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Technology implementation: What does the future hold for construction?

Dr Alice Chang-Richards; Xichen Chen; Dr Antony Pelosi and Dr Nan Yang

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The University of Auckland, Victoria University of Wellington, Callaghan Innovation

1222 Moonshine Road
RD1, Porirua 5381
Private Bag 50 908
Porirua 5240
New Zealand
branz.nz

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Executive summary

The BRANZ supported research project, *Technology adoption roadmap for the New Zealand construction sector*, began in 2019 and involved extensive data collection. The project included an international literature review; a state-of-play survey of 428 architectural, engineering and construction organisations; and 38 in-depth interviews. In addtion, five deep dive case studies into the technology adoption and digital transformation journeys of AECOM, Beca, WSP, Downer and Hawkins were conducted.

Computer-aided design (CAD), cloud-based technology, global positioning systems, building information modelling (BIM), internet of things (IoT), smart sensors and virtual reality (VR) were technologies employed by the surveyed businesses. In addition, the large and established companies surveyed also showed rising interest in automation, artificial intelligence (AI) and digital twinning.

A number of insights were identified from the research that will prove helpful for industry planning. For instance, in terms of technology readiness, the top-performing engineering and construction companies were ahead of their peers by approximately 30%. These top performers have over 100 employees, and a technological divide was observed with small businesses having lower readiness levels.

Cost and client interest were the main factors influencing businesses' decisions on whether or not to introduce new technologies. However, a number of barriers to the uptake of technologies, predominantly around cost, legal aspects and human factors, were discovered.

Construction companies are generating more data than ever before, but only a very small portion of this data is usable. This seems to be a challenge throughout the whole process, from knowing what data to collect to understanding how to manage project data effectively. Construction professionals are also looking for tools that streamline every process, from pre-construction to closeout, by making smart, data-driven decisions.

The findings highlighted that digital literacy is central to technological transformation and identified skill gaps in the industry, such as building information modellers, data scientists/analysts, software programmers and digital project managers. Industry investment in capability building and skills training will be the most impactful enablers for faster technological and digital competency pathways. In addition, integrating data science principles into construction processes is important to achieve a more optimised way of working and improving decision making.

More needs to be done to support technology adoption laggards (i.e. most small and medium-sized enterprises [SMEs]) in effective change management. SMEs must understand how existing and emerging technologies can help support productivity gains and leverage adoption where it has been most successful. Attention should also be paid to supply chain businesses such as manufacturers and product distributors, as they form an essential part of the construction sector and their level of innovation and digitalisation is low.

While the economic benefits of technology implementation are evident from this research, further modelling is needed to evaluate the effectiveness of various interventions for adopting technologies. This modelling could provide evidence-based research to drive behavioural change towards technology adoption among SME organisations and individual practitioners in the sector.

"*The technology of the future is here today; the challenge is implementation*."

Jon Williams, Executive Director, Beca

This BRANZ commissioned research shows that many organisations in the architecture, engineering and construction (AEC) sector in New Zealand are in the midst of rapid innovation to compensate for many years of falling behind the technology revolution. The driving force for this is the need to "work smarter, not harder" while creating a tech-enabled future with enhanced productivity. With the rapid shift caused by the COVID-19 pandemic, the industry has taken on the daunting challenge of fostering innovation for a more productive and sustainable future.

Technology use internationally and in New Zealand

Internationally, BIM appears to be the single most commonly used technology in the AEC sector. It creates a common digital platform for improved data connectivity from other digital tools such as unmanned aerial vehicles (UAV)/systems (UAS), geographic information systems (GIS), light detection and ranging (LiDAR) and multidimensional modelling to realise a specifically defined benefit of a project (Chen et al., 2021). The research found that within New Zealand's large tech-savvy engineering consultancies and construction companies, BIM, combined with the Cloud, has been a pivotal asset that changes design, project communication and management processes.

Large companies are establishing technology innovation departments and investing in new technologies such as VR/AR, digital twinning, automation and on-site implementation testing. Most SMEs struggle to determine if the investment of time and capital is worth the resulting efficiency improvements.

A comparison of technology usage between international and New Zealand practice shows that large public and commercial building projects and leading engineering consultancies in New Zealand drive innovation. They have focused on applying **BIM, IoT and VR/AR technologies** (see case studies below). However, implementing these technologies still falls behind on smaller project scales.

In more digitally advanced countries/regions such as Europe, USA and Asia (e.g. Singapore, China, Japan), their construction industry is moving towards a more data-driven integrated value chain, from manufacturing to design and to construction and even operation. In these areas, AI and automation seem to play a major role throughout the whole lifecycle of a building project. The lack of innovation in the manufacturing and supply chain process in New Zealand might explain the insufficient interest in using building product tracking technologies such as radio-frequency identification and smart sensors that have been used widely in other countries.

Box 1: Case study: Implementation of BIM at full scale and VR in the City Rail Link project

> The City Rail Link is a first-of-its-kind project for New Zealand, which will provide new standards and inroads for the use of BIM throughout the country. The entire project is hosted on BIM 360. The project-specific Revit API tools "LKA Express Suite" developed by Roy Qian (Technical Principal – Design Automation) and his team allowed the project team to create a custom interface for data processing, documentation automation and computational modelling, saving 8,000 hours in design time. The Link Alliance also benefits from wide applications of VR for many aspects of the project, from design reviews to site safety and training.
>
> *"Linking the physical and digital worlds is a game-changer. With BIM, we can take the data from construction and automatically update the models, allowing a real-time feed to continuously update the design for optimised scheduling, time, and cost."*
> Brice Gaudin, former BIM Manager, Link Alliance
>
> Source: Interviews with Brice Gaudin and Laura Asis (former and current BIM Manager), Link Alliance Roy Qian (WSP), Chris Vorster (AECOM), Cameron Hyndman (Downer)

Governments in countries such as the UK have seen BIM as a "game changer" for the construction sector. With government-led impetus and mandating of BIM for public projects, industry has responded rapidly and positively with large scale adoption of BIM. This research exhibits a striking contrast in New Zealand where innovation has been largely driven by cost and client interest. Additionally, companies face resistance from subcontractors and tradespeople who perceive technologies such as VR as slower, less efficient and incapable of adapting to unpredictable site conditions.

For example, a large number of small engineering companies still consider CAD to be sufficient for drawings and design, and that BIM is only useful for large projects that involve large players. Unless driven by client requirements (such as the City Rail Link project), small businesses have little incentive to invest in BIM.

Our case studies of five large tech-leading engineering and construction companies (AECOM, Beca, WSP, Downer and Hawkins) show that their maturity in technology implementation comes to fruition after almost a decade of perseverance in trials and learning. The pace of using new technologies in various engineering and construction activities has increased over the past five years. This period has also seen a growing number of engineering professionals with technological skills and expertise that take the lead in leveraging data, especially big data. Below is a case study showcasing how home-grown expertise in New Zealand used AI to improve construction site management and operations (see Box 2 below).

Box 2: Case study: AI and IoT implementations in Wynyard 100

Wynyard 100 is New Zealand's first connected construction site – a collaboration of asBuilt (a technology provider), Microsoft, Spark and NZ Strong (a construction company). Wynyard 100 combines intelligent IoT devices, Microsoft's Azure Cloud and Power BI technology, drone and 3D camera imaging, and geolocation technology. A digital twin of the building is hosted in asBuilt's Vault platform and is accessible to the Wynyard 100 team to monitor people, the plant and the environment.

Machine learning is used to count people, measure environmental parameters (such as light, sound, CO_2, temperature and particles), read license plates, and identify whether personnel are wearing safety equipment or entering exclusion zones, for example. External equipment tracking plugins from contractors such as crane providers are integrated via Azure Cloud and external data streams from ERP systems and telematics providers.

"IoT enabled real-time noise monitoring has helped the project team manage council noise compliance on the construction site."
Leo Yang, AsBuilt

"The equipment and people location tracking has also established a safer construction environment and helped the project to gain greater efficiencies in construction management."
Ryuji Battad, Building Services Engineer, NZ Strong

Source: Interviews with Leo Yang (Associate Building Services Lead, asBuilt) and Ryuji Battad (Former Building Services Engineer, NZ Strong)

Asset management projects in the public sector have also taken the lead in implementing new technologies. Hastings District Council's construction of a digital twin for Toitoi – Hawke's Bay Arts and Events Centre, is understood to be the first application of digital twinning for asset management in New Zealand (see Box 3 below).

Box 3: Case study: Digital twin in Toitoi Hawke's Bay Arts and Events Centre

The Toitoi Arts and Event Centre BIM and digital twin project commenced and was completed in 2021. Hastings District Council initiated and implemented the project as part of its asset management digital transformation strategy. The overall objective was to use BIM to create a digital twin of the Toitoi building and establish a digital asset management platform that enables various management functions across the Council's property portfolio, comprising 140 public buildings. The BIM and digital twin project was driven by the Council's decision to adopt a BIM-based asset management system to support the asset's lifecycle planning through a consolidated digital management platform. The platform was developed on a GIS-based interface portal, which can host various data sources created from BIM and digital twins. The Council selected Toitoi as the pilot project for its overall BIM implementation programme, given the building's culture and heritage significance. The scope of Toitoi BIM and the digital twin project included laser scanning to collect data on the building's existing condition, 3D modelling based on scanned data and as-built documentation, and developing a BIM/user interface.

"As a key outcome, the BIM-based platform enables that all buildings across Council's property portfolio can be managed using a user interface with enhanced visualisation and reporting capability. The platform also provides easy access to asset data and information through a single source of truth. Most importantly, a BIM-based platform enables a whole range of management applications, such as operation, maintenance, programming, space and logistics management, renewal and upgrade planning, and any other applications that can be developed and implemented in a phased and modular fashion."
John Jiang, Property Assets and Projects Manager, Hastings District Council

Source: John Jiang (Property Assets and Projects Manager, Hastings District Council)

Forward thinking: Technology implementation in New Zealand

Figure 1 shows international practice and trends in technology applications at a project level. According to Boston Consulting Group research, full-scale digitisation may help the construction industry save between $1 trillion and $1.7 trillion annually worldwide (Gerbert et al., 2016). 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.

Most clients, however, being risk-averse, were reluctant to pay for work packages that involved new technologies unless there were cost and time savings that could justify technology investment decisions. The City Rail Link project, however, is hoped to be a real-time exemplar to demonstrate how substantial value (e.g. cost and time savings, improved quality, health and safety, as well as sustainability outcomes) can be achieved by extensively adopting **BIM, the Cloud, AR/VR, and digital** devices throughout its life cycle.

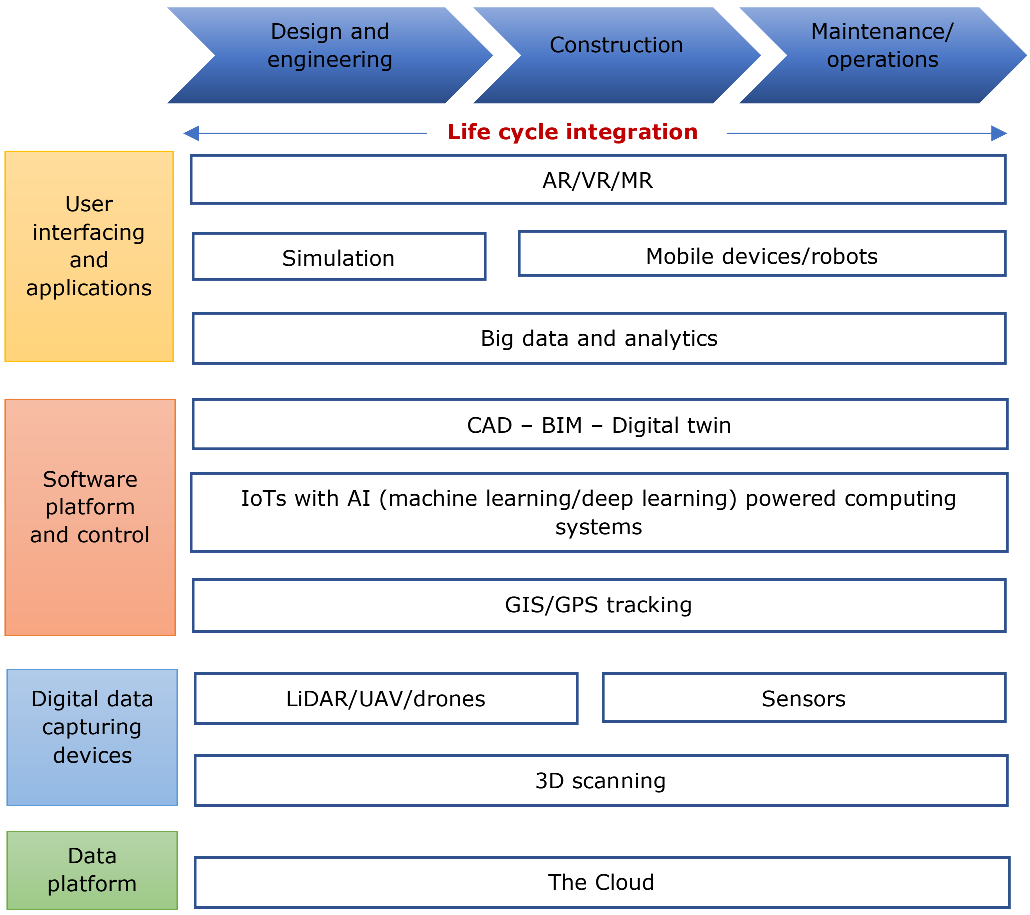

Figure 1: International practice and trend in technology applications at a project level (Adapted from World Economic Forum, 2016)

In particular, research shows that the application of the following technologies or further development should be pursued in the next five to ten years to unlock their full value and potential:

- Big data: Although each construction project is unique and has its own characteristics, the processes of planning, design, construction and even maintenance/operations have similarities. A large project contains a myriad of data (images, documents, drawings) that can be mined to generate new insights and inform design and construction decisions. Lessons learned from one project can also be applied to subsequent projects. Data mining and big data analytics skills are crucial to help individual companies/clients/project managers better collate and utilise project data. BIM-based big data will be useful for integrating data science principles into construction processes to achieve a more optimised way of working and improve decision making.
- AR/VR/MR: These immersive technologies can enable a virtual experience of a building throughout the lifecycle of a project. Some companies in this research have utilised this technology for health and safety induction/training, checking design errors and stakeholder engagement. However, advanced simulation can offer remote solutions for quality inspections of many structures and can be widely used in many other areas, such as guiding contractors with road maintenance work or undertaking underground utility work.
- Robotic technology and automation: This is an area that New Zealand construction companies need to monitor. Various robotic and automation devices are already in the market, market-ready, or close-to-market. However, this technology requires a higher initial investment with the benefits realised over the entire project lifecycle. Significant collaboration between research and development (R&D) institutions and construction companies is required to invent robots or automated systems fit for purpose to address labour shortage problems and improve efficiency.
- Digital twinning: With real-time data, simulation and AI, a digital twin building project can support decision making, from planning to building operations and asset management. To leverage digital twinning, five case studies of AECOM, Beca, WSP, Downer and Hawkins highlighted the need to have a national digital strategy in New Zealand, given the fast speed of digital transformation seen in many engineering and construction companies.

"A digitally built New Zealand that brings all the digital information together in a national way would better inform decision making."

Thomas Hyde, Chief Digital Officer, Beca

Current state-of-play in technology implementation

A state-of-play survey of 428 ACE organisations across New Zealand revealed that technology readiness is fragmented. Technology readiness assessment scores varied across different sub-sectors and tiers of organisations. On average, the technology readiness of the studied 428 organisations resided in the medium to high category. However, this result might be over-optimistic due to the self-reported nature of organisational/individual performance assessment. Further interviews have confirmed this assumption.

The business sizes of companies who participated in the survey reflected the general composition patterns of the construction sector in New Zealand. According to the Small Business Council (2019), there were nearly an equal number (41%) of small businesses (fewer than 20 employees) and large businesses (over 50 employees) that participated in the survey, plus 8% medium-sized businesses.

A technological divide is prominent between large and small businesses. The top-performing engineering and construction companies were ahead of their peers by about 30% in technology readiness. These companies already had business models and financial and amenities frameworks to adopt new technologies. A technological divide was observed, with small businesses having lower levels of readiness. Evidence shows that most SMEs had little financial ability to fund R&D and its infrastructure for adopting new technology.

A further 38 in-depth interviews with various companies and five case studies revealed the following patterns of technological implementation trajectories (see Table 1 below).

Table 1: Technological implementation trajectories of studied organisations

	Technology adoption laggards	**Technology adoption aspirants**	**Technology adoption leaders**
Investment (% of R&D, technology investment and innovation)	≤ 1% None or a few patched trials of technologies for proof of concepts in different application areas	1%–5% One or two work domains have been fully digitalised or with some technologies implemented	≥5% Business-wide digitalisation (especially BIM and/or Cloud enabled)
Skills/talent	None or having to outsource some work packages to technology providers	Recruiting technology talent	At scale, can provide in-house training and reskilling initiatives
Governance	None or being led by a business functional unit that requires assistance from technology providers	Pulling of technology and skills resources from across the business	Structured governance (e.g. having a digital engineering unit or chief digital officer)
Technology/data	Lack of clear technology and data strategy, disconnected data sources	Emerging transformative protocols for technology implementation and data consolidation	Having workflow and data standardisation and a clear technology implementation plan
Business model	A conventional business model or with none or a few technology use cases	A business model transforming to data-/knowledge-driven	A coalition of business, technology and analytics expertise
Culture/human factor	Resistance to change or low awareness of technologies and their benefits	Reactive change management initiatives for technology adoption	High digital literacy and technology-driven operations

What distinguishes the technology adoption leaders is the level of **leadership engagement and committed investment**. For instance, having a digital engineering unit or a chief digital officer in technology-leading engineering consultancies was a key feature. A coalition of business, technology and analytics expertise in those companies drives ownership of technology implementation and outcomes across the business. They also invest more in standardisation, setting clear milestones, and continue to upskill to achieve high digital literacy.

Barriers to effective technology implementation in construction

An issue to overcome in New Zealand is that more needs to be done for engineering/ construction SMEs to increase their awareness of the benefits that technologies offer, as the economic imperatives to drive further uptake of technologies are clear. The barriers to technology uptake fall into the three main categories: 1) cost concerns, 2) lack of legal support and 3) resistance to change complicated by human factors (see Figure 2 below).

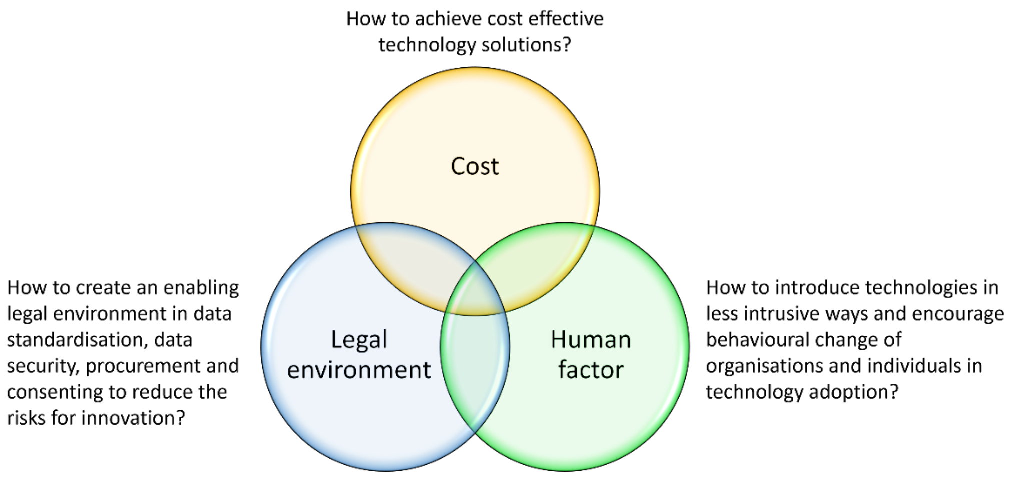

Figure 2: Issues to overcome for effective technology implementation in the New Zealand construction sector

"Achieving a digitally built New Zealand requires a national master plan, building regulatory frameworks to be flexible to allow for cost-effective technology adoption, and people to change their behaviours."

Cameron Hyndman, Digital Engineering Manager, Downer

Cost concerns

The cost of technology adoption includes initial costs to purchase hardware and software, staff training, and costs associated with establishing operating processes to adopt such technology. Most clients, however, were unwilling to pay this whole-of-chain cost unless the use of the technology would provide a return on investment. Like clients, small companies tend to be risk-averse unless compelled by a real need to adopt new technology. They are yet to see the real value in investing in digital technologies as their traditional business processes and operations seem adequate.

Lack of legal support for adopting new technologies

New Zealand is at risk of falling behind due to regulatory/policy hurdles. The legal framework of the construction sector is risk-based as opposed to value-driven. This discourages the use of introducing something new to construction projects unless the benefits and risk assessment have been thoroughly considered. Furthermore, the risk-based approach has ripple effects on a chain of actions in the sector, such as needing to design to Code and the decisions for resource or building consents by local authorities.

Interoperability issues for different data formats and operating systems and a lack of country-specific data standards impede the industry from increasing its future technological capabilities. The "single source of truth" was a phrase that highlighted the need across the sector for a single suite of BIM software such as Revit to address design and data interoperability issues. Players in one project often faced challenges with different data formats used in various devices, such as drones, LiDAR and sensors. Standardisation is needed for integrating data into a common digital/computing format.

Information hoarding is another major impediment to adopting many digital technologies across construction projects, as they are based on platforms that require information sharing. Commercial intellectual property and copyright impacts project participants' willingness to share data. Data security and privacy might be a good defence against information leaks potentially leading to disputes or contractual claims; however, this can also impede openly sharing learning with the wider sector.

Human factors – Resistance to change

Most SMEs expressed their reluctance to change unless there were client requirements or peer pressure from the market. This is partially due to cultural or human factors, where business as usual is considered to be good enough. However, for companies that are still indecisive about whether or not to adopt new technologies, market competition and peer pressure, combined with technology promotion in the wider sector (e.g. through use cases and technology requirements for publicly funded construction project procurement) are likely to propel them to act.

However, the research identified the importance of supporting technology adoption laggards (i.e. most SMEs) in effective change management. SMEs must understand how existing and emerging technologies can help support their productivity gains and leverage adoption where it has been most successful. Therefore, the change (or the willingness to change) can come directly from the value proposition of businesses themselves towards technology adoption instead of being compelled by external market competing factors.

Steps to successful technology adoption/implementation

"Key to successful technology implementation is taking a systemic approach and a business model that includes a people-focused talent strategy, an operational plan for process and an organisational culture of technology adoption."

Glen Mitchell (Services Engineer) and Christian McCartney (BIM and Technology Systems Lead), Hawkins

Step 1: Establishing the reason for adopting the technology

This very first step involves evaluating the value of implementing technologies. The decision about whether or not to adopt a certain technology could be based on emerging project opportunities, client requirements, the need to work smarter or to gain market advantages. A feasibility check is needed to see if the benefits outweigh the time, effort, talent and capital investment required by technology adoption.

For SMEs it is important to have a clear view of:

- Where the pinch points are
- Where the value of adopting technology is going to be
- What certain technologies or tools can (and cannot) do
- Who the technology providers are
- Who the other organisations are, such as technology providers or technology solution consultants and universities that can support technology adoption
- Emerging client or customer behaviours, supplier dynamics and regulations that warrant the use of a particular tool

Step 2: Identifying capacity and capability requirements

This step requires a business owner or senior management team to take a step back and assess the capacity and capabilities of the organisation needed to initiate technology adoption (e.g. what needs to be done by whom and when, and what needs to be in place and by when). This needs to be followed by developing a roadmap and detailed plans for technology adoption, including the necessary resources to deliver it. It is crucial that companies set up a strategic framework to enable technology competency. A detailed plan for tackling upcoming challenges when adopting technologies would be of significant benefit to a company during this process.

For most SME technology adoption laggards, this step can involve them forming strategic partnerships with technology providers. This can be done through consultation with Callaghan Innovation, who will provide insights into current technology solutions, benefits they can offer and technology providers in New Zealand or overseas.

Step 3: Creating or adapting the business model

For large companies that aspire to become technology-enabled, technology specialists and employees in other functional units need to work together to deliver incremental improvements continuously. These improvements might be driven by technology requirements for a construction project or changes in customer behaviours. The business also needs to be agile and to learn and adapt quickly.

It is crucial that SMEs can implement effective change management at this step by better communicating the likely changes regarding introducing new technologies to employees. This can include how technology implementation might impact stakeholders, the benefits it can deliver, and provide guidance on technology uptake.

Step 4: Buy-in and engagement

It is important to have staff on board who are influential and can communicate effectively to bring about a change in culture and mindset amongst employees at all levels, including:

- Educating clients/customers
- Getting leaders and executives on board
- Getting subcontractors and suppliers on board.

Our research showed that taking a “project driven” approach is highly effective. For instance, businesses and/or individuals with little technology experience can be quickly upskilled by participating in large and/or collaborative projects, as they can receive opportunities to be trained and learn from working with technology-mature companies.

Step 5: Changing organisational culture

Encouraging employees to explore and embrace a culture of lifelong learning is also key. Business owners should be tuned to technological changes and their potential business implications. They need to be willing to step out of their comfort zones and embrace change. Business owners are encouraged to attend and/or support their employees to attend industry seminars, workshops and events that showcase technology in real projects.

Technological competence or performance can also be included in employee KPIs. The types of support needed by individual employees to upskill concerning their technology competence or digital literacy could be reviewed regularly. Technological competence should also be included in employees’ career/personal development.

Step 6: Upskilling and recruiting

Upskilling and training includes comprehensive development programmes for employees to develop technical skills. Business owners or construction project managers need to articulate the critical skill sets needed for dynamic project portfolios or customer bases. There is a balance that needs to be achieved between relying on third-party developers/technology and providers/tech companies and incubating “home grown” solutions by recruiting or upskilling. The focus should be not just on keeping the right talent, but also on building people’s skills within the organisation.

Recruiting technical experts is a good option if there is currently limited in-house technology capability. Some large companies may want to establish and resource a digital construction or digital engineering unit to upskill employees and provide technical support to workers at the core of their business or a project.

Step 7: Starting small technology adoption trials

First, the focus should be on quick wins through testing and trialling some technologies in a few business areas or certain operational procedures tied directly to measurable business outcomes. Examples from companies interviewed included trialling drones to collect site data, using AR/VR to visualise building products and change the customer experience, creating a digital model using BIM, or automating a process within the business or on a construction project.

Scaling up or accelerating technology adoption comes from many small digital pilots, trials and proof of concept projects. Documenting the lessons learned from each initiative and creating a library of use cases of different technologies is essential for generating coherent and sustained efforts and ensuring the sustainability of technology adoption programmes.

What more could be done?

The New Zealand construction sector is data-rich but analytics-poor. This means that **capabilities need to be built around creating processes and expertise, including knowing what data to collect to understanding how to manage project data effectively**. It is important to understand that the role of technologies (as tools) is not to create this process, but to underpin it. With an eye to the future, the technology-laggard AEC businesses and those in the supply chain should leverage the experience of technology early adopters, effectively leapfrogging to become tech-competent. Below are some suggestions for what could be done to support innovation and encourage technology uptake.

Governance and leadership

- The industry itself should take the lead in developing technology implementation protocols.
  Idea/recommendation: Industry associations should take the lead and work together to develop a strategy that can enable member organisations to find technological solutions for their business domains. The umbrella organisation, Construction Industry Council (CIC), can enhance its mission of "A better built environment for all New Zealanders", by leveraging its network to provide construction businesses with resources and support in the three categories– cost, legal environment and human factors. What makes fertile ground for nourishing the uptake of digital and technological advances is the standardisation of data formats and protocols of technology implementation. Under the same technology implementation protocols, individual industry bodies can develop detailed steps for properly implementing innovative technology on-site – focused on minimal intrusiveness on workforce/behavioural change and maximum cost-effectiveness. CIC's support will provide those SME technology adoption laggards with the resources they need to start the construction technology revolution.

- International practice shows that government agencies can play a pivotal role in leading the digital transformation of the construction sector.
  Idea/recommendation: The New Zealand Government, through the Ministry of Business, Innovation and Employment, should look into innovation in the construction sector holistically, focusing on standards, procurement policies, improving regulatory approaches to code of compliance and consenting, and supporting partnerships with industry and education and training institutions. In addition, government agencies, as a client, should consider mandating digital engineering or BIM for all public projects.

- Small firms would benefit from "touching and/or seeing" the technology to determine its relevance.
  Idea/recommendation: Institutions such as BRANZ, Callaghan Innovation and universities/research centres in New Zealand need to work together to create a national technology hub or innovation centre. Such a facility could showcase how current and emerging technologies can help support productivity gains and leverage adoption where it has been most successful. For instance, Germany's Technical University of Munich has organised a platform of industry players that trains participants in digital construction through boot camps, hackathons, immersive days and peer exchanges (McKinsey, 2019).

Skills and training

- Industry investment in capability building and skills training will be the most impactful enablers for faster technological and digital competency pathways.
  Idea/recommendation: The industry's current skill gaps include building information modellers, data analysts/scientists, software programmers and digital project managers. The focus of both large organisations and SMEs should be on increasing digital literacy. For instance, a good starting point for construction SMEs could be hiring a drone operator, with management trained in accessing drone data, and subcontractors or tradespeople instructed how to work around them.

- Individuals and businesses in the AEC sector would benefit from flexible learning opportunities to upskill their technology skills.
  Idea/recommendation: While New Zealand universities (e.g. University of Auckland, Massey University, Unitec) are starting to offer courses such as BIM, construction informatics, digital engineering, construction technology and innovation for those entering tertiary education, there is a lack of micro-credential and flexible learning opportunities in multi-year qualifications. Short courses that offer on-site technology training would be a good option moving forward.

- A standalone disciplinary approach will no longer be helpful in creating critical talent capabilities in the sector.
  Idea/recommendation: The need for current and future skill sets in the sector is also changing. Technical skills such as machine learning and deep learning expertise are needed to create algorithms to derive new insights from construction project data and building operations. With AR/VR technologies, advanced simulation skills are needed to help identify interdependencies, conflicts, and errors during the design and engineering stages, and enable a virtual building experience to assist with design, construction, and maintenance. Education and training providers should look into smart delivery methods to embrace these opportunities in the curriculum.

SMEs' organisational capability building

- Partnerships would help small companies start adopting technologies.
  Idea/recommendation: SMEs that aspire to adopt new technologies should be more proactive by exploring government funding channels for grants and seed investment, and establishing partnerships with research groups and technology providers through Callaghan Innovation mechanisms.

- The easiest/quickest and most cost-effective way of learning the use of new technologies is on the job.
  Idea/recommendation: Where possible, SMEs should bid and participate in large construction projects where technologies play an important role and where in-house training is provided by the project office for all project participants.

- Being able to learn and adapt is another critical capability SMEs need to possess, especially in the post-COVID-19 era.
  Idea/recommendation: SMEs should embed a culture of experimentation/trials, learning and iterating, and empower employees by giving them clear roles and responsibilities to own a technology-enabled imitative while allowing them to take a certain level of risk and make mistakes.

While the economic benefits of technology implementation are evident from this research, further modelling is needed to evaluate the effectiveness of various interventions in adopting technologies. This modelling could provide evidence-based research to drive the behavioural change towards technology adoption among SME organisations and individual practitioners in the sector.

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- New Zealand Chinese Building Industry Association (NZCBIA)
- Association of Consulting and Engineering New Zealand (ACENZ)
- Prefab New Zealand (PrefabNZ)

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- WPS: Anderson Fang (Technical Principal) and Roy Qian (Technical Principal – Design Automation)
- Downer: Cameron Hyndman (Digital Engineering Manager)
- Hawkins: Glen Mitchell (Services Engineer) and Christian McCartney (BIM and Technology Systems Lead)

Appendix 1: Key technologies in the construction sector

Technology	Definition
Wireless local area networks (WLANs)	WLANs are radio-signal-based positioning systems, supported by underlying radio frequency (RF) and infrared (IR) transmission technologies.
Barcoding	Barcoding technology tags materials with symbols that can be scanned electronically using a laser or camera.
Mobile computing (MC)	MC allows the user to access data and information by using a computer without a fixed physical link.
Eye-tracking	Eye-tracking technology can track the rapid movements of the eye between fixation points followed by an eye-movement data analysis.
Zigbee	Zigbee is a short wireless network protocol based on IEEE 802.15.4.
Bluetooth	Bluetooth is a wireless technology capable of exchanging data and communicating over short distances.
Wireless sensor networks (WSNs)	A WSN is a self-organised wireless network consisting of a large number of sensor nodes that interact with the physical world.
Internet of Things (IoTs)	IoT enables real-time monitoring of devices dynamically achieved by multiple types of available sensors, and the interconnection of these smart objects into a global network.
Unmanned aerial vehicles/systems or drones (UAVs/UASs/drones)	Aircraft that work without a human pilot onboard. Primarily used to acquire information.
Ultra-wide band (UWB)	UWB is applied as a network of receivers and tags that communicate with one another.
Geographical information system (GIS)	GIS is a computer-based system to collect, store, integrate, manipulate, analyse, and display data in a spatially referenced environment.
Light/laser detection and ranging or 3D scanning (LiDAR/LADAR)	An optical remote sensing technology that can determine the distance between a sensor and an object or a surface.
Global positioning systems (GPS)	GPS is a satellite-based navigation system made up of a network of satellites.
Photogrammetry (photogrammetry or image processing or video-grammetry)	This technology acquires point cloud data by re-organising 2D images or videos that have overlapping intervals into 3D point clouds.
Sensor technology	Sensor technology enables smart sensors, such as FBG (Fiber Bragg grating) sensors and/or piezoelectric sensors to monitor people or buildings.
Radio-frequency identification (RFID)	RFID is a location system characterised with superior predispositions, including the recognition of multiple markers, communication ranges from five to six metres, and a storage database for thousands of data files.
Big data	Big data is capable of transforming the way in which organisations can visualise, function, and perform routines and practices which deal with large amounts of data.
Artificial intelligence (AI)	AI techniques include latent class clustering analysis (LCCA), hybrid models of case-based reasoning (CBR), analytic hierarchy processes (AHP), artificial neural

Technology	Definition
	networks (ANN), fuzzy logic (FL), genetic algorithms (GAs) and their derivatives.
Virtual prototyping (VP)	VP is a computer-aided design and manufacturing process concerned with the construction of virtual prototypes and realistic graphical simulations that address the broad issues of physical layout, operational concepts, functional specifications, and dynamic analysis under various operating environments.
nD (3D/4D/5D modelling)	nD models contain 3D geometric information and enable users to visualise the progress of a project when added to a time factor.
Immersive media (IM) including augmented reality (AR), virtual reality (VR), mixed reality (MR), and gaming technology	IM technologies enable users to visualise large amounts of complex data through free navigation in real time within a 3D environment.
Building Information Modelling (BIM)	BIM combines design and visualisation capabilities with rich parametric objects and the maximum level of detail in geometry.
Web services	Web services allow collaborative management under conditions of decentralised coordination and enable users to access, modify and update projects in accordance with a user's level of authority.
Additive manufacturing or 3D printing (AM)	AM is a manufacturing procedure that produces layers to create solid 3D objects from digital models, allowing engineers, architects and designers to create customised designs in one step.
Digital prefabrication (DFab)	DFab is based on a combination of computational design methods and automated construction processes, which are typically categorised as subtractive, formative or additive.
Robotics	Robotic technology covers systems from manually manipulated mechanical machinery, remote controlled semi-automated or automated devices, to more sensible and intelligent autonomous robots.

(Source: Chen et al., 2021)

Appendix 2: Technology use case examples

Technology	Use cases/comments by **engineering companies**
Cloud-based	"Online cloud-based GIS platform (e.g. ArcGIS pro) is essential for work planning in the water industry, especially for underground infrastructures that cannot be observed directly. Engineers from water authorities/companies rely heavily on those tools for design, construction, land investigation, etc. Other cloud-based tools include Maximo for asset management, instructing front line workers by scheduling their daily work, and recording their work progress accordingly. All the relevant data are stored in an online data warehouse in which data analysts can extract what they want flexibly. This tool is essential for the decision making of local infrastructure authorities/councils."
	"Dropbox is the main cloud-based tool for our company to store and remote monitor project data and related documents, and it is super convenient, safe as well as improved real-time communication during lockdown."
	"Cloud-based technology allows us to work remotely without being significantly affected by unanticipated influence factors, like a pandemic virus."
CAD	"CAD is needful and is the most common tool that has been used for structural designers. We are a small company with less than 10 staff, and most of our business is small-sized residential housing design and CAD is enough to fulfil all our daily job requirements. Besides, CAD is the most skilled tool that has been used to undertake nearly all our projects with both accuracy, efficiency, and time-saving."
	"CAD is a common tool used by architects and engineers, but I still prefer to use more advanced 3D modelling software like Tekla and Revit for structural shop drawings. BIM is too costly for a small business like us."
Sensors	<u>Water engineering industry</u>: "We use sensors to measure rainfall data, flow levels in streams and rivers and analysis of flooding levels, waste water levels in existing pipes. All data collection relies on sensors." (EC3) "Sensor technologies include those electronic devices widely installed in local water/wastewater networks, e.g. water meters, reservoir level sensors, river flow sensors, etc. Data provided by those devices are the very foundation of the water industry." (EC4)
	<u>Transport engineering:</u> "As a transport engineer, we use sensors for vehicle detection to collect data and control traffic lights. But this needs to couple with AI for plate detection, image recognition, and object tracking."
	<u>Infrastructure and asset management:</u> "IoTs and sensors, plus cloud are commonly used in surveillance and monitoring of infrastructure like dams."
	<u>Buildings – structural engineering:</u> "Sensor technology has been used in monitoring the structural health, for instance the deformation of structures, providing vulnerable data for seismic assessment and research."
UAV/drones	"UAV was used to generate aerial images, to enhance discussions, especially with clients and public without engineering background" (EC6). "UAV was used to generate aerial images so that we can receive different points and overview of the land in early phase land investigations. Besides, quite often we use those captured images in our annual meeting with clients or stakeholders." (EC7)
	We usually use UAV for topography survey of a large area. This survey data is particular important for flood routing analysis and design. Taking a dam breach analysis as an example. In the past, an engineer relies on surveying a limited number of cross sections along the dam downstream watercourse. Information between surveyed sections can only be interpolated. With drone survey, we are able to obtain continuous survey data for a massive area at a reasonable cost, which significantly addressed the limitation of analysis due to previously limited survey data."
	"UAV was mainly used for taking site photos and we then send to clients to report the construction progress. UAV is more flexible and precise when compared to traditional picture taking devices."

BIM	"Using BIM in projects, such as Revit, Navisworks, or Infraworks to model and collaborate with others such as architects, clients, other engineers, modellers, and public. It made a huge difference, better efficiency and collaboration, time-saving and more productivity."
	"CAD/BIM and even drones help a lot for the design, and then BIM is easy to use for better communication between different teams on-site."
	"We are mainly working on infrastructure projects which involve various working groups. We need to show clients a BIM management plan. BIM combines everything together. Every working group can communicate through BIM (communication channels) to revise or comment drawings or other working materials. BIM models can also fit in AR/VR models which we use to show the work flow to clients visually."
VR/AR	"We need to pre-design the night maintenance work by using VR/AR to optimise design for actual project."
	"We had VR/AR for health and safety induction in tunnels and other site hazards on-site."
Robotic technology	"We used robotic devices for CCTV in the pipes to do the inspections."

Technology	Use cases/comments by **building and construction companies**
Cloud-based	"We use Microsoft Cloud as a main tool for daily work."
	"We use BIM 360 another Autodesk service/product for cloud server – BIM 360 as the cloud server where everyone in the construction project or design project can work on the same model."
BIM	"We use BIM to check the design sketch of some house decoration jobs."
	"We use Autodesk Revit for shop drawings and create a 3D model of buildings. For a previous couple of projects, client kept taking them (BIM models) out as there's no capability within the main contractor or on the contracting side to use."
	"We use BIM for almost every project now. It helps us to check design errors and detect risks. This reduces the cost associated with risks as these risks could be flagged at an early stage of the project."
CAD	"Everyone loves a single source of truth. This is a phrase we always use. So for most subcontractors and SMEs, CAD is still the most commonly used tool for engineering design and drawings."
	"BIM software is too costly for us to use. When we propose our design proposal to customers, CAD drawings are sufficient, and also our product manufacture is using CAD, so there is no need for us to change to a 3D model unless it makes us more competitive."
	"Most building products are based on CAD, so in the residential sector, the design for most houses is not complex, CAD serves everyone well in the sector well."
UAV/drones	"We use it to investigate the topography of a large area during the construction planning phase."
	"For the drones, we use it for surveying of site conditions and a lot of information from the drones can be incorporated in the BIM model. Drone data is very high resolution and of high quality as well, that enhances the quality of our BIM model."

Appendix 3: Booklet – Best practice guidelines for technology adoption

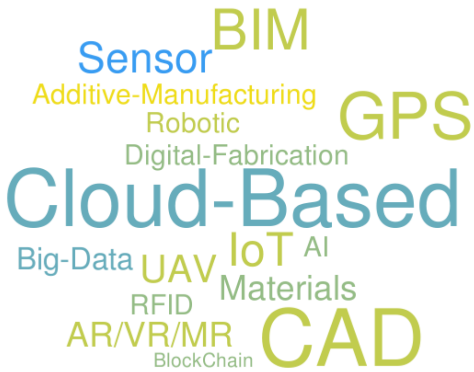
IMPROVING THE ODDS OF SUCCESS

BEST PRACTICE GUIDELINES TO TECHNOLOGY ADOPTION

Simple steps
to help your organisation
to be ready
for technology disruptions
and become confident and
competent in technology adoptio

A digital future lies ahead

With new and emerging technologies on the horizon, many construction businesses have no idea about where to start and how to respond to technology disruptions.



Technologies come in all types and functions, from smart sensors, drones, Building Information Modelling (BIM), Virtual Reality/ Augmented Reality (VR/AR) to Internet of Things (IoTs) and even large automation equipment. However, successfully implementing technologies within a project or an organisation continues to be a complex undertaking.

This short guide draws on findings from a BRANZ-funded research project "Technology landscape in the construction sector", including:

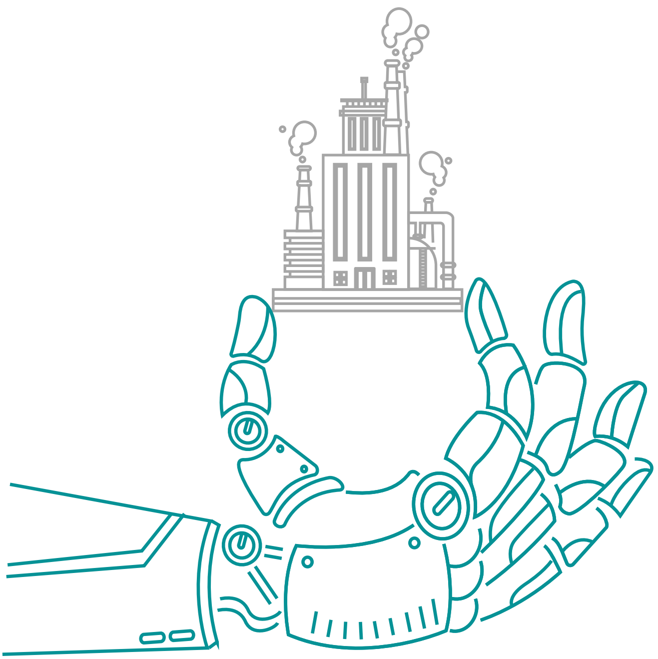
- A survey of 428 construction organisations
- 38 in-depth interviews
- Five case studies involving deep dives into the technology adoption and digital transformation journeys of Beca, AECOM, WSP, Downer and Hawkins.

This guide presents a 'big picture' view of transferable lessons learnt about effective technology adoption, highlighting the keys for success.

It has been created primarily for companies in the AEC (architectural, engineering and construction) sector seeking guidance and practical solutions to inform their technology adoption discourse.

Core Principles

- Know-how
- Start small
- A systemic approach
- Proactive, bold and persistent
- Flexible and adaptable



Know-how

Having a clear view of

- where the pinch points are for your business
- where the value of adopting technology is going to be
- what certain technologies or tools can (and cannot) do
- who the technology providers are
- what the other organisations are that can support your technology adoption
- emerging client or customer behaviours, supplier dynamics and regulations
- technology readiness through the development of a road map

Start small

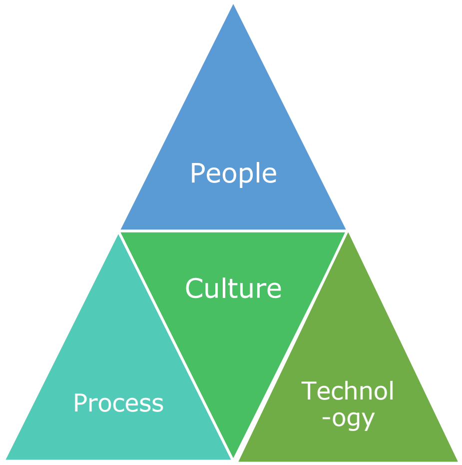
- Start with digital pilots and initiatives
- Aim for quick wins
- Take an incremental approach
- Embrace an active scaling-up approach through ongoing testing and continuous improvement

> *Adopting technologies is a 'corporate muscle' which construction organisations need to build; it isn't simply about training, but about embedding a culture of learning by practising experimentation and iterating.*

A systemic approach

People, Process, Technology and Culture (PPTC) form the golden triangle for technology adoption success, with culture at the core.

（Glen Mitchell, Hawkins）



Technology adoption cannot reap its full benefits without a business model that includes:

- A talent strategy (People)
- An operational plan (Process)
- An organisational culture of technology adoption (Culture)

> *While some companies may have recruited with talent in technology in mind, purchased the necessary devices, tools and software, changed the relevant processes and operational procedures, developed proof of concepts, and undertaken trials and pilots, this has not always resulted in the form of sustainable momentum needed to drive forward transformation in business technology. An effective organisational culture and a people-focussed approach are also needed to drive the digital engine and hardwire the benefits that technologies can offer.*

Build the plane as you fly

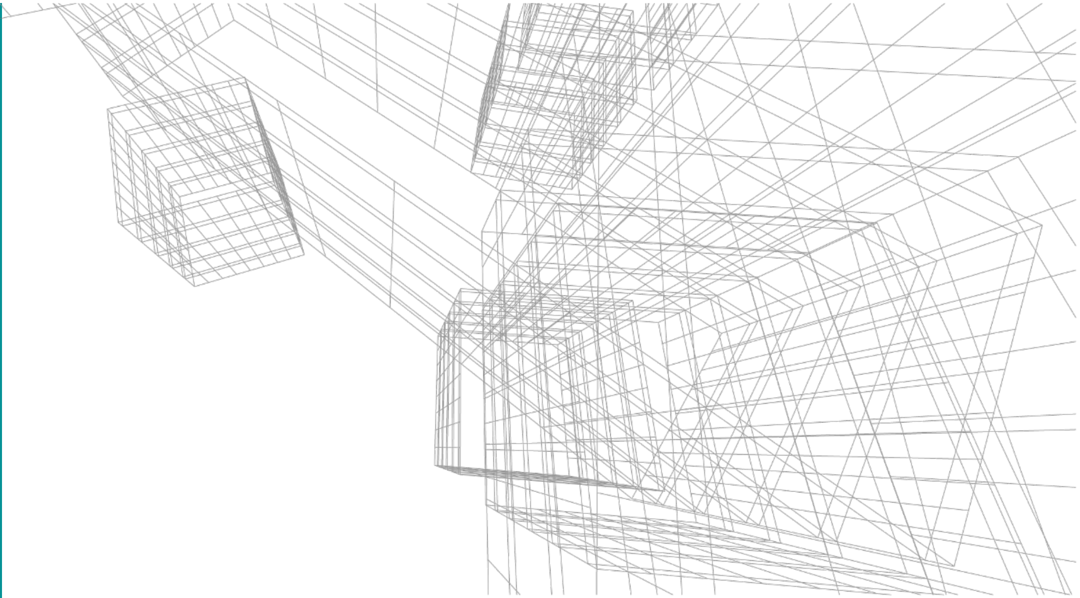
(Cameron Hyndman, Downer)

Proactive, bold and persistent

- Be bold in your approach with respect to decision-making and take actions tempered with an appreciation of risk
- Take on a forward-thinking mentality
- Think outside of the box - what can be done differently?
- Be prepared to fail and acknowledge that there is a learning curve involved

Flexible and adaptable

- Be open-minded and welcome to change
- Be able to learn and adapt
- “Catch them before they catch you” - move quickly and act early in technology adoption



> “*The case studies of five top-performing engineering and construction companies in technology adoption highlighted that technology should be a core driver of value, not merely a support function.*”

Best practice

Leadership

- Top leaders values innovation and provide support and resources

Organisational Culture

- Encourage employees to explore and try new things
- Set up information and knowledge sharing programmes and construct a rewarding system for knowledge sharing
- Run regular seminars or meetings to showcase technical deliverables

Training

- Provide internal training to employees
- Support employees to attend training and workshops provided by third parties

Recruitment

- Recruit technology experts or technology managers (e.g. Chief Digital Officer) to lead a technical team
- Recruit talents who are willing to learn and try new things

Strategy plan

- Collect information of new and emerging technologies, including the benefits, maturity, marketability, etc.
- Set up a strategic framework to be technology-competent step by step
- Adopt a people-process-technology system approach

Project-driving

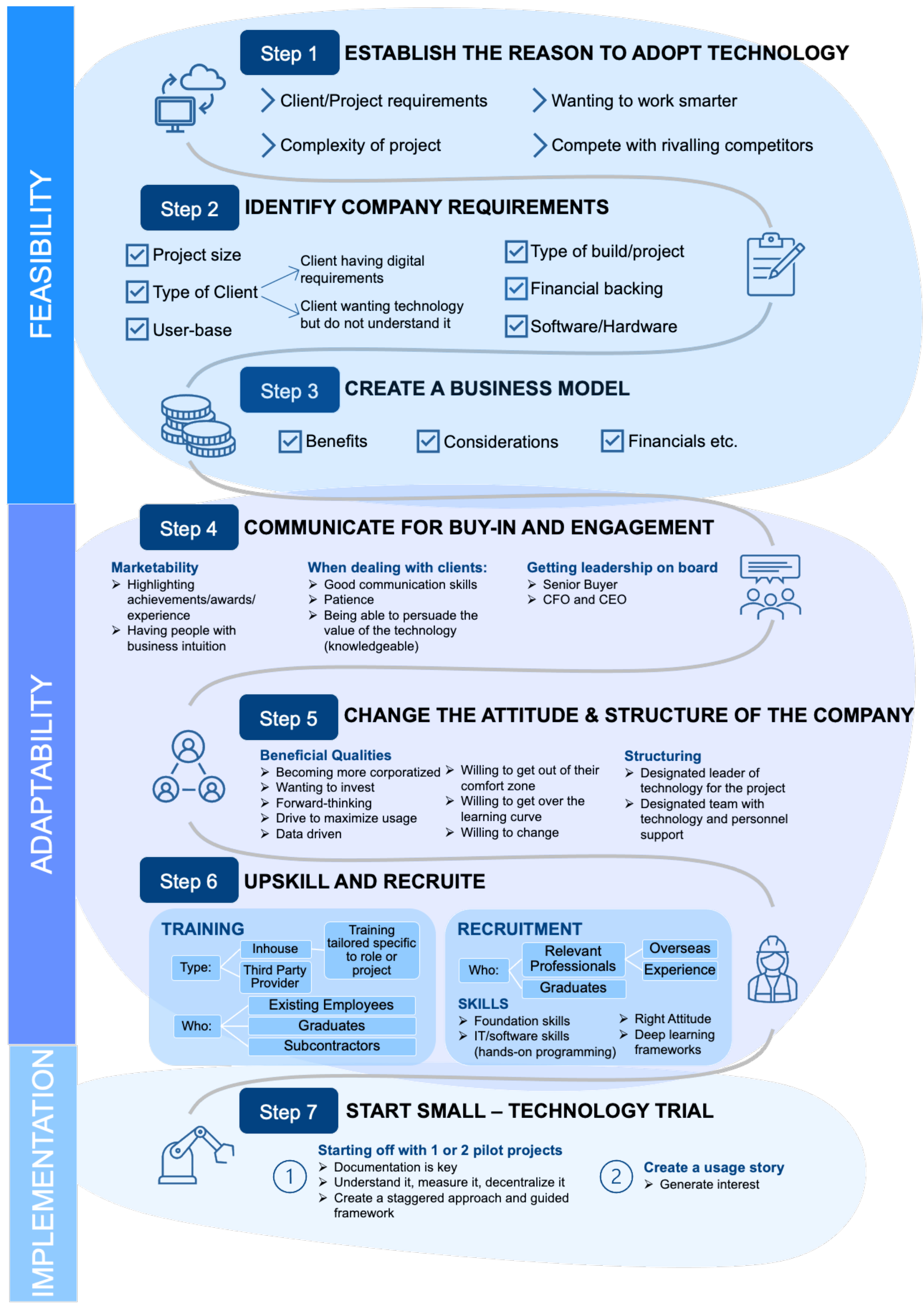
- Participate in big projects or collaborative projects that has a technology or digital requirement so that stuff and other subcontractors get upskilled
- Build-up digital engineering or construction portfolio across different projects

> *Our research shows that the top-performing engineering and construction companies in technology adoption were ahead of their peers by about 30 percent in terms of technology readiness. The companies that moved early and decisively are now leading technology transformation in the sector.*

SEVEN STEPS

FOR TECHNOLOGY ADOPTION

Moving towards digital and technology-enabled solutions is a proven strategy for improving productivity and unleashing the benefits of technology. However, many construction businesses, especially those that form part of the supply chain, face numerous challenges and barriers to technology adoption and are less inclined to start their journey towards adoption.


FEASIBILITY
ADAPTABILITY
IMPLEMENTATION
Step 1 ESTABLISH THE REASON TO ADOPT TECHNOLOGY
Client/Project requirements
Wanting to work smarter
Complexity of project
Compete with rivalling competitors
Step 2 IDENTIFY COMPANY REQUIREMENTS
Project size
Type of Client
User-base
Client having digital requirements
Client wanting technology but do not understand it
Type of build/project
Financial backing
Software/Hardware
Step 3 CREATE A BUSINESS MODEL
Benefits
Considerations
Financials etc.
Step 4 COMMUNICATE FOR BUY-IN AND ENGAGEMENT
Marketability
➢ Highlighting achievements/awards/ experience
➢ Having people with business intuition
When dealing with clients:
➢ Good communication skills
➢ Patience
➢ Being able to persuade the value of the technology (knowledgeable)
Getting leadership on board
➢ Senior Buyer
➢ CFO and CEO
Step 5 CHANGE THE ATTITUDE & STRUCTURE OF THE COMPANY
Beneficial Qualities
➢ Becoming more corporatized
➢ Wanting to invest
➢ Forward-thinking
➢ Drive to maximize usage
➢ Data driven
➢ Willing to get out of their comfort zone
➢ Willing to get over the learning curve
➢ Willing to change
Structuring
➢ Designated leader of technology for the project
➢ Designated team with technology and personnel support
Step 6 UPSKILL AND RECRUITE
TRAINING
Type:
Inhouse
Third Party Provider
Training tailored specific to role or project
Who:
Existing Employees
Graduates
Subcontractors
RECRUITMENT
Who:
Relevant Professionals
Graduates
Overseas
Experience
SKILLS
➢ Foundation skills
➢ IT/software skills (hands-on programming)
➢ Right Attitude
➢ Deep learning frameworks
Step 7 START SMALL – TECHNOLOGY TRIAL
1
Starting off with 1 or 2 pilot projects
➢ Documentation is key
➢ Understand it, measure it, decentralize it
➢ Create a staggered approach and guided framework
2
Create a usage story
➢ Generate interest

STEP 1: Establish the reason for adopting the technology

This very first step is about evaluating the value of implementing technologies. The decision about whether or not to adopt a certain technology could be based on emerging project opportunities, client requirements, the need to work smarter or to gain an advantageous position in the market.

This is a feasibility check to see if the benefits and other key considerations, such as finance, social, and political aspects, outweigh the time, effort, talent and capital investment required by technology adoption.

STEP 2: Identify capacity and capability requirements

This step requires the business owner or senior management team to take a step back and assess the capacity and capabilities of the organisation needed to initiate technology adoption (what needs to be done by whom and when, and what needs to be in place and by when).

This needs to be followed by the development of a roadmap and detailed plans for technology adoption and the necessary resource put in place to deliver on it.
It is crucial for companies to set up a strategic framework for enabling competency in technology. A detailed plan for tackling the upcoming challenges when adopting technologies will be of significant benefit to the company during the process.

STEP 3: Create or adapt the business model

To become technology-enabled, technology specialists and employees in other function units need to work together to continuously deliver incremental improvements. These might be driven by technology requirements from a construction project or by changes in customer behaviour.

The business also needs to be agile, able to learn and able to adapt quickly.

STEP 4: Buy-in and engagement

Having on board staff who are influential and able to communicate effectively to bring about a change to culture and mind-set amongst employees at all levels, including:

- Educating client/customers,
- Getting leaders and executives on board, and
- Getting subcontractors and suppliers on board

Our research shows that taking a “project-driven” approach is highly effective. For instance, providing opportunities for organisations with little experience in adopting BIM, AR/VR or sensing technologies to work with technology-mature companies in large-scale or collaborative projects that have a digital requirement is the quickest way to up-skill in technology adoption.

STEP 5: Change organisational culture

Encouraging employees to explore and embrace a culture of life-long learning is also key. Business owners should be tuned to technological changes and their potential implications for the business. They need to be willing to step out of their comfort zone and embrace change.

Business owners are encouraged to attend, and/or support their employees to attend, industry seminars, workshops and events that showcase the use of technology in real projects.

Technological competence or performance can also be included in employee KPIs, and the types of support needed by individual employees to upskill with respect to their technology competence or digital literacy can be reviewed on a regular basis.

STEP 6: Upskill and recruit

Upskilling and training require comprehensive development programmes for employees initiated by companies to develop technical skills in the use of technologies.

Business owners or construction project managers need to articulate what critical skill sets are needed for dynamic project portfolios or customer bases. There is a balance that needs to be achieved between relying on third party developers/technology providers/tech companies and incubating "home grown" solutions by recruiting or upskilling. The focus should be not just on keeping the right talent but also on building the skills of people the organisation already has in place.

If there is currently limited in-house technology capability, recruiting technical experts is a good option. Some large companies may want to establish and resource a digital construction or digital engineering unit to upskill employees and provide technological support to workers at the core of their business or on a project.

> *Our research shows that companies displaying a higher technology readiness score prioritise the development of highly-skilled or talented people and/or attracting employees with strong digital, analytics and coding capabilities.*
>
> *It is also evident that high-scoring large engineering and construction companies have a chief digital officer (CDO) who is part of the executive team and plays a pivotal role in the company's technological transformation.*

STEP 7: Start small technology adoption trials

To begin, focus on quick wins through the testing and trialling of some technologies in a few business areas or in certain operational procedures that are tied directly to measurable business outcomes. This could be through trialling the use of AR/VR to visualise building products and the outcome of an installation in a building project to change customer experience, the creation of a digital model using BIM, or automating a process within the business or on a construction project.

The scaling up or acceleration of technology adoption comes from many small digital pilots, trials and proof of concept projects. Documenting the lessons learned from each initiative and creating a library of use cases of different technologies are essential for generating coherent and sustained efforts and to ensure the sustainability of the technology adoption programme.

Detailed Action List

- Have the leadership and management team on board to support technology adoption
- Create a roadmap, accompanied by plans and strategies for technology adoption and assign ownership (roles/responsibilities) and resources to each initiative
- Make sure the organisational culture values and welcomes technological innovation or change
- Adapt a business model that supports technology-enabled business areas or projects
- Recruit the right people with technology capabilities
- Train and upskill employees in both knowledge about and competence in the use of new technologies
- Invest in adequate hardware and software systems or equipment infrastructure
- Participate in big projects or collaborative projects that have a digital requirement for gaining upskilling opportunities
- Take an ecosystem approach, seek help from technology/solution providers in NZ or internationally where needed
- Attend industry seminars, workshops and events that showcase technology use cases

The University of Auckland
Dr Alice Chang-Richards
Senior Lecturer
yan.chang@auckland.ac.nz

Xichen Chen
Research Assistant, Ph.D. Candidate
xche751@aucklanduni.ac.nz

Victoria University of Wellington
Dr Antony Pelosi
Senior Lecturer
antony.pelosi@vuw.ac.nz

Callaghan Innovation
Dr Nan Yang
Research Scientist
nan.yang@callaghaninnovation.govt.nz

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References

Chen, X., Chang-Richards, A.Y., Pelosi, A., Jia, Y., Shen, X., Siddiqui, M.K. and Yang, N. (2021), "Implementation of technologies in the construction industry: a systematic review", Engineering, Construction and Architectural Management, DOI: https://doi.org/10.1108/ECAM-02-2021-0172

Gerbert, P., Castagnino, S., Rothballer C., Renz, A., and Filitz R. (2016), "The transformative power of building information modeling: Digital in engineering and construction, Boston Dynamics Group, https://www.bcg.com/publications/2016/engineered-products-infrastructure-digital-transformative-power-building-information-modeling

World Economic Forum (2016), "Shaping the future of construction: A breakthrough in mindset and technology", May 2016

Small Business Council (2019), "Defining small business", https://www.mbie.govt.nz/assets/defining-small-business.pdf

McKinsey & Company (2019), "The impact and opportunities of automation in construction", https://www.mckinsey.com/business-functions/operations/our-insights/the-impact-and-opportunities-of-automation-in-construction