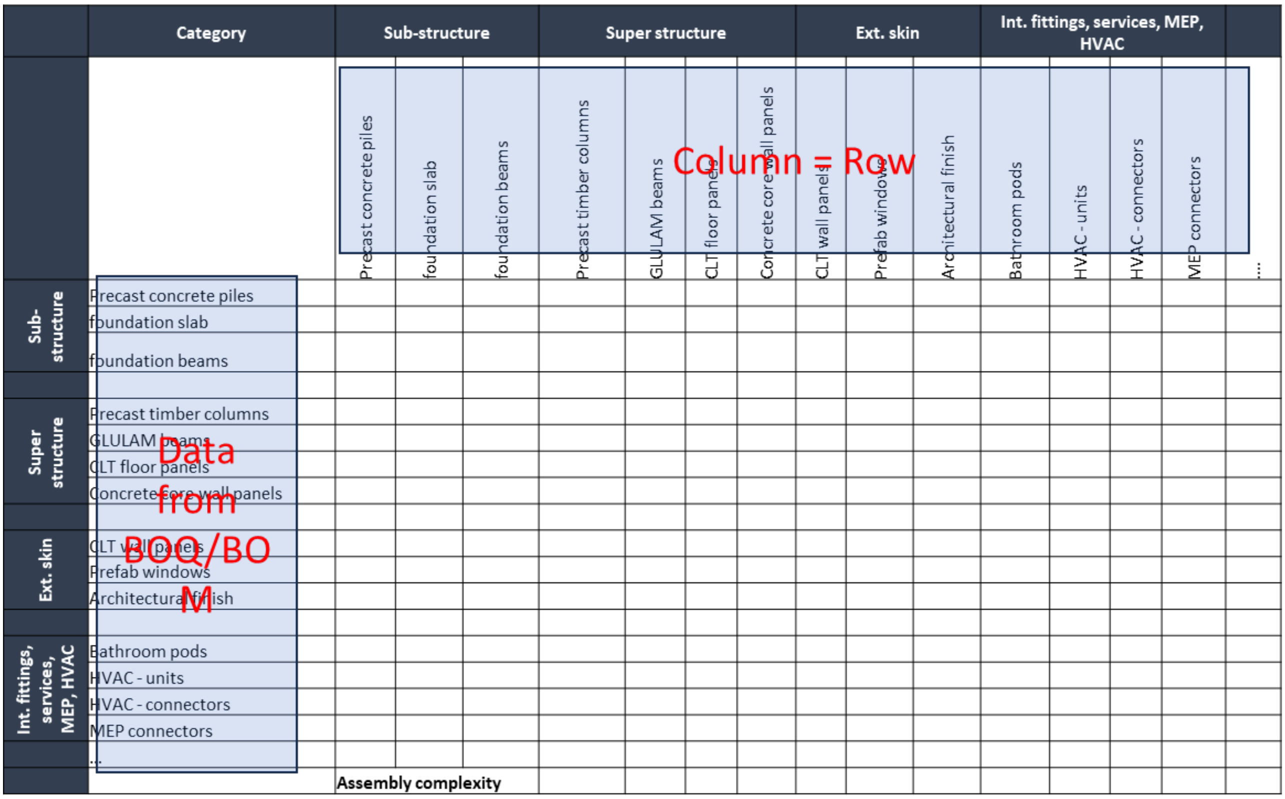


It is important to note that the proposed methodology is useful in comparing two or more hybrid construction projects with each other for their construction savings. Readers are advised that the percentage savings in the construction schedule proposed through the following methodology are susceptible to external factors such as supply chain delays, on-site incidents, design delays, payment delays and so on. Nevertheless, building on the commonalities of different hybrid construction projects, it was possible to construct a framework to estimate the potential to reduce the construction schedule.

Elemental interfaces in the building project

The first step towards analysing the potential savings in the construction phase of the project is to analyse major construction interfaces between two or more elements of the building. Be it a conventional building element or an offsite fabricated building product, the construction phase of the project would involve bringing two or more elements together to create the structure of the building. Towards that, it is of vital importance to understand how two or more systems of elements and products connect with each other on-site. Table 12 shown below is a matrix with rows and columns populated with a list of major building components segregated by four major construction phases viz., sub-structure (foundation), super-structure, external skin (façade), and internal Fit-outs/MEP/HVAC. The following methodology is inspired by the “Product Platform Rulebook” strategic document produced by Construction Innovation Hub, UK in 2023 (Hub, 2023).

Table 12. *Building product matrix*



	Category	Sub-structure			Super structure				Ext. skin			Int. fittings, services, MEP, HVAC				
		Precast concrete piles	foundation slab	foundation beams	Precast timber columns	GLULAM beams	CLT floor panels	Concrete core wall panels	CLT wall panels	Prefab windows	Architectural finish	Bathroom pods	HVAC - units	HVAC - connectors	MEP connectors	...
Sub-structure	Precast concrete piles															
	foundation slab															
	foundation beams															
Super structure	Precast timber columns															
	GLULAM beams															
	CLT floor panels															
	Concrete core wall panels															
Ext. skin	CLT wall panels															
	Prefab windows															
	Architectural finish															
Int. fittings, services, MEP, HVAC	Bathroom pods															
	HVAC - units															
	HVAC - connectors															
	MEP connectors															
	...															
		Assembly complexity														

Site assembly complexity factor

In the next step, each interface between building elements listed in the above matrix is rated against the set criteria for its on-site assembly complexity. On-site assembly complexity accounts for (i) craning requirements, (ii) connection type between two elements, (iii) temporary structures requirement, and (iv) compatibility factor between the two systems. The average on-site assembly score is taken as the weighted average of the first three categories multiplied by the compatibility score, mentioned below. The weights 1, 10 and 10 for crane time, connection type and temporary structures respectively are assigned from the perspective of time delay caused by each activity.

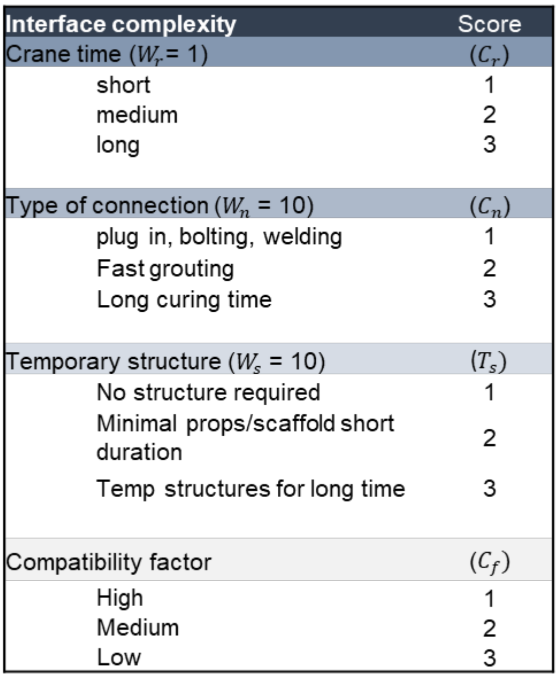
- The time delay of long crane times may be of the order of several hours to a day (Hussein & Zayed, 2021),
- Time delay of long curing time may be of the order of 20-25 days for concrete,
- And time delay for temporary structures may also be of the order of 20-25 days.

This demarcates the relative importance of rigging methodologies, joining methodologies and temporary support methodologies of the structure during the construction time of the assembly under scrutiny. The compatibility factor is introduced to ascertain the way 2 parts of the building would interact with each other during the structural assembly process on-site.

- **High compatibility** would be assumed when the product supplier has nominated proprietary or off-the-shelf connection methodology between two building elements under consideration. The details of the connections are certain, and the parts are readily available in the market. These connections may involve proprietary brackets, anchors, plugs, grouts, bolts etc.
- **Medium compatibility** would be assumed when the elements being connected at the site do not have a fixed method of connection and rely on structural assessment of the site works through temporary works engineers. These connections may involve welding, bolting and grouting on-site post-structural assessment.
- **Low compatibility** would be assumed between the two elements when the offsite products do not have explicit connection methods prescribed by their suppliers for the required

interfaces. These connections would require considerable site work to produce jigs, frames, and brackets upon engineering assessment involving welding, bolting, grouting and so on. All types of wet joining methods would be included in this category requiring formwork, scaffolding and long curing times.

Table 13. *Interface complexity parameter evaluation*



Interface complexity	Score
Crane time (W_r = 1)	(C_r)
short	1
medium	2
long	3
Type of connection (W_n = 10)	(C_n)
plug in, bolting, welding	1
Fast grouting	2
Long curing time	3
Temporary structure (W_s = 10)	(T_s)
No structure required	1
Minimal props/scaffold short duration	2
Temp structures for long time	3
Compatibility factor	(C_f)
High	1
Medium	2
Low	3

Once the on-site assembly factors are determined according to Table 13 for each elemental system interface, the interface complexity (IC) score for that interface is calculated as follows for each pair of row and column intersection as shown in Table 12. Assembly complexity factor takes values between 1 and 9, 1 being highly streamlined and 9 being highly complex on-site procedures.

$$IC = \frac{(W_r . C_r + W_n . C_n + W_s . T_s)}{(W_r + W_n + W_s)} \times C_f$$

This procedure must be repeated for each cell of the matrix in Table 14, where each cell represents the interface complexity (IC) between any two systems/elements of the building.

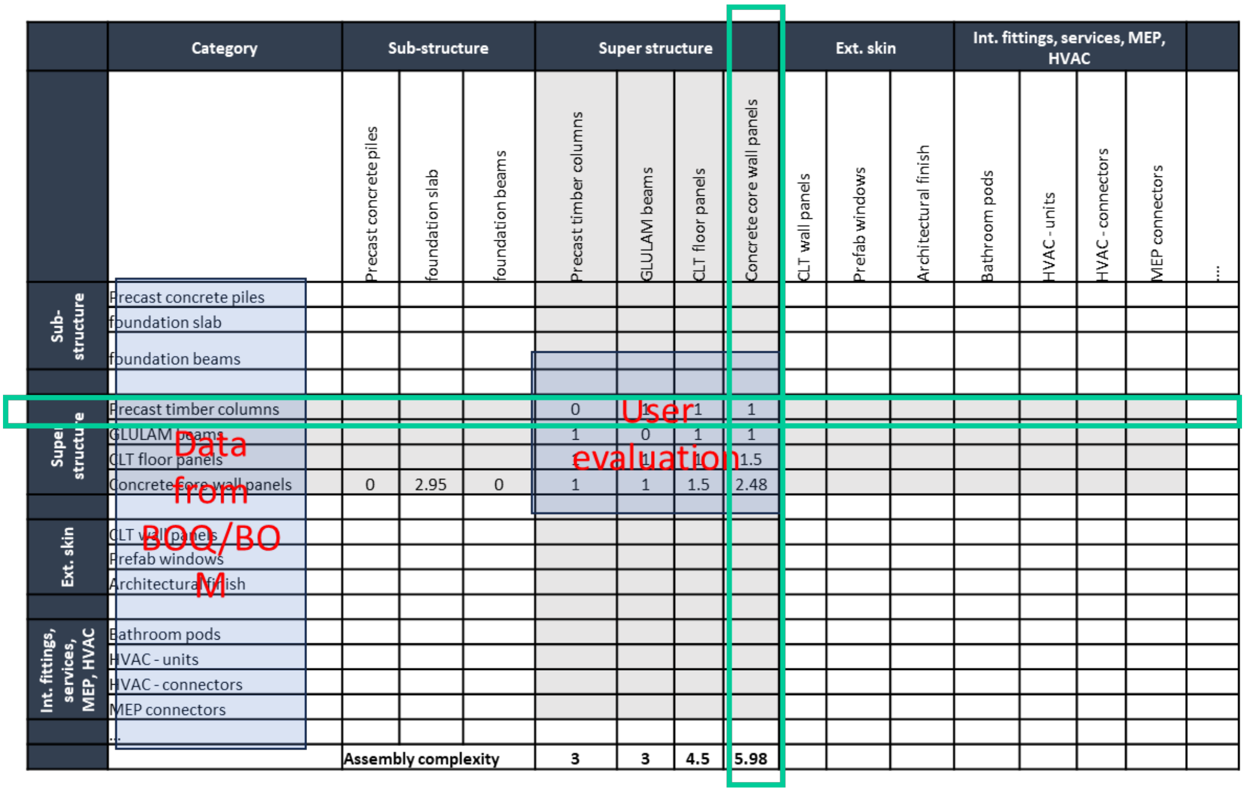
Building product compatibility assessment

Table 14 demonstrates the assembly complexity score calculated for super-structure of the building. Summation of the interface complexity scores (ICs) along the row or column (either is same) would indicate the total complexity score of a particular element/system with all other elemental systems of the building, also termed as assembly complexity score (AC).

$$AC_i = \sum_{j=1}^{n} IC_{ij}$$

The above expression means that the AC of an element/system $'i'$ is the summation of all ICs of that element/systems with every other element/system in the building.

Table 14. Evaluation of assembly complexity based on building product matrix



	Category	Sub-structure			Super structure				Ext. skin			Int. fittings, services, MEP, HVAC				
		Precast concrete piles	foundation slab	foundation beams	Precast timber columns	GLULAM beams	CLT floor panels	Concrete core wall panels	CLT wall panels	Prefab windows	Architectural finish	Bathroom pods	HVAC - units	HVAC - connectors	MEP connectors	...
Sub-structure	Precast concrete piles															
	foundation slab															
	foundation beams															
Super structure	Precast timber columns				0	1	1	1								
	GLULAM beams				1	0	1	1								
	CLT floor panels				1	1	1	1.5								
	Concrete core wall panels	0	2.95	0	1	1	1.5	2.48								
Ext. skin	CLT wall panels															
	Prefab windows															
	Architectural finish															
Int. fittings, services, MEP, HVAC	Bathroom pods															
	HVAC - units															
	HVAC - connectors															
	MEP connectors															
	...															
		Assembly complexity			3	3	4.5	5.98								

Construction schedule reduction

Having determined the AC for all element/systems and building product compatibility, the final step would involve estimating the potential of the chosen construction methodology in saving time during the construction phase of the project. For this, we invoke the offsite category index (OCi) framework from Table 5. As stated before, the construction phase of the building is divided into four major chunks viz., sub-structure (foundation), super-structure, external skin (façade), and internal Fit-outs/MEP/HVAC. The mass of the building elements in each construction phase is tracked. OCi for each construction phase is calculated alongside the average OCi for the entire building.

Mass fraction (M_f) of each element/system is determined by dividing the total mass of a system by the total mass of all systems in a construction phase. Ex., in calculating the mass fraction of precast concrete piles, we divide the total mass of all precast concrete piles with the total mass of all elements that belong to the 'sub-structure' phase of construction.

Assembly complexity$(\boldsymbol{AC})$ for each element/system is the on-site assembly complexity score as determined before.

Average assembly complexity $(av.AC)$ for an element/system, is determined by dividing its assembly complexity score by number of interfaces relevant for that element/system. Ex., in the given example, precast timber columns interface with 3 other structures in the super-structure construction phase viz., Glulam beams, CLT floor panels and concrete core wall panels. Therefore,

$$av.AC = \frac{AC}{3}$$

Assembly schedule saving factor $(\boldsymbol{S_a})$, estimates the potential on-site time savings based on assembly complexity of each element. Figure 46-b describes the assumed scale for potential reduction in time of construction for each element assembly. In this scale, an assembly complexity score (AC) of 1 is assigned a 90% reduction potential and an assembly complexity score of 9 is assigned a 10% reduction potential compared to conventional in-situ monolithic construction. Assembly schedule reduction factor (S_a) also includes the mass fraction of each element. Algebraically, the assembly schedule reduction factor is:

$$S_a = M_f \times \left(0.9 - 0.1(AC - 1)\right)$$

Where, M_f is mass fraction of an element/system, and AC is the assembly complexity factor of that element/system.

Category schedule saving factor ($\boldsymbol{S_c}$), estimates the potential on-site time savings based on the offsite product category of the given element/system being received at the construction site. Figure 46-a adopts a similar scale for estimating the potential reduction in time of construction due to an increased level of pre-assembly in a construction product. The scale assumes that a fully furnished volumetric 3D element of a building (category 1) product would save the associated construction time by 100%, whereas a category 6 product which is classified as “processed material” would reduce the construction time by 0% when compared with in-situ construction. Category 6 products are essentially processed construction materials that are cast and strengthened in-situ thereby describing a conventional type construction.

Algebraically, the category schedule saving factor is:

$$S_c = 1 - 0.2\left(OCi_{phase}\right)$$

Where, OCi_{phase} is the offsite construction index of a given phase of the construction schedule. For all elements belonging to a particular construction phase, the OCi for that phase is used.

Expected schedule reduction ($\boldsymbol{T_i}$), is estimated by multiplying S_a and S_c for each element/system of the construction project phase-by-phase. This schedule reduction is estimated for each of the four construction phases individually. Algebraically, expected schedule reduction per element/system is:

$$T_i = S_{a_i} \times S_{c_i}$$

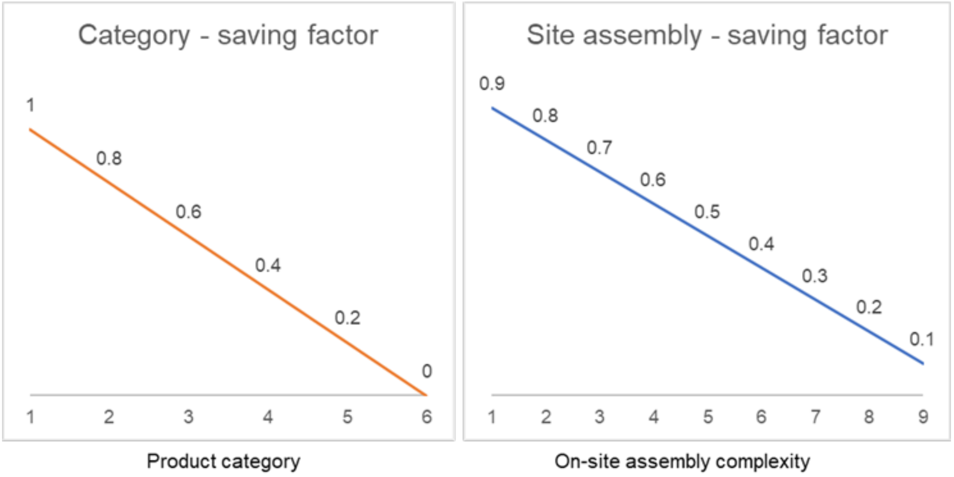
Schedule reduction per construction phase ($\boldsymbol{T_{c_i}}$) is the potential construction schedule reduction per construction phase. This is estimated by adding the individual time saving potentials of elements/systems.

$$T_{c_i} = \sum T_i$$

Total schedule reduction ($\boldsymbol{T_R}$) is the weighted average of individual construction phase savings $\left(T_{c_i}\right)$ with the mass of each construction phase is then used to estimate the total construction schedule savings for a chosen construction methodology;

$$T_R = \sum_{i=1}^{4} M_{f_i} \times T_{c_i}$$

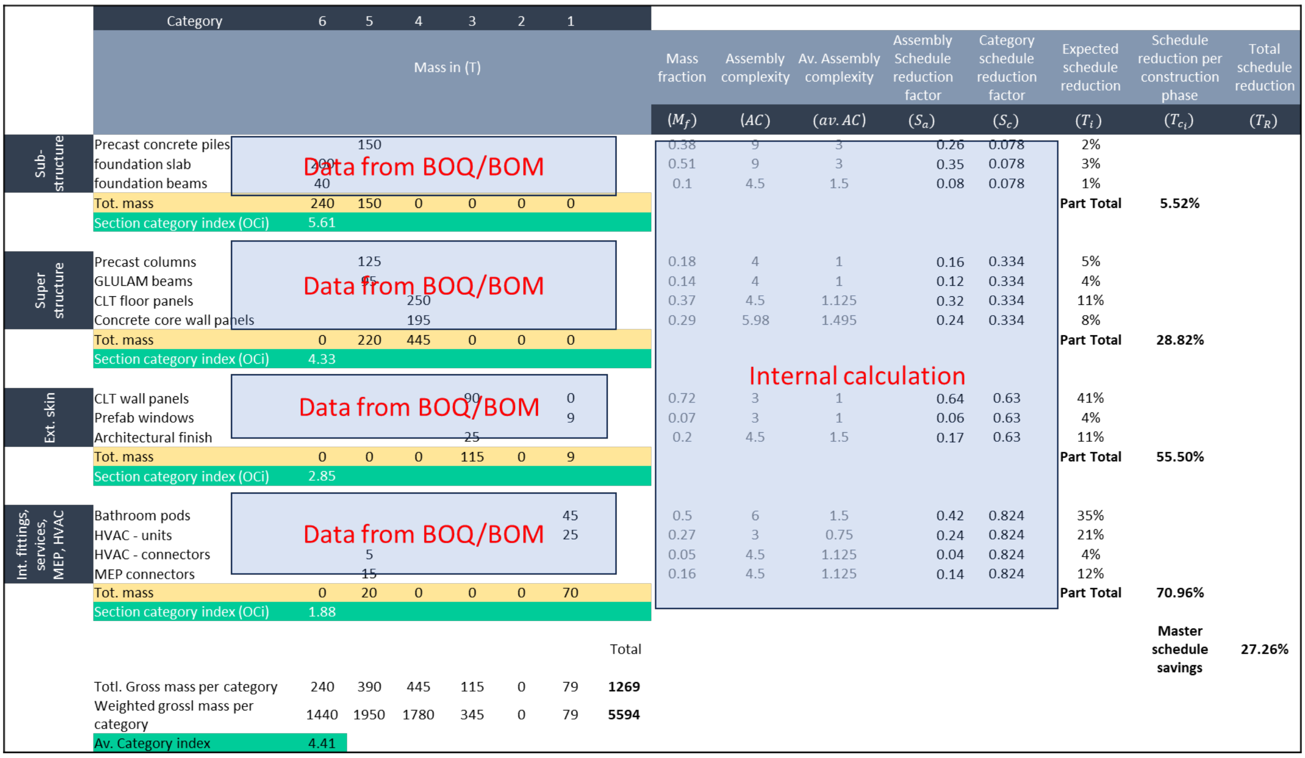
Where, M_{f_i} is the mass fraction for a construction phase $'i'$.



(a) (b)

Figure 46. *Rating scales for % time savings due to product category and assembly complexity*

Table 15. *Combined assessment of construction phase time savings*



	Category	6	5	4	3	2	1		Mass fraction	Assembly complexity	Av. Assembly complexity	Assembly Schedule reduction factor	Category schedule reduction factor	Expected schedule reduction	Schedule reduction per construction phase	Total schedule reduction
	Mass in (T)								(M_f)	(AC)	$(av.AC)$	(S_a)	(S_c)	(T_i)	(T_{c_i})	(T_R)
Sub-structure	Precast concrete piles		150						0.38	9	3	0.26	0.078	2%		
	foundation slab	200							0.51	9	3	0.35	0.078	3%		
	foundation beams	40							0.1	4.5	1.5	0.08	0.078	1%		
	Tot. mass	240	150	0	0	0	0							**Part Total**	**5.52%**	
	Section category index (OCi)	5.61														
Super structure	Precast columns		125						0.18	4	1	0.16	0.334	5%		
	GLULAM beams		95						0.14	4	1	0.12	0.334	4%		
	CLT floor panels			250					0.37	4.5	1.125	0.32	0.334	11%		
	Concrete core wall panels			195					0.29	5.98	1.495	0.24	0.334	8%		
	Tot. mass	0	220	445	0	0	0							**Part Total**	**28.82%**	
	Section category index (OCi)	4.33														
Ext. skin	CLT wall panels				90		0		0.72	3	1	0.64	0.63	41%		
	Prefab windows						9		0.07	3	1	0.06	0.63	4%		
	Architectural finish				25				0.2	4.5	1.5	0.17	0.63	11%		
	Tot. mass	0	0	0	115	0	9							**Part Total**	**55.50%**	
	Section category index (OCi)	2.85														
Int. fittings, services, MEP, HVAC	Bathroom pods						45		0.5	6	1.5	0.42	0.824	35%		
	HVAC - units						25		0.27	3	0.75	0.24	0.824	21%		
	HVAC - connectors		5						0.05	4.5	1.125	0.04	0.824	4%		
	MEP connectors		15						0.16	4.5	1.125	0.14	0.824	12%		
	Tot. mass	0	20	0	0	0	70							**Part Total**	**70.96%**	
	Section category index (OCi)	1.88														
								Total							**Master schedule savings**	**27.26%**
	Totl. Gross mass per category	240	390	445	115	0	79	**1269**								
	Weighted grossl mass per category	1440	1950	1780	345	0	79	**5594**								
	Av. Category index	4.41														

Outcome

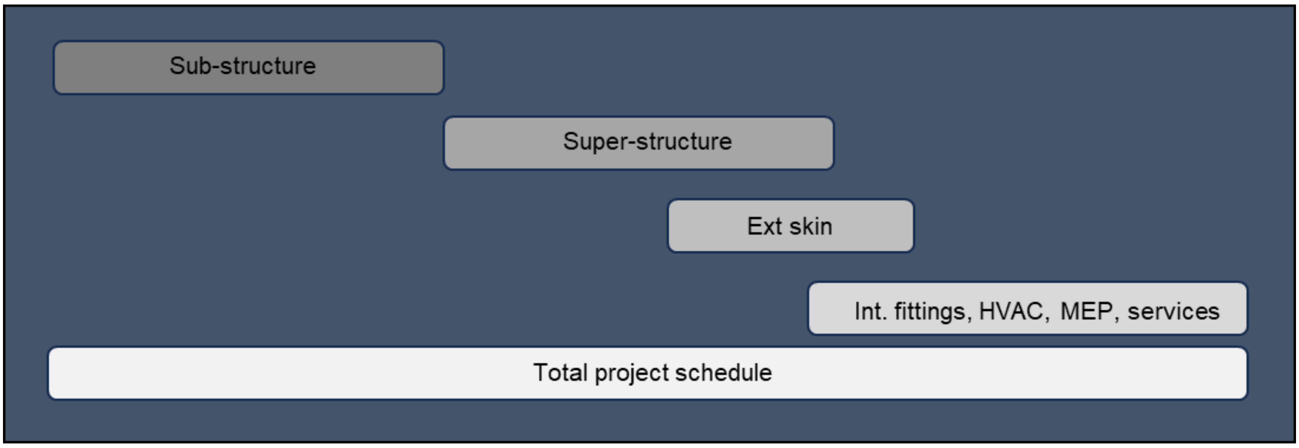
The proposed framework accounts for construction-specific attributes of offsite and on-site product assemblies including:

1. System interfaces identified by the evaluator,
2. compatibility between interfaces evaluated considering on-site assembly works required based on:
    a. Craning efforts
    b. Physical connection characteristics
    c. Requirement of temporary supports

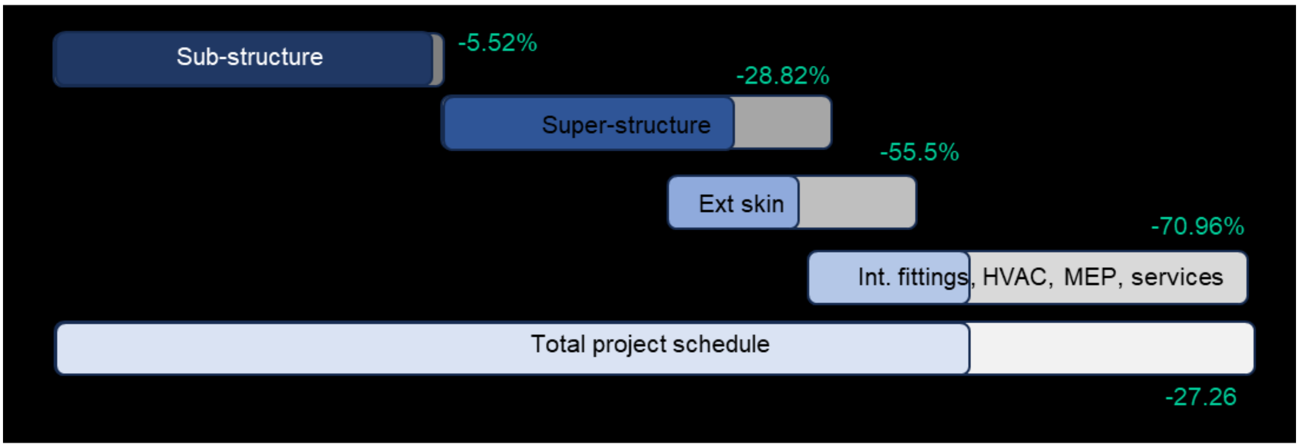
   d. And physical compatibility between different offsite/on-site products

3. Time reduction per interface and construction phase based on parametric estimation.

The outcome of this framework would help estimating the potential for time reduction in the construction phase of the building project involving various mixes of offsite and on-site activities. Once set up, the evaluator should be able to select different construction methodologies to evaluate potential time savings in each case. Figure 47, presents the outcome of the case study structure presented in this report. The potential for time savings could be positively correlated with the OCi for each construction phase. i.e., the higher the OCi (towards 1), the higher the potential for construction time savings. Potential time savings are also directly influenced by interface complexity. Lower construction complexity naturally drives the potential for construction time savings. The percentage savings in the construction schedule are based on the time projections of conventional construction (or category 6) construction of the building under consideration.



Conventional building master schedule



Proposed hybrid construction methodology

Figure 47. *Construction phase time savings due to hybrid construction methods (illustration)*

RECCOMENDATIONS AND FUTURE DIRECTIONS

The selection of construction methodology is driven by certain predetermined value outcomes. Over the centuries, construction materials and construction processes have evolved to deliver more effectively the expected outcomes of the time. The value expectations from the built assets are dynamic. In the first century, we find ourselves grappling with various challenges such as mass urbanisation, rising housing affordability crisis, climate change and increasing carbon emissions to name a few. Apart from these overarching global concerns, each construction project is challenged by low productivity, quality of delivered assets, cost of construction, time for completion, health and safety of workers and occupants, local and global supply chains, transport logistics, energy usage of the asset, sustainability and circularity strategies, effect on surroundings, and so on.

The framework presented in this report is expected to assist the project stakeholders in making informed decisions about construction strategies about productisation. It is aimed at assisting the relevant decision-makers of each module in selecting appropriate strategies available under those modules. For example;

1. The **product typology** would help the user understand the impact of selecting different levels of productisation in a construction project. It is aimed to standardise the use of offsite index for a building project which could effectively capture the level of prefabrication in any construction project.
2. The **procurement module** is aimed at informing the clients of the most aligned pathways of procurement based on specific project value expectations from a list of 18 value attributes.
3. The **sustainability module** established a methodology to evaluate sustainability indicators of a building project based on available material quantity information. The framework highlighted different databases in use across the world and in Australia. Victorian Government sustainability targets are used to create a benchmarking scale that would aid the categorisation of future building projects on their environmental footprint. These metrics are expected to act as control measures for new building developments in steering them towards Australian net zero targets by 2030 and 2050.
4. The **circularity framework** established the 9Rs framework and highlighted available methods to increase the inherent circular economic value of a project. The framework used the National Waste Database, Australia 2022 and provided a quantitative assessment of the building project against the potential end-of-life circular economic value of the project.
5. The **supply chain framework** aimed at quantifying a regional capacity to consistently deliver prefabricated building components of a certain typology. SCCi or supply chain category index was proposed as a metric to quantify a supplier product volume based offsite building category metric. This metric would notionally indicate the spread of suppliers on a product category scale. The importance of SCCi in quantifying the trends of supply chain capacities over the years was established. It was proposed that a project with ‘offsite category index’ or OCi and SCCi resembling closely, would find it increasingly easier to source required materials, have a competitive bidding process, and have larger control over price.
6. The **logistics framework** established a site evaluation approach based on its location, road access network, locality, regulatory permits, site storage, handling and craning friendliness and others. The methodical approach is aimed at creating a logistics profile of the proposed construction project in a holistic manner.
7. The **constructability framework** encapsulates the physical interfacing of two or more building products on-site not limited to offsite building products. The evaluators, most likely those with construction management knowledge would be able to use this framework to analyse all component-level interactions in the construction phase of the project for all components from category 6 to category 1 (i.e., processed materials to fully fitted 3D volumetric building units). The interface being analysed is quantified for its ease (or conversely, complexity) of assembly on-site using a term coined here as ‘assembly score’. This assembly score would be used to estimate the complexity of the overall construction strategy for a given level of productisation and can be leveraged in estimating the potential schedule savings of the project.
8. **Schedule savings** are primarily based on the interface complexity of the construction phase of the project as evaluated before. The interface complexity in each of the four construction phases of the project (viz., sub-

structure, super-structure, exterior façade, interior fittings) is appropriately normalised based on the total amount of work done in each phase of construction. The amount of work done in each phase of construction is underpinned by the mass of materials/elements/components included in each phase of construction.

Recommendations

Product typology mapping

The product OCi is inspired by a comprehensive literature review and stakeholder interactions about offsite product categorisation and its potential use in benchmarking the extent of prefabrication.

- The OCi could help monitor the progress of the construction industry in Australia in a more meaningful way than the current metrics of quantifying the market penetration of prefab construction systems.

Procurement method selection

- For the construction industry to meet the managerial, technical, and social challenges, both the industry and its participants must welcome “change” and allow innovative procurement methods to grow, which is a client-driven process supported by the rest of the building team.
- The future adoption of ECI relies heavily on the results and outcomes of more completed projects that have implemented ECI schemes. As more projects utilise ECI, the industry will gain a better understanding of its benefits and effectiveness, leading to increased confidence and potential for wider application in future projects.
- Further efforts are needed to adapt the decision-making process to the Australian context, by including more data sources such as lessons learned from previous case studies, and questionnaire survey from experts in the industry.

Sustainability and circularity

- The accuracy of the sustainability indicators is underpinned by the accuracy of the emission and embodied energy factors in the relevant databases. As outlined in this module, there are plenty of environmental sustainability databases available in Australia. For a consistent and standardised evaluation across the building sector in Victoria, it is advisable to follow a standardised suite of emission factors approved by the Government.
- Figure 34, illustrates the positioning of the project at hand with respect to SCORS scale of sustainability footprint post-evaluation. Although sustainability evaluation of the projects is a relatively new phenomenon in Australia, there is a scope to track the building footprint of each building asset category as a statistic in the Australian Bureau of Statistics.

  The metric can be leveraged to create a sustainability scale to benchmark projects based on Australian/statewide standards.
- Circularity is a multi-pronged approach. Industry feedback indicated a strong agreement on the lack of end-of-life supply chain infrastructure in Victoria and Australia. Multiple strategies such as recycling, repurposing, upcycling, downcycling, reusing and remanufacturing require significant capacity building. Government incentivisation for end-of-life logistics, transport, and processing can significantly impact the methods of project evaluation against circular economic values.

Supply chains

- The SCCi (supply chain capacity index) could be used to quantify a region's capacity to cater to similar kinds of projects quantified in terms of OCi (offsite category index).
- OCi, expresses the project demand and SCCi expresses the supply capacity. OCi, is dynamic and changes with each iteration of the design whereas SCCi, is reasonably static and changes only with the change in suppliers in a region.
- The decision maker would be required to analyse the SCCi vs OCi, for different distances from the construction site, and for required KPIs for the suppliers from the data to find the best suited construction method and the associated materials.
- The user or the decision maker would have to analyse the trends in SCCi for a given region to assess the regional capacity to fulfil the requirements of a hybrid construction project.
- It is noted that a large gap between the SCCi and the OCi of a project in a given location would not necessarily mean the unviability of a project in the given region. An individual small-scale offsite building project may require only a few supply chain players in the region that satisfy the building project requirements. However, a higher gap between the SCCi and the OCi would point towards a smaller availability of required supply chain players required by the project which would increase the risk of the project in case the available supplier defaults.

The decision-making process

The project brought to light the limitations of existing generic frameworks and tools that have been published thus far in terms of delivering the promised advantages of productisation. This deficiency primarily arises due to the general nature of these tools and frameworks, which fail to adequately capture project-specific information and data. When a framework lacks reliance on project-specific information, it tends to be too broad in scope and incapable of meeting the precise expectations set by the client. Consequently, a framework's effectiveness greatly relies on its connection to project information collected during the phases spanning from the initial brief to the concept and detailed design stages. This connection ensures that the framework possesses the requisite specificity to yield pertinent decision-making outcomes.

Nevertheless, the most significant opportunity to influence the project's outcome lies at the earlier stages of its life cycle. Unfortunately, acquiring project-specific information at this early stage is often a rarity. This situation leads to a scenario in which the effectiveness of the decision-making process gradually diminishes as the project advances through its life cycle. However, there is a silver lining in that the availability of information to input into a comprehensive decision-making framework increases as the project progresses.

The framework introduced in this project attempts to strike a balance, avoiding excessive focus on a single objective like cost, time, or sustainability, while also steering clear of being overly generic. It positions itself at the intersection of two critical phases: the increasing availability of project-specific information and the declining effectiveness of the decision-making process.

Unlike seeking binary outcomes such as whether to use prefabrication or on-site construction, the framework doesn't simplify the decision-making process in such a manner. Instead, it guides users in identifying which aspects of the building could be optimally prefabricated to attain the established objectives and expectations. The argument put forth is that concluding with outcomes like "full volumetric prefabrication," "partial non-volumetric prefabrication," or "complete conventional construction" might not yield favourable results since these determinations could be overly broad and therefore less precise.

In contrast, the proposed framework is designed to empower users by highlighting specific project performance indicators and how they are influenced by different combinations of productisation techniques within a project context.

Issues of data unavailability for decision-making

In this section, we address the issue about the unavailability of required data by the Government clients and other decision-makers at the upstream of the project life cycle. As addressed before, the best way to ensure the project delivers on the said objectives is to analyse the project with as much detail as possible. The level of detail is obviously restricted at the upstream of the project when very little about the final structure is known. It is proposed that the clients (be Government or private) should emphasise setting the decision-making criteria evaluated through the DMSF presented in this report rather than push for a design or construction methodology for the project. This is motivated by the understanding that there could not be a single cookie-cut approach to all types of construction and the ground reality of each project is most likely to dictate the best possible solution. There could be many possible ways of building a structure that can satisfy one or more objectives set out by the clients. As an example, a precast concrete structure where precast elements are available from a manufacturer situated very close to the site may be a better alternative to an imported CLT structure from a cost, time, and risk of uncertainties standpoint. In another example, precast concrete columns supporting CLT floor slabs may give better outcomes from design, constructability and sustainability perspectives than complete timber construction for certain types of sites.

The clients should ideally put forth the assessment criteria for the designs created for a building through the process of ECI by the architects, engineers and a head contractor. A forward-looking view of the construction project life cycle hints at an eventual state of an ecosystem whereby the supplier information of all the different parts of the buildings would be digitally available through digital product platforms. The supply chain data collection suggested in this report helps the Government to play a key role in supply chain digitisation to facilitate a faster transition to digital product platforms.

A future role of a ‘Productised building design evaluator’ could be foreseen in this project value chain or an ecosystem. Such ‘evaluation consultants’ would be equipped with the knowledge of the status of the supply chain in the region, different configurations and compatibility of offsite solutions available in the market and the power of digital design automation through the rise of AI and generative design.

In the proposed DMSF there are several requirements for data collection suggested in various modules of the report. Some of them would require re-arranging already available data, and some may warrant a collection of new data or both.

Evaluation	Level of New data required	Action required
Product typology	LOW	1. Categorise building products on the scale of Cat-6 to Cat-1 (from processed materials to finished volumetric building units). 2. Such a data table could be hosted on official Government web channels.
Procurement & contracts	MED	3. Lessons learned from Australian projects need to be collected to check the efficacy of procurement routes in delivering the said project objectives in Victoria.
Sustainability	HIGH	4. Sustainability indicators for Australian projects (recently built) should be tracked and included as a construction sector statistic on Australian Bureau of Statistics database. 5. This database can be leveraged to guide future developments based on per square metre footprint of sustainability indicators.
Circularity	MED	6. Codify 9R strategies for Victoria based on the project report to include expected steps required under each R strategy towards circularity. 7. Update construction waste recycle database to inform current and future developments for the avenues of the end-of-life stage of the materials.
Supply chain	HIGH	8. Initiate online survey to collect supplier information regarding supply capacity, type of material and product fabricated/supplier, location and other associated KPIs. 9. Put in place a mechanism to update this information every year or as required through a similar exercise.
Logistics	LOW	-
Constructability and schedule savings	MED	10. Forward-looking exercise to involve a platform creation that would include supply chain products and their cross compatibilities. 11. Until such platforms are created, this exercise should be carried out by construction managers and 'offsite project integration' consultants who have domain knowledge of different construction systems and can assess their inter-compatibilities.

Logic behind the creation of decision-making process

The decision-making framework so far has resulted in an evaluation schema for 7 co-dependent sets of objectives as shown in Figure 48. The iterative process is aimed at achieving the required project performance objectives set out in the decision-making criteria. The iterative nature of the project evaluation calls for a departure from the conventional linear project value chain type processes and invites more inclusive and collaborative designing paradigms into the project value chain.

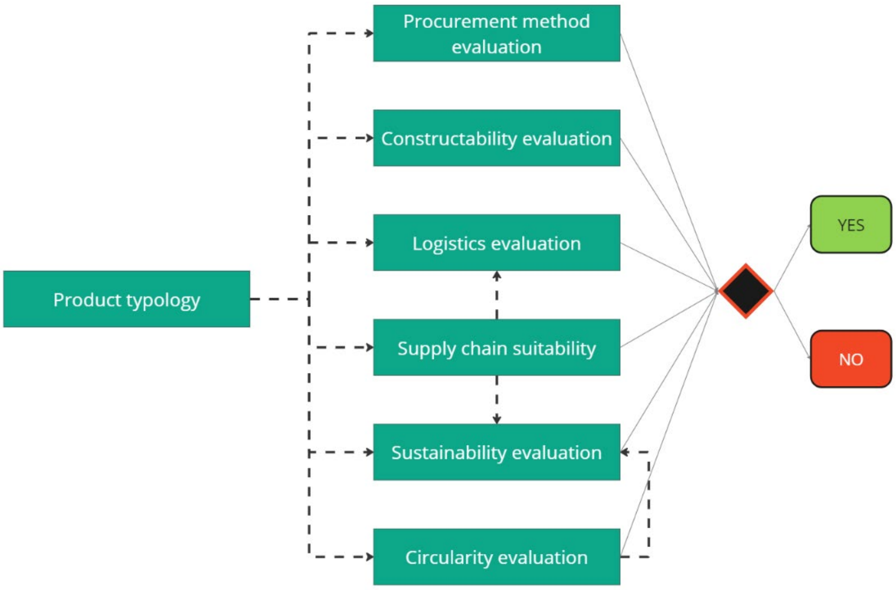


Figure 48. *Project evaluation process*

Design impact through product typology selection can be immense in many aspects of the project. This framework could provide a guide towards exploring different product typology options to reach the desired performance levels from the perspectives of the decision criteria established in this work.

A set of seven figures with a potential “user input – processing - outputs” mapping is presented in Figure 49 to Figure 55. These mappings represent a decision-making point. The block to the right of the decision-making point describes the decision-making criteria and requirements that would ideally be set by regulating bodies/Governments or the clients of the project.

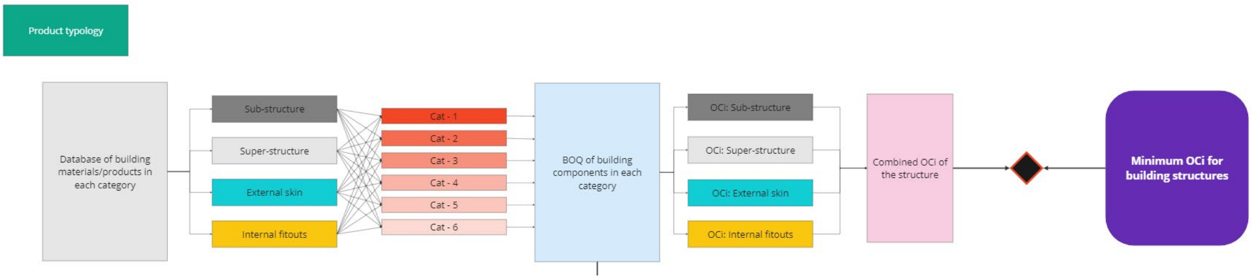


Figure 49. *Logic: Product typology mapping in a structure*

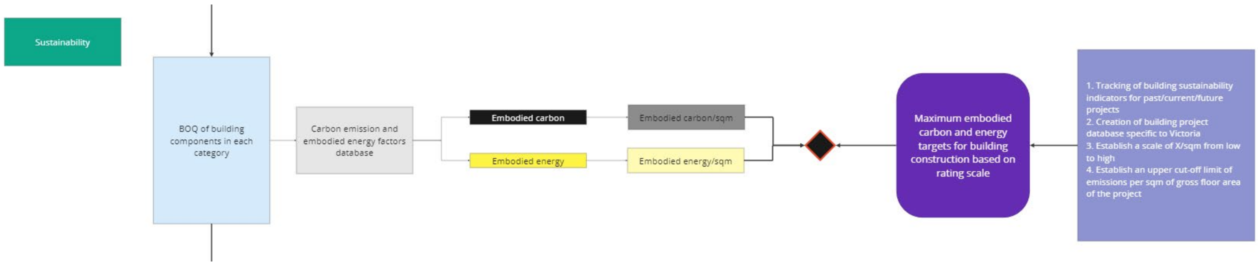


Figure 50. *Logic: Sustainability evaluation for a project*

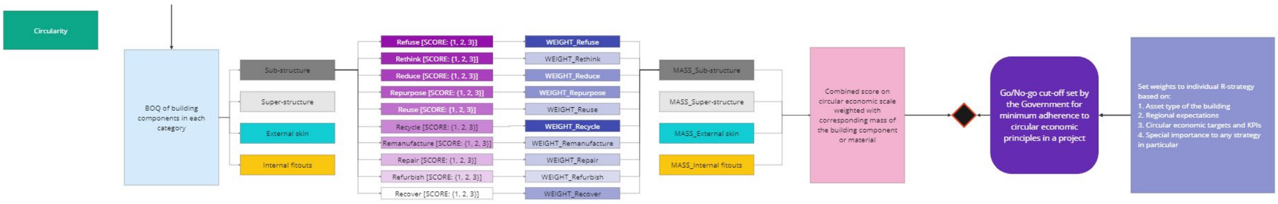


Figure 51. *Logic: Circular economic evaluation of a project*

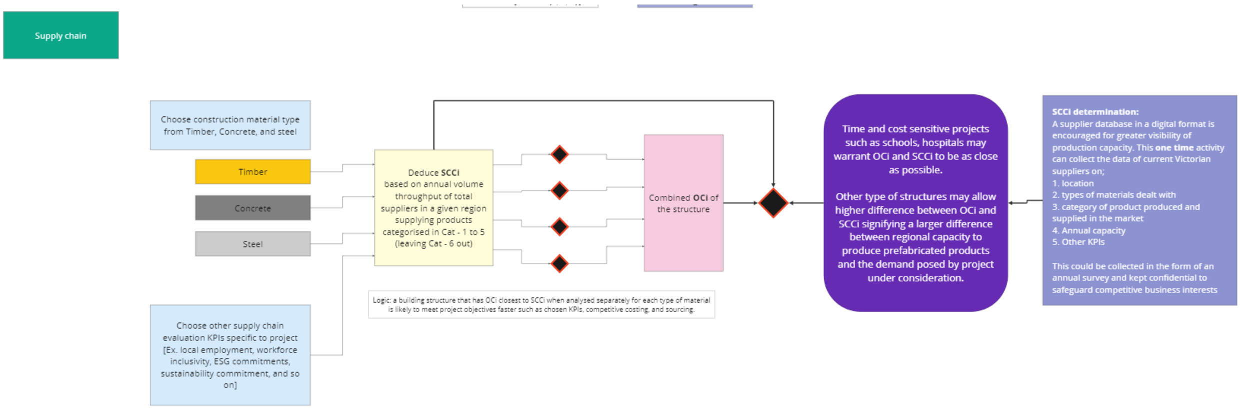


Figure 52. *Logic: Supply chain suitability for a project*

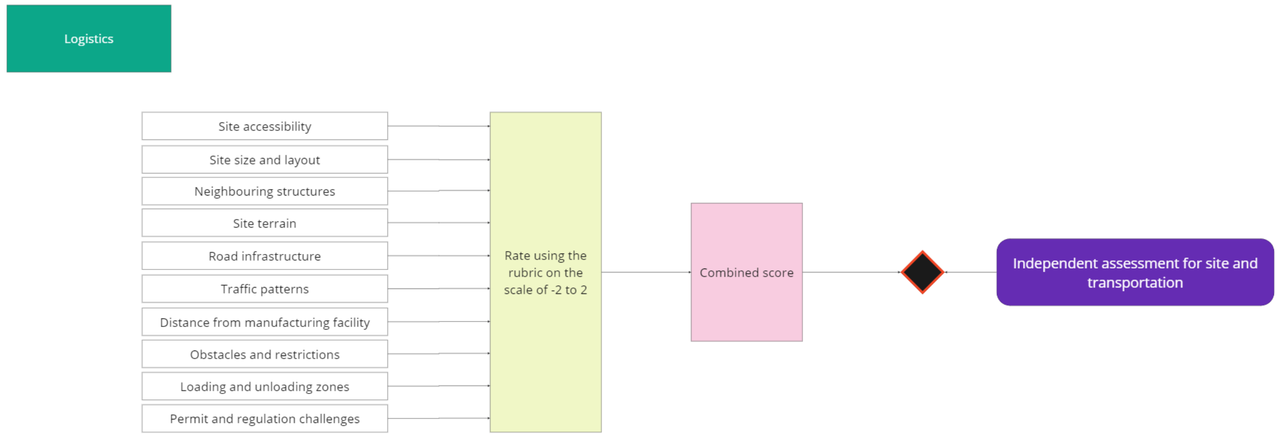


Figure 53. *Logic: Site logistics and transportation suitability for a project*

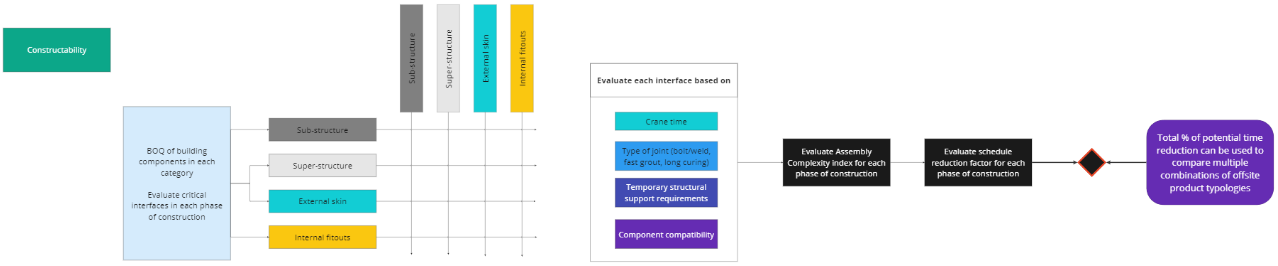


Figure 54. *Logic: Potential for construction time saving evaluation.*

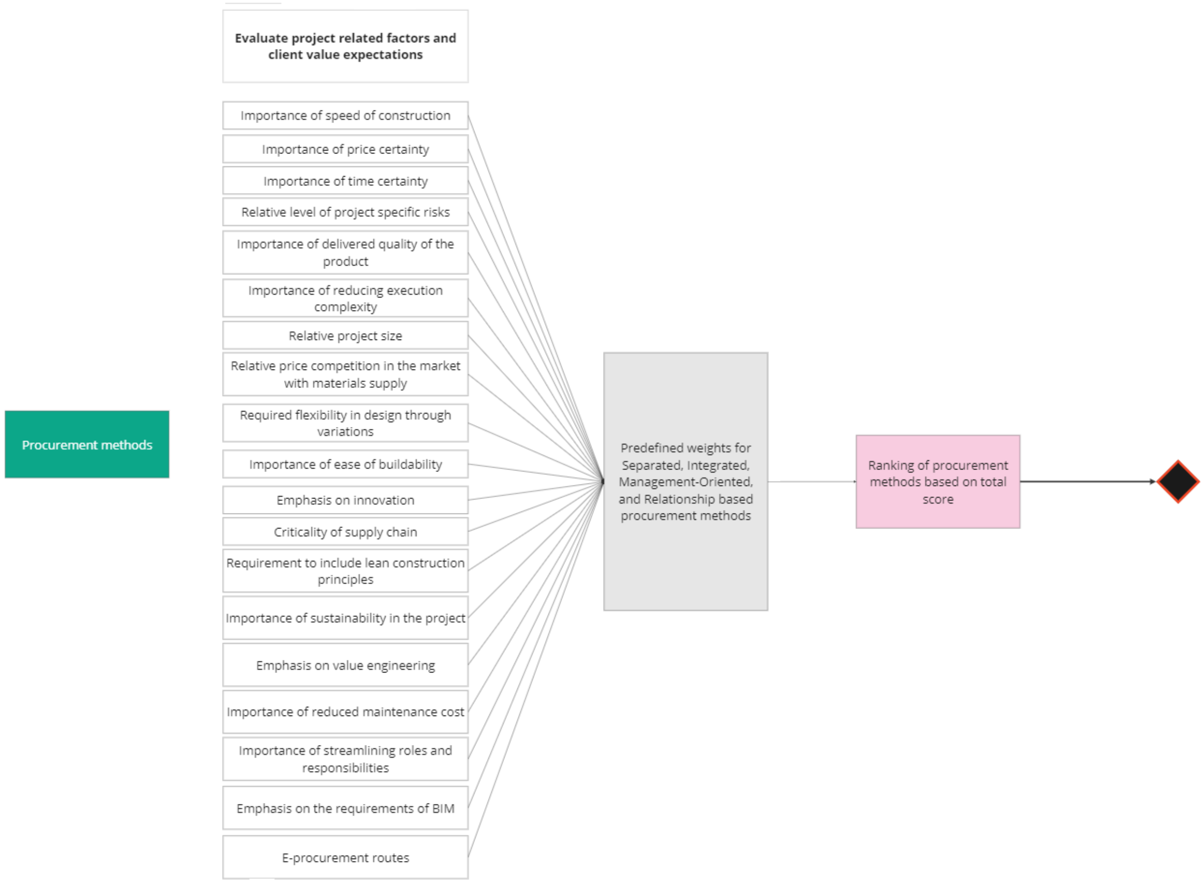


Figure 55. *Logic: Procurement method evaluation for a project*

In summary, we have 7 decision-making points:

9. The minimum OCi of the structure for each building asset type
10. Suitability of procurement contracts
11. Compatibility with supply chain capacity SCCi
12. Embodied energy/carbon in the structure
13. Circular economic value score of the structure
14. Ease of site logistics
15. Potential for construction time savings.

The intent is to integrate these decision-making criteria into the project proposal during the initial phase. Beyond conventional goals like total expense, health and safety, regulatory compliance, functional architecture, and structural resilience, and eco-friendly design, these criteria aim to direct the project more towards the established objectives. The comprehensive decision-making procedure is illustrated in Figure 56. From this flowchart, it becomes clear that the set of selection criteria drives the decision about the extent of productisation in a project where appropriate. It is highlighted that the selection criteria are method agnostic in the sense that it does not favour a particular type of construction system over the other. Appropriate values for the selection criteria can be chosen by the regulatory bodies in line with a larger scheme of goals. The performance of a building project evaluated as per the decision-making process can be tested against the selection criteria and conclusions can be made regarding the acceptance or rejection of a particular design of the building.

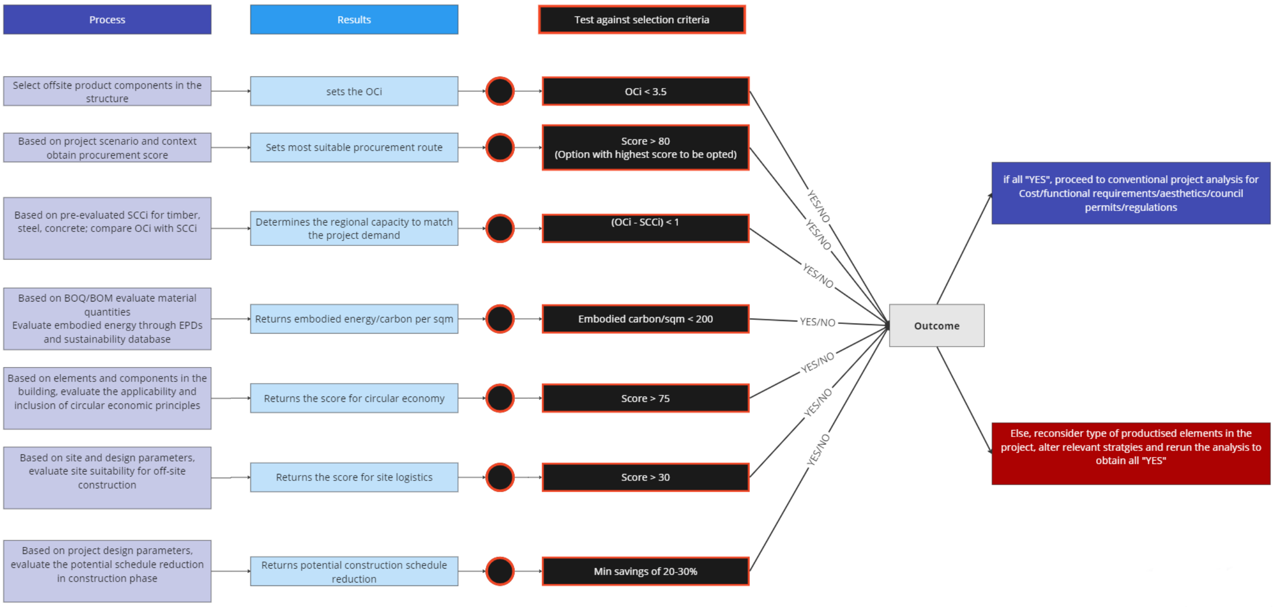


Figure 56. *Decision-making process flow chart*

DMSF outcomes with a case study

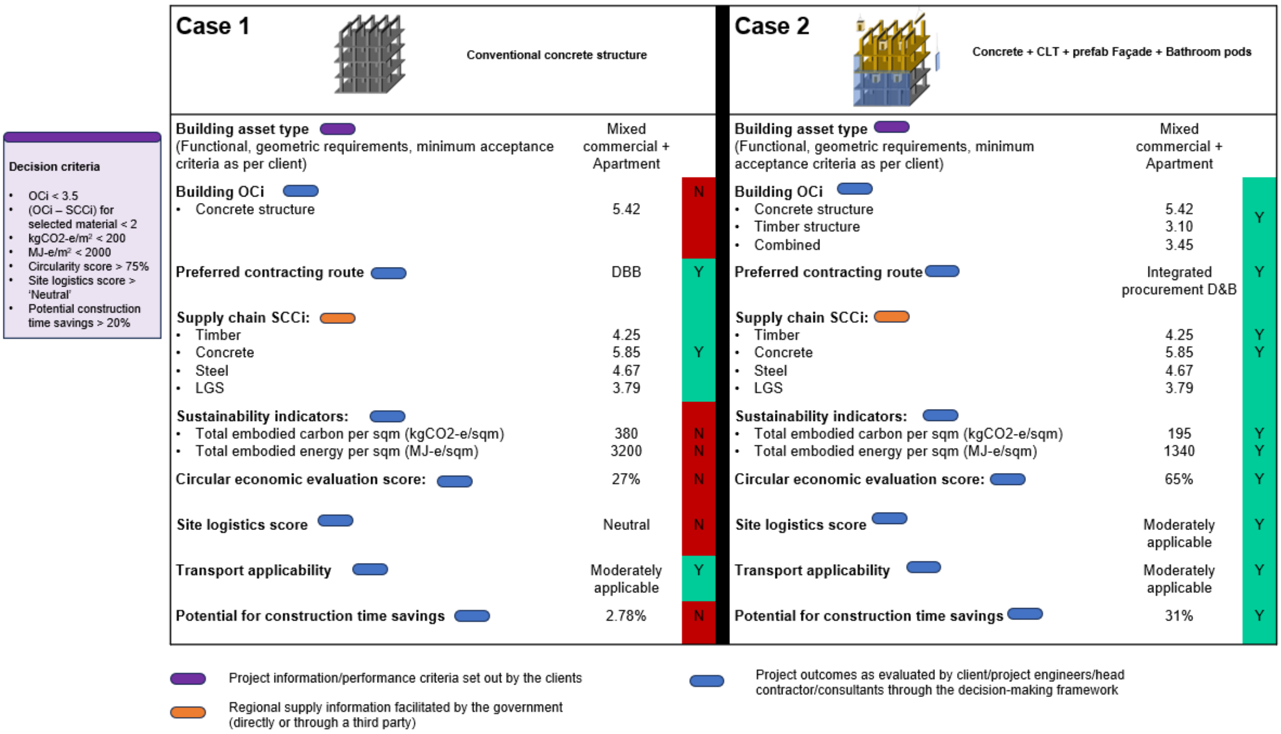
A case study is presented here with two hypothetical structures. The structures represent a mid-rise mixed-use (apartment housing and commercial) building. Both the structures are assumed to have been designed for near identical functional usage and near identical external look thereby making them equivalent from the regulatory approval point of view. The location of the project is hypothesised to be a moderately dense population centre. Skipping the project details, the outcome of the project evaluation through the decision-making process is presented in Table 16 for comparison.

It is expected that the decision-making criteria (shown in purple box) would be set by the clients and the requirements will be shared with the design team (which is thought to comprise architects, designers, engineers, manufacturers and contractors through a contracting model similar to ECI). Multiple designs may be proposed with the help of parametric design techniques at the end of the preliminary design outcome. Two such outcomes could be (i) conventional concrete construction, and (ii) cross-laminated timber structure built upon a concrete podium with prefabricated bathroom pods and prefabricated façade.

The following conclusions can be drawn by comparing the outcomes of the decision-making process performed on the design information of these two design alternatives:

1. OCis are estimated based on the portion of the structure constructed from concrete, timber, steel or light gauge steel (LGS) structure. In case-1, the entire structure is made of concrete and hence the single OCi represents the OCi for the entire structure (5.42). In case 2, the structure comprises of concrete podium and CLT structure on top and hence requires two distinct OCis calculated one for the concrete part of the structure and the other for the timber part of the structure.
    a. Higher combined OCi (5.42) in case-1 structure compared with 3.45 in case-2 highlights that the case-1 structure has much lesser proportions of prefabricated components and elements in totality.
2. Based on project requirements the preferred contracting route for case-2 is integrated procurement D&B.
3. Comparing the OCi and SCCi for the chosen construction materials, it would appear that:
    a. The difference between the OCi and the SCCi for the concrete supply chain is (5.85 – 5.42 = 0.43) for case-1
    b. The difference between the OCi and the SCCi for the timber supply chain is (4.25 – 3.15 = 1.10) and for the concrete supply chain it remains the same as before (i.e., 0.43).
    c. This indicates how well the structural material and components can be sourced from the supplier network from within the chosen region. The lesser the difference between OCi and the SCCi for a particular construction material, the higher would be the source-ability of that construction material. Source-ability could imply a higher proportion of supply chain players operating in the domain. Innovative solutions and emerging technologies in prefabrication will naturally show large differences between the OCi and SCCi. Hence a building design that incorporates novel methods of construction might show large differences between its OCi and SCCi. Such designs could be restricted or encouraged by setting the allowable difference between OCi and the SCCi in the decision-making criteria.
4. Sustainability indicators such as embodied carbon and embodied energies are improved by adopting to CLT system in the upper portion of the structure in case 2.
5. The circularity score of the case-2 structure can be seen to have improved from 27% in the case to 65%. This may indicate a greater opportunity to reuse/recycle/repurpose factory-manufactured elements in the design of case-2 structure over case-1.
6. Due to higher productisation, the site score may be improved as seen from case-1 to case-2. This could result from several factors such as decreased construction time and therefore the disturbance to the surroundings improving the site score, or decreased requirement for concrete pumping at heights due to the adoption of CLT systems for the upper floors and so on.
7. Due to the level of prefabrication and choice of products in the building design, the potential for construction time savings could be seen to improve considerably from case 1 to case 2.

Table 16. *Comparison between two hypothetical buildings with near identical architectural and functional requirements designed using different levels of Productisation (for illustration only)*



Decision criteria

- OCi < 3.5
- (OCi – SCCi) for selected material < 2
- kgCO2-e/m² < 200
- MJ-e/m² < 2000
- Circularity score > 75%
- Site logistics score > 'Neutral'
- Potential construction time savings > 20%

Case 1 Conventional concrete structure			**Case 2** Concrete + CLT + prefab Façade + Bathroom pods		
Building asset type 🟣 (Functional, geometric requirements, minimum acceptance criteria as per client)	Mixed commercial + Apartment		**Building asset type** 🟣 (Functional, geometric requirements, minimum acceptance criteria as per client)	Mixed commercial + Apartment	
Building OCi 🔵 • Concrete structure	 5.42	N	**Building OCi** 🔵 • Concrete structure • Timber structure • Combined	 5.42 3.10 3.45	Y
Preferred contracting route 🔵	DBB	Y	**Preferred contracting route** 🔵	Integrated procurement D&B	Y
Supply chain SCCi: 🟠 • Timber • Concrete • Steel • LGS	 4.25 5.85 4.67 3.79	Y	**Supply chain SCCi:** 🟠 • Timber • Concrete • Steel • LGS	 4.25 5.85 4.67 3.79	 Y Y
Sustainability indicators: 🔵 • Total embodied carbon per sqm (kgCO2-e/sqm) • Total embodied energy per sqm (MJ-e/sqm)	 380 3200	 N N	**Sustainability indicators:** 🔵 • Total embodied carbon per sqm (kgCO2-e/sqm) • Total embodied energy per sqm (MJ-e/sqm)	 195 1340	 Y Y
Circular economic evaluation score: 🔵	27%	N	**Circular economic evaluation score:** 🔵	65%	Y
Site logistics score 🔵	Neutral	N	**Site logistics score** 🔵	Moderately applicable	Y
Transport applicability 🔵	Moderately applicable	Y	**Transport applicability** 🔵	Moderately applicable	Y
Potential for construction time savings 🔵	2.78%	N	**Potential for construction time savings** 🔵	31%	Y

🟣 Project information/performance criteria set out by the clients

🟠 Regional supply information facilitated by the government (directly or through a third party)

🔵 Project outcomes as evaluated by client/project engineers/head contractor/consultants through the decision-making framework

The iterative process could thus explore additional offsite productisation choices following the decision-making framework. Government regulators or private clients could steer the development of offsite design by setting the appropriate parameter values for the decision criteria. Acceptable solutions could then be analysed and compared following traditional layers of scrutiny such as cost of materials, cost to build and so on.

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