De-risking the uptake of new technologies for effective change management

Alice Chang-Richards, Na Zhou, Jieyu Bai, Antony Pelosi, Nick Sterling and Tim Harris

Project No. LR16304

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Glossary

BRANZ	Building Research Association of New Zealand
AEC	Architectural, Engineering and Construction
SME	Small and medium-sized enterprises
R&D	Research and development
AI	Artificial Intelligence
BIM	Building Information Modelling
MBIE	Ministry of Business, Innovation and Employment
ENZ	Engineering New Zealand
VR/AR	Virtual Reality/Augmented Reality
IoT	Internet of Things
AMPD	Advanced Manufacturing and Prototyping for Design Lab
SDL	Smart Digital Lab
BAU	Business As Usual

Executive summary

This report presents research findings from BRANZ-funded project "*De-risking the Uptake of New Technologies for Effective Change Management*" which explores the solutions to de-risk changes introduced by engineering and construction businesses associated with technology adoption. The sector faces a skills and productivity crisis exacerbated by COVID-19, together with technological disruptions, necessitating a shift towards digitalisation and leveraging innovative technologies to remain competitive. There have been cases of resistance to change in the sector and the past decade has seen the impact of businesses investing in the wrong technology or not investing in any technology.

The primary objective of this research is to support small and medium-sized enterprises (SMEs) in the Architectural, Engineering and Construction (AEC) sector with effective change management strategies for technology adoption. The research is grounded in behavioural sciences and system thinking to identify 1) the types of behaviours that can be changed, 2) the stakeholders who can influence these changes, as well as 3) the mechanisms or interventions that can lead to positive technology uptake outcomes.

The research highlights the importance of behavioural change in technology adoption, emphasising that successful strategies must address the component of awareness, attitude, intention, and action in behavioural change model. Lack of technology uptake is also a systemic issue. At a building project level, digitisation of data or converting information related to the building into digital data has been a key to unlock the potential of technological innovation. There has been a lack of the efficient flow of digital data between all parties involved in the project life cycle (from planning/design to construction and maintenance/operation) which is an inherent impediment to technology adoption in the sector.

The biggest challenge facing those SMEs is the financial burden or financial risk for implementing technology trials. Interventions from other stakeholders, such as government agencies, industry associations and training organisations, would make a difference for SMEs to step out of their comfort zone and leap their faith. The research team designed several interventions to facilitate this process, including immersive workshops, on-site or lab-based demonstrations, and utilising existing financial support mechanisms. These interventions proved to have delivered benefits by addressing the primary barriers faced by SMEs.

Given the current climate, with the change of policy and funding, a number of AEC sector initiatives have altered significantly. The economic conditions in the market have also changed, which made it more difficult or reluctant for AEC SMEs to organise themselves to access benefits directly. Therefore, the implications of interventions introduced, and benefits delivered in case studies call for wider roll out or scaling of those interventions so that **the balance of risk can be shifted, making companies more willing to invest**. Several key recommendations are concluded:

- **Government agencies** reprioritising R&D investment to align to new strategic government focus areas and current market conditions that AEC businesses are operating within, especially with a focus on a new key area (Artificial Intelligence (AI) in AEC) that has grown significantly over the past 6 months and like to continue to grow in both scale and in importance. In addition to existing grant schemes, providing tax incentives and other benefits to companies that invest in technological advancements would further reduce the financial risks associated with technology adoption.

- **Simplifying regulatory requirements**: Simplifying compliance regulatory processes and developing prescriptive health and safety policies or protocols for use of technologies would encourage innovation and provides businesses with confidence needed for introducing changes.
- **Training and education:** Organising workshops and seminars by industry associations and jointly organised by industry-university (e.g. Lab Open Day) has proved the benefits for upskilling the workforce, ensuring they are well-versed in the benefits and applications of new technologies. Hands-on experience through practical demonstrations (e.g. on-site demonstration of using robotic dogs) and trials also helps SMEs to foster a culture of continuous learning and adaptability, which is vital for successful technology integration.
- **Strategic planning and engaging technology specialists:** Effective technology adoption requires clear strategic planning and strong leadership. Previous learnings from tech-leading engineering and construction companies (e.g. Beca, WSP, Fletchers, Hawkins and Southbase Construction, etc.) suggested that organisations would have success in their technological transformation when they had a clear vision and roadmap for integrating new technologies, driven by top management. Engaging technology specialists is a great way to translate the vision into reality and ensure that the integration process is effective.
- **Pilot/proof of concept projects and real-world testing:** Starting with pilot projects allows SMEs to test new technologies in real-world scenarios, providing valuable insights into their feasibility and benefits. Laboratory co-location (test bed) with universities or research institutions which offer lab or facilities for businesses to try new ideas is a great initiative. These small-scale implementations help identify potential challenges and refine the technological solution before full-scale adoption. It also provides research opportunities for universities or research institutions, bridging the gap between research and practice.
- **Industry-research collaboration and partnerships:** Collaboration and partnerships are key to de-risking technology adoption. As evidenced in the University Lab Open Day and learnings from international lead laboratories, industry-academia collaborations leverage cutting-edge research and innovations, providing businesses with access to the latest technological advancements, which they would otherwise not be able to access. These collaborative efforts ensure that businesses have the support they need to successfully integrate new technologies.

In all, providing SMEs with the targeted financial assistance, training, and access to technological resources are essential to de-risk the uptake of new technologies. The interventions introduced in this research are based on the behavioural change (Awareness, Attitude, Intention, Action) model and have proved their effectiveness in case studies. The interventions demonstrate a flexible approach to addressing the concerns, barriers and challenges faced by some SMEs as well as how various involved stakeholders can be engaged.

This report has two primary audiences. The first are various government agencies and other industry leaders who contribute to the development of practical guidelines and policies in supporting innovation with SMEs. The second audience is organisations with R&D capabilities such as universities and research institutions in New Zealand as they can play a significant role in co-implementing recommended solutions to ease burdens of technology trials. Both audiences are important to the advancement, adoption and wider implementation of technologies in the sector.

Acknowledgements

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We are grateful for the time offered by industry practitioners who participated in the interventions introduced by the research team and offered valuable insights. We would like to give special thanks to the Hawkins' management team of the visited construction site for their assistance in organising the site visit and facilitating data collection for this research. In particular, we would like to thank the Hawkins' team Steve Ritchie, Scott Redmond, Nicholas van der Lee and Paul Wikiriwhi for gracious support.

Background

Many organisations in the architecture, engineering and construction (AEC) sector in Aotearoa New Zealand are in the midst of rapid innovation to compensate for many years of falling behind the technology revolution. The sector is experiencing a workforce skills crisis that has long been in the making and exacerbated by COVID-19 [1,2]. As we shift our response to adapt to post-COVID era, organisations need to re-position themselves to tackle the skills crisis, productivity and sustainability issues head-on [3].

Post-Covid era, however, presents new opportunities for AEC firms, driven by the need for digitalisation. With the revolutionary release of Open AI at the end of 2022, society and the business communities are yet to comprehend the profound impact AI would have on our workplaces and how it would enable transformation in the AEC sector. At the time of preparing this report, the Minister of Public Service Judith Collins has prioritised 6 industry sectors believed to benefit the most from AI[1] and the AEC sector is one of the high potential sectors prioritised [4]. One thing becomes certain than ever before – engineering and construction companies have realised that adopting and using emerging technologies, including AI, is no longer an option, but a 'must to have' capability to stay competitive.

Some companies and building projects have begun leaning into the potential and power of digital technologies to enable their workforce to focus on creative and value-added tasks, ultimately increasing productivity and project success. Despite early adopters of digitalisation (e.g. Building Information Modelling (BIM)) and new construction techniques (e.g. prefabrication), a BRANZ study found that the uptake of technology across the AEC sector in New Zealand is low at the company level [5]. Our recently completed BRANZ-funded project (LR12069) "*Technology implementation in the New Zealand construction sector*" examined the technology implementation status of more than 400 AEC businesses, and reinforced that cost, legal aspects and human factors, such as social inertia, act as primary investment barriers to technology implementation [6].

According to Boston Consulting Group research, full-scale digitisation may help the construction industry save between $1 trillion and $1.7 trillion annually worldwide [7]. In comparison, the sector in New Zealand has had some breakthroughs in implementing certain technologies at various stages of projects. Nevertheless, there is a lack of a lifecycle mindset toward technology adoption and a lack of expertise and skills for technology integration. More needs to be done to support the technology adoption laggards, especially SMEs[2], in effective change management [6].

Our previous BRANZ-funded project (LR12069) shows that it is crucial for SMEs to understand how existing and emerging technologies can help support their productivity gains and leverage adoption where it has been most successful. Therefore, the project presented in this report leverages the previous project and extends to evaluate the effectiveness of various interventions in adopting technologies. It is hoped to provide evidence-based research to drive the behavioural change towards technology adoption among SME organisations and individual practitioners in the sector [6, 8].

To influence behavioural changes of construction SMEs, interventions introduced should be not only demonstrate how existing and emerging technologies can help support their productivity gains and where the use of some technologies has been most successful, it also needs to shift the balance of

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[1] AI Blueprint for NZ (July 2024) https://aiforum.org.nz/wp-content/uploads/2024/07/AI-Blueprint-for-Aotearoa-2024.pdf and January 2025 update https://aiforum.org.nz/wp-content/uploads/2025/02/January-2025-Update-AI-Blueprint-for-Aotearoa.pdf

[2] New Zealand's business community and government commonly use the following definition for small and medium enterprise (SME): 0 to 49 FTE employees, see https://www.mbie.govt.nz/assets/defining-small-business.pdf

risks. Therefore, understanding the critical drivers for change at different stage of technology readiness to move SMEs towards successful technology adoption is the primary aim of this research. It is hoped that through this research, government agencies (i.e. MBIE, Callaghan Innovation), industry associations (e.g. Engineering New Zealand (ENZ), Civil Contractors, Master Builders, etc.) and support groups such as BRANZ, universities will gain insights into how the risks are balanced and shifted, making companies more willing to invest; so collectively work together to support SMEs in making proactive changes towards technology adoption.

Research plan

The research presented in this report seeks to provide evidence-based research to understand the key ingredients for initiatives supporting those technology adoption laggards (i.e. SMEs) in the AEC sector for effective change management towards technology uptake.

To achieve this goal, grounded in behavioural sciences and system thinking, this project aims to

1) Identify the types of behaviour that could be changed and the desired change outcomes for businesses who lag behind in technology adoption and long for effective change management;
2) Identify the actors or stakeholders in the system (including people, institutions, regulation, technologies etc) who can influence change and the mechanisms/interventions that potentially lead to the change and positive technology uptake outcomes;
3) Trial interventions with selected businesses, leading to new tools and practical solutions to change behaviour while de-risking innovation and uptake of promising technologies;
4) Assess the effectiveness/success of trialled interventions empirically with businesses and scientifically quantify the change by using system dynamics modelling or agent-based modelling.

As shown in Figure 1 below, we have undertaken the project in four stages (below the term 'tech' is short for 'technology'):

1) **Stage 1 Behavioural analysis**: collecting information on the types of behaviour that could be changed and the desired change outcomes for selected businesses who lag in technology adoption (through in-depth interviews and consultation with our project advisory panel);
2) **Stage 2 Systemic assessment**: collecting empirical data on the actors in the system (including people, institutions, regulation, technologies etc) who can influence change and the mechanisms/interventions that can lead to positive changes in technology uptake (using a systems approach and case studies);
3) **Stage 3 Intervention trialling**: case studying selected construction businesses to work with the research team to trial certain technologies through a series of interventions;
4) **Stage 4 Success assessment**: Using pre-intervention and post-intervention surveys to collect empirical data for case studied businesses on the effectiveness of intervention trials. And further using behavioural sciences and system approach to validate the change.

Stage 1 & 2 Design of interventions	Stage 3 Intervention implementation	Stage 4 Intervention assessment
Work carried out with key stakeholders and end users/partners to identify the types of behaviours that can be changed and types of interventions to trial for change.	Case studies conducted to monitor change management of SMEs towards technology uptake and how it is shaped by the influence of interventions.	System approach used to assess the change in practice that has taken place and measure that technology adoption has improved workforce performance and productivity.

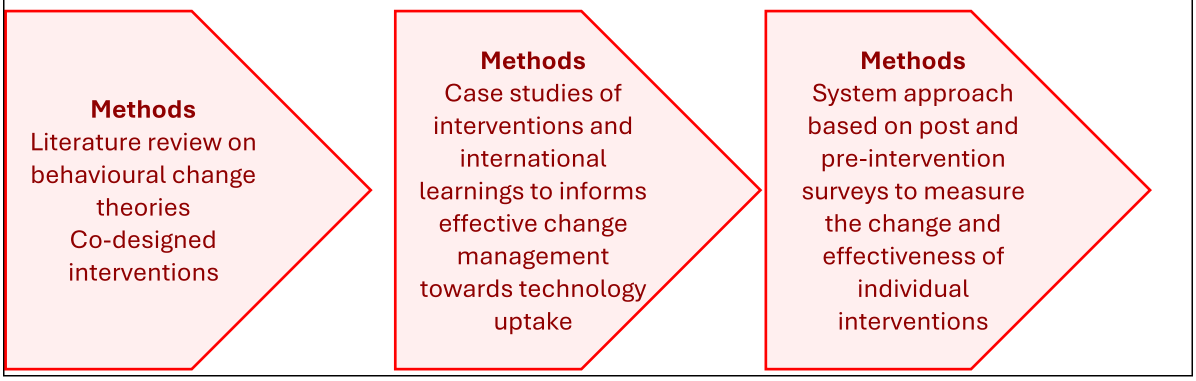


Figure 1: Research design and implementation pathway

Behavioural change: Drivers and trajectory

Behaviour change can be difficult. The vast quantity of publications retrieved in behavioural science primarily have focused on the identification of drivers of behavioural change and stages of behavioural transformation. Successful behavioural change strategies can be initiated by the individual (i.e., self-control) or others (e.g., a benevolent employer). Many factors affect such a change, including such as a personal capacity to regulate impulses, the ecosystems in which humans operate including shared structural affordances and impediments, social norms, and culture-wide practices [9]. Malott & Glenn (2006) connected the drivers of behaviour change with operant contingencies, macro contingencies and meta contingencies [10]. This categorisation helps to distinguish between interventions designed to change conditions produced by the behaviour of one individual or generated by the combined behaviour of multiple individuals.

The process model of behaviour changes (shown in Figure 2), proposed by Duckworth & Gross (2020), explained the development of behaviour change [9]. It presented that behavioural responses are the outcome of a recursive cycle. Changes evolve in a recursive cycle, when impulses reach a certain threshold, they are enacted and continued to the next phase. Technology acceptance model (TAM) proposed by Davis (1989) (shown in Figure 3), indicates that to introduce any innovation, the perceived usefulness is a key precedent before individuals change their attitudes towards the usage. Once a positive attitude towards using a technology is established, it is more likely the person will use it, leading to the actual actions [11].

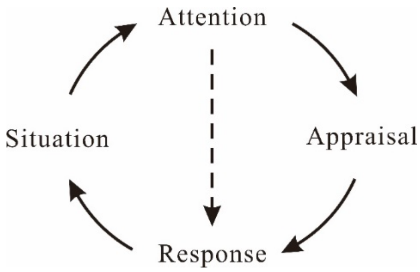


Figure 2: The process model of behaviour changes (Duckworth & Gross, 2020)

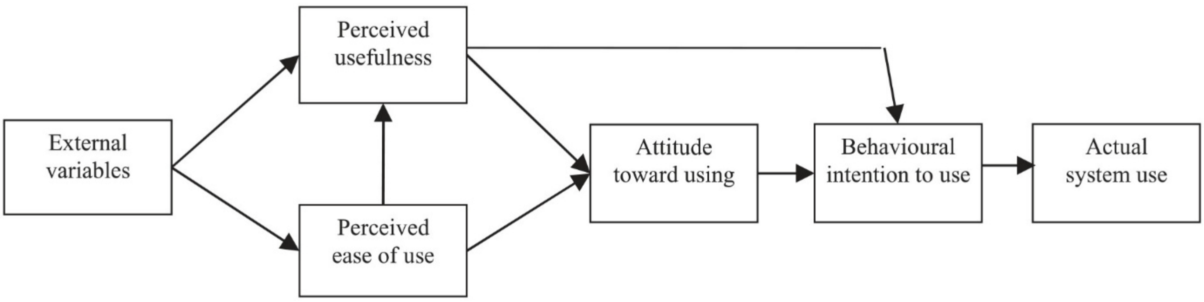


Figure 3: Technology acceptance model (Davis, 1989)

Policy interventions developed and implemented by countries and regions towards innovation and technological transformation vary. They are also regarded as the influencing factors on the AEC sector's innovation trajectory and capability development. In many cases, government agencies supported AEC organisations' innovation plans with the necessary financial and technical support. However, in the market where innovation is not perceived as a critical element for competition or stay competitive, initiatives from the government agencies may not attract adequate attention from the sector.

The TAM model in Figure 3 suggested that organisations are likely to adopt technology if they perceive the utility of the technology for their performance. This seems to be the case in the construction sector. Murguia et al. (2023) found that contractors were likely to adopt BIM if they see its adoption can lead to improved project performance [12]. The past decade has seen engineering and construction companies favoured towards engaging in technologically related education and training programmes as they have recognised the benefit of technology applications [13]. In New Zealand, large engineering and construction companies have hired modelling consultants or create digital-savvy in-house BIM/digital engineering teams to assist project teams to perform digital tasks. The advantages of BIM and other technologies have driven the change in the AEC industry. There are a number of models of behavioural change, each one designed to help understand what drives behaviour and how decisions are made. The detailed review of international literature on these behavioural change theories and models as well as the drivers that influence the behavioural change are presented in Appendix.

Critical interventions

This research project draws on the awareness, attitude, intention and action (AAIA) model, which is similar to TAM model in Figure 3 to design the interventions for construction SMEs at the different stage of behavioural change towards technology adoption. The model provides insights into four component, with each playing a pivotal role in producing the following component of behaviour and thus changing the behaviour. The very first component, awareness, needs to be changed in order to facilitate effective activation of the next component, the attitude. By changing both perceived benefits of using technologies and the opportunities those technologies may bring to the organisation, we can influence the organisation or the individual decision makers' motivation for executing the plan for technology adoption, namely the intention of using. If financial and technical obstacles get tackled, the intention will land for final materialisation of actions.

Table 1 below outlines why and how the particular technologies were used in the study, as well as their relevance to the industry and what they can help achieve. Table 2 (overleaf) explains what these interventions are, and how they are aligned with different stage/component of behavioural change, and the key ingredients that have made a difference to drive the step change.

Table 1: Summary of technologies demonstrated in the study and their relevance to the industry

Technology	Use case/relevance demonstrated in case studies	What technology can help achieve
UAV/drone	• Conduct land surveying • Inspect site activities	Outputs for site planning, architectural design, quality inspection, construction progress monitoring, estimation of earthwork
Robotics/robotic dog	• Map construction site when equipped with sensors, cameras, and other data collection devices • Able to operate autonomously in potentially hazardous or challenging environments	Data collected such as construction site topography, structural integrity, location of equipment, and environmental conditions are useful for planning, monitoring progress, enhancing quality and safety.
Digital twin	• Visualise and simulate projects, thus reducing design errors and enhance planning capability for construction • Infrastructure/building management digital twins are used for managing infrastructure assets/buildings	By providing a virtual model, teams can access real-time data and updates, which will lead to opportunities for optimising the design and construction processes, reducing risks, material waste and labour costs.
VR/AR	• Create an immersive environment of project designs and simulating construction processes for health and safety training • Allowing clients/customers to explore different material/product options or building designs	It allows for a more intuitive understanding of environment or scene being simulated and assist with decision making of users.
Sensors	• Building environment monitoring • Site condition monitoring • Structural health monitoring	Sensors collect data on various parameters, such as temperature, humidity, and structural integrity. By analysing this data, teams can ensure safety and compliance with regulations.

Table 2: A summary of interventions and stage of behavioural change which the intervention has influenced

Case study	Business issue to be addressed with help of technology	Behavioural change Stage	Intervention	Key ingredients
Case 1: Hawkin's Site	Labour-intensive site surveying and monitoring	Attitude	Taking the robotic dog to the construction site	• On-site demonstration in a real-world environment - a more tangible and interactive experience • Hands-on interaction and benefits feedback related the robotic dog's functionality and how it can perform certain tasks
Case 2: Aronui Industry 4.0 Navigator	Low efficiency in production and supply of building products	Awareness	Providing guided sessions that immerse participants in Industry 4.0 applications	• Technological awareness – introducing Industry 4.0 applications • Using benefits/value local use cases • Strategic planning and road mapping by creating an immersive environment for businesses to think strategically about Industry 4.0's potential across operations
Case 3: Construction Activator Connect	Lack of digitisation in business operations	Awareness	Introducing events, workshops, online tools such as knowledge and resource hub, and expert consultations	• Collaboration and networking opportunity • Advise on where to start and how • Technological awareness – introducing the challenges in the construction sector NZ and how businesses could benefit from digital products, services and expertise support
Case 4: University Lab Open day	Using digital twin for construction planning and VR/AR for health and safety training	Intention	Showcasing of demonstrations of new technologies	• Collaboration and networking – to foster collaboration and knowledge exchange among businesses • Hands-on interactions-practical experiences on participants' understanding and perception of technologies
Case 5: Arduino Sensors and Guest Lectures	IoT related smart and connected site	Awareness	Introducing guest lectures and demonstrating the use of Arduino sensors in real engineering practices	• Hands-on practices • Technology awareness- getting familiar with technologies • Training and education
Case 6: Callaghan Innovation R&D support	Lack of funding and technical support	Intention	Providing funding to build R&D skills and capabilities of new business	• Financial assistance • Training • Technological resources and expert guidance
Case 7: Southbase Technology Specialist	Lack of in-house know-how technological personnel	Action	Engaged a technology specialist to set up the digital engineering unit	• Support from the executive/top management team • 'Know-how' is accomplished by engaging a technology specialist • Investment in a completely brand new digital engineering unit to change the business model

Below we provide a list of practical examples of interventions to demonstrate how those initiatives have de-risked the use of technologies for SMEs and encourage their behaviour change.

- **Awareness/knowledge**: Individual business owners/managers of AEC organisations may not know or know little about a certain piece of technology they can leverage to improve the performance of their business. In this case, workshops and training sessions on technology utilisation in real projects and the use cases can help an individual develop their knowledge and enhance awareness. Interventions such as Callaghan Innovation's Aronui Industry 4.0 Navigator, Construction Activator Connect and University's industry guest lecture introducing the technology applications in real engineering projects could inspire SMEs with regard to the application areas they could benefit from by using technologies and opportunities to implement them.
- **Attitude**: As revealed by the previous BRANZ study, the perceived cost and time constraints alongside the lack of opportunity to 'touch and see' certain technologies may be barriers to their implementation [6]. In particular, engineering and construction SMEs may not recognise the need for utilising technologies for some types of services they have been providing in the sector from the cost perspective. In order to change the attitude, opportunities to interact with technologies need to be provided which can encourage practitioners to think out of box and try things differently. A typical intervention designed for this purpose was the on-site demonstration of site surveying and scanning using a robotic dog on one of Hawkin's construction sites. It offered interactive experience for all site workers in a real-world project environment to have hands-on interactions with the robotic dog and understand how this technology and its functionality can directly relate to their day jobs.
- **Intention**: Some companies may already be aware of the opportunities available and have a positive attitude towards technology adoption but feel some trials or a deeper understanding starting with a proof of concept is needed before they commit resources. To incentivise SMEs, especially those start-ups to move on the trajectory towards intention of using technologies, it is crucial for them to obtain some kind of financial and technical support. In this regard, one of the critical interventions which the research team have designed was called "laboratory co-location", which was to provide free lab open day at the University (Smart Digital Lab[3]) with intensive technical support sessions on drones, VR/AR equipment, 3D scanners and sensors. In addition, Callaghan Innovation's R&D support provides funding to build R&D skills and capabilities of businesses in AEC sector, making proof of concept type of technology trials seem feasible for SMEs.
- **Action**: If the above components are all in place, the individuals' behaviour will lean over to cross the 'action' line. By engaging in trial activities, the individual organisations may have improved understanding of where they wish to use technologies and begun to see the opportunities they can bring forth for the long term benefit of the organisation. The final drive to take actions comes from how technology plays a role in the organisation's strategic development. A classic example comes from how the executive/top management team at Southbase Construction have seen the need to embed technological transformation in their business model by engaging a technology specialist to assist with the setup of its new digital

[3] University of Auckland Smart Digital Lab (SDL): https://www.auckland.ac.nz/en/engineering/our-research/engineering-research/research-areas-and-facilities/sdl.html

engineering unit. The dedicated unit of such kind provides technical support to all other business divisions and building projects, driving innovation-led productivity improvement.

The assumption is if the above interventions are successful, the individual's behaviour will change towards technology adoption. More articulated intervention strategies may be needed to promote technology-driven innovation within SMEs. Seven case studies were conducted in line with the interventions designed and trialled, which aim to 1) uncover and represent the key ingredients needed for the success of that intervention for SMEs that are at different stage/component on behavioural change spectrum; and 2) support the identification and evaluation of intervention strategies according to the feedback collected via pre- and post- intervention surveys or empirical data from participating SMEs. The case studies and the key ingredients that are translated as key variables in a system dynamics modelling are provided in detail in the following section.

Case Study 1: Hawkins Construction workers' perceptions of using robotic dogs

Intervention introduced

Hawkins Construction, a leading construction firm in the vertical sector, is known for its commitment to innovation and technology integration. The company aims to enhance efficiency and safety on construction sites by adopting advanced technologies. This case study was designed to improve the attitude of on-site workers and project management personnel towards the use of robotic dogs for site surveying and planning. It involves a demonstration of robotic dogs, providing interactive experience for site workers, with a survey of their perception of towards adoption of robotics on construction sites.

The demonstration on 8th September 2022 (See Figure 4) showed the advanced mobility and adaptability of Unitree's A1 robot dog. By connecting the robotic dog with sensors, laser scanner and web cameras, the onsite crew could see how the data captured by those devices about the site conditions could be fed into the cloud for further analysis. For instance, the images captured by the robotic dog could be used to measure construction progress and improve project payment process.

Figure 4: Trial of a robotic dog undertaking site surveying

Evaluation of the effectiveness of this intervention

A questionnaire survey was designed to assess the effectiveness of using technology demonstration to change the attitude of construction workers towards the use of robotics on site. The survey participants included site workers in various roles. Figure 5 below shows the individual role of ten onsite workers who participated in the survey.

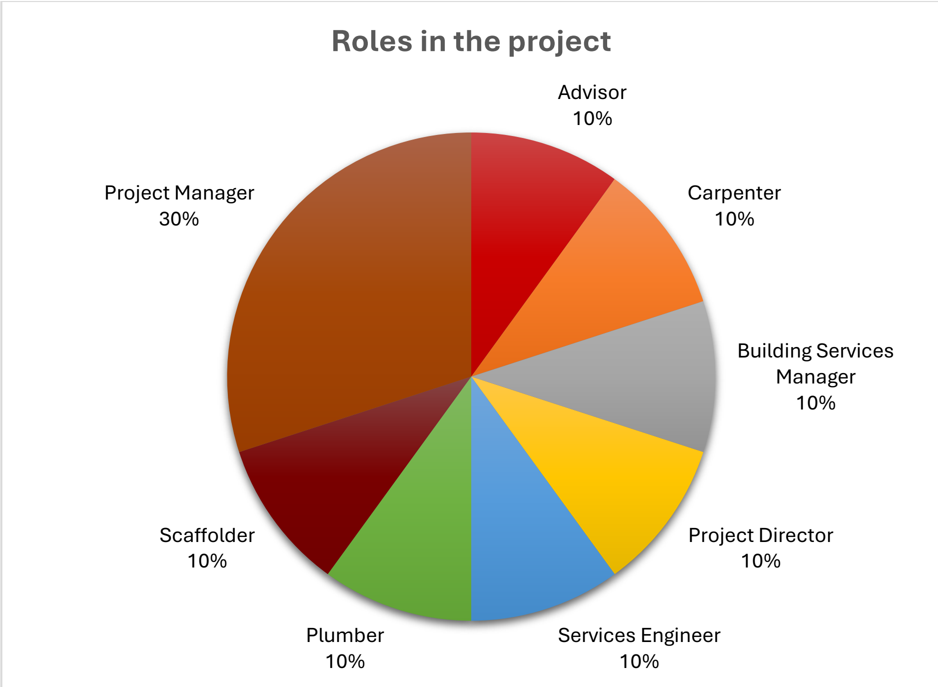


Figure 5: Survey participants on Hawkins' site for robotic dog demonstration

As shown in Figure 6, out of ten workers surveyed, eight of them do not believe their jobs will be replaced by robots shortly, reflecting a general confidence in the security of their roles despite technological advancements.

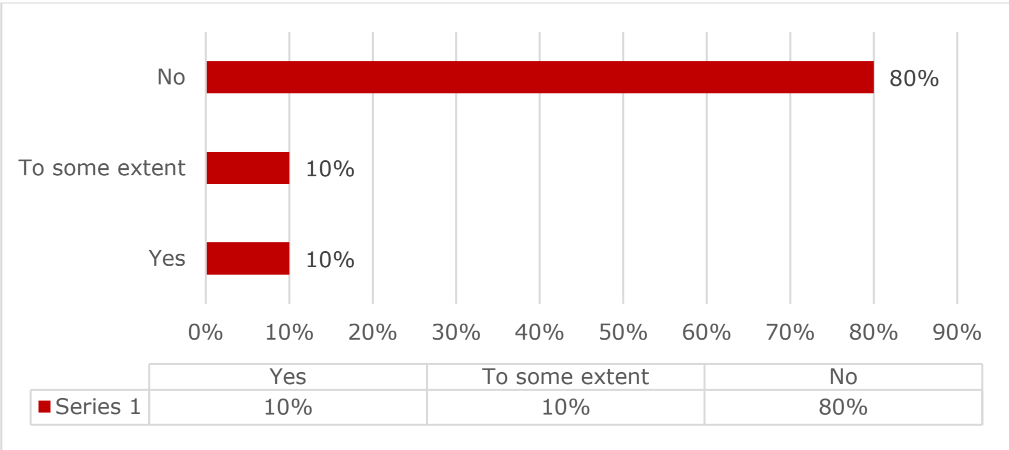


Figure 6: Perceived threat from technology

The perspectives on the impact of robotics on the workforce were mixed. While four people believed it would lead to upskilling, one felt it could lead to job losses ('perish'), and the rest had a neutral or mixed view, recognising both potential benefits and challenges. However, privacy and capability concerns were minimal, with eight workers expressing no concerns about the service robot, indicating a high level of acceptance and curiosity about the technology (See Figure 7).

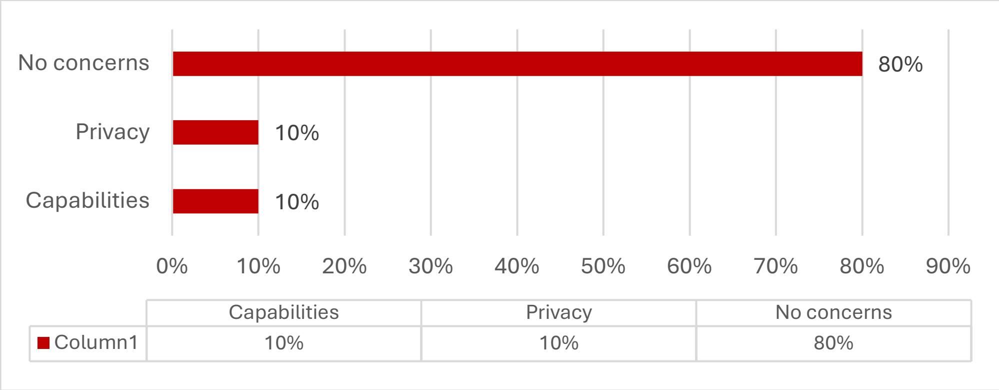


Figure 7: Concerns about robotics adoption in construction

Opinions varied on the tasks suitable for robots (Figure 8 below). High-risk tasks, repetitive tasks, and measurement tasks were frequently mentioned, indicating a recognition of the potential for robots to handle dangerous and monotonous activities, thus improving safety and efficiency on sites. There was no clear consensus, but repetitive and high-risk tasks were frequently mentioned.

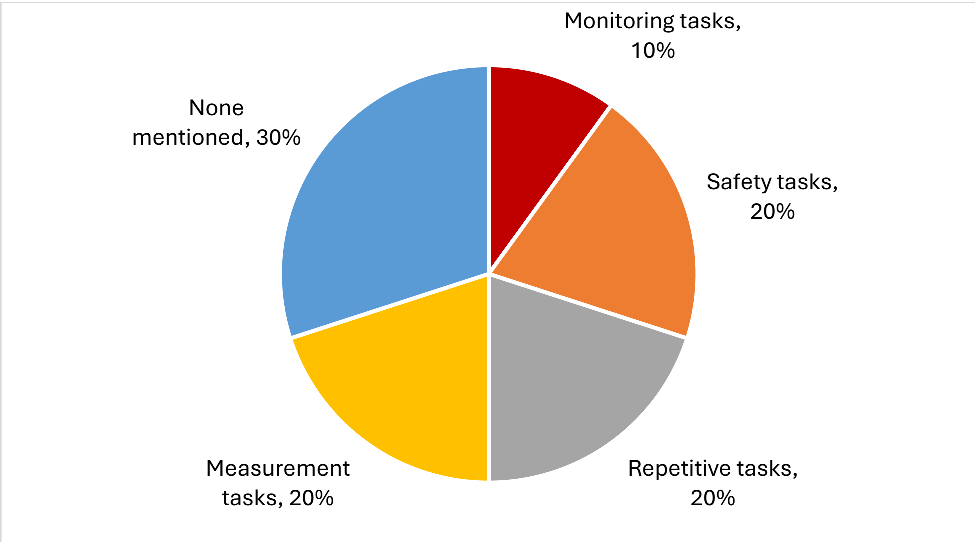


Figure 8: Perceived application areas or tasks for robots on site

Workers, however, showed a preference for robots to be used in high-risk and repetitive tasks, highlighting their potential to enhance safety and productivity. Figure 9 shows that some also saw value in robots assisting with managerial tasks such as using the robotic dog to monitor the construction progress, thus enabling an alternative way of verification for construction payment.

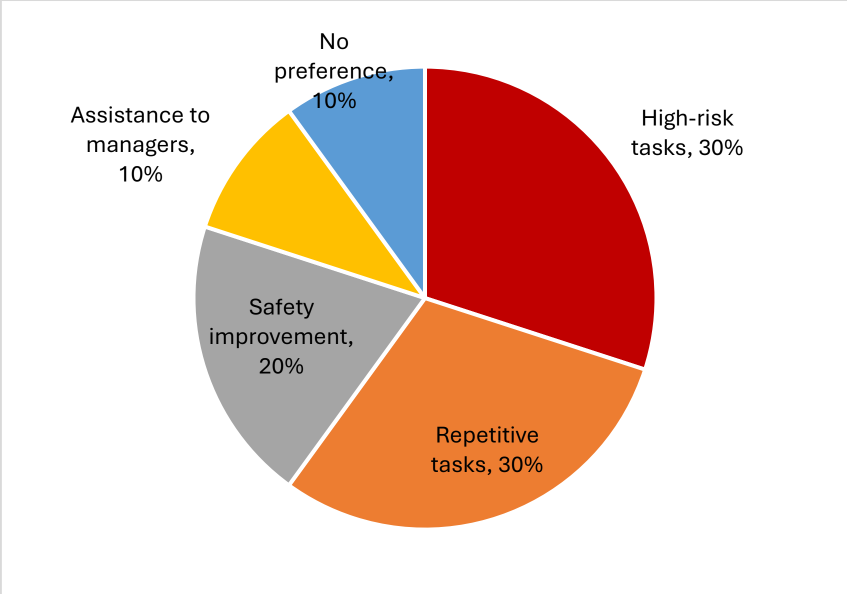


Figure 9: Perceived application areas for the robotic dog in construction

When asked if their attitude towards robotics in construction has changed after they have had the interactive experience with the robotic dog, six workers expressed interest in attending training or workshops, and being willing to learn how to further use robotics on site. Another three participants expressed conservative opinions, as they have seen the potential but concerned about health and safety risks for the unknowns the robotics can bring onto site. Only one participant was uncertain or resistant to the use of robotics as such, suggesting that he believes the robots can only do minimal and many on site jobs require significant human interventions/supervision.

How does the site demonstration of robotics de-risk its uptake?

The findings indicated mixed feelings towards adopting robotic technologies in construction. Generally, workers recognised the potential benefits robots can do, expressed the concerns about job security, and life safety risks and emphasised the need for comprehensive operational training, if they were to work with a robotic dog. These issues highlighted the necessity for strategic interventions systemically.

Using a system approach to look at this, as revealed in the causal loop diagram in Figure 10 below, the following key enablers play a significant role in driving the behavioural change towards adopting robotics.

- Proof of benefits: Compared to other automated solutions, robotic dogs seem to be more affordable and feasible to use to complete certain manual tasks on site, such as capturing the images and scanning. The proof of concept was achieved through on-site demonstration, with benefits witnessed by workers themselves. Providing training workshops and certification programmes at the sectoral level by the government agencies, certifying organisations and even accredited training institutions is needed to equip workers with the skills needed to operate and collaborate with robotic systems.
- Exposure and hands-on experience: The more construction workers see the work of robotic dogs on real construction sites, the easier for them to accept the use of it. Such an exposure, as

demonstrated in the case study, together with hands-on experience will make the use of robotics a business as usual (BAU).

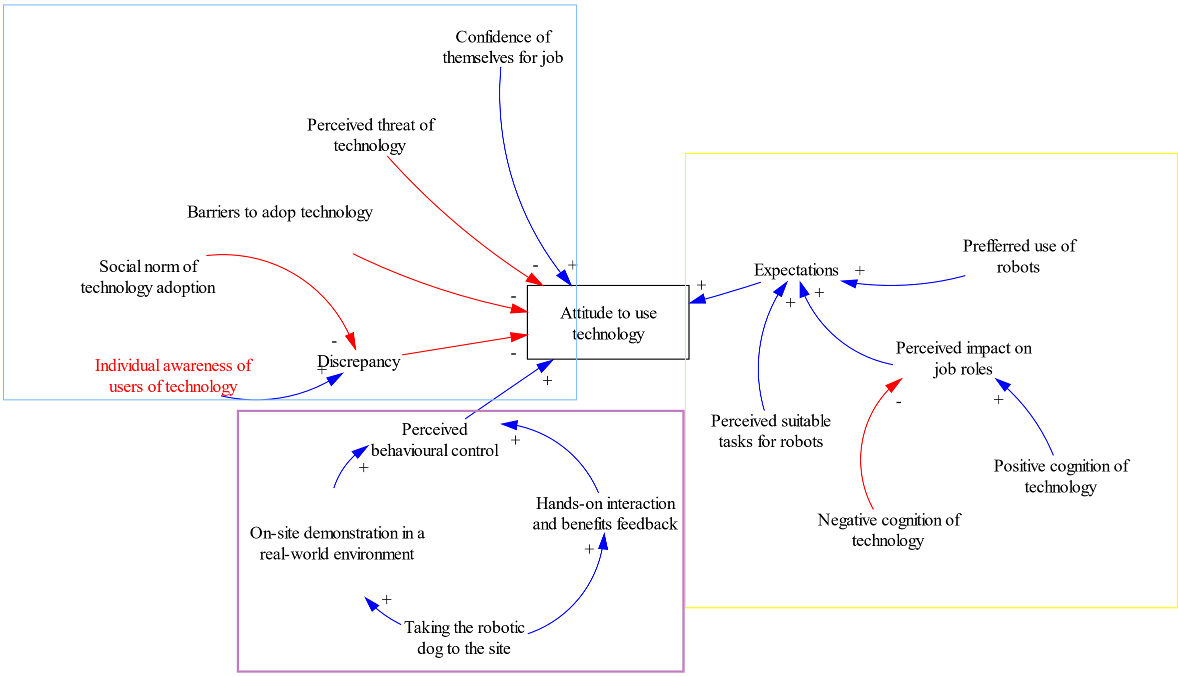


Figure 10: Casual loop of critical drivers that enable the change of attitude towards robotics adoption

This case study highlighted the importance of addressing technological and human factors in adopting robotics in the construction industry. By focusing on **trials and exposure** and having tangible benefits for the projects and businesses seen, the inertia to resist change within individuals will also reduce, which further lead to the change of attitude towards what has been introduced.

Case Study 2: Aronui Industry 4.0 Navigator

Intervention designed

Callaghan Innovation is a government agency that supports innovation and R&D in Aotearoa New Zealand. It launched the Aronui Industry 4.0 Navigator to help business leaders and senior managers get their heads around what Industry 4.0 means. The guided, interactive experience creates a unique environment to think strategically about how Industry 4.0 can address current and future disruptors to their business. The Aronui Industry 4.0 Navigator is free for Callaghan Innovation customers. This case study examines the effectiveness of Aronui Industry 4.0 Navigator in helping SMEs boost productivity and growth through the adoption of Industry 4.0 technologies.

Callaghan Innovation's Techweek Open day at the Aronui Industry 4.0 Navigator learning space provides the businesses with the opportunity for learning about Industry 4.0 and how it could be used to pursue productivity gains. The Aronui Navigator, funded by Callaghan Innovation, involves interactive digital touchscreens and spatial design to facilitate understanding and actionable planning for construction business leaders (See Figure 11 below). In particular, Techweek Open day is operated in a workshop format with a facilitator walking businesses through the evolution of industrial revolutions and highlighting the benefits of embedding Industry 4.0 technologies in business operations by showcasing use cases. For instance, participant businesses get to understand how smart machines are digitally connected with one another, creating and sharing information in real time to create competitive advantage.

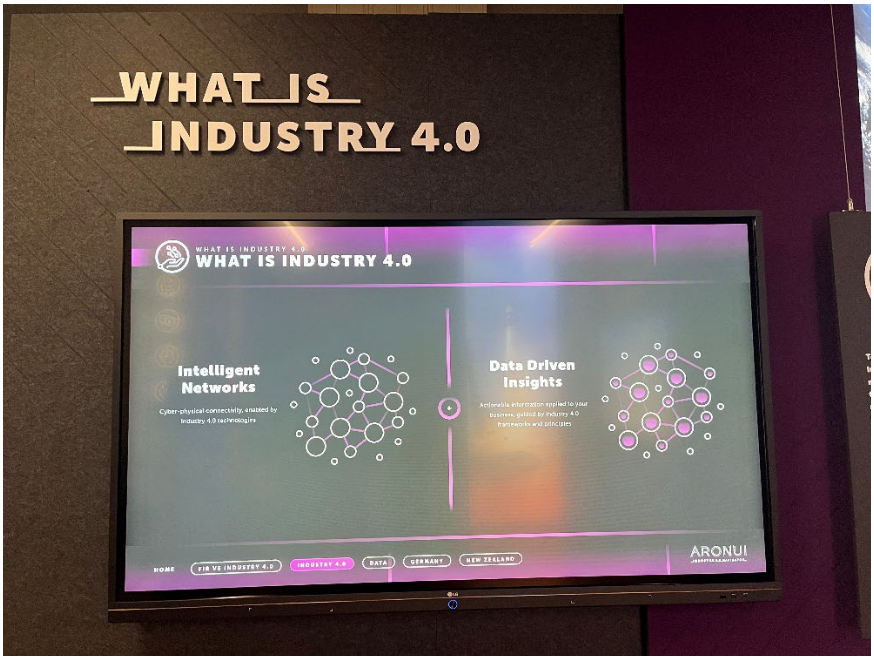


Figure 11: Aronui immersive workshop about Industry 4.0

Evaluation of the effectiveness of this intervention

Amongst many businesses in the manufacturing sector, Rinnai New Zealand was one of manufacturing businesses that provide products and services to the construction sector. Surveys were used to collect from participants about their opinions on the effectiveness of Aronui Industry 4.0 Navigator. The feedback received from Dean Cooper, Rinnai New Zealand's Manufacturing Manager who participated in Aronui Industry 4.0 Navigator was positive. He suggested that "*The Aronui Industry 4.0 Navigator was a really positive experience for our senior leadership team. It helped them understand what Industry 4.0 is all about and gave them confidence that this was the right path for us*."

Aronui Navigator not only explains the principles of Industry 4.0, it also demonstrates the case for change and helps businesses create an actionable strategy to move forward. It is designed in an immersive environment so that business representatives could immerse themselves in and engage with the facilitator/instructor as well as other like-minded people at the workshops. According to Dean Cooper, "*It puts everyone into the right headspace and guides you towards taking action*." And "*One of the big takeaways we got from the Aronui Industry 4.0 Navigator was that we had a very narrow view of what Industry 4.0 was. The experience showed us that Industry 4.0 presents so many other opportunities beyond the manufacturing processes and that we're just on the first leg of that journey*."

Rinnai New Zealand recently took its first step in its Industry 4.0 journey, piloting the use of real time data on its production lines, providing teams on the factory floor with immediate insights into their own performance and the ability to act on those insights.

How does Aronui Industry 4.0 Navigator de-risk uptake of Industry 4.0?

As shown in the casual loop diagram in Figure 12, the guided sessions at Aronui Industry 4.0 Navigator immersive learning space put everyone into the right headspace to think about and discuss the issues and opportunities faced in the engineering industry. Collectively, participants benefits from such walk through experience by understanding how Industry 4.0 applications could benefit the industry and transform how their businesses operate. Successful case studies were presented so that businesses could find relevance of applications in areas where they need innovative solutions to increase their efficiency or productivity.

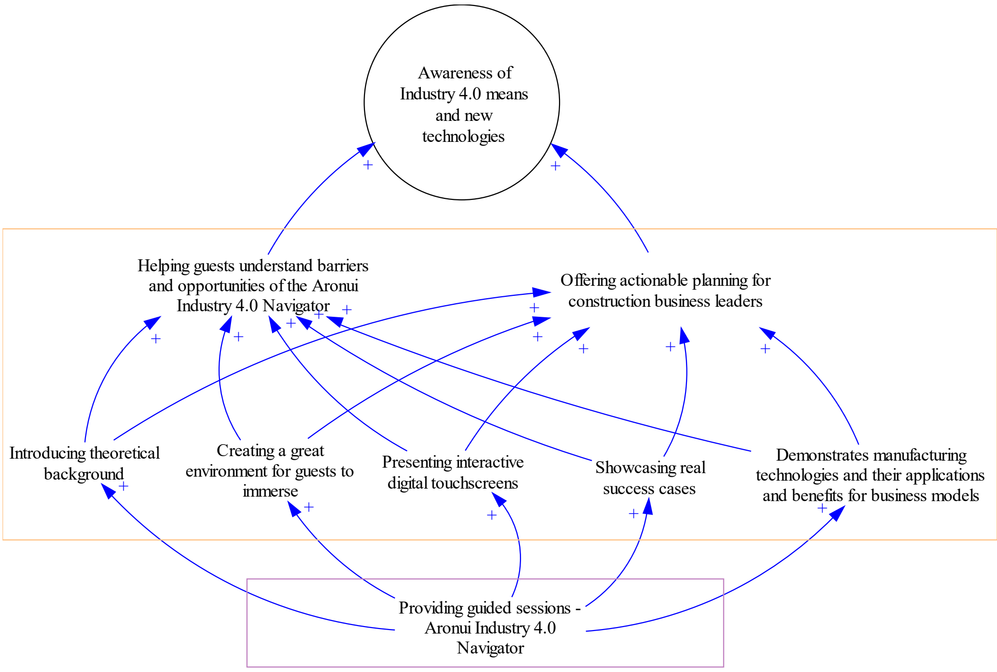


Figure 12: Casual loop of key measures included in the Aronui Industry 4.0 intervention

The feedback from other business participants in Aronui Industry 4.0 Navigator suggested that such an initiative has greatly enhanced their technological awareness. For several of businesses who received follow up assistance from Callaghan Innovation such as R&D grants, training, access to technical and expert support, it was a game changer in their innovation capabilities and overall business performance. The case study emphasised the role of government to support technology adoption through agencies like Callaghan Innovation.

Case study 3: Construction Activator Connect

Intervention introduced

The Construction Activator Connect (CAC) is an initiative comprising a series of workshops, events, online tools, and expert consultations led by Callaghan Innovation and the Construction Sector Accord. Since 2023, workshops were designed to offer technological application knowledge and successful stories of technology implementation with the wider audience in the sector, aimed at raising awareness about the profound impact, urgency and opportunities presented by technologies.

Evaluation of the effectiveness of this intervention

A survey was used to collect the attendees' feedback on workshops. The question "What, if anything, could be improved with the format or the flow of this event?"

A summary from data is presented below:

- Demonstrations of successful stories from companies like QOROX, Neocrete and ZXJ Construction highlighted the importance of building partnerships and networking, enabling knowledge sharing;
- Many participants appreciated the chance to connect with others in the industry, emphasising the importance of networking and exchanging ideas with regard to technology adoption as well as knowledge sharing as a positive aspect of the event;
- It was perceived well for participants being able to engage with industry leaders at the workshops to discuss challenges and explore innovative solutions collectively.

How does the Construction Activator Connect de-risk the uptake of technologies?

The casual effect relationships in Figure 13 below demonstrate how Construction Activator Connect workshops have influenced participating construction organisations' awareness of technologies on the behavioural change chain.

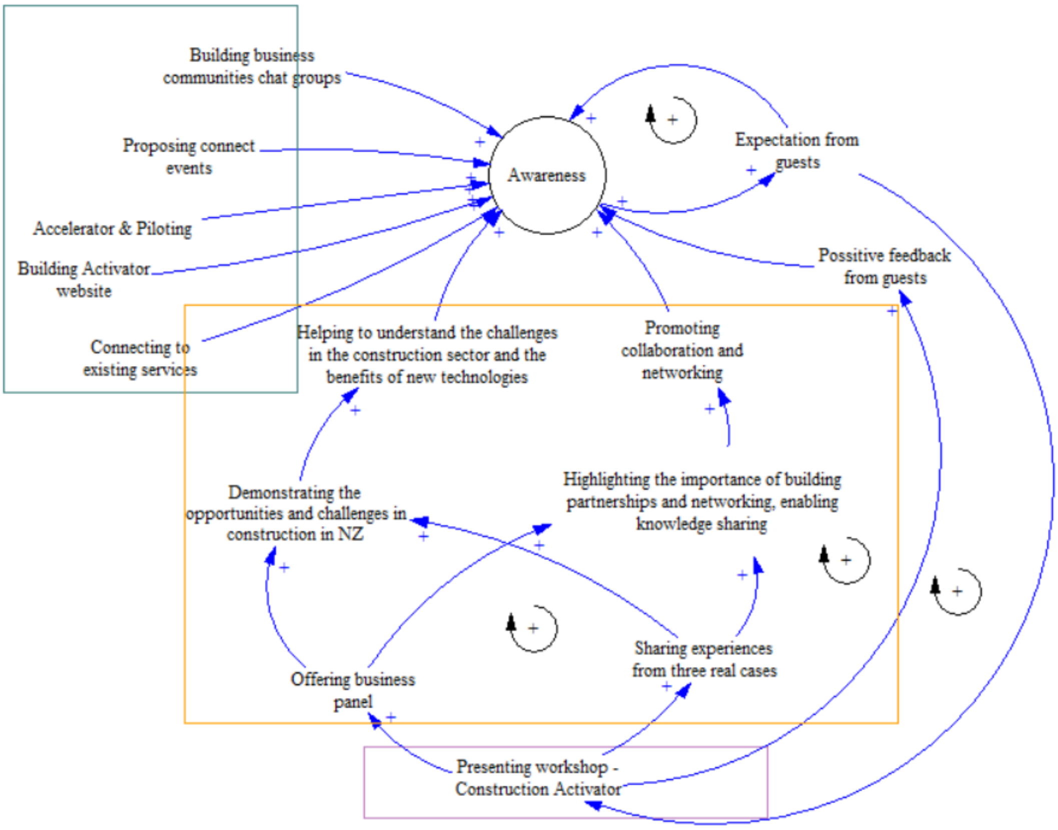


Figure 13: Casual loop of Construction Activator Connect influencing awareness about technological applications in the sector

Those workshops have provided the access to knowledge in technological applications. This result pointed to the importance of supporting innovation in the AEC sector by connecting them with success story of technology adopters or use cases so that the businesses can be encouraged and inspired.

Case study 4: Lab Open Day

Intervention introduced

This intervention was introduced to leverage the university's resources to support the innovation within the AEC sector. The universities are ideally positioned to bridge the gap between cutting-edge research and industry applications. The University of Auckland's Smart Digital Lab offers state-of-the-art facilities for both research and teaching in engineering innovation, featuring advanced technologies such as robotics, augmented reality (AR)/virtual reality (VR), 3D scanners, drone simulations, optical tracking systems, high-performance computing for simulations, digital twin modelling, and TRIMBLE technologies for precision engineering.

The University of Auckland, in collaboration with Callaghan Innovation and supported by Southbase Construction and 2KO Engineering Ltd, organised a half-day Lab Open Day on 15th August 2023. This intervention served as a platform to showcase a range of advanced technologies such as VR/AR applications (Figure 14), sensing technologies (Figure 15), and robotics (Figure 16) and introduce cutting-edge approaches to delivering construction projects. The goal was to facilitate knowledge sharing, promote technology adoption, and provide construction SME attendees with insights into the real-world applications of these innovative solutions.

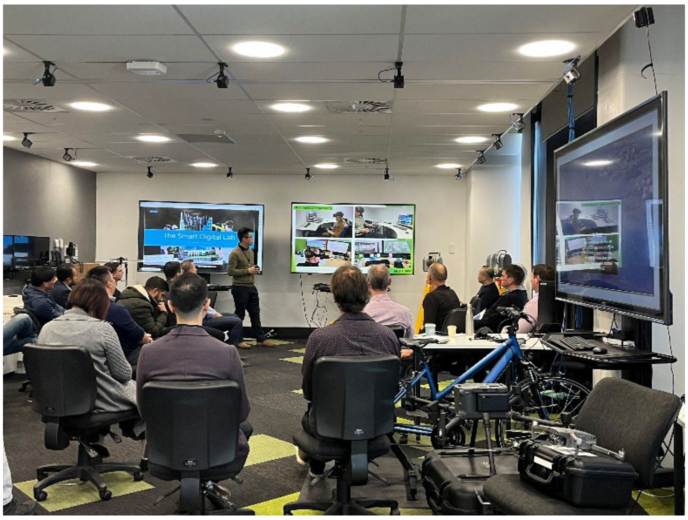


Figure 14: Demonstration of VR/AR applications in engineering projects by Benny Huang, South base Construction

Figure 15: Demonstration of using sensors to create a connected construction site by Leo Yang, 2KO Engineering

Figure 16: Demonstration of the application of a robotic dog in scanning and surveying by Dr Roy Davies and Na Zhou, the University of Auckland

Evaluation of the effectiveness of this intervention

Both a pre-survey and a post-survey were conducted to evaluate the effectiveness of this intervention. The pre-event survey collected demographic data from attending SMEs, and the expectation of what participants wanted to take away, while the post-event survey captured their feedback and evaluation of the event. These surveys provided valuable insights into the needs, interests, and the level of readiness of participating SMEs for adopting new technologies. A total of seventeen SMEs participated in the open day, however, eleven has completed the survey.

Key insights derived from participants' feedback

- **Informative content encourages behavioural change**: All participants who completed the survey found the session informative, with five strongly agreeing. Participants found the content effectively engaging and they were appreciative of the showcase of a series of technologies and introduction of the latest approaches to construction projects using these technologies. Nine out of those 11 participants reported a change in their mindset towards technology adoption, with five agreeing that the session helped them feel more confident about using technology. Such mindset shift suggested that this type of intervention which was focused on technologies in real projects applications proved to be effective in addressing the concerns or hesitations many SMEs hold towards adopting new technologies.
- **Hands-on experience**: The lab sessions provided a valuable opportunity to interact with the technologies. Participants appreciated the "touch and feel" aspect, which is important for enhance their connection with a particular type of technology in which they were interested. According to the feedback received, such an exposure to cutting-edge innovations was one of the most helpful aspects of the event.
- **Networking and knowledge sharing**: Several participants were especially appreciative of this opportunity of practical lecturing in a workshop format, it also connected them to other technology-leading businesses such as 2KO Engineering and Southbase Construction, fostering industry-wide connections and knowledge sharing.
- **Research support**: It proved that the effectiveness of co-location laboratory within research institutions for businesses to access key equipment resources and research expertise.
- **Attitudes on the adoption of new technologies:** Eight participants indicated that they plan to look into trialling some technologies in the next 3 to 6 months.

How does Lab Open Day de-risk the uptake of digital technologies?

There are critical ingredients within this intervention that had led to its success. Based on survey results, diagram in Figure 17 shows how each key ingredient or factor has contributed to driving the intention of some participating business participants towards pursuing implementing some technologies they had interacted with at the Lab Open Day.

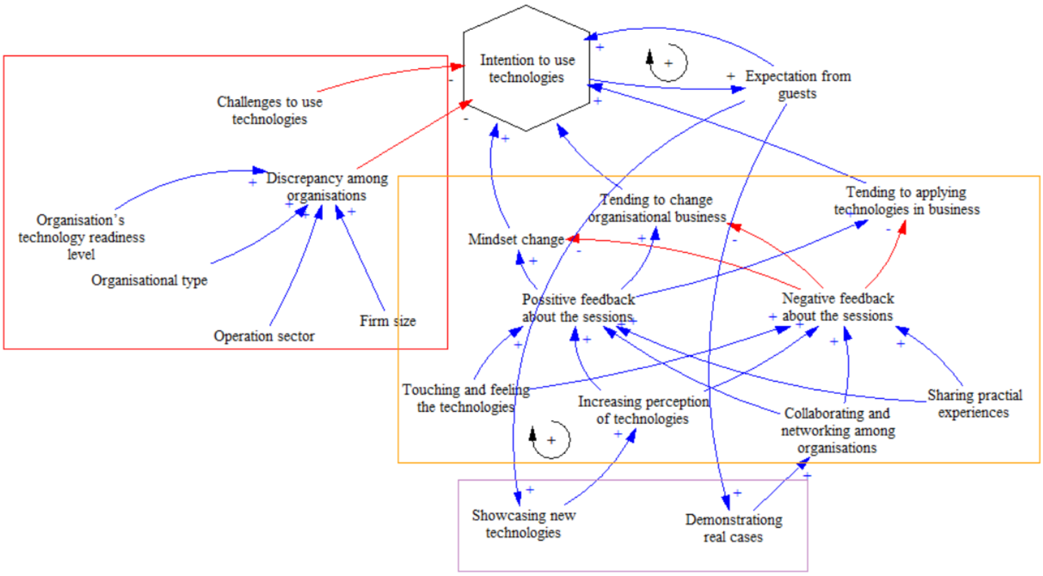


Figure 17: Casual loop of University Technology Lab Open Day influencing the technology adoption decisions

- **Education and training**: Despite understanding the benefits of applying technology, some participants found it challenging to decide which technologies would provide the most value, especially in terms of learning and implementation. There was also concern about the difficulty of learning new technologies, highlighting the need for more user-friendly training and educational resources.
- **High implementation cost**: The challenge of funding and resource allocation for adopting new technologies was raised by multiple participating SMEs. This highlighted the importance of knowing where the funding opportunities to support trials or innovation are for businesses to access.
- **Need for further hands-on engagement:** While the participants agreed on the benefits of lab sessions, some participants felt that the opportunity to interact with the technologies could be improved, such as offering more practical demonstrations and opportunities to test the technologies themselves could enhance the learning experience. This could help companies see the value of adopting new tools and approaches in their operations.
- **Government and regulatory support**: Some responses indicated that they yet to know how to align the use of technologies with government health and safety requirement at workplaces and the regulatory compliance can be barriers to technology adoption. Future events could explore these issues in more detail, perhaps by inviting policy experts or providing resources on navigating government regulations.

It is worth nothing that the research team had set up another Lab Open Day with a focus on construction robotics and 3D printing at the Advanced Manufacturing and Prototyping for Design (AMPD) Lab, Wellington Faculty of Architecture and Design Innovation, Victoria University of Wellington. However, there was a lack of attendance at the Wellington open day. While we had confirmed number of participants due to a busy period for the industry, none turned up. For future initiatives as such, it may be important to have better timing/on site or in-office experiences for people to better understand how to engage with technology uptake.

Case study 5: Arduino Sensors and Guest Lectures

Intervention introduced

This intervention was part of a postgraduate course at the University of Auckland designed for students from architectural, civil engineering, and construction management backgrounds. This course aims to enhance students' understanding of what future construction would look like and develop students' skills in technological implementation and innovation within these areas. The course combines theoretical knowledge, case studies, practical lab sessions, and guest lectures to emphasise the practical application of digital technologies, construction methods, and building systems.

The course introduces students to smart sensors, Building Information Modelling (BIM), robotics, and Augmented/Virtual Reality (AR/VR) through theoretical lessons and practical experiments. As a large number of postgraduate students undertake this course part time while working in the engineering/construction sector or some have had industry experience, this intervention was to introduce Arduino Sensors[4] for them to understand Internet of Things (IoT) concepts (See Figure 18) and its applications, as well as exposing them to guest lectures to understand how sensing technologies can be practically applied in construction projects.

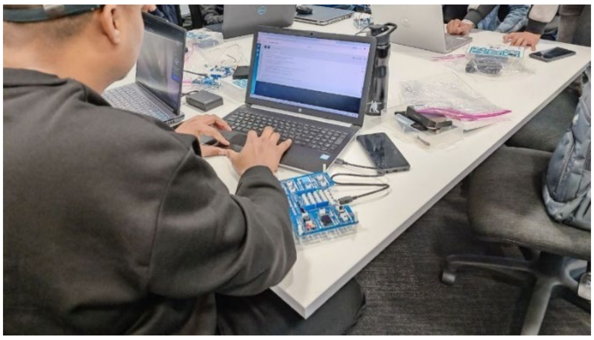
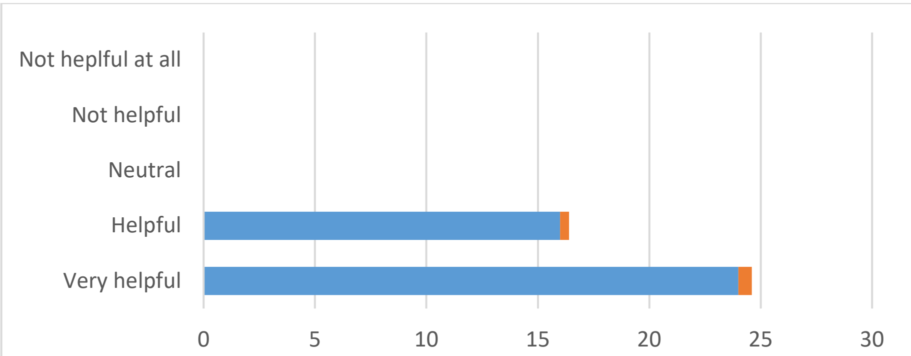


Figure 18: Students learning hands-on experience to build and programme Arduino sensors

Evaluation of the effectiveness of this intervention

Quantitative data was obtained from students' feedback from a survey on the effectiveness of the Arduino experiment on their learning. Survey responses were collected for the question: "Please select how helpful you found the Arduino experiment to improve your understanding of smart sensors and the loop of a cyber and physical system concept under Construction 4.0," with options ranging from "Very helpful" to "Not helpful at all." Qualitative data was obtained from the overall evaluation of the course, particularly focusing on the guest lectures.



	Very helpful	Helpful	Neutral	Not helpful	Not heplful at all
Count	24	16	0	0	0
Percentage	60%	40%	0%	0%	0%

Figure 19: Evaluation results of intervention effectiveness

Figure 19 above indicates a highly positive reception of forty students towards the Arduino hands-on trial. Most (60%) students found the experiment to be "very helpful" in enhancing their understanding of smart sensors and the cyber-physical system concept within Construction 4.0. Additionally, 40% of the students rated the experiment as "helpful." None of the respondents selected "neutral," "not helpful," or "not helpful at all," reflecting the agreement on the experiment's effectiveness. These results suggested that the practical, hands-on approach significantly contributed to students' learning

[4] Arduino is an open-source electronics platform based on easy-to-use hardware and software. See https://www.arduino.cc/

and comprehension of advanced technological concepts in how sensing systems work and can be applied in areas to solve real world problems.

The qualitative feedback highlighted the significant impact of guest lectures on students' learning experience. Students appreciated the insights industry professionals provided, emphasising how these sessions helped bridge the gap between theoretical knowledge and practical applications. As one student mentioned, "*I greatly appreciated the modules that demonstrated how these technologies are currently being utilised in construction sites. This contextual understanding made the concepts more relatable and emphasised the transformative impact of these tools on the industry*."

Students found the experiences shared by industry professionals to be highly applicable and beneficial to their learning. Another feedback stated, "*The guest lectures provided very in-depth and applicable experiences*." Additionally, the guest lectures' high quality and standards were frequently highlighted.

How does the practical hands-on experiments and guest lectures de-risk the uptake of technologies?

The causal loop diagram in Figure 20 below suggests that the combination of hands-on experience and exposure to industry practical applications of technologies significantly contributes to the heightened awareness of benefits or potential use cases of technologies such as the sensing technology.

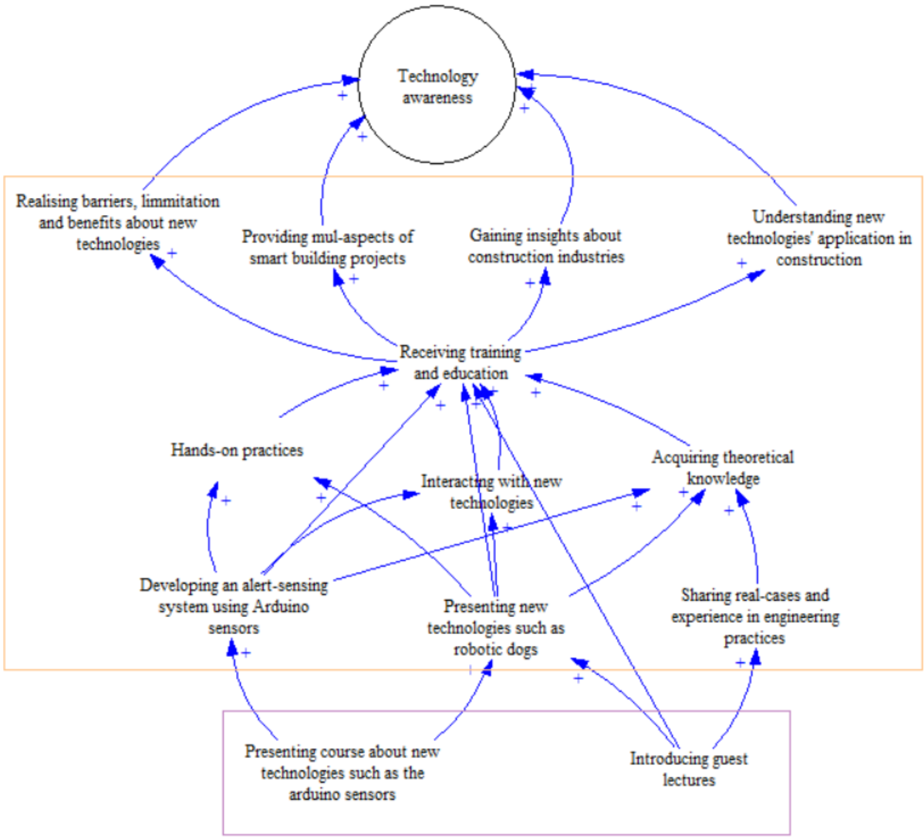


Figure 20: Causal loop of hands-on experience and guest lectures contributing to technological application awareness

This course combines practical experiments with theoretical lessons and industry insights and has proven highly effective in enhancing students' understanding and readiness for adopting new technologies. The hands-on trials on Arduino sensors are essential for bridging the gap between theoretical knowledge and real-world application, which enabled students to grasp complex concepts more effectively and develop practical skills.

Furthermore, guest lectures by industry professionals provided valuable insights and real-world context, which are crucial for students to understand the practical applications and benefits of new technologies in the construction industry. As future engineers, architects, and construction managers, the attitudes and knowledge of these students (the next generation of AEC professionals, or the upskilled existing workforce) towards new technologies will significantly influence their adoption within the industry and possibly lead their future companies towards innovation. Ultimately, these successful educational interventions will lead to a more technologically advanced and competitive AEC sector. It is anticipated that interventions of this kind would help the industry meet the evolving demands of construction and deliver better education outcomes.

Case study 6: Callaghan Innovation R&D support

Intervention introduced

This case study examines how the role of government to support technology adoption through agencies like Callaghan Innovation and how its R&D as an intervention strategy can lead to the change of behaviours of construction SMEs towards positive actions in adopting technology. As a public agency, Callaghan Innovation aims to help SMEs to boost productivity and growth through the innovation of smart technologies. It provides them with financial support, expert advice, innovation training programs and access to advanced technological resources.

One of the interventions from Callaghan Innovation is to provide financial assistance (R&D Grant) to support SMEs' research and development (R&D) of new products, services, and processes. Training and education programmes will also be offered to enhance the innovation capabilities of those businesses who seek support from Callaghan. Expert guidance and business mentorship will be granted to help those businesses that aim to accomplish the complex technical issues of innovation and technology adoption.

Evaluation of the effectiveness of this intervention

Callaghan collected data/information from those construction SMEs that received their R&D support and have started the innovation projects. Below is a list of feedback that are representative of the common comments from one 3D printing concrete start-up company XDi.

- Importance of funding and workforce: "*One of the biggest challenges with startups is funding, but also getting people to see the potential in a new technology. Callaghan Innovation has helped a lot in terms of [helping us] understand the market pain points, as well as seeing the potential of this technology to tackle those challenges*"; "XDi also accessed an R&D Experience Grant to support an Auckland University structural engineering student to undertake Master's research around 3D concrete printing."
- Financial performance and return "*and all at a competitive cost.*"

- Impact on practices: "*With varying efforts and grants, Callaghan Innovation has helped accelerate the R&D process, helping adapt overseas technology to suit the New Zealand market*"; "*By 3D printing concrete, substantial advantages over traditional construction methods can be achieved*."
- Improvement in productivity and efficiency: "*This includes the ability to build 75 per cent faster*."
- Improvement in sustainability: "*with 70 per cent less waste and 40 per cent less carbon emissions*."

How does the R&D support de-risk the uptake of technologies?

As shown in the causal loop of diagram in Figure 21 below, there are three important ingredients for the effectiveness of Callaghan Innovation's R&D support for SMEs, namely, 1) financial assistance, 2) training, and 3) access to technological resources and expert guidance.

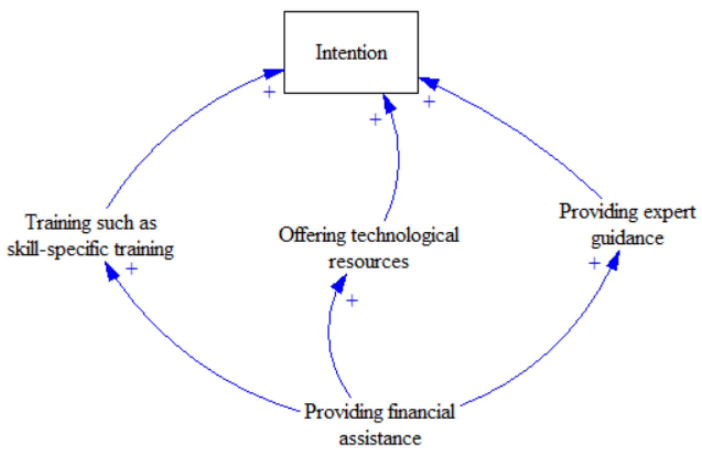


Figure 21: Causal loop of Callaghan Innovation's R&D support for construction SMEs

It needs to note that those SMEs who seek R&D support from Callaghan Innovation are largely those that at the point of intending to innovate to gain productivity gains. Therefore, 'where to start' is often the question they ask. Stepping out of their comfort zone and into an unknown terrain also introduce significant risks, including the financial cost and lack of technical expertise. Acknowledging these realities, this intervention from Collaghan Innovation emphasises their immediate need to access those resources. The findings also underscore the importance of providing financial support in parallel with technical support to de-risk the technology adoption. It is crucial for SMEs who are at the stage of wanting to go for a journey of trial and error. This ultimately delivers better outcomes for supporting the growth of technology adopters.

Case study 7: Southbase engaging a technology specialist

This cases study was prepared with the input from Benny Huang (Construction Technology Director at Southbase Construction) in the BRANZ-funded research project (LR12069) [6]. The lessons learned from Southbase Construction in terms of how they have taken the final step of investment to become technology ready will benefit other engineering and construction businesses as they navigate technological transformation.

Before the Covid-19 pandemic, the top management team at Southbase Construction was considering a call to action for embracing technologies within the business. They assessed the capacity and capabilities within the organisation and identified where the gaps were for the company to embrace digital technologies in all their engineering and building projects (e.g. what needs to be done by whom and when, and what needs to be in place and by when). This was followed by the development of a roadmap and detailed plans for technology adoption, including the necessary resources to deliver it. The company had set up a strategic framework to enable technology competency. The goal was to create or adapt the business model by creating a brand-new technology unit (BIM/Digital Engineering). They have therefore engaged a technology specialist to advise on how to set up this new technology or digital unit in terms of the unit structure, workflows and hardware and software, skillsets needed to make it functional supporting other units of the business (See Figure 22).

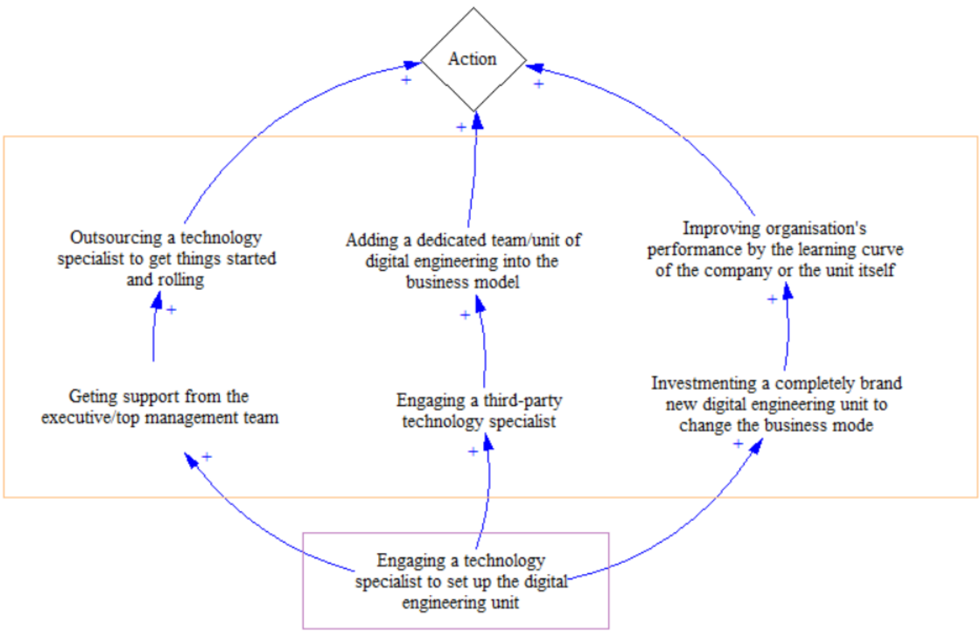


Figure 22: Casual loop of moving to action for embracing technologies within business

It is proven that this move was successful that the new digital engineering/BIM unit has been systematically integrated into the business at all levels. Experiences from this case study suggested that for businesses that take a lead role in integrating technologies into engineering or construction practices, the leap comes from commitment to a dedicated tech team that have also fundamentally changed how the business operates. Top management’s vision and action in engaging a specialist technologist to achieve this vision was crucial for the vision to eventuate.

Summary

The published "Industry Report on Digitalisation of Design and Construction of Class 2 Buildings in New South Wales" identified the key barriers to digital engineering in Australia, which bear the similarity to New Zealand AEC sector. The key barriers included high costs for software, digital tools and setting up equipment and IT specialists, inadequate design fees, and a lack of internal training programmes. Therefore, de-risk the uptake of technologies by addressing these barriers will be essential for promoting the industry's broader adoption of digital technologies.

The case studies and interventions introduced in this research suggested that successful technology adoption depends not only on the innovation itself but also on demonstrating the benefits (such as time and cost savings) to stakeholders and technology users. If the industry players could see the value of adopting new technologies and have done trials or pilot studies, it may help reduce resistance to change. Therefore, the low cost or no cost lab co-location is extremely beneficial as it provides a space and platform to showcase how technologies can be used in construction processes or project delivery, making them more efficient and reducing the need for human labour in repetitive or hazardous tasks. As shown in the interventions automated BIM (digital twin) for construction progress management, robots for site inspections and UAVs for surveying, have all demonstrated efficiency gains, cost savings and safety improvements, which are crucial outcomes when engaging the industry.

The next step for those who want to take the first step is conducting pilot programmes, substantial financial and technical support can help move the businesses forward toward making investment in embracing technologies. The education and training should follow through, in a format of workshops and courses, they help bridge the knowledge gap, making it easier for technology users to understand and implement these innovations. This is essential for technology adoption, as knowledge dissemination reduces resistance to change. Providing education and training could ensure that industry professionals are equipped to use them effectively.

Key implications

The system approach to analysing the interventions introduced shows that consistently *training, financial support, and hands-on demonstrations* significantly impact SMEs' readiness to adopt new technologies. The behavioural change model (Awareness, Attitude, Intention, Action) is crucial and interventions should be designed to target at different stage of behavioural change chain in order to effectively drive change. In particular, to de-risk technology adoption for SMEs, interventions shall be designed to shift the balance of risk, addressing the issues of perceived high costs and lack of expertise to make companies more willing to invest. Engaging multiple stakeholders in education and training, including government agencies, industry associations, and educational institutions, is critical for creating a supportive ecosystem for technology adoption. Figure 23 below summarises the list of interventions that proved to be effective to drive the behavioural change of SMEs toward technology adoption.

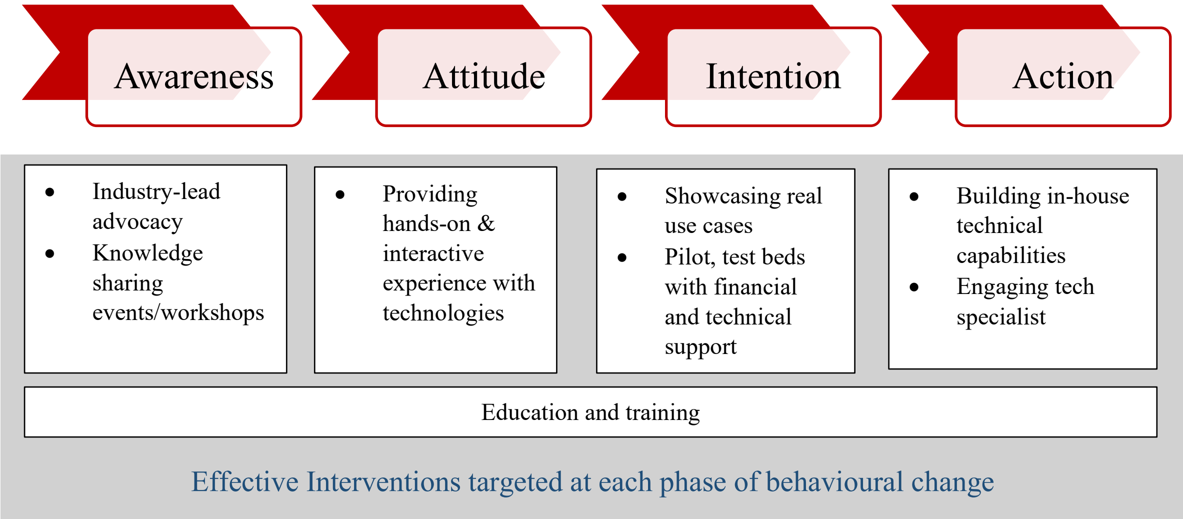


Figure 23: Summary of effective interventions driving the behavioural change of SMEs toward technology adoption

Case studies with selected SMEs highlighted the role of government policies and financial support in facilitating technology adoption. Simplified regulatory processes in terms of health and safety at workplaces that involve the use of new technologies and incentives are crucial. Continuous education and training programmes are essential at any stage of an organisation's technology readiness pathway to equip the workforce with the necessary skills for technology adoption. These implications collectively highlight the importance of a multi-faceted approach involving education, financial support, strategic leadership, and collaborative efforts to drive successful technology adoption in the AEC sector.

Recommendations

Based on the case studies and findings from analysis, below are a list of tailored recommendations for different types of organisations to create interventions to be widely adopted in the AEC sector that can de-risk technology adoption and encourage the change of behaviours.

- **Government agencies:** It is important for agencies such as Callaghan Innovation to continue to provide R&D grants and subsidies to reduce the financial burden on SMEs for innovative technology adoption. Central government agencies (i.e. MBIE) should also consider other means of financial support such as innovation vouchers and tax incentives. It is important for government agencies to look at how to simplify regulatory processes (e.g. compliance, health and safety at workplaces) to make it easier for companies to adopt new technologies. Government agencies can also work with industry associations to launch initiatives to raise awareness about the benefits of technology adoption and provide information on available support programmes.
- **Industry associations:** Professional bodies shall increase industry-lead training and education, such as workshops, seminars, and training programmes to upskill the workforce and educate them about new technologies and their applications. These events will benefit

when successful companies can share their experiences with regard to real use cases and the pathways of their technology adoption and learn from each other's successes and challenges. The professional bodies shall also advocate for the interests of the industry to government agencies, ensuring that policies and regulations support technological innovation.

- **Small and Medium Enterprises (SMEs) in the AEC sector:** It is a good practice to start with small-scale implementations of new technologies to manage risks and costs; start with technologies that offer clear and measurable benefits in terms of productivity, efficiency, and cost savings then gradually scale up based on the success of initial trials. In addition to business as usual, SMEs should leverage external support, looking for available financial and technical support from government programmes and industry initiatives to offset the costs and risks associated with technology adoption.
- **Education and training organisations (including research institutions):** In addition to university curriculum which integrates courses on digital technologies, AI, and other emerging technologies, it is important for research institutions especially universities to partner with industry to provide co-op programmes such as co-located labs, and collaborative research projects. Training organisations should also consider offering continuing education programmes and professional development courses for industry professionals to keep them updated on the latest technological advancements. Where possible, establishing research centres and labs that focus on developing and testing new technologies would provide great benefit for both academic research and industry application.

Each organisation plays a pivotal and indispensable role in fostering a culture of innovation and encouraging the widespread adoption of new technologies in the AEC sector. As development of technology advancements are rapidly developing, it is critical for the digital infrastructure such as data standardisation, cyber security, health and safety protocols associated with using devices such as robotics, sensors, etc to be in place. This will enable safe and effective use of technologies in the AEC sector to be part of BAU in the near future.

Appendix: Review of international literature on behavioural change models

Behavioural change models/theories

The evolution of behaviour change theories has been foundational in understanding the mechanisms underlying human actions (details in Table 3). Early theories, such as Hull's Drive Reduction Theory (1940s), focused on internal drives, suggesting that behaviours aim to maintain physiological balance [14]. In the mid-20th century, Leon Festinger's Cognitive Dissonance Theory (1960s) introduced the role of psychological discomfort in motivating changes in beliefs or actions, emphasising internal conflict as a driver of behaviour [16].

Table 3: Behaviour change models/theories

Time	Theory	Proposed by	Key Idea	Ref
1940s	Drive Reduction Theory	Clark L. Hull	Behaviour is motivated by biological drives (e.g., hunger, thirst) to reduce internal tension and maintain homeostasis	14
1954	Social Learning Theory	Julian Rotter (later expanded by Albert Bandura)	Behaviour is influenced by observational learning, imitation, and modeling within a social context	15
1960s	Theory of Cognitive Dissonance	Leon Festinger	People are motivated to reduce discomfort caused by conflicting beliefs and behaviours by changing either their attitudes or actions	16
1977	Self-Efficacy Theory	Albert Bandura	A person's belief in their ability to succeed in specific situations strongly influences their behaviour and persistence	17
1979	Health Belief Model (HBM)	Social psychologists at the U.S. Public Health Service	Behaviour change occurs when individuals perceive a health threat, understand the benefits of action, and overcome barriers to change	18
1980s	Theory of Planned Behavior (TPB)	Icek Ajzen	Intention to perform a behaviour is influenced by attitudes, subjective norms, and perceived behavioral control	19
1983	Transtheoretical Model (Stages of Change)	James Prochaska and Carlo DiClemente	Behaviour change is a process that occurs through six stages: pre-contemplation, contemplation, preparation, action, maintenance, and relapse	20
2000s	Behavioral Economics and Nudging	Daniel Kahneman, Amos Tversky,	Small changes in choice architecture (nudges) can lead to significant behavioural changes without	21

		Richard Thaler	restricting options	
2011	COM-B Model and Behavior Change Wheel	Susan Michie et al.	Behaviour is influenced by capability, opportunity, and motivation (COM-B), and interventions can target these factors systematically	22
2010s	Dual Process Theories	Various researchers	Human behaviour is governed by two systems: a fast, intuitive, emotional system (System 1) and a slow, deliberate, rational system (System 2)	23

By the late 20th century, more sophisticated models emerged, integrating psychological, social, and environmental factors. The Transtheoretical Model by Prochaska and DiClemente (1983) proposed that behaviour change is a process involving stages, from pre-contemplation to maintenance, highlighting readiness as critical to interventions [20]. Ajzen's Theory of Planned Behavior (1980s) focused on intention as a central predictor, influenced by attitudes, norms, and perceived control [7].

More recently, contemporary models like the COM-B framework by Michie et al. (2011), which includes nudging techniques, have provided actionable insights for designing interventions [22]. The COM-B model emphasises capability, opportunity, and motivation as the drivers of behaviour, offering a comprehensive tool for tailoring change strategies. Dual Process Theories (2010s) introduced a nuanced understanding of decision-making, distinguishing between intuitive and deliberate processes [23]. These models collectively demonstrate the increasing complexity and interdisciplinarity in understanding and influencing human behaviour, forming a robust foundation for modern intervention strategies.

Drivers/factors caused behaviour change

Behaviour change is driven by a complex interplay of factors such as personal factors, social and cultural influences, and environmental and situational conditions (sources are shown in Table 4). Personal factors such as beliefs, attitudes, and emotions are critical determinants of behaviour. Ajzen's Theory of Planned Behaviour emphasis that attitudes towards a behaviour, combined with perceived control and intention, predict the likelihood of behaviour change [19]. Similarly, Lerner et al. (2015) primely reviewed works on emotion and decision-making, then proposed the emotion-imbued choice model [34]. The results indicated how different personal emotions impacted judgment and decision-making. Emotional states, such as fear (e.g., health-related fears) or joy, act as powerful motivators, influencing both short-term and long-term behavior adjustments [35, 39]. Intrinsic motivations, such as the pursuit of personal goals, and extrinsic motivators, for instance, rewards or societal approval, often operate simultaneously, shaping behavior in nuanced ways [26].

Table 4: Drivers for behavioural change

Perspectives	Factors/Drivers	Ref
Personal factors	Beliefs and attitudes: changes in personal values, opinions, or worldviews can lead to behavior change.	[27, 31]
	Emotions: fear, happiness, sadness, or guilt can strongly influence decisions and actions.	[26, 33, 35, 39]
	Motivation: intrinsic or extrinsic motivations (e.g., personal growth, rewards) play a critical role.	[26]
	Cognitive biases: pre-existing mental shortcuts or perceptions that influence decision-making.	[33, 37, 42]
Social and cultural influences	Social norms: pressure to conform to societal or group expectations.	[25, 37]
	Peer influence: observing and imitating behaviors of friends, family, or colleagues.	[38]
	Cultural values: deep-seated traditions, practices, or beliefs of one's community.	[32, 40]
	Social identity: the need to align behavior with one's perceived social role or group identity.	[30]
	Regulations and laws: enforced rules that mandate or encourage specific behaviors.	[41]
Environmental and situational factors	Economic conditions: financial incentives or constraints.	[28]
	Physical environment: changes in surroundings, like urban planning or climate changes, can influence habits.	[29]
	Technology: exposure to new technologies or digital platforms that reshape habits.	[25, 36]

Social and cultural influences significantly shape behavior through social norms, peer pressure, and cultural values. Social Learning Theory by Bandura (1977) illustrates how individuals adopt behaviours by observing role models within their social networks [24]. Cultural frameworks also play a pivotal role; for instance, collectivist cultures may prioritise community well-being over individual autonomy, affecting health behaviors or environmental practices [32]. Peer influences are especially pronounced among adolescents and young adults [38]. The role of identity—both personal and social—is critical; individuals often align their behaviors with how they perceive their social roles or memberships in groups [30].

Environmental and situational factors encompass economic conditions, physical surroundings, and technological motivations. Opportunities, shaped by the availability of resources and supportive environments, are pivotal [28]. Physical surroundings, for example, urban form, may influence human activity and, in turn, prompt behavior change [29]. The driver 'technology' should be highly mentioned and discussed separately. With the rapid development of science, technological influences have increasingly become a prominent driver of behavior change. The benefit of technology adoption is clearly visible. Digital platforms, new technologies, and mobile applications leverage and accelerate behavioural change while causing more explorations and issues. As a fourth category for our moral psychology to deal with: artificial intelligence (AI), Bonnefon et al. (2024) pointed out that the very recent and rapid emergence of AI-driven technology is colliding with moral intuitions forged by culture and evolution over the span of millennia [25]. Innovations in new technologies like AI and BIM provide personalised feedback, nudges, and reminders. However, further sustained behaviour change and morality conflict should be noticed.

By integrating insights from personal, social, and environmental perspectives and leveraging modern technological advancements, behaviour change interventions can be tailored to address the diverse factors influencing human actions.

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