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Digitalisation of the New Zealand Building Industry

Capturing the Benefits of Digital Technologies on the Planning, Design, Construction and Management of Buildings.

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Foreword

Digital technologies have pervaded almost every area of our lives. Without necessarily understanding how they work, we enjoy the benefits of digital technologies in the cars we drive, home appliances, logistics, communications, business systems, and many other seen and unseen applications.

Most sectors of industry are relentlessly driven to exploit technology to improve the functionality, performance and cost-effectiveness of their products and services. The consequences of not getting technology strategies right can be swift and devastating. Nokia is a good example of how quickly fortunes can turn. Their share of the global smartphone market fell from 50% to less than 5% over a period of six years, largely due to the decisions they made concerning digital technologies. This level of drive to exploit technologies to improve products and services is not so evident in the building industry.

As this paper points out, construction sits markedly lower in the rankings of all sectors when it comes to developing and using digital technologies, although some technologies such as BIM are starting to penetrate parts of the sector. Some commentators believe the slow uptake of digital technologies provides opportunities for disruptive innovation of the sector. While this may be true, there are many hurdles to digitalising construction, which makes innovation in this area challenging.

This paper is thoroughly recommended to the reader as it identifies the value potential and the opportunities and development and implementation challenges associated with existing and emerging digital building technologies, from the perspective of the New Zealand construction sector.

The information in this paper should be useful to all construction-related organisations when they go through the process of developing their technology strategies. Information in this paper will also be used by the Building Innovation Partnership to support the uptake of digital building technologies by industry.

Lindsay C Crossen

Chair: BIP Overview Panel

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Executive summary

The building industry globally recognises that it has lagged behind other sectors in productivity improvements and the uptake of technology, and that there is a need for change. Major international studies show that productivity in this industry is near the bottom of all sectors, and technology supported change is not as prevalent as it is in other sectors.

Digital technology offers enormous potential to increase value for money in terms of productivity and competitiveness. Leading companies across the world have demonstrated the benefits that can accrue from technology supported change. New Zealand companies can learn from these experiences and gain benefits across the phases of planning, design, construction, operation and demolition or recycling.

Increased digitalisation of the building industry should not be seen as an end in its own right. However, the need to transform the building industry, as recognised by the recent government and industry Construction Accord, will rely heavily on digital technologies.

While the benefits and value of a technological intervention are dependent upon many factors contributing to an individual project, it is clear from overseas experience that perseverance and embedding change will unlock the benefits.

To ensure that New Zealand's building industry gains the maximum benefit from technological transformation we make the following recommendations for 2020-2025:

- That the government commissions and commits to a digital transformation blueprint with a clear vision of the future of the building industry.
- That the technology sector is supported and developed through national showcases, case studies and grass-roots initiatives that allow transfer of knowledge within the sector. For example, a range of forums for individual technological innovations such as the successful BIM forums run in Christchurch, Wellington and Auckland.
- That companies and construction projects are supported to embed change into their processes to achieve the scale required to unlock technology supported improvements.
- That whole of industry approaches are developed to fix pain points currently impeding technology supported change.
- That the regulatory framework is adapted to incentivise investment decisions and new ways of contracting.
- That clients, including government agencies, are educated to mandate the use of best practice technologies and standards on their projects (e.g., requiring as-built BIM models for operations and asset management).
- That Central Government shows leadership through procurement rules that incentivise an all-of-government approach to the use of BIM.
- That a greater focus is placed upon training and skill development of the whole workforce for the digital future. This must encompass managers through to those on construction sites.
- That industry and government choose, or develop, data standards and standard approaches to technology deployment for the nation.
- That security and privacy become a standard consideration for all technological innovations.

Acknowledgements

The development of this white paper has been significantly enhanced by generous input from a wide range of individuals. Jon Williams from Beca provided an extensive review of the late draft of this paper providing many important recommendations and commentary. Matt Thomas of The Garage Business Consultants provided recommendations which would transform the whole NZ building industry. Ben Broad from Trimble and on the BIP Industry Advisory Board provided suggestions on directions and technology.

Greg Preston and Dr Robert Finch from the Quake Centre and the BIP provided direction and guidance through the many iterations of this paper.

The NZ survey participants provided great insight into the current state of technology adoption with some surprising outcomes in comparison to the rest of the world.

Profs Larry Bellamy and Robert Amor were privileged to be hosted by many of the top companies and organisations around the world on their study tours leading into this white paper, they include: Gehry, Land Information Center, CIC, CITAC, BCA, Beca, Trimble, DPR Construction, CIFE, CDBB, MTC, Bentley, DAFNI, BRE, Robert Bird Group, Fraunhofer, Leonhard Obermeyer Center, Tekla, Helsinki Chief Digital Office, TU Delft Design Informatics, Semmtech, and Arcadis.

We are also grateful to the hundreds of researchers who have contributed to national strategies across the world, and upon whose shoulders we stand to develop our recommendations for New Zealand's building industry.

About the Building Innovation Partnership

The Building Innovation Partnership (BIP) is an industry-led research and delivery programme focussed on supporting the New Zealand building industry in becoming a world leader in applying digital methods to asset planning, design, construction and management processes, and the development of engineering solutions that improve the resilience and value of buildings and horizontal infrastructure (i.e., infrastructure)

This seven-year research programme (2018-2025) is a Quake Centre initiative, based at the University of Canterbury and is jointly funded by industry and the Ministry of Business Innovation and Employment's Government Research Partnerships Scheme. The BIP programme is being delivered through three inter-linked themes:

- **Theme 1 –** better investment decisions
- **Theme 2 –** enabling integrated design, construction and operation
- **Theme 3 –** fit-for-purpose building components

This report is an output from Theme 2, which aims to provide the NZ baseline for digital innovations and an understanding of the potentials in the NZ marketplace for new and emerging digital technologies.

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Section 1: **Introduction**

Within New Zealand, the building industry was ranked top of 19 industries for business growth, with nearly 13,000 more enterprises and over 45,000 employees added over the five-year period to February 2019 [1]. Similarly, construction was accountable for 25% of the total employment growth over a three-year period to March 2020 [2].

However, the industry has been fraught with challenges with at least five large construction firms entering receivership or voluntary liquidation, some owing >$100 million [3, 4]. In turn, this is having a negative impact on sub-contractors, who are also facing financial difficulties [5].

Many underlying factors have led to these circumstances, including:

- Clients predominantly adopting a lowest price procurement model,
- A highly competitive market creating the need for tight margins to win work,
- An unreliable and cyclic market,
- Integrated and interdependent supply chain in complex contractual agreements, creating multiple points at which the process can break down,
- Continuing escalation in cost of materials and production,
- Construction inefficiency,
- Lack of training in specialised areas.

While some of these issues are beyond the control of the industry (the unreliable and cyclic market for example), or require a change in mind-set by the players and greater trust across the industry, others could benefit from the use of digital technologies to improve the effectiveness and efficiency of managements processes' (Figure 1).

Figure 2 shows the key to digital transformation is to reduce fragmentation in the building industry through process-driven change, categorised by five key focus areas. Digital technology's role is to support those processes, which fundamentally need to focus on improving:

- Coordination,
- The management of quality, cost and risk,
- Whole of life costing,
- Handover and operations,
- Health and safety outcomes.

The need for organisational and national level Standards in 'Digital Data' are important to ensure consistent definition and delivery of data, all whilst trying to achieve the above list. Equally important for the functional use of data is interoperability.

As will be discussed in later sections of this paper, asset owners will use data in a variety of systems and tools that are unique to each owner for asset management (Section 6.3). At the same time, developments are happening within New Zealand for the semi-automated processing of building consents using BIM (Section 4.2). These developments require simple and seamless processes, and tools need to be available to allow the interoperable use of data and to avoid data duplication.

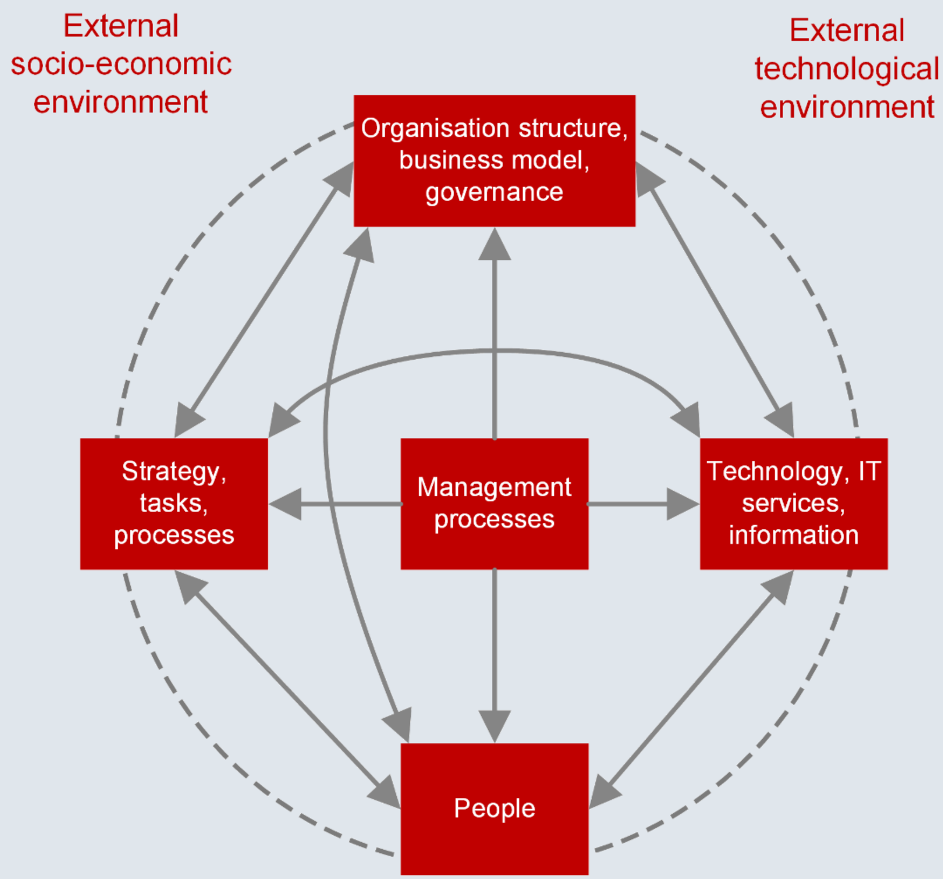


Figure 1: Modified Leavitt's diamond theory of technology impact [6]

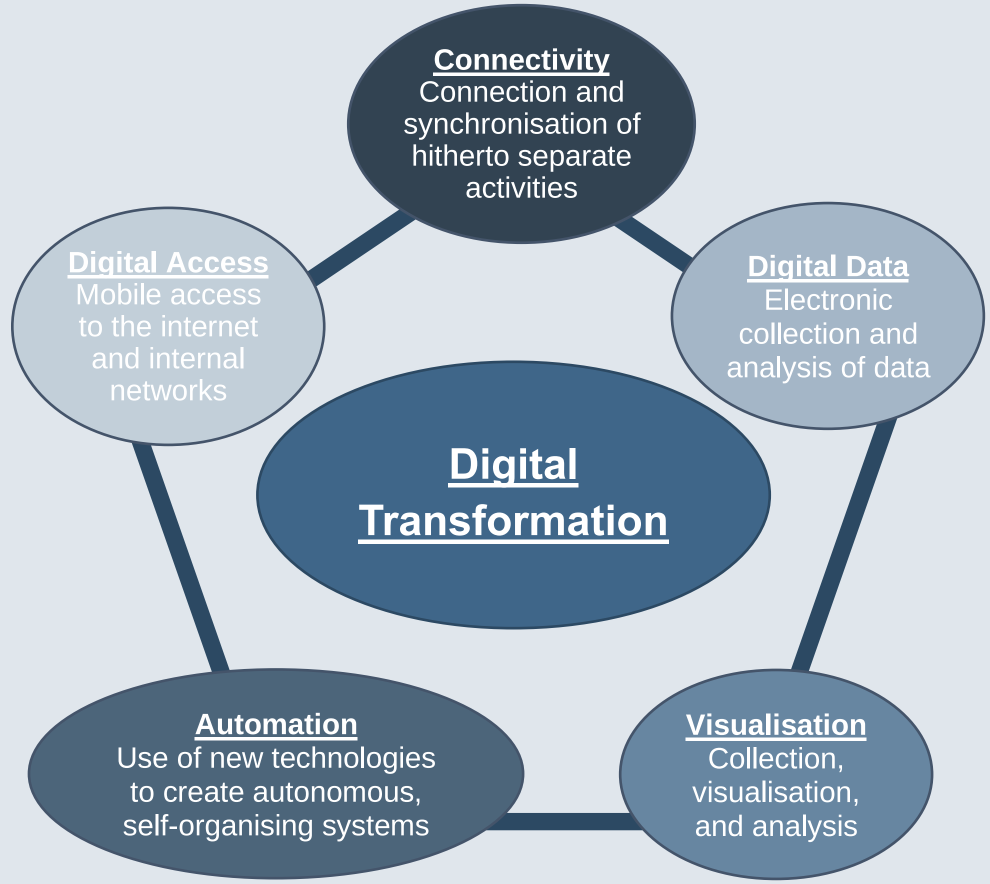
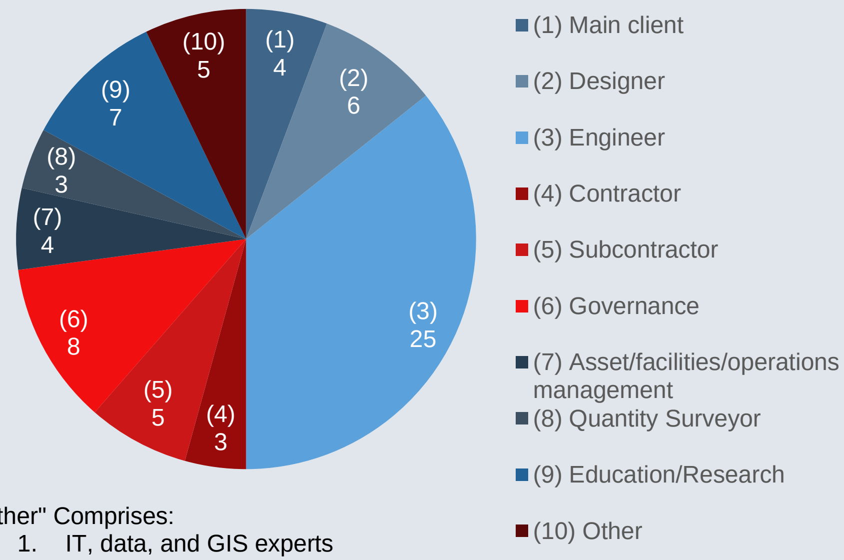


Figure 2: Five keys to the digital transformation, modified from [7]

To benchmark New Zealand's current position on awareness and usage of digital technologies in the building industry, a survey was conducted using an anonymous online survey tool. Over 150 candidates were identified from a compiled list of contacts known to the BIP team, with responses received from 70 participants (Figure 3). Respondents were also asked to comment on their organisations' biggest challenges, and where and how they believe processes could be improved using different digital technologies (See Appendix A).



"Other" Comprises:

1. IT, data, and GIS experts
2. Software provider
3. Land Information NZ (LINZ) - management and publisher
4. Industry non-government organisation
5. Digital management

Figure 3: Survey participant industry sector distribution

1.1 Objectives

This paper has four objectives:

1) To provide a high-level review of impactful digital technologies currently in use and in development in the building industry, nationally and internationally,
2) To identify digital processes and technologies of significant benefit to New Zealand over the next ten years,
3) To share insights with the broader infrastructure community, including all levels of government and private sector organisations,
4) To raise awareness of the need for digital technology in a project's whole lifecycle and to promote innovative thinking on the concepts underpinning digitalisation of the building industry in the infrastructure community.

1.2 Insight

To complete these objectives, this paper aims to provide the following:

- An insight into the current use of digital technology in the building industry both domestically and internationally using high-profile projects where digital technologies provided significant benefits,
- Lessons learned, observations, and trends from overseas through published reports and technology foresight documents,
- Identification of areas with the greatest potential to improve New Zealand's productivity through a project's whole lifecycle, and of technologies considered most applicable to the New Zealand marketplace,
- Characterisation of areas where New Zealand lacks knowledge when trying to answer the question 'How might we exploit digital technologies more effectively to improve building and infrastructure performance and affordability?'

1.3 Document Structure

The structure of this document follows the asset phases of planning, designing, constructing and managing a building, with each given its own section (Sections 3 to 6). Throughout these phases, certain work streams may be interlinked, and dependent on the delivery of information from earlier asset phases either within the same work stream (e.g. good delivery of design information to support building consent, translating through construction to confirmation of as-built, in order to obtain building consent code compliance certification), or between different work streams (such as information required for scheduled maintenance during the operate and maintain phase being identified in the planning phase as part of the design intent).

In each of these work streams, and at each asset phase, there are opportunities to improve the process through the application of digital engineering. By using this structure, we will explore some of the available technologies and processes that could have the greatest impact on improving coordination, and managing quality, cost and risk.

Table 1 presents a matrix of technologies identified as being used, or investigated for use in the building industry. These technologies have been investigated and surveyed in this paper, through an international literature review and from experience within the BIP team. The table also contains a brief definition of the technology, and where BIP considers its applicability in the asset lifecycle.

At the beginning of each asset phase section, two graphs are presented. The first shows the survey respondents’ views on the impact and likelihood of implementation of the technologies, the second presents the opportunity offered to the building industry from the uptake of each technology plotted against the degree of implementation (i.e., current use) of each technology. Both graphs also include the respondents’ views on the perceived cost savings from using each technology.

Following these graphs, example work streams have been chosen which are utilising, or can utilise, the technologies that the survey respondents identified as being impactful for that phase. Throughout the main body of the report, ‘pull-out’ boxes with commentary and recommendations from BIP and industry experts can be found.

1.4 Caveats

Within each asset phase in Sections 3 to 6 there are sections related to individual work streams. Not all work streams are covered in all stages, either because there is little impact of the work stream on that phase, or we currently have insufficient information to provide a valuable insight. Similarly, the enormous range of possible technologies available and work streams within a typical building project, does not allow full coverage in this paper. The aim is to identify those areas that will add the most value to the client, designer, contractor and or operator. Up until 2025 in the BIP programme, we will be adding more example work streams and associated digital technologies through delivery of case studies, and updates to the survey found in this paper, all of which can be found on the BIP website.

Section 2:
Context and Background

The building industry is a risk-averse industry that has been slow to innovate. This is reflected in the fact that productivity has not improved significantly [8-10], whilst other industries have increased productivity by a factor of 10-15 since 1945 [9]. Innovation generally occurs through two common strategies, the technology push and the market pull [11]. As Figure 4 shows, the market pull is the predominant factor driving innovation in some components of the infrastructure industry such as utilities, which is making progress in digitalisation. Although real estate and transportation, for instance, are slower, they have progressed more than the construction sector, which is one of the slowest sectors in terms of uptake of digital technologies, second only to agriculture and hunting [12].

According to a McKinsey report [9], if productivity in the building industry increased to match the total economy, it would raise the sector's value by approximately USD1.6 trillion, worldwide. However, Forbes have claimed that as parts of the industry have computerised and industrialised, they are reclassified as advanced manufacturing [13]. Therefore, whilst it is perceived that construction is being left behind in the digital transformation, some of the improvements to advanced manufacturing are in fact attributable to improving construction's productivity.

Where activities are directly relatable to the building industry, the lack of innovation and uptake of digital technologies are due to several factors including:

- Poor validation or value perception of the proposition,
- Low profit margins,
- Absence of clear leadership or common strategic intent,
- Capacity and capability gap,
- Procurement and contracting practices,
- Management of risk,
- Investment in training,
- Cost to implement,
- Uncertainty created by boom-and-bust cycles,
- Bespoke nature of buildings.

In addition, the industry is segmented into many professions and trades and coordination between these segments is seen as difficult. With each segment concentrating only on its task, the perception is that the benefits that can be realised by investing in digital technologies are small. Similarly, where investment and return accrue to different parties, this creates a perception of biased benefit e.g., a higher expectation in the design phase to reduce contractor and subcontractor workload in the construction phase.

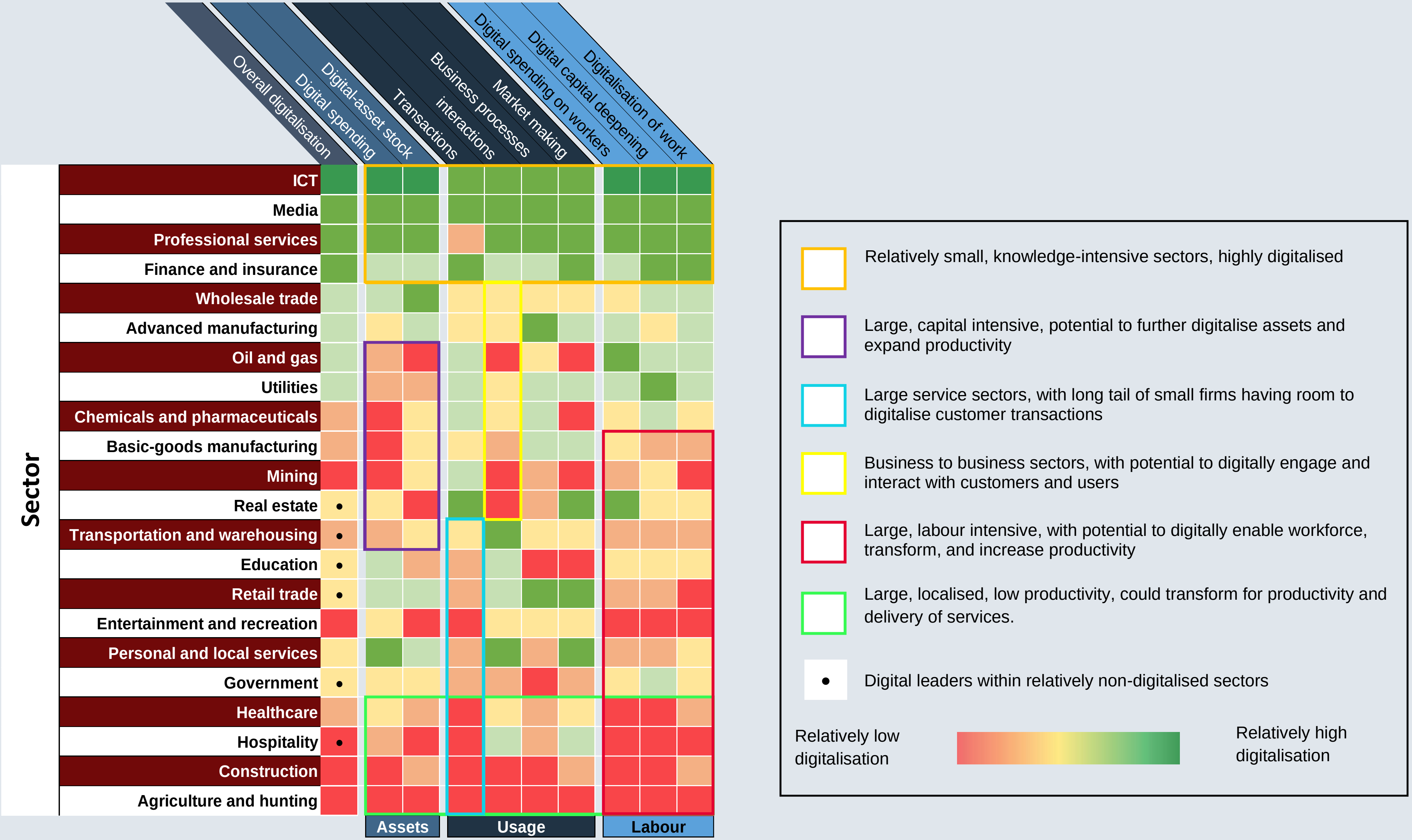


Figure 4: Digital processes in industry modified from [12]

"In construction, time has always been money [14]."

According to the 2018 JBKnowledge *Construction Technology Report* [15], at least 24% of construction companies spent more than 2% of their revenue on technology and IT in 2018 (around 12% didn't know how much was spent), compared to 20% of companies in 2017 (with 13% not knowing). By contrast, in the 2015 report [16], only 7% of companies were spending more than 2%, demonstrating a 17% increase in the number of companies spending more than 2% on technology from 2015 to 2018. However, a significantly larger proportion of those surveyed did not know company expenditure on IT in 2015 (42%), resulting in a potentially less accurate reflection of true spending. Similarly, the number of companies who bill IT expenditures to projects has increased over the same period from around 36% in 2015, to just over 57% in 2018 [15, 16].

Asset owners are poorly served in projects through minimal transfer of information generated during the asset lifecycle. Concurrently, many asset owners lack the capability and maturity to leverage data, so there is a lack of demand side pressure to invest in and deliver data. A Digital Built Environment (DBE) is designed to provide an evidence-based understanding of the built environment, and with the proper implementation benefits can be realised through the creation, management and maintenance of information across the whole asset lifecycle from concept design to eventual disposal of the building.

The industry has seen many recent ups and downs. Construction has recovered from the 2008 financial crisis, but the modern construction landscape is vastly different. There are fewer young workers entering the industry, leading to a rapidly diminishing talent pool and with the increasing complexity of projects, tighter deadlines and shrinking profit margins, there is pressure from all sides, particularly on contractors and project managers, to look to emerging technologies to keep their projects on time and on budget [14].

2.1 The Built Environment Ecosystem

It is well documented that the building industry is fragmented and ripe for change, with massive benefits potentially resulting [17-19]. There are many parts to the built environment ecosystem (Figure 5) with subtle differences between public and private ownership models. The use of a DBE in the building industry allows all stakeholders associated with an asset (Figure 6) to take advantage of access to real-time federated data sources that are linked to the physical built environment, widely referred to as the "Internet of Things" (IoT) or a Digital Twin (DT).

By combining a virtual representation of a physical object or system with sensor technology, a DT acts as a feedback loop between the digital and the physical worlds, enabling understanding, learning and reasoning, leading to efficient building design, planned and effective construction, and efficient maintenance, resulting in reductions in time, cost, and risk, and improvements in quality.

For a DBE to thrive, all parts of the ecosystem need to participate. The sector generally recognises this and within New Zealand several organisations and committees have been tasked to address this area, including:

- Construction Sector Accord,
- Industry Transformation Agenda,
- Construction Industry Council,
- Construction Clients Group,
- Civil Contractors New Zealand,
- Infrastructure New Zealand,
- New Zealand Infrastructure Commission,
- BRANZ,
- National Technical Standards Committee,
- BIM Acceleration Committee.

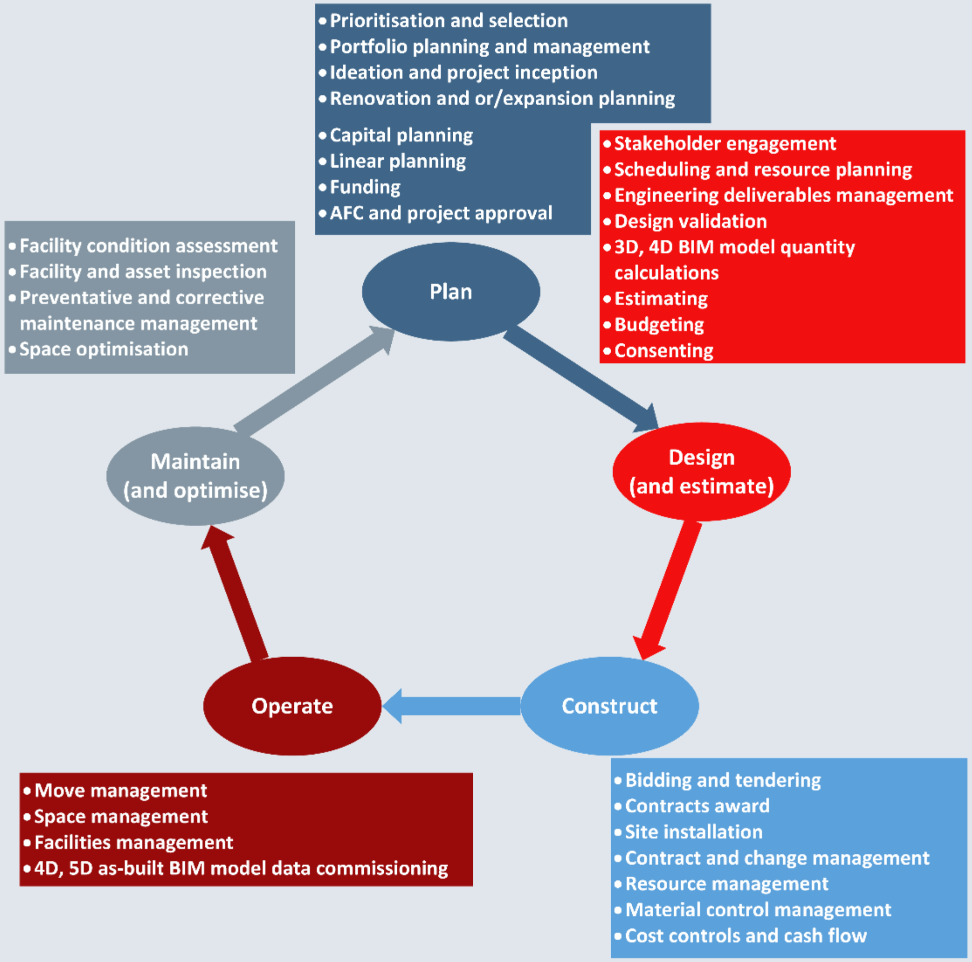


Figure 5: Asset Management Lifecycle

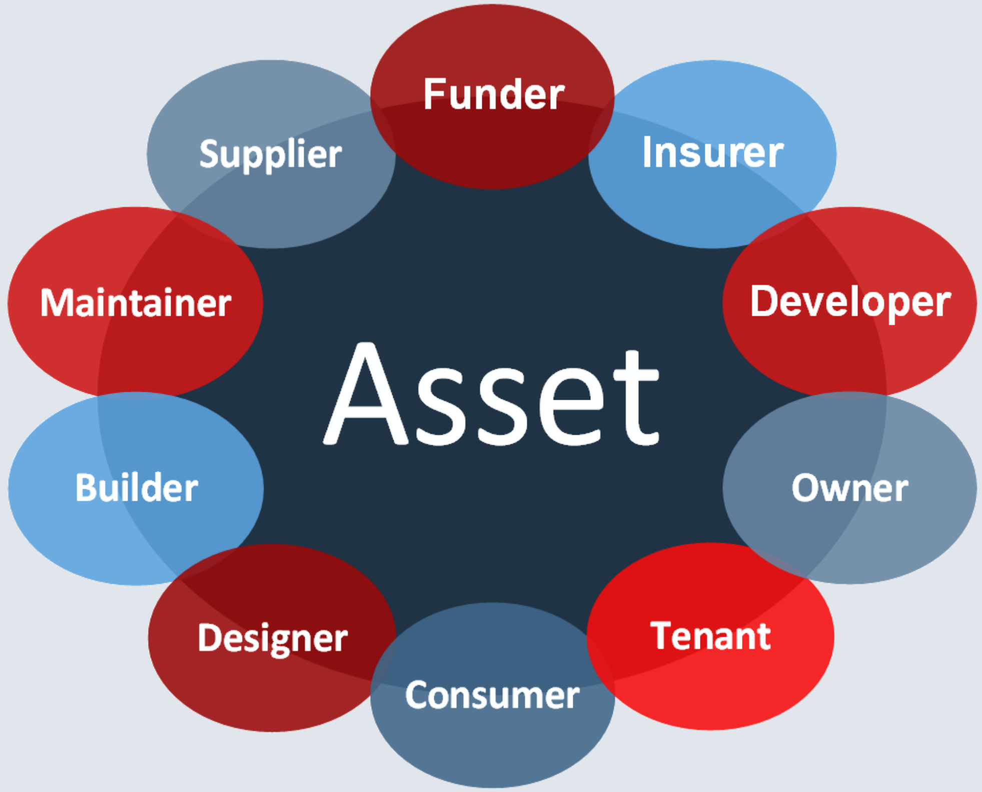


Figure 6: Actors associated with the ecosystem of an asset

2.2 Digitalising the Building Industry

The potential benefits of digitalisation within the building industry are numerous. As well as improving data and information sharing, communication among different players, and monitoring, digitalisation can also facilitate the implementation of methodologies for testing and surveying.

Digital transformation, as described by the European Commission, is characterised by a fusion of advanced technologies and the integration of physical and digital systems and their effect on buildings and energy efficiency in buildings [20].

A Cyber-Physical System (CPS), which lies at the cross-section of the physical and digital worlds (Figure 7) aims to monitor and control the physical processes. The "monitoring" component of a CPS loosely equates to the "understanding, learning, and reasoning" of a DT, but the "control" component is beyond the scope of a DT.

Alongside the DT and CPS, there is the notion of a Common Data Environment (CDE) which allows the information held by all parties on a project to be communicated and worked on in a seamless and collaborative manner. When combined, the DT, CPS, and CDE, form the major parts of a DBE.

The demand for a DBE should, in theory, emanate from asset and infrastructure owners. But, much like the treatment of risk in procurement strategies, the perception of value for money needs to evolve – this will take time but the success of Melbourne's long-term Economic Development and Town Planning attests to the success of a multigovernmental and multigenerational approach [20].

The value of a DBE is greater than the sum of its parts – just focusing on aspects of the lifecycle or subprocesses within it may not generate benefits that are worthy of the investment in time and money. But, if a whole of life view is taken, investing in capability now could yield significant dividends in the future.

Appropriate technology will maximise benefits from a DT by increasing understanding of how an asset needs to operate and recognising where the biggest gains can be made, for example:

- Linking physical modelling with financial modelling and generative design in preliminary estimating to better understand the total cost of ownership for the client,
- Utilising IoT data to evaluate real space utilisation in similar assets to design a smaller, more efficient building,
- Delivery of design simulation models (such as energy profiling) to act as benchmark data for review and comparison against the actual as-built. This could be used for feedback into future designs or interrogation if the as-built isn't performing as designed.

Industry says:

Too many projects are benchmarked on what other projects listed as the capital cost on the consent, or the tendered value. There is very little data on actual costs (i.e., not what the client paid, but what it actually cost to construct). I think more research in linking physical and financial modelling would be valuable.

Our response:

The linking of physical and financial modelling relates to cost data management and the type of data that is collected, where, and how it is stored. This would only be applicable to large asset owners as the visibility of this type of information could be considered sensitive. It would also depend on the similarity of assets.

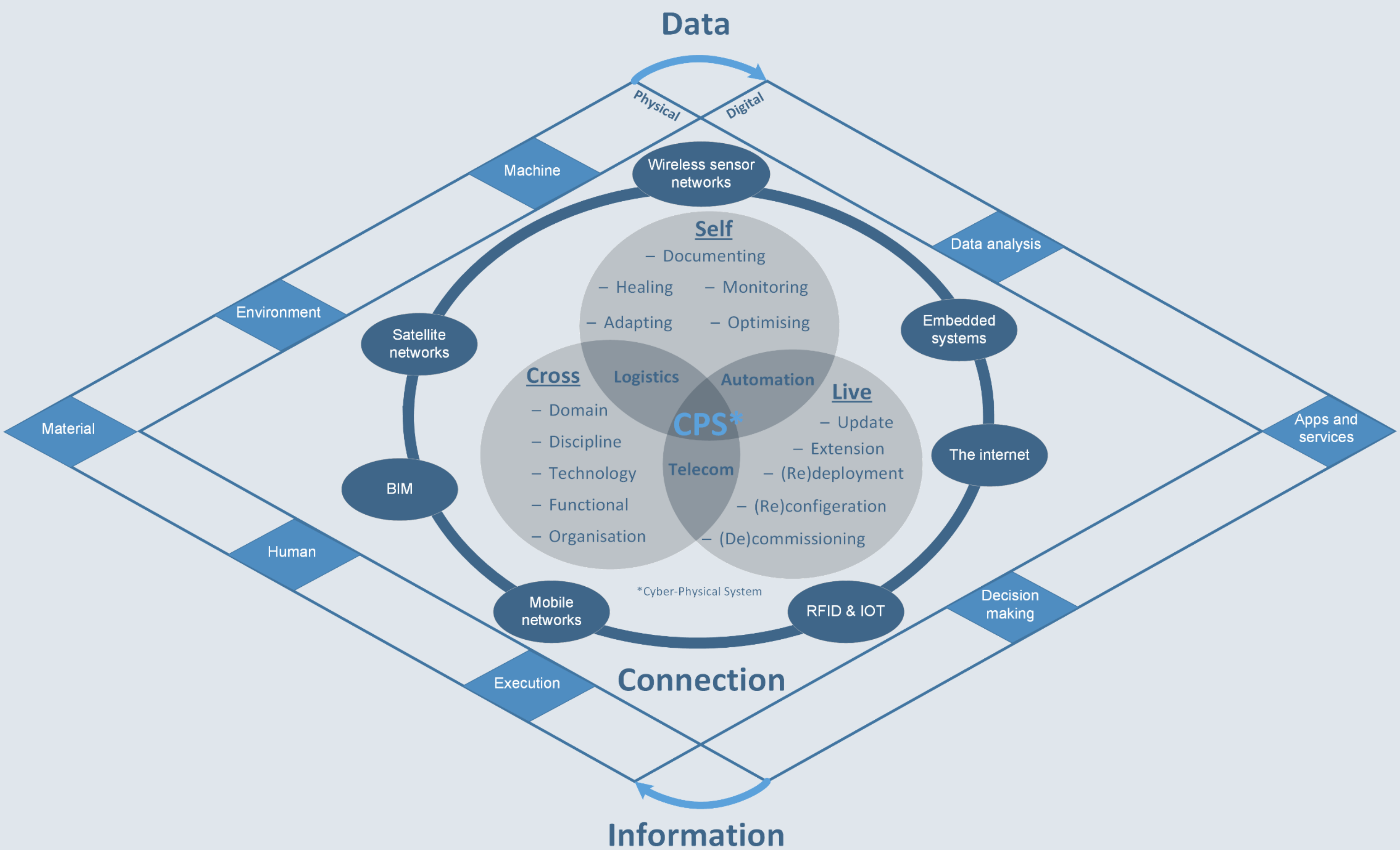


Figure 7: Interaction of physical and digital worlds, modified from [21, 22]

The phrase "starting with the end in mind" is used in several publications [23-25] to raise awareness of the information requirements of asset and facility operators as part of the procurement model. The modified MacLeamy curve in Figure 8 demonstrates that the ability and cost of changes are inverse to each other as the asset lifecycle progresses. The same model could also be applied to the procurement of information relating to an asset.

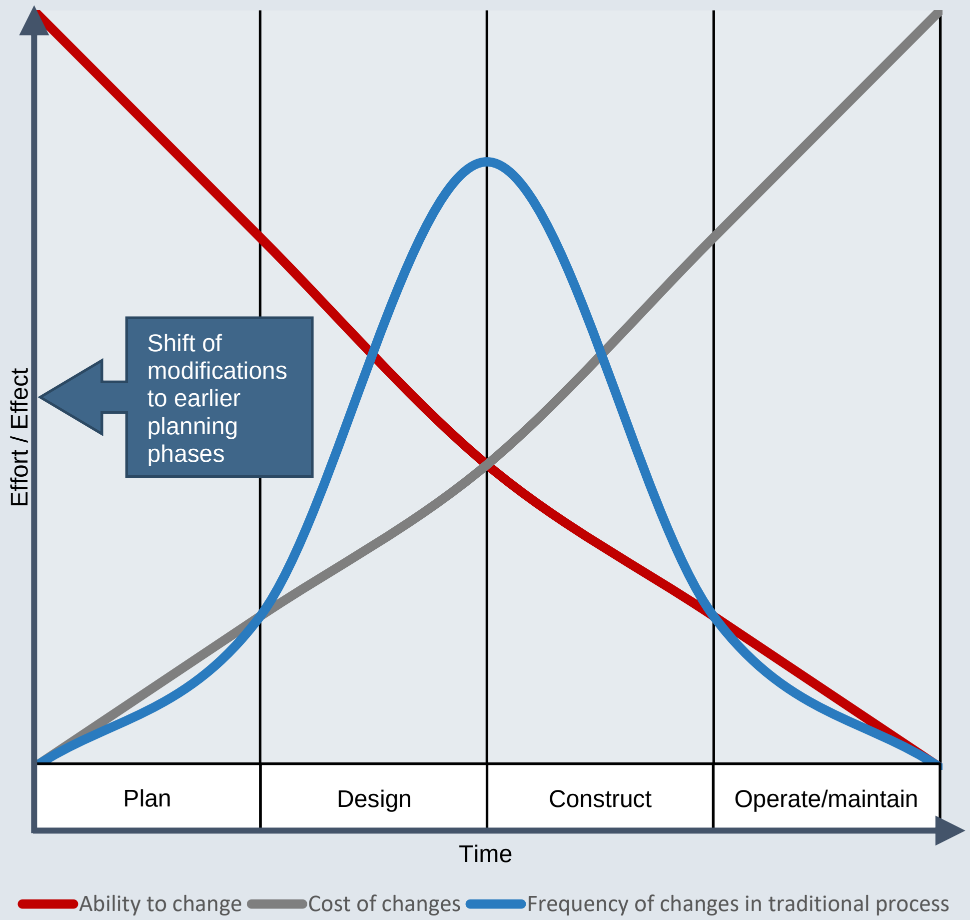


Figure 8: Cost of changes in building lifecycle [8]

Traditional facility lifecycle processes go through many peaks and troughs with regards to the production, loss and maintenance of information, particularly when using paper-based documentation or basic asset management and facilities management systems (*Figure 9*).

However, through collaborative digital-based information delivery, as indicated by the blue shade in *Figure 9*, the value of information is greater, but the effort required to consistently produce and maintain information is less. One of the key messages in *Figure 9*, irrespective of the information delivery method, is that at the transition from build to facility start up, the value of information spikes, highlighting the importance of good, accurate as-built data.

As will be discussed further in Section 7, the fundamental basics with regards to building information are:

- Collect consistent digital data: clear data specifications and robust Quality Assurance (QA) and Quality Control (QC) processes will ensure the data that is delivered is consistent and will improve accuracy of analytics,
- Gather more meaningful data: ensure there is an accurate and complete pool of data. Only then can benchmarks be set and KPIs measured,
- Manage risk: with more information, risk can be better managed, resulting in a more predictable outcome,
- Deliver better projects: use building data to identify areas of improvement to continually deliver high-quality projects.

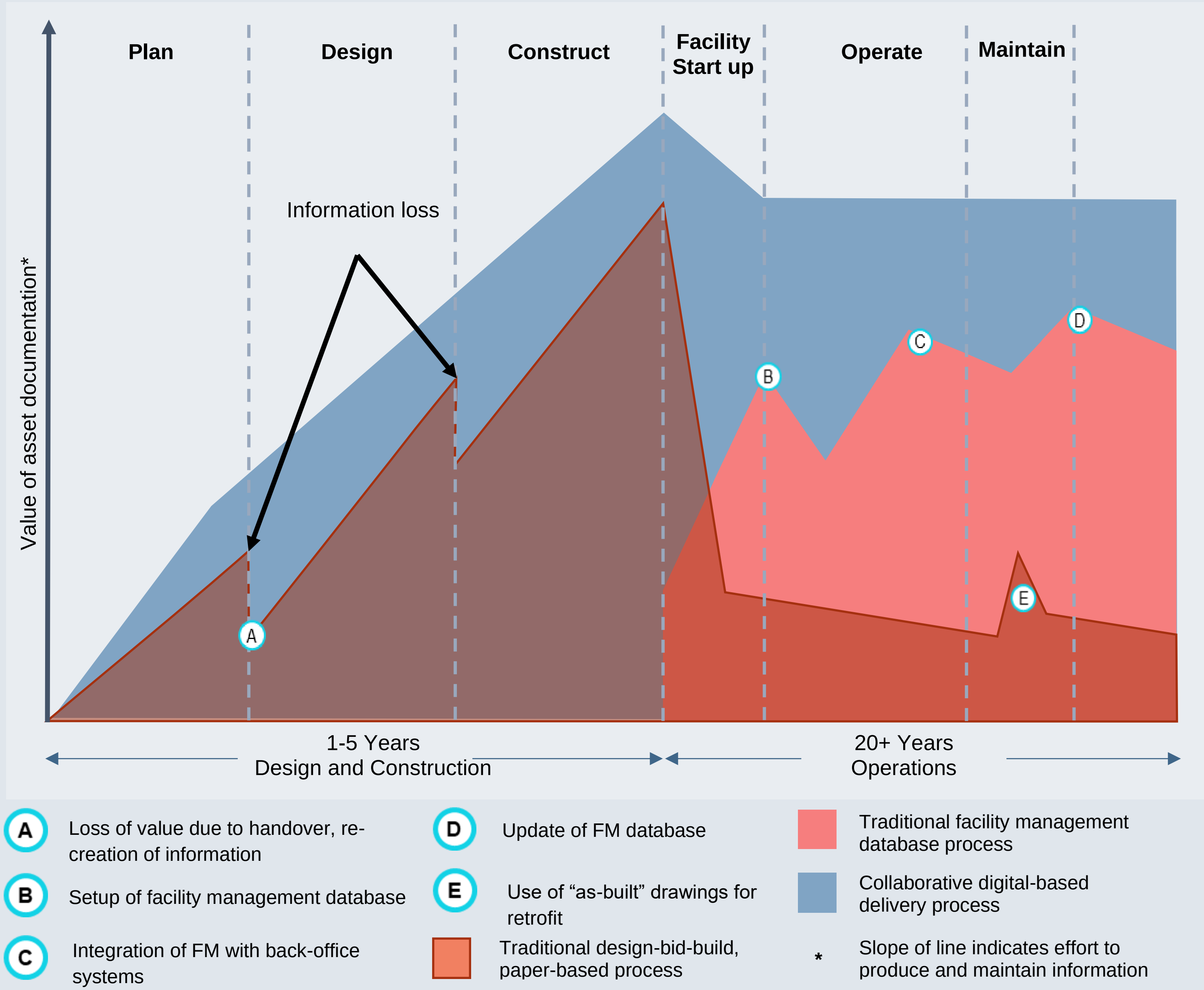


Figure 9: Facility lifecycle modified from [26]

Industry has asked:

What would the effort to produce and maintain information line on the collaborative digital-based delivery process look like during the operate and maintain phases if asset performance information was fed back into the OM and FM analytical systems?

Our response:

We are investigating this as part of a performance metrics project that BIP is undertaking.

2.3 The Technologies That Could Help

Over the years, the evolution of technology and construction has changed the building industry (Figure 11). Where construction jobs previously took months, if not years, to complete, simply because communication, transportation and production took longer [27], innovation today is focussing on creating shortcuts, making work easier, and is a principal source of differentiation and competitive advantage. McKinsey cites three main clusters where digitalisation is happening: back office integration, digital collaboration and on-site execution [28]. This is demonstrated in the design phase with designers moving away from paper-based drawing boards to computer-aided design practice, and from there to the progression of embedded use of Building Information Modelling (BIM) [29].

The rise of mobile devices, cloud computing, Unmanned Aerial Vehicles (UAV) and laser scanning is creating new opportunities for quick and efficient capture, sharing, and management of data anywhere, thus improving communication in activities such as early conflict identification, and management of contractors and subcontractors. Mobile devices, cloud computing and UAV are also facilitating the ability to autonomously process and analyse large datasets in real-time. This provides the ability to make better informed decisions about everything from site monitoring to production of as-built design plans and offers greater visibility on whether equipment is being operated safely. The rising development and utilisation of Artificial Intelligence (AI) and Big Data Analytics (BDA) will improve the automation of these processes even further.

Operations and Facilities Management within the industry is advancing with the use of remote monitoring and Digital Twins, creating Smart Assets. In combination with Building Management Systems (BMS) these are providing managers with improved spatial awareness and the ability to carry out predictive maintenance, among other things.

Information technology (IT) can be considered as the exchange and integration with industrial technology and intelligent technology (Figure 10) The use of the Internet of Things (IoT) allows the real-time collection of data for storage in cloud computing systems. BDA and AI can effectively mine useful information and knowledge, thus improving intelligence and better satisfying dynamic service demands.

From the sources reviewed for this report, in particular those identified by the World Economic Forum's Shaping the Future of Construction [8], a list of 18 technologies has been compiled (Table 1). These technologies were used to test the knowledge and awareness of the New Zealand building industry as part of the survey whose results are presented in Section 2.4 and throughout Sections 3 to 6.

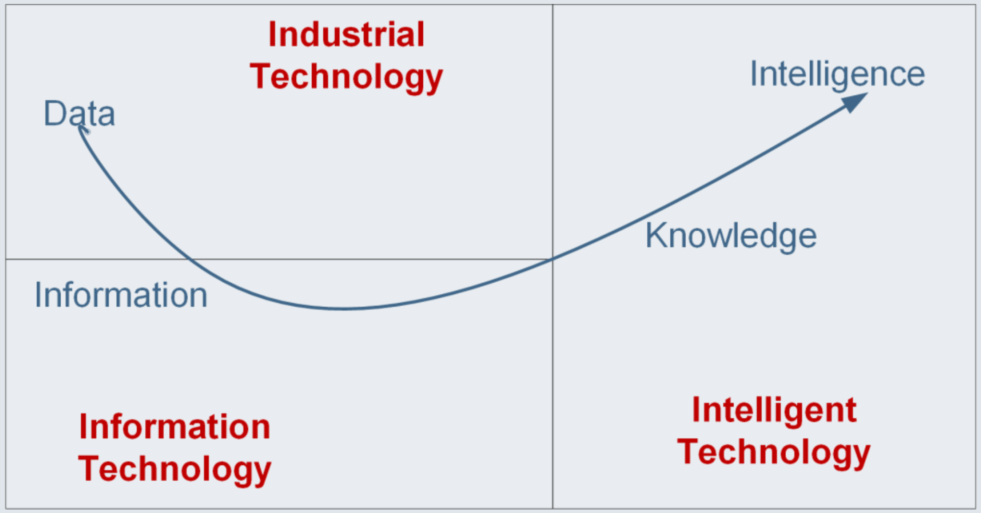


Figure 10: Integration of industrial, information, and intelligent technologies [21]

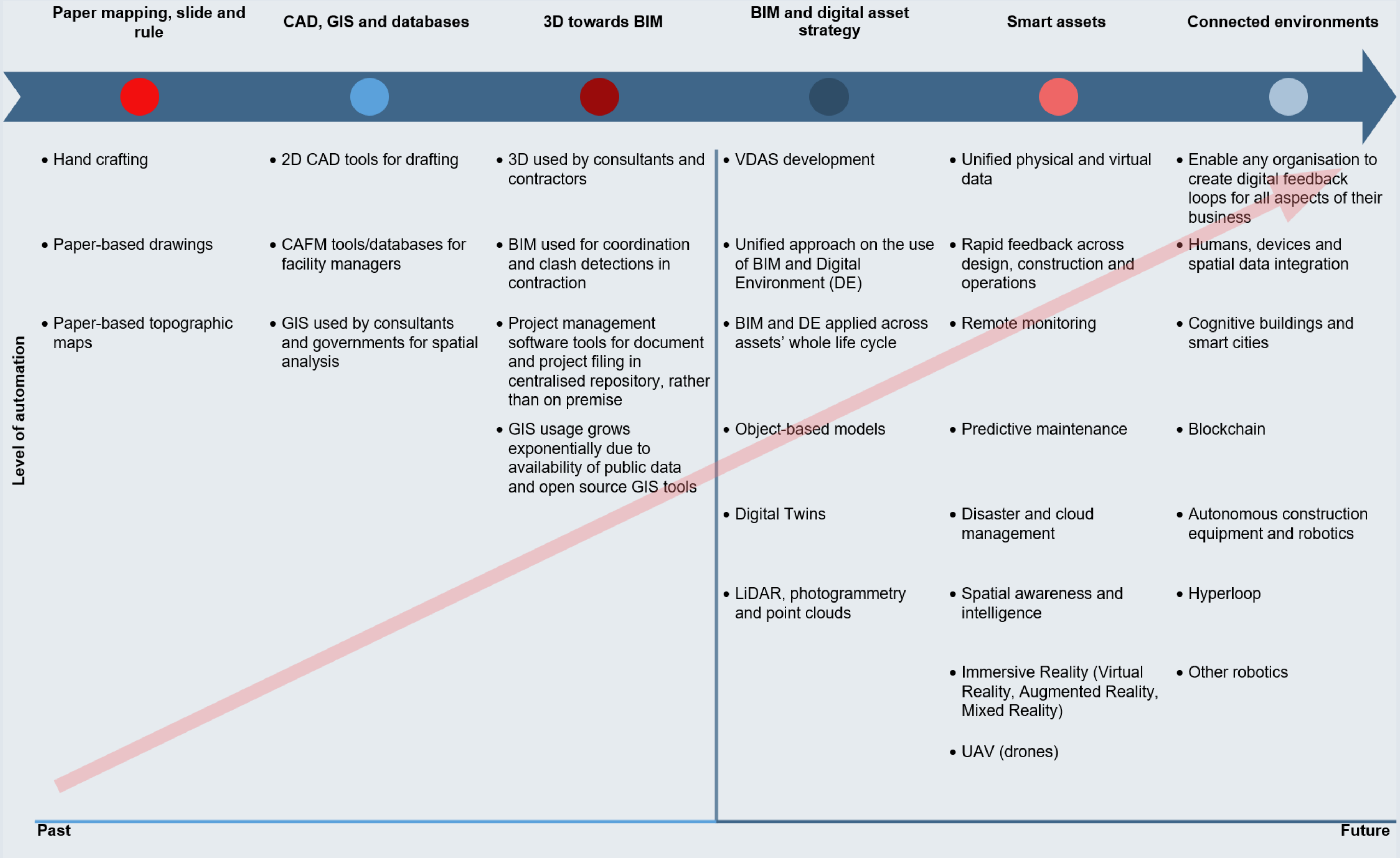


Figure 11: Technology evolution in building industry [20]

Table 1: Technology application matrix

Tech ID	Technology	Definition	Asset development phase technology could be used			
			Plan	Design	Construct	Operate/ maintain
1	3D laser scanning	A technology that uses lasers to measure and capture environments in 3D. A fired laser records an xyz point value for every hit surface and will simultaneously record the surface reflectivity, giving an intensity value. Some scanners also contain in built cameras that provide an RGB value to each point. All laser scanners work via line of site. This means that generally, multiple scans are needed from different vantage points to ensure a more complete data set.	Y	Y	Y	Y
2	Additive manufacturing	Additive manufacturing is the process of making a 3D solid object from a digital model. The 3D object is created where layers of material are laid down successively in different shapes. This differs from traditional manufacturing techniques that mostly rely on the removal of material (cutting, drilling etc.).		Y	Y	Y
3	Artificial Intelligence (AI) Knowledge Based Systems (KBS) Machine Learning (ML)	AI is the simulation of human intelligence processes by computer systems. Common AI processes include learning (acquiring information and rules for using information), reasoning (using rules to reach conclusions) and self-correction. KBS (using rules to reach approximate or definite conclusions) and ML (the ability to receive data and use statistical analysis to predict and update outputs as new data becomes available) are both examples of AI application.		Y		Y
4	Immersive reality – Augmented Reality (AR) Virtual Reality (VR) Mixed Reality (MR)	VR – Technology that completely immerses a user in a computer-generated reality, usually via a headset. AR – Technology that overlays digital information on the real world. Different to VR, AR enhances the real world with images, text, and other virtual information via devices such as heads-up displays, smartphones, tablets, and smart lenses/glasses. MR – Is an extension of AR that allows users to interact in real-time with virtual objects placed in the real world (also usually requires a headset)	Y	Y	Y	Y
5	Autonomous construction equipment and robotics	An autonomous or driverless vehicle can interpret (using advanced control systems) sensory information to detect obstacles and navigate the most appropriate path with the use of a combination of sensors, cameras, radar and AI, all without human input.		Y	Y	
6	Big data analytics (BDA)	BDA examines large amounts of data to uncover hidden patterns, correlations and other insights and provide speed and efficiency, compared to traditional analytics. No single technology encompasses BDA, several types work together to get the most value from information. Some of the key technologies include Machine Learning, Data Management, Data Mining, in-memory analytics, predictive analytics, and text mining.	Y	Y	Y	Y
7	Blockchain	A blockchain is a time-stamped series of immutable records of data that are managed by a computer cluster not owned by any single entity. Each block of data is verified by the computer cluster distributed around the net and is secured and bound to each other using cryptographic principles (a chain). A shared and immutable ledger, the information in it is open for anyone to see, creates a unique record with a unique history. Falsifying a single record would mean falsifying the entire chain in millions of instances, which is virtually impossible.	Y	Y	Y	Y
8	Building Management Systems (BMS)/ Building Automation Systems (BAS)	BMS are computer-based systems used to monitor and control building services such as: lighting, HVAC, fire and smoke detection and alarms, CCTV, ICT systems, lifts, industrial processes or equipment, shading devices, and smart meters. BMS may now be integrated with BIM to allow performance in use to be compared with design criteria and design simulations. This can help identify potential problems in operation or design and can help validate modelling techniques. BIM might also include information about the O&M of building components.	Y			Y
9	Computer vision	Computer vision is the field of study surrounding how computers see and understand digital images and videos (i.e., the 'visual' component of autonomous vehicles, robots, and image or object recognition).			Y	Y

Tech ID	Technology	Definition	Asset development phase technology could be used			
			Plan	Design	Construct	Operate/ maintain
10	Digital Twin (includes Smart Building and Digital or Smart City)	A digital twin is a digital representation of a physical object or system. The technology behind digital twins has expanded to include large items such as buildings, factories and even cities. Digital Twins can be used to run simulations before the physical equivalent is built and deployed. They are also changing how technologies such as IoT, AI and analytics are optimised. The twin is constructed so that it can receive input from sensors gathering data from a real-world counterpart. This allows the twin to simulate the physical object in real-time, in the process offering insights into performance and potential problems. There is also a feedback loop from the digital to the physical world allowing analyses to impact the physical performance.	Y	Y	Y	Y
11	Generative and parametric design	A goal-driven approach to design that uses automation to give designers and engineers' better insight to make faster, more informed design decisions. Specific design parameters are defined that produces numerous potential solutions and from these potential solutions, software is used to identify the optimal design solution along with data rationalising the best performing design.		Y		
12	Integrated BIM	Integrated BIM intends to create a productive and collaborative working environment throughout the entire project life-cycle. It is a collection of technologies and managerial processes to enhance project performance and productivity throughout various stages of project life (plan, design, construct, O&M).		Y	Y	Y
13	Prefabricated building components	Prefabricated construction is the practice of assembling a variety of components of a structure at a manufacturing site and transporting those sub-assemblies to the location of the construction jobsite. The benefits of prefab building components include: eco-friendly, financial savings, flexibility, consistent quality, reduced site disruption, shorter construction time, and safety.			Y	
14	Real-time mobile collaboration	Real-time collaboration is a term used for software or technologies that allow multiple users to work together on a project in real-time, or simultaneously (e.g., cloud computing, file sharing, real-time editing by multiple users, instant messaging, shared access, etc.).			Y	Y
15	Simulation	Simulations support all phases of a building project and uses tools to simulate and visualise processes in the building, facilitating the implementation process, improving quality and contributing to increased security. In architecture, simulations can be used for scheduling, lighting, landscaping, and virtual rendering to present the model as realistically as possible. In engineering simulations can be used to calculate structural and geometric configurations which can then be used in computer analyses to predict the behaviour of the material and deformations that result from given conditions. In construction simulations can provide the ability to assess procurement of materials, planning operations, and logistical support.	Y	Y	Y	Y
16	UAV (Drones)	Drones provide an aerial view of sites with high frequency up-to-date images, allowing for an almost real-time assessment of construction progress. Drones allow builders the chance to develop better plans, track progress and monitor construction issues. Drones also provide the ability to conduct land and building surveying, and data capture.		Y	Y	
17	Ubiquitous connectivity and tracking	Ubiquitous computing is technology that recedes into the background, becoming part of the environment. Embedded computers, IoT and convergence (integrations of technologies e.g., smartphones) all combine into ubiquitous computing. Examples of ubiquitous computing include digital signage replacing traditional billboards, PayWave, and Smart homes in which the lights, climate, security, and entertainment are automated.		Y	Y	
18	Wireless monitoring (IoT)	The term IoT encompasses everything connected to the internet, and is used to define objects that "talk" to each other from simple sensors to smartphones and wearables.			Y	Y

2.4 NZ Industry Awareness of Technologies

Figure 12 and Figure 13 drawn from the BIP industry survey results, show that generally, technologies considered to make a higher impact are more likely to be used (and therefore provide a higher opportunity). Equally, if they are already being used, the perceived cost savings are also greater. The size of the bubbles in both graphs indicate the average awareness or knowledge of each of the technologies from the survey results.

The value in presenting the results in two different graphs are demonstrated by comparing ‘UAV’ (16). In Figure 12 it sits relatively central, whereas Figure 13 presents its opportunity as almost less than low despite bordering the upper end of ‘emerging’ by way of implementation. Similarly, the results indicate that industry considers UAV to provide a modest degree of cost savings and so presents a technology that industry may not wish to invest in significantly at this time.

The survey results also show that the NZ building industry does not consider additive manufacturing (2), Blockchain (7), AI/KBL/ML (3), autonomous construction equipment (5), and digital twins (10) to provide any opportunity or cost savings and have had little uptake. Conversely, technologies such as 3D scanning (1), BMS/BAS (8), integrated BIM (12), and prefabricated building components (13) are widely used and provide value to the industry.

It should also be noted that these two graphs are the aggregated results representing the technologies’ use across the whole asset lifecycle. The graphs are broken down into each of the four main asset development phases (Plan, Design, Construct, Operate and Maintain) and are presented at the beginning of Sections 3 to 6.

Figure 14 presents the biggest differences in views between the WEF report [8], the BIP team’s initial view of technology placement, and the results of the BIP industry survey. As shown by the graph, there was an even split between over and under-estimation of different technology use in New Zealand. For example, the WEF report survey considered UAV drones (16) and 3D scanning (1) to have much less impact, and a somewhat lower likelihood of use in the construction industry than what the NZ-based respondents believed. Conversely, prefabricated building components (13) and real-time mobile collaboration (14) were considered to make a higher impact, but still lower likelihood than the BIP industry survey showed when compared to the WEF report. The full graph with all technologies can be found in Appendix A.

2.5 Building Project Work Streams

Within a typical building project lifecycle there are multiple phases of work from planning through to operations and maintenance. Throughout these phases, there are various work streams, some of which are interlinked, and dependant on the delivery of information from earlier asset phases, either within the same work stream or between different work streams (Figure 15).

This paper will discuss in further detail how the following building project work streams are currently undertaken, our view on where New Zealand is or should be heading in the future, and the actions required to achieve that outcome. The three work streams examined are:

1) Façade and the external building envelope,
2) Consenting,
3) Preventive and predictive maintenance.

We will also highlight what the implications are from doing, or not doing, particular processes may be on both the work stream being discussed (across the other asset lifecycle phases), and any linkages to the work streams throughout the building lifecycle.

In the following sections we will look at the different lifecycle phases and discuss the potential benefits of digital technologies. We will start by looking at the planning phase and the role of digital technologies in some of the work streams.

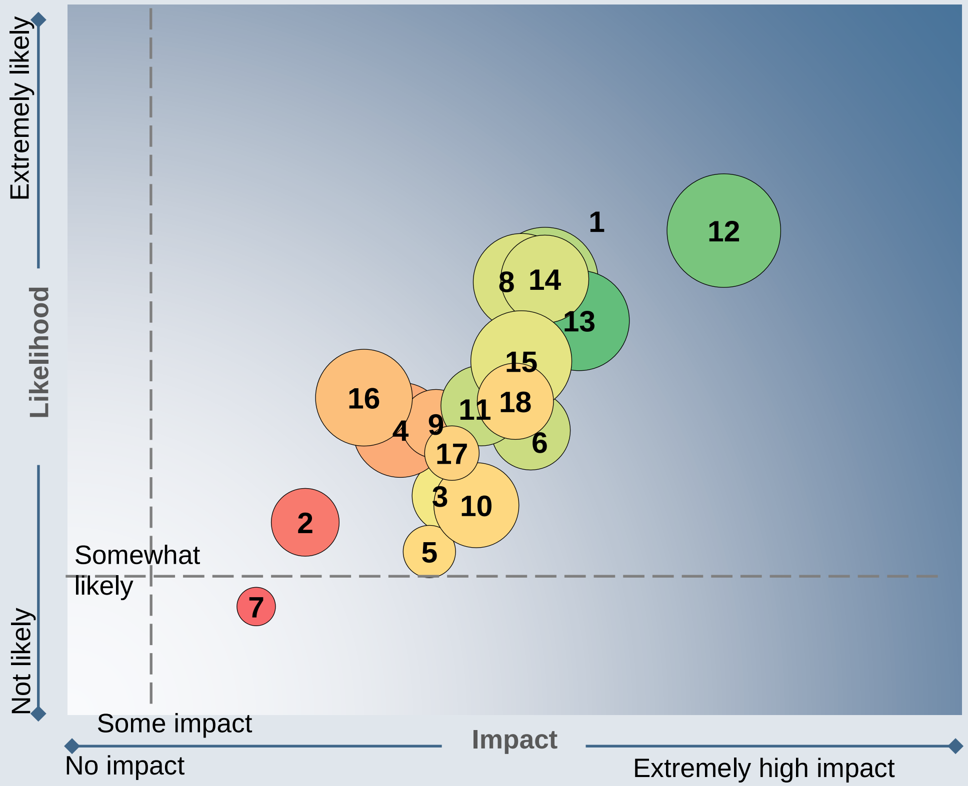


Figure 12: Impact versus likelihood of technologies

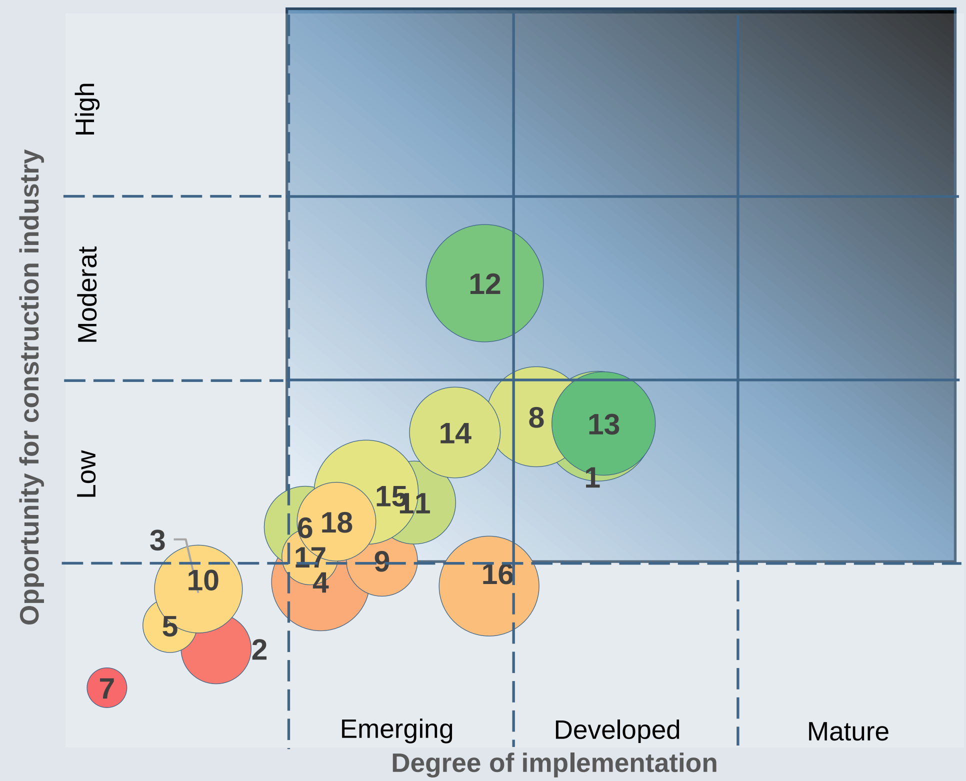


Figure 13: Trend radar of technology usage

Where:

1 – 3D Scanning
2 – Additive Manufacturing
3 – AI/KBS/ML
4 – Immersive Reality
5 – Autonomous construction equipment and robotics
6 – BDA
7 – Blockchain
8 – BMS/BAS
9 – Computer vision
10 – Digital Twin
11 – Generative/Parametric design
12 – integrated BIM
13 – Prefab building components
14 – real-time mobile collaboration
15 – Simulation
16 – UAV (drones)
17 – ubiquitous connectivity and tracking
18 – Wireless monitoring/Internet of Things (IoT)

Perceived cost savings

Low High

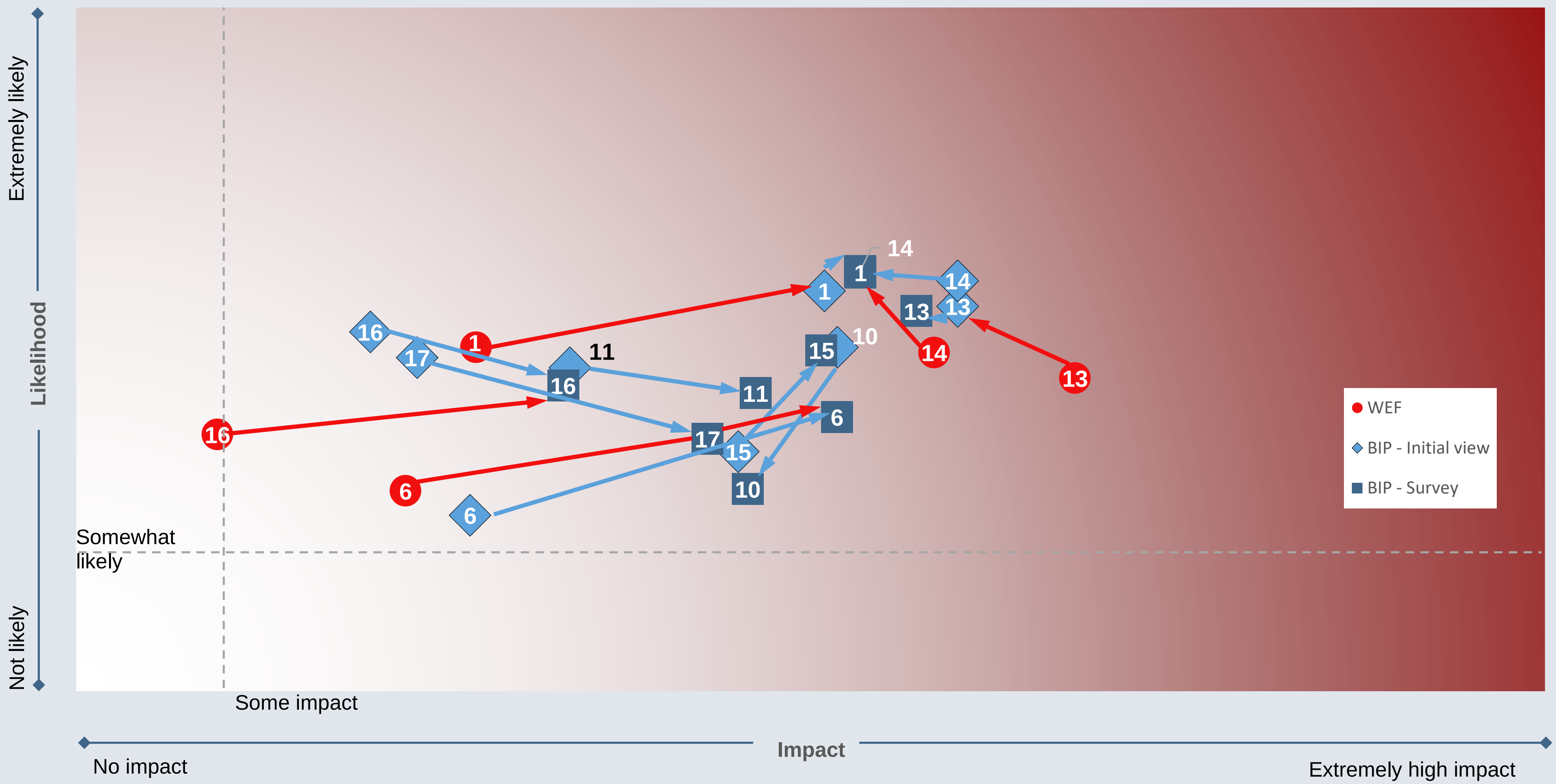


Figure 14: Biggest differences between WEF report [8], BIPs initial views, and BIP survey results

Where:

1 – 3D Scanning
2 – Additive Manufacturing
3 – AI/KBS/ML
4 – Immersive Reality
5 – Autonomous construction equipment and robotics
6 – BDA
7 – Blockchain
8 – BMS/BAS
9 – Computer vision
10 – Digital Twin
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16 – UAV (drones)
17 – ubiquitous connectivity and tracking
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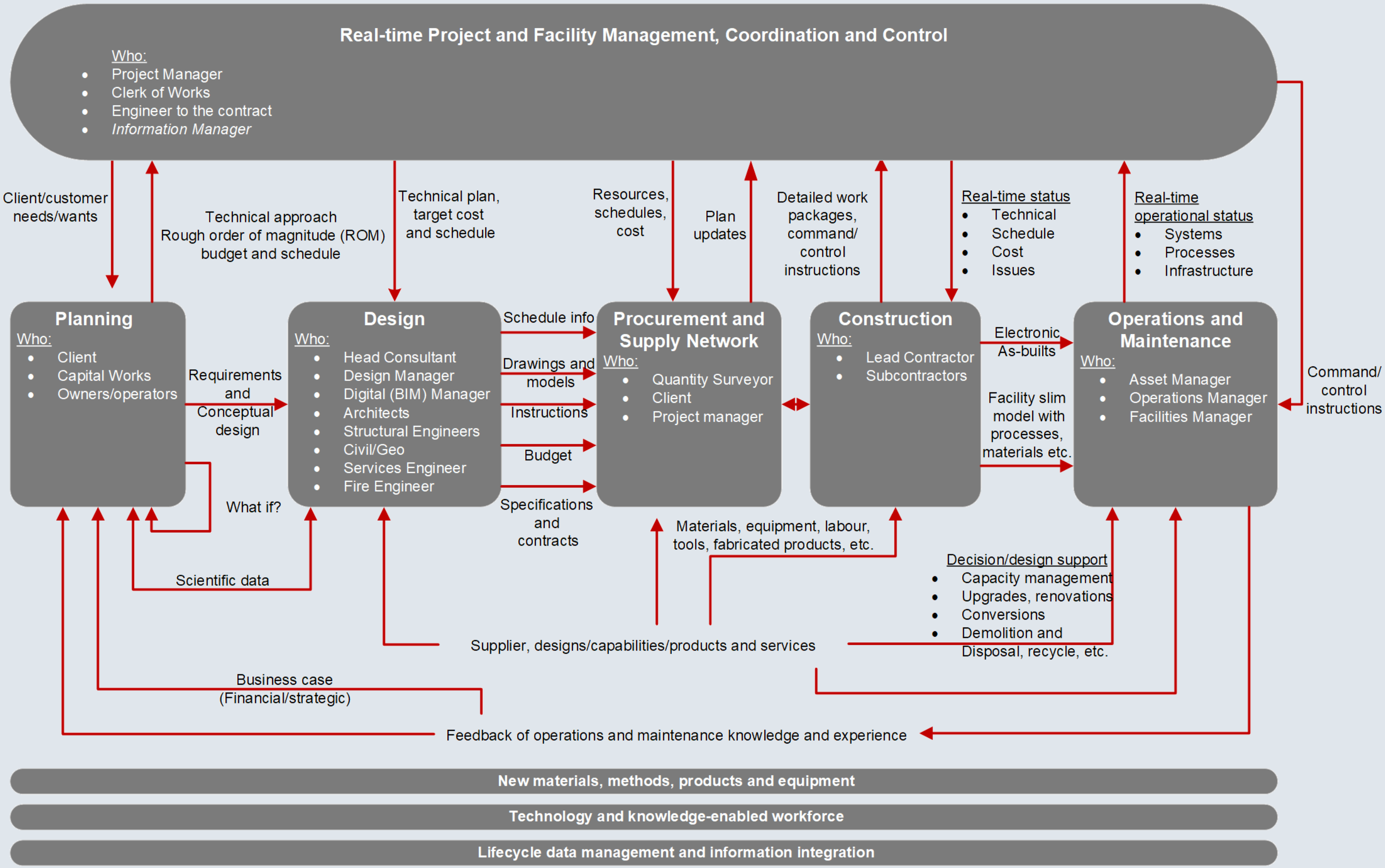


Figure 15: Typical construction workflow [30]

Section 3:
Planning Phase

Normally, a project starts with the client. The goal of the planning phase is to define the project's objectives, consider alternative ways to attain those objectives, and ascertain whether the project is financially feasible. In this process of planning and feasibility study, a project brief will be developed, more details will be set forth in a programme statement, various sites may be investigated, public input may be sought, a preliminary cost estimate will be prepared, funding sources will be identified, and a final decision on whether to proceed with the project will be rendered.

Common activities and decisions during the planning phase are often governed around resource consent requirements, particularly environmental and geographical aspects [31], such as how the finished building sits in relation to:

- Water, electricity and other services,
- site boundaries,
- access onto and around the site (e.g., paths, driveways and door placement),
- any hills or slopes (and their effect on finished height and width),
- existing features (e.g., trees or outbuildings),
- weather (e.g., sun, wind snow), and
- neighbouring sites.

To answer the above and identify how digital technologies could assist, Figure 17 indicates that the BIP industry survey respondents considered very few technologies were “developed” for use in the planning phase. This somewhat contradicts Figure 16 which shows the majority of technologies as having moderate likelihood of being used.

This presents an opportunity for research providers to investigate how some of the “emerging” technologies could assist in the planning phase. For example, by combining 3D scanning (1) and UAV (16), clients could scan potential sites and generate detailed 3D digital elevation models (DEMs). By adding basic building shapes to the DEMs and undertaking simulations (15) such as accounting for wind, sun, site access and existing services, parametric design (11) could be implemented to identify the optimum location and orientation for the proposed structure.

Similarly, using BDA (6) to interpret data from neighbouring sites, surrounding buried services, and other publicly owned data would aid in the selection of a site. From Figure 17, the following technologies are considered of interest for future planning phase research:

- BMS/BAS (8),
- Computer vision (9),
- Generative/parametric design (11),
- Prefab building components (13),
- Real-time mobile collaboration (14),
- Simulation (15).

The following sections identify other technologies that could provide benefit to the planning phase activities of the three chosen work streams (where applicable); façade and the external building envelope, consenting, and scheduled maintenance processes.

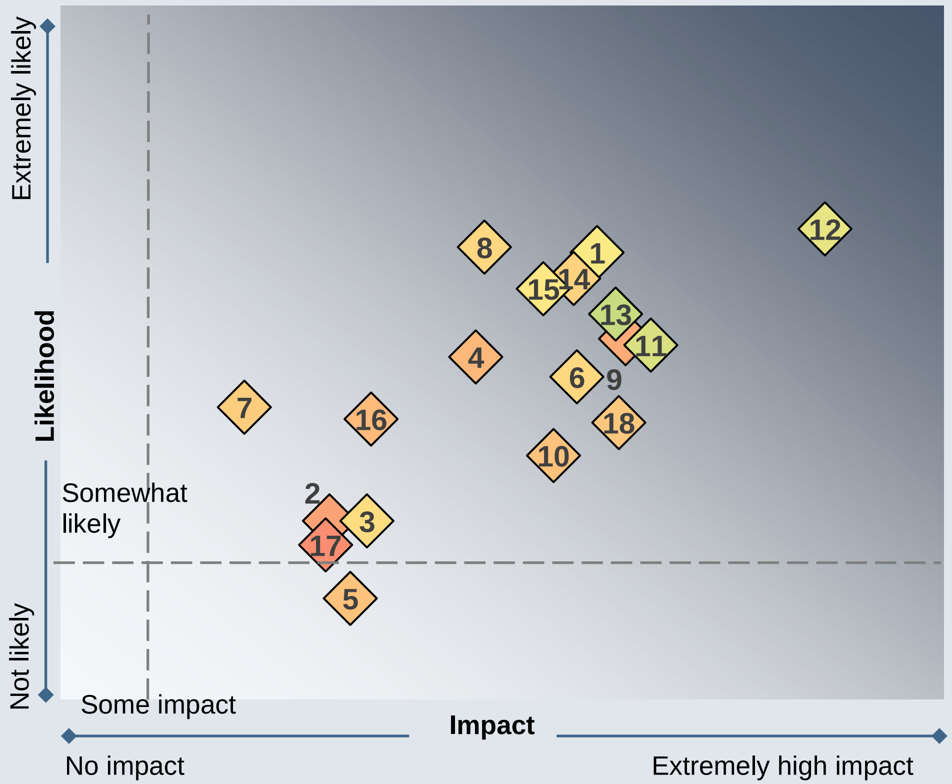


Figure 16: Impact versus likelihood of technologies during planning

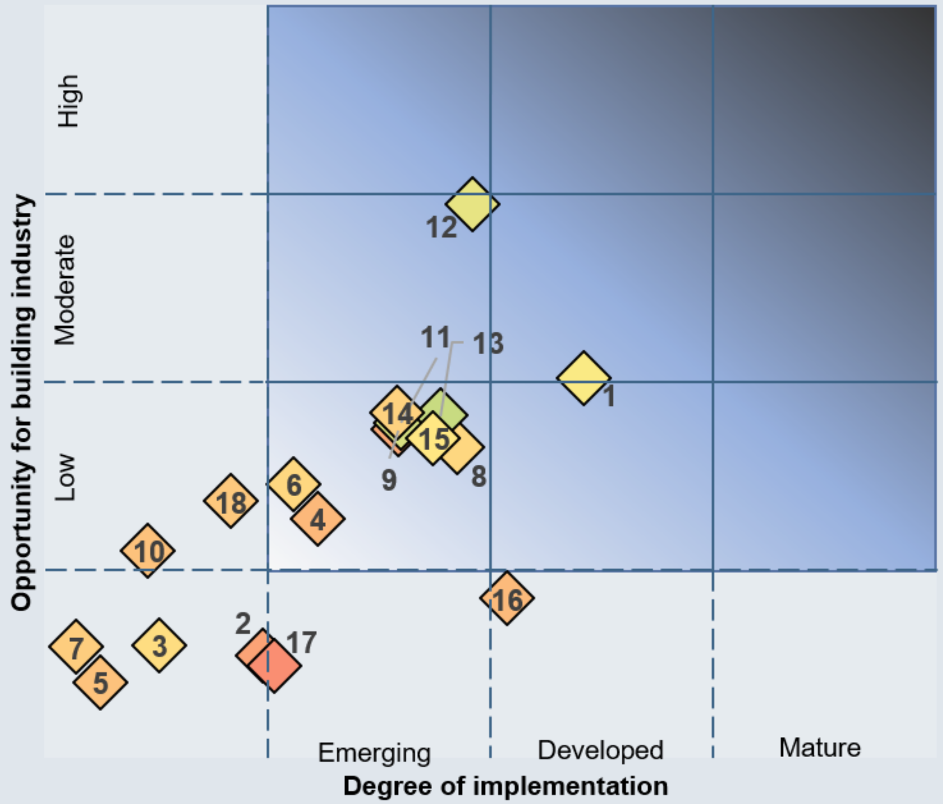
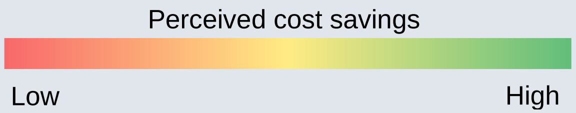


Figure 17: Trend radar of technology usage during planning

Where:

1 – 3D Scanning
2 – Additive Manufacturing
3 – AI/KBS/ML
4 – Immersive Reality
5 – Autonomous construction equipment and robotics
6 – BDA
7 – Blockchain
8 – BMS/BAS
9 – Computer vision
10 – Digital Twin
11 – Generative/Parametric design
12 – integrated BIM
13 – Prefab building components
14 – real-time mobile collaboration
15 – Simulation
16 – UAV (drones)
17 – ubiquitous connectivity and tracking
18 – Wireless monitoring/Internet of Things (IoT)



3.1 Façade and External Building Envelope

The façade is generally not a key work stream in the planning phase of a typical building project, beyond an initial conception of form and consideration for runoff as part of a future resource consent [32].

Although not limited to the façade and the external building envelope, one implication to consider at the planning phase that would offer an opportunity for big gains to be made in later project phases (see Sections 4.1, 5.1, and 6.1), would be the promotion and contractual obligation of designers to specify explicit systems and equipment during the design phase, rather than generic which is often the current norm.

3.2 Consenting

Consenting is a major consideration in the planning phase where the implications of decisions made will influence the design and how this can be consented.

3.2.1 Current industry position

There is little support for consenting at the planning phase with a reliance on internal processes and documentation to capture client requirements and manage these through to design requirements (though requirements management software exists for other industries such as defence), which ultimately will need to be consented.

3.2.2 Vision for the future

The use of BIM across all project phases provides a valuable repository of planning phase information that can be managed across all future phases. Requirements specified by a client can be captured and checked against the evolving design.

Information collected about the project site (e.g., drawn from a wide range of council and government repositories and drone-based aerial surveys), and client and project requirements, can be integrated to satisfy resource consent needs. Appropriate structures and templates can be established from these requirements to guide later design developments and data capture, ensuring correct and enough information is available when a design is put forward for code compliance checking with the BCA. These structures and templates also ensure that compliance checking can be undertaken by design professionals prior to submittal through to a BCA. AI approaches will allow for appropriate company design styles and precedent to be identified and brought to bear for the design phase.

3.2.3 How do we get there?

Significant research and development need to be undertaken to reach this vision for the future. This includes research into:

- Systems which can capture client requirements in a form that can be assessed against an evolving BIM model,
- Big data systems which can scrape sufficient information from currently disparate data sources to support the requirements of resource consent applications (e.g. NSW Spatial Digital Twin [33]),
- AI approaches to systematising and codifying company-specific design styles and patterns to be brought to bear in the design phase, e.g., extensions of current parametric modelling approaches.

3.2.4 Implications

Developments in this area will provide greater assurance to clients that the building which will be designed will meet their requirements and will be developed in accordance with appropriate codes and Standards to smooth the downstream consenting process.

3.3 Preventive and Predictive Maintenance

The scope of O&M for an organisation includes the activities, processes and workflows required to keep the entire built environment in a condition appropriate to its intended function throughout its lifecycle. These activities include preventive, predictive and corrective (repair) maintenance. Preventive and predictive maintenance seek to mitigate failure through planned maintenance of components and equipment either via time-based activities (preventive), or through the detection of onset deterioration (predictive), while corrective maintenance is a reactive repair.

Requirements will vary from a single facility, to a campus, to groups of campuses and as the number, variety and complexity of facilities increases, the organisation performing the O&M should adapt in size and complexity to ensure the requirements are sustained. In all cases, O&M requires a knowledgeable, skilled and well-trained management and technical staff and a well-planned maintenance programme.

3.3.1 Current industry position

O&M activities start with the planning of a facility and continue through its lifecycle. During the planning phase, O&M personnel identify maintenance requirements for inclusion in the design, such as equipment access, built-in condition monitoring, sensor connections, and other O&M requirements that will aid them when the built facility is turned over to the owner or operator.

The philosophy behind the development of a maintenance programme is often governed by the O&M organisation's capabilities. The goals of a comprehensive maintenance programme generally include:

- Reduce capital repairs,
- Reduce unscheduled shutdowns and repairs,
- Be sustainable and resource efficient, conserving energy and water,
- Extend equipment life, thereby extending facility life,
- Meet the comfort and health and safety requirements of the building occupants,
- Realise lifecycle cost savings,
- Provide safe, functional systems and facilities that meet the design intent.

Presently, the predominant mechanism for O&M personnel engagement is verbal and written consultation during the planning process. There are few technologies identified which are specifically used in the planning phase associated with preventive and predictive maintenance activities.

However, during this phase, the technologies that could provide benefit later in the asset lifecycle, and the actions that need to be undertaken in the planning phase to ensure the right information is procured and in the right format, should be considered.

NZ Experience:

NZ Industry notes very few commercial facilities (even hospitals) focus on anything other than corrective maintenance. Manufacturing and pharmaceutical are better at it.

Our response:

There are slight nuances between client as an owner and client as a landlord relationships that will impact the O&M aspect of an asset. However, we've predominantly focussed on the former.

3.3.2 Vision for the future

For procurement, there would be a New Zealand Standard for clients covering how they procure asset information, like ISO 19650 [34]. This would take the form of standardised contract specification documents that convey clear asset information requirements [35]. For each asset type (windows, doors, plant equipment etc.), the asset owner would define the following:

- **What** attributes of an asset they want information on (colour, size, material type, model, manufacturer, warranty period etc.), and a clear definition of that attribute,
- **How** that information is formatted (naming conventions, numbering, units of measure, the use of a classification system etc.),
- **How** the information is delivered (use of IFC[1], COBie[2], etc.),
- **Where** the information is delivered (i.e., the use of a CDE),
- **When** that information is delivered to the client (some may be required during design to make informed decisions about construction, other information might not be needed until the end of construction, prior to handover),
- **Who** is responsible for delivering the information?

It provides a benchmark for the asset owner to audit the information being received and consistency between projects (vital for BDA of multi-building asset owners). Clear asset information requirement documentation also provides the O&M team the ability to review and update to ensure all information received is in the correct format, and still relevant.

Defining this information clearly in the planning phase ensures the supply chain and project team have a set of clear requirements to follow.

Consistency could also be achieved using asset-owner provided BIM authoring templates that include the schema and required attributes. This would reduce the designer's workload who generally must replicate the schema for each project even for the same client and, if different consultants are used between projects, this also ensures a level of consistency for the asset-owner.

There is a perception in New Zealand that as BIM was predominantly introduced by designers, combined with a lack of awareness or understanding of BIM capabilities from asset owners, that information expectations from the latter have generally been a case of 'happy to receive any information able to be delivered'. For BIM and digital technologies to be successful in New Zealand, there needs to be a dynamic shift back towards the asset owner providing explicit instructions on their information needs and the expectation that this is delivered to.

This is where the use of BIM authoring templates and tools provided by the asset owner can empower and provide a digitally auditable document. However, this requires significant upskilling and training of the asset owner to procure information in this way. The challenge is that, with many buildings, the end client isn't always the occupier. Therefore, operations or maintenance costs are of no great concern as they are often passed on to the tenant.

Over time, when an asset owner moves towards the role of maintainer of Digital Twins or Smart buildings, the use of BDA on an already Smart system (IoT and wireless monitoring of equipment) will aid in identifying equipment and machinery with high repair rates, or those which degrade faster than expected (i.e., moving into predictive maintenance rather than planned).

[1] https://technical.buildingsmart.org/standards/ifc/
[2] https://cobie.buildingsmart.org/history/

The information gathered on the well-performing equipment and machinery could be used to help with the management and procurement of comparable equipment, reducing the variety and quantity of spare parts, which will inherently reduce O&M costs. It would also ensure that poor performing equipment is not procured in the future, but well performing is. However, presently there is a lack of a close out of this feedback loop preventing this value from being realised during the planning phase of future projects.

3.3.3 How do we get there?

O&M personnel should be well represented on the project development team so they have visibility of the types of controls, equipment and systems to be maintained once the facility is open and operational. Consideration should be given to professionally developed system-level O&M manual(s), rather than typical vendor-supplied equipment manuals. There also needs to be emphasis on a flexible information exchange mechanism that can be tailored to each type of project and client need (e.g., the COBie initiative). For larger complexes, O&M staff should consider system-wide integration and compatibility of proposed products with existing systems, including tools, equipment and cleaning supplies. This is where the full system commissioning process starts.

At a technology level, to implement a feedback loop of equipment performance, a regime shift from one of reactive and preventive maintenance to predictive is required through the promotion and use of IoT and BDA technologies. However, to action successful feedback loops, organisations need to shift their philosophy whereby more emphasis is placed on the operational and maintenance requirements of an asset at the planning phase (i.e., closer collaboration between Capex and Opex, and mandating a whole of life costing approach and review).

Other key specifics to be implemented during the planning phase to improve preventive and predictive maintenance include [36]:

- **Formal maintainability programme** — Corporate-level resources that are committed, developed and supported, including clearly identified maintainability roles and responsibilities. A structured work process provided to facilitate implementation of maintainability,
- **Pilot maintainability programme** — Low risk, testable small-scale programmes to identify benefits and costs of maintainability,
- **Contract specifications** — Effective specifications that include maintainability objectives, thorough O&M documentation, training needs, and maintenance management system requirements,
- **Cross-functional involvement** — Input from O&M personnel incorporated into the maintainability planning and design,
- **Integration into existing programmes** —Identify best practices for integration into existing activities such as reliability analysis, process hazard analysis, and front-end planning, with minimal cost and effort,
- **Standard design practice** —Improving maintainability through Designed–in features such as equipment accessibility, standardisation, modularisation, ease of maintenance, etc.,
- **Comprehensive tracking** — Development of methods to capture, document, archive and share project maintainability lessons learned.

3.3.4 Implications

The funding for new projects comes from capital finances, while running costs, including maintenance and cleaning, are revenue expenses. The preference is often to have lower capital costs so, unless such funding restrictions are reviewed, the emphasis on prioritising future maintenance is less likely.

Operation, maintenance and repair costs are greater than three times the cost of initial construction and equate to 60-80% of a building's lifecycle costs [36, 37]. Having such a profound impact on a building's financial outlay, it is very important that O&M considerations be discussed at the beginning of any construction activity to optimise the lifecycle of the building. Maintainability is a subject that should be thoroughly explored, not only in the construction and O&M phases of a project, but also during the planning phase as well.

By shifting to predictive maintenance with the use of IoT and BDA of real-world equipment performance in similar asset types, a better understanding of whole of life costs can be achieved and factored into the procurement of future projects, thus hopefully achieving better value for money (organisational philosophy shift required – “starting with the end in mind”). However, as noted previously, the client does not always directly bear the operation and maintenance costs, which often fall to the tenant.

The underlying challenge is a failure on the part of the asset owner to include the whole asset lifecycle in their management of data standards. Data standards for asset hierarchies, classifications, characteristics and domain values generally provide improvement to asset management performance. Nevertheless, the fact still remains that even where these standards may exist, they rarely appear in the handover requirements that the project team must include in its bid submission.

This generally reflects the lack of an entity with the authority to span from capital works into O&M. It follows that without a requirement for the foundational data, the maintenance strategies are also overlooked, and will continue to be without investment in and attention to O&M during the early phases of the project.

CASE STUDY

Client-facing building information consultant

Gehry Technologies consulting services were early leaders in the use of BIM, computer-aided design and other digital technologies to improve building design and construction. Acquired by Trimble in 2014, this consultancy continues to develop innovative digital building solutions for industry. One innovation successfully commercialised by this group is the services of a client-facing building information consultant. Working for the building developer (not for the designers or contractors) this consultant extracts information from the project's BIM models to improve decision-making and risk management by the developer.

Information supplied to the developer may include: design visualisation; design progress and clashes; construction progress and variations; and building information quality. It appears the role of this consultant includes being a 'steward' of the project's digital data and information, i.e., ensuring data and information is fit-for-purpose

NZ Experience:

An NZ Consultant notes they have undertaken this role on a few projects in Auckland which utilised dashboards showing progress on information population during the construction phase through to handover. However, it was difficult getting the contractors to comply.

Section 4:
Design Phase

The design phase is often separated into several sub-phases (concept, preliminary, developed, detailed) with each generally increasing in detail. Greater focus is placed on the building systems (e.g., structural, mechanical, HVAC, plumbing and electrical), the interior and exterior finishes, and the building site (hard and soft landscaping, external services). Project budget and schedule are also significant considerations which the design is marked against. The purpose of the design phase is to undertake the following:

- Determine the areas, physical requirements and relationships of all building spaces and components, confirming or revising the total building area,
- Select interior and exterior building materials and finishes,
- Provide control strategies for all equipment and systems relating to building services such as security and fire alarms, and define the technical requirements for IT needs (phones, data, cable and audio/visual etc.),
- Interior building fit out (such as furniture and equipment selection, cabinetry and custom fabrications, lighting and technology designs, mechanical, electrical and plumbing systems),
- Codes (including compliance to meet safe and hygienic occupation requirements).

Floor and site plans, and building elevations are reviewed, scrutinised for possible errors or omissions, and refined for functionality, usability, code compliance, security, safety and aesthetics. Stakeholder engagement is also vital and they have the most input in this phase. Plans are shared and discussed with user groups such as maintenance services, custodial services, logistics, information technology and public safety, to identify possible problems and to coordinate with the needs and practices in these areas.

By the end of design, drawings and specifications are sufficiently complete to establish construction documents, obtain compliance with applicable building codes and standards with the local authorities, and provide a more accurate estimate of all associated costs.

Within the design phase, those who responded to the survey indicated that they believe the following technologies are currently the most widely used within NZ, and also provide the biggest cost benefit and opportunity for the industry (Figure 18 and Figure 19) from the list of technologies in Table 1:

- 3D scanning (1),
- Generative and parametric design (11),
- Integrated BIM (12),
- Prefabricated building components (13),
- Real-time mobile collaboration (14),
- Simulation (15).

Some of the results from Figure 18 and Figure 19 are aligned with what was expected, particularly autonomous construction equipment and robotics (5), ubiquitous connectivity and tracking (17), and wireless monitoring (18), as these are not considered to be of use during the design phase. However, the application of additive manufacturing (2), immersive reality (4) and AI/KBS/ML (3) extend into the design phase and pose areas for future investigation by research providers. For example, using additive manufacturing to produce physical prototypes of building designs and components, or immersive reality in the production of digital prototypes for exploration.

When considering the whole asset lifecycle, a combination of AI/KBS/ML (3) with BDA (6) and existing BMS/BAS (8) could be used to identify areas of existing assets that are particularly troublesome (based on historical works orders), and ensure they are factored into the new design. Other examples (discussed in the subsequent sections) could include the use of AI and BDA in automated and digitalised consenting.

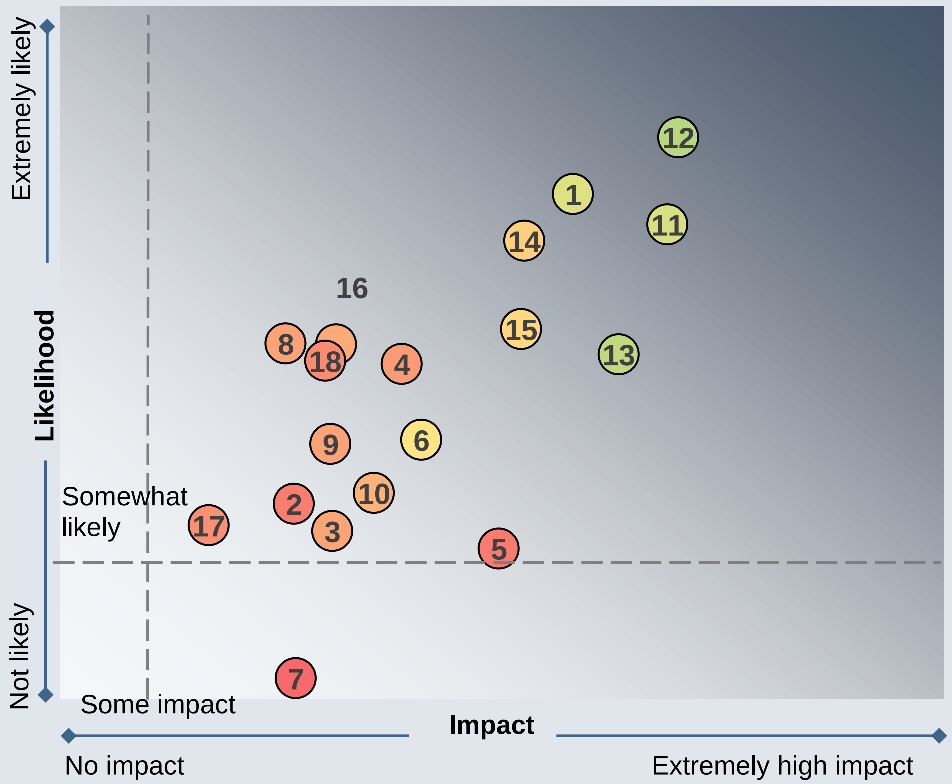


Figure 18: Impact versus likelihood of technologies during design

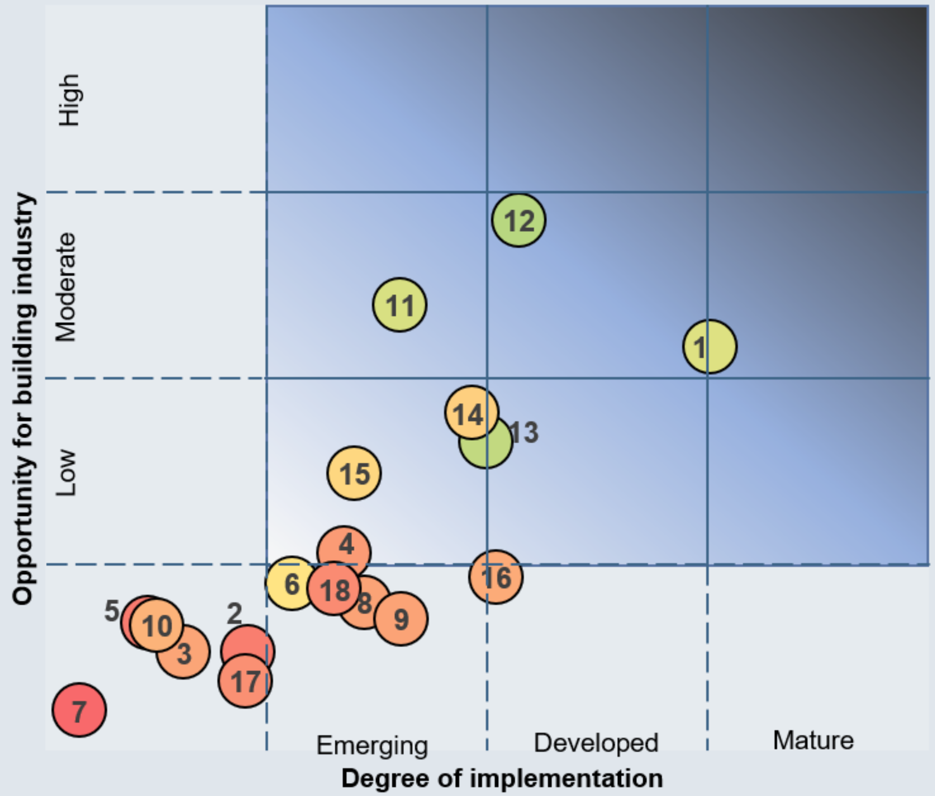


Figure 19: Trend radar of technology usage during design

Where:

1 – 3D Scanning
2 – Additive Manufacturing
3 – AI/KBS/ML
4 – Immersive Reality
5 – Autonomous construction equipment and robotics
6 – BDA
7 – Blockchain
8 – BMS/BAS
9 – Computer vision
10 – Digital Twin
11 – Generative/Parametric design
12 – integrated BIM
13 – Prefab building components
14 – real-time mobile collaboration
15 – Simulation
16 – UAV (drones)
17 – ubiquitous connectivity and tracking
18 – Wireless monitoring/Internet of Things (IoT)

Perceived cost savings

Low High

4.1 Façade and External Building Envelope

During the design phase, the form and function of the façade and external building envelope are further developed. A properly designed and engineered façade can help reduce the building's energy consumption, improve natural lighting, and offer better airflow. Sustainability is a key issue in today's construction industry with many products being used in ways and combinations that will hopefully bring about a lower environmental impact in the future.

The building's intended use and occupancy are also important, as it needs to provide a comfortable space in which to operate. Natural and artificial lighting, and external environment noise levels are some of the requirements that have to be taken into account. Couple this with the green issues (carbon footprint, energy consumption and disposal of façade materials at the end of the building's lifecycle) and it is evident that façade engineering poses many challenges.

Also, during this phase, increasing consideration is needed for aspects of production, installation, maintenance and demolition. Similarly, there are many existing codes and standards for façade design which have to be followed.

4.1.1 Current industry position

From Grasshopper scripting to smart materials, technology is constantly changing the way architects and designers think about façades [38]. However, whilst the general principles have predominantly remained the same over the last 20 years or so, technology is replacing many of the traditional physical modelling techniques (such as solar and wind modelling) with digital counterparts [39, 40].

With regards to specification of design elements, the current approach often relies on designers specifying somewhat generic systems and equipment with the intent for more detailed 'as-built' information to be populated at a later date during construction.

4.1.2 Vision for the future

The progress of computation technology and the availability of diverse software and coding platforms are providing more creative opportunities to define design problems and frameworks of design processes unique to projects and designers, which can then be solved with the assistance of computation.

Some examples of computation technology and its potential use in façade design include:

- Generative and parametric design – pre-design analysis (BDA of existing façades and their performance) [32],
- Digital Twins of façades for exploratory investigation,
- Multi-parameter performance-based simulation within a single model (solar and wind, thermal performance, structural properties of building skin etc.),
- AI assessing codes and standards of façade design,
- Preparation and numbering of complex surfaces all designed digitally (façade construction scheduling),
- The use of BIM in full building lifecycle management.

3D printing (additive manufacturing) is also a rapid prototyping technology that could help architects realise their ideas quickly through scale modelling and prototyping, allowing them to more easily visualise shape and form than in a virtual environment.

The development of modular façade systems with optimised interfaces and standardised functional principles will enable more efficient planning and execution. While the modules can be transported and fitted to consoles already installed on the structure (reducing construction time on site), the design requires greater use of materials, more work during prefabrication, experienced construction engineers during installation, and an increased amount of planning and pre-planning.

A shift in design ethic moving from generic to specific equipment and systems promotes the philosophy of design, draw and populate the information once.

The future of external building design will be based on the continuous digitalisation of the process and supply chain, connecting architects and engineers with main contractors, system suppliers, and façade and maintenance companies.

NZ Experience:

Weathertightness is one of the biggest challenges and risks with façade design in New Zealand today and historically, especially when multiple systems are combined. Whilst multi-parameter performance-based simulation would identify issues, many designers will not specify specific façade solutions due to the liability it attracts.

4.1.3 How do we get there?

The key to improved façade design is through further development of software that is quick and easy to use, and that can display and record information.

Examples include tools generated from gaming software that allow users to navigate around a Digital Twin of their façade and contain design information, construction records or progress photos, which can eventually be passed on to the building owner and those who will operate and maintain the building.

Also using tools that both simplify and enrich the process. By combining different skills, analysis programs and IT platforms, these interactive apps allow designers to explore design options on the fly whilst avoiding lengthy iterative loops.

The shift in design ethic to become more specific can be achieved through better collaboration between the client, O&M personnel and the design team, and embedding specialist trades during the design phase, rather than designers specifying generic elements, such as façade components. 3D catalogue libraries for use in BIM which contain O&M data, and more detailed specifications could be heavily utilised and move towards the specific equipment selection methodology.

4.1.4 Implications

The identification of the process and supply activities, and their data requirements is paramount. Besides functional and formal aspects, advanced façade design and technology takes into consideration aspects of production, installation, maintenance and demolition of façades.

Specifying more explicit systems and equipment during design reduces rework (design, draw, populate with information once approach), gives the client an earlier indication on whole of life costs, and provides better insight for the O&M personnel into how a system would operate so they can plan accordingly (although if the approach of a completed feedback loop were implemented as per Section 3.3.3, the equipment choices would already be known to an extent). It would also reduce data entry requirements during construction (with the exception of where systems and equipment have changed from the original design).

For example, there is a risk that as computation technology, design automation software and AI technology are increased and evolve, the range of designs would converge into similar results due to the tendency and underlying design frameworks innate to each software. However, if design frameworks, processes and methods are defined and used with a suite of software and technology that assists that design process, then this would diversify the design outcomes.

Also, factors such as the complexity of the façade design and the impact on fabrication methodologies would need to be factored into the construction programme. If complex surfaces were digitally prepared in BIM, then, with the use of tessellation and numbering of each facade piece, the construction process could be simplified allowing almost self-assembly and saving time on site (see Section 5.1.1).

Or, what impact does the façade design have on a maintenance contractor’s ability to clean the external building envelope? Can AI twinned with generative and parametric design take required maintenance and installation into consideration when designing the façade?

Other key design considerations for the operation and maintenance of the façade include [41]:

- The surrounding environment - How will the mechanisms and moving parts perform during contraction or thermal expansion in temperature extremes or in corrosive environments such as sea spray zones? What are the longevity and maintenance implications?
- How will the façade interact with control systems? If the design integrates heating and cooling systems, can the automation be manually overridden to prevent unwanted consequences (e.g. the Occidental Chemical Centre in Niagara Falls [42]),
- If an adaptive or kinetic façade, what happens when the façade stops working? Or what impact shutting down the adaptive façade has on the building performance? e.g. If the façade is designed to reduce heat gain, how will the building regulate heat during shut down, or generate power in a photovoltaic façade system?
- How will the façade be maintained? Can moving parts be replaced easily? How will maintenance personnel access the systems safely?
- The maintenance programme – ensure there is a preventive programme in place and it is prominent. Request the programme and cost from the façade contractors at time of tender and guarantee it does not end up buried in specification documents. The greater the awareness of maintenance requirements, the better preparedness and resource planning can be carried out,
- Adaptability of design – if the façade is to last a long time, it needs to be adaptable to the likely change in function of the building. Whilst the design may be subject to different users' tastes, the façade will always need to function and operate during its lifespan, so alternative solutions for changing conditions need to be identified.

If BIM is procured appropriately during design, the modelling of façades can be set up in such a way that it can mitigate information loss during BIM-based design delivery during the transformation of 2D-design to 3D-fabrication (see Section 5.1.2). However, with hindrances such as a lack of unified data exchange standards and limited professional application capability of software, the smooth transfer of full lifecycle information for façade fabrication is restricted [43].

NZ Experience:

Whilst in some areas the use of tessellation and numbering has been successful in NZ (such as HVAC and plant equipment), for façades, simple, robust and repeatable processes, to drive up performance and quality, and drive down costs are needed.

4.2 Consenting

Consenting is a core milestone in the design phase where the documentation (labelled "For Construction") must be assessed by a Building Consenting Authority (BCA), which is usually the local council. The BCA ensures that the design meets all relevant codes and standards for the proposed location and building type. Once a design has gained consent the project can proceed to the build phase.

4.2.1 Current industry position

Current approaches are very paper-centric in the majority of BCAs. The most recent innovations from BCAs are to allow electronic versions of design documents to be submitted and then managed through a Document and Workflow Management System within the BCA. This speeds up the internal handling of the voluminous document set for a design as it passes between different sections of the BCA and ensures that the complete checking process is followed – a significant benefit for BCAs and their clients.

4.2.2 Vision for the future

With the development of automated consenting systems across the world it is clear that software tools will exist that are able to automatically check a design against significant portions of the codes and standards in a country. This is especially true where the codes and standards are prescriptive in nature, such as with many of the Acceptable Solutions developed for New Zealand. Automated consenting tools will be available for designers and engineers to pre-check evolving designs against particular portions of a nation's codes and standards.

Similar tools will be available for BCAs to automate the majority of checks required prior to their signing off consents for a building. These tools will significantly speed up the consenting process and give greater certainty to projects that their design meets required codes and standards prior to submittal to a BCA. The tools will also ensure that designs are thoroughly checked and that consistent decisions are made across all BCAs.

4.2.3 How do we get there?

There are a number of steps required to reach the described future state. The major ones are:

- All paper-based codes and standards need to be digitally encoded, both for the written content and for the semantics, logic and formulae which exist in the code. There are approximately 600 codes and standards applicable in the New Zealand context and to date 15 of them have been encoded through a National Science Challenge (NSC) project, representing priority codes and standards specified by one NZ council,
- Electronic codes and standards need to be owned, served and maintained by an appropriate authority who can guarantee the equivalence of the electronic code to the written code,
- BCAs need to specify the BIM requirements for designs which will be sufficient to undertake the automated code compliance checking. These requirements also need to be checked when a BIM model is submitted to a BCA for checking,

- BCAs need to agree a common approach to the checking and interpretation of codes and standards which can be computerised in a workflow-based checking system,
- Designers and engineers need to modify their processes to ensure that the required information needed for automated consenting is gathered prior to a design being submitted to a BCA. For example, by developing templates for BIM tools to ensure requisite data is requested during the project development,
- Research is needed into AI tools which can automatically enrich and correct BIM models to meet the requirements of the code checking tools. This recognises that humans will never be perfect and different approaches to BIM creation can interfere with the ability to correctly consent BIM models,
- Code checking tools need to be deployed within BCA and for designers and engineers to utilise for their checking processes. The tools for the BCAs need to be certified to be correct when applying electronic codes and standards to a BIM model if a consent is going to be based on the results of the tool.

4.2.4 Implications

Generally, the tendering process to engage contractors is done in parallel with the consenting process. A range of downstream processes will be affected and improved through the development of an automated consenting process (either for staged or complete consents) as described, including:

- Timeliness of subcontracting for the build phase will not be as dependent upon, or delayed by, the current iterative consenting process,
- Residential building inspections by Territorial Authorities could be automatically driven by the output of the automated consenting process, and tools developed to support this process (e.g. the Artisan tool from BRANZ [44]). For commercial buildings, the engineers' reports and producer statements could also be driven and checked through the output of the automated consenting process.

Industry says:

There could also be some debate on if the performance nature of our Building Code is devolving the innovation that it was intended to, or just promoting confusion. A more prescriptive Code would be easier to codify and automate.

4.3 Preventive and Predictive Maintenance

When design choices are made without the maintenance point of view, the result can be a facility that is expensive (or difficult) to maintain.

4.3.1 Current industry position

Designers and architects do a very good job of meeting the function and design requirements of a building, but once it is handed over to the building manager and the O&M personnel, who must maintain it for the next 30 to 40 years, things can unfold very differently. From the maintenance standpoint, buildings often meet expectations aesthetically and functionally from an intended use perspective, but a lack of maintenance considerations during design can result in a building that cannot be sustained over its expected life.

There are several factors in the design process that do not necessarily complement each other including budgets and timetables, customers to satisfy, and reputations to be maintained. During design where budgets are sometimes strained, value engineering is often used. Value engineering was once used to refer to design that accounts for long-term costs, but more recently its use predominantly refers to cutting costs.

When decisions are made regarding design without the maintenance perspective, this can often lead to a facility that is more costly to maintain than necessary, or that has components that simply cannot be maintained, for example [45]:

- Ceiling lights that can only be accessed and changed out with scaffolding, or are not accessible at all, and ultimately abandoned when the lamps fail,
- Inferior-quality components installed to save up-front money. For a small initial cost increase, the long-term costs could be reduced substantially,
- An air-conditioning unit installed above a drop ceiling with no room for a ladder, resulting in the unit not being properly maintained and potentially needing to be relocated,
- Installing a complex architectural facade which requires an expensive piece of equipment to facilitate cleaning.

4.3.2 Vision for the future

The optimum scenario is one where those involved with the project take into consideration:

- The designers' reputation and viewpoint,
- The reputation of client representatives responsible for approving the design,
- The wider stakeholder requirements,
- The energy efficiency and carbon emissions,
- The costs and long-term practical and functional maintainability of the facility that is necessary for building maintenance professionals.

Design for Maintainability (DfM) emphasises the importance of timely integration of design and construction knowledge with O&M experiences into project designs at an early stage. Implementing DfM decreases the risk of equipment reliability and uptime being impacted and total lifecycle costs increasing significantly [36, 46]. This could include the implementation of lifecycle costing, the remunerated annual cost of a building that includes capital costs, installation costs, and operation and maintenance costs over its life [45].

If a New Zealand based detailed product library was developed which included the average operational costs of plant and equipment, and linked to design BIM models, then with the use of AI/KBS/ML, generative and parametric design, and simulation, the optimum operational design could be achieved. Using this method would provide valuable input into the design decision-making process, which could reduce the total expense for the asset owner over the lifetime of the facility.

Also during the design process, the asset owner could pre-emptively develop maintenance schedules for new builds, once the design team have populated the data into BIM (such as the make, model, manufacturer etc. of proposed equipment) [47]. Although there is a risk that some of the equipment may change during construction, the majority will go unchanged, providing valuable lead-in time before handover to prepare for the O&M phase. It also reduces the risk of error or omission in the often-painful tail-end process of O&M data population which habitually gets left as a rushed afterthought at the end of construction. However, as noted in Section 4.1.2, this would only be possible if a specific, rather than generic, design philosophy was adopted.

4.3.3 How do we get there?

Given the maintenance issues that arise, in order to make facilities more maintainable and, therefore, less costly to operate during the building life, the following should be considered:

- There must be meaningful dialogue between engineers, architects, designers, the asset owner, O&M personnel and, eventually, contractors when the job is awarded,
- Just as the architectural or engineering firm uses its staff for quality control or a contractor for constructability review, the in-house O&M group should also be considered a resource for design review [47]. This group can point out items that may lead to long-term maintenance issues or increased maintenance costs. However, not all Facilities Maintenance (FM) industry professionals have the skills and training to achieve this (see Section 7.10),
- Similarly, O&M personnel providing input into the selection of plant and equipment during design. Leveraging their knowledge and awareness of other buildings (in a multi-asset site) can reduce the variation of spare parts for similar plant equipment (for example air filters for each type of air handling unit),
- The knowledge of the O&M personnel on the operational requirements and specifications of plant equipment. For example, knowledge of air handling units (AHUs) whereby the unit that was specified (without input from the O&M team) eventuated to be excessive for the requirements for the building. Not only was the physical size of the AHU an issue, requiring additional installation resources, but also the disproportionate capacity increased the operational costs for that building,
- There must be close interaction throughout the design and construction phases, including input to and review of design drawings and specifications by O&M personnel. This could be achieved by assigning a knowledgeable maintenance professional to be part of the design and build team, and minimising their routine maintenance activities for the project duration,
- Adequate time must be allowed for review of documents. The organisation needs to acknowledge the importance of the input from O&M personnel and schedule adequate time so reviews are meaningful and input is well thought out. Early involvement of O&M personnel can supply the necessary in-depth assessment and avoid last-minute reviews, where only a cursory glance may be undertaken. The more time spent reviewing during design, the greater the chance of improved maintenance workloads and reduction in the asset owner’s operational costs for the life of the building.

Industry says:

Specialist O&M firms are usually much better than owner O&M teams, as they improve their margins by providing lower operational costs.

Our response:

How could the improved margins for external O&M firms be modified to be useful for in-house O&M personnel?

4.3.4 Implications

Choices made during the design phase set in place the long-term operating performance, as well as the long-term operations and maintenance costs for the more than 30-year life of the asset. Poor choices can have significant ramifications for an asset owner by incurring unnecessary lifecycle costs, reaching into hundreds of millions of dollars for some large projects [36].

A UK study in 2010 [48] found that respondents to a survey recommended the inclusion of O&M personnel at the design stage to reduce the future maintenance burden. However, some comments from O&M personnel suggested that architects and designers are reluctant to accept the input of the maintenance team or to take advice from others. In contrast, the architects' responses indicate the desire for O&M personnel input. Despite all respondents recommending input, only 25% of project designs received input from the maintenance team indicating a significant gap in the design process.

CASE STUDY

Virtual design and construction

Robert Bird Group is a global consulting engineering firm with a reputation for successfully delivering innovative design and construction engineering solutions to high-profile building projects, such as Terminal 5 at Heathrow Airport and The Shard building in London. Exploiting virtual design and construction methods is a key element of their business growth strategy. They are championing the use of digital tools such as 4D BIM for construction visualisation and computational software (e.g., parametric modelling, genetic algorithms and artificial intelligence) for design automation and optimisation.

Expertise in these tools enable Robert Bird Group to deliver buildings with reduced material quantities, which provides cost and sustainability benefits, as well as increased building structural performance.

Section 5:
Construction Phase

The construction phase of a building project could be considered the most complex with many moving parts all happening concurrently, requiring a robust scheduling and monitoring programme from multiple stakeholders. Site set-out and foundation construction, framing, exterior and interior fit-out, roof and mechanical services all need to be coordinated from both construction and logistics perspectives. It is also during this phase that the health and safety on the project is of significant importance as the degree of risk increases on an active site when compared to the works undertaken during the planning and design phases.

During the construction phase the design becomes reality. Therefore, the greater the level of detail included in the design documents, the easier it is to both build to that design, and improve the ease with which to verify that the design has been achieved. The construction phase is also where the level of detail in design documents can have implications for time and cost of construction as it is generally recognised that the size and quantity of variations is greatest during construction, and not always due to the fault of those building the asset.

Another key component of this phase is the handover of the asset to the client. This includes all operation and maintenance manuals, equipment and plant registers, and as-built drawings and models (depending on the contractual agreements). Depending on the size and use of the asset, the amount of information required at handover varies significantly. As such, robust and accurate data capture and collation tools are key to a successful handover.

Within the construction phase, those who responded to the survey indicated they believe the following technologies from the list in Table 1 are either currently the most widely used within NZ, provide the biggest cost benefit, and provide the biggest opportunity for the industry, or any combination of those three (Figure 20 and Figure 21):

- 3D scanning (1),
- Integrated BIM (12),
- Prefabricated building components (13),
- Real-time mobile collaboration (14),
- Ubiquitous connectivity and tracking (17).

Figure 20 shows autonomous construction equipment (5) to have a moderate impact, but, due to its considered low likelihood, it sits further towards the lower left quadrant of Figure 21. However, as the survey has shown that respondents consider it to provide moderate cost savings, this technology would warrant further investigation into its use to drive a higher degree of implementation and identify where it could provide a greater opportunity.

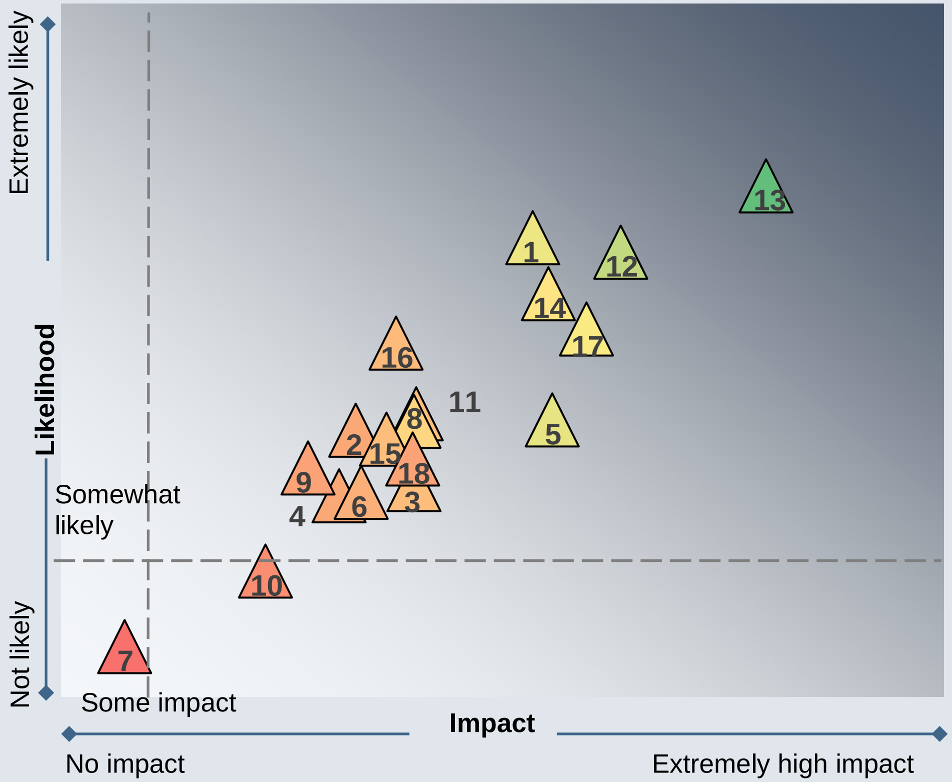


Figure 20: Impact versus likelihood of technologies during building

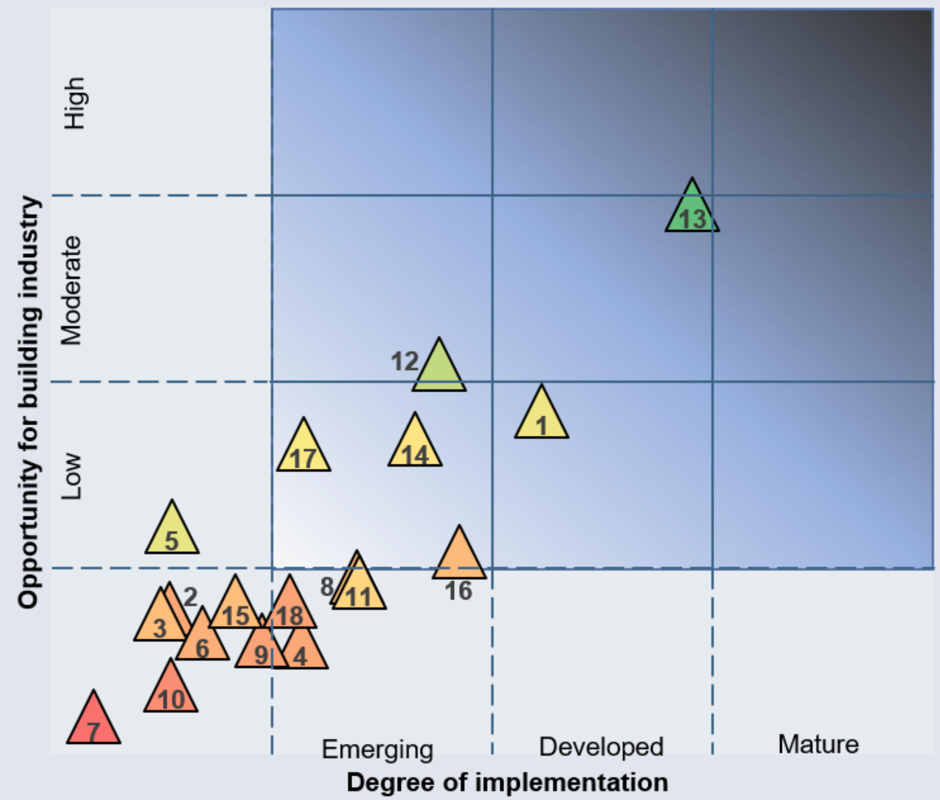


Figure 21: Trend radar of technology usage during building

Where:

1 – 3D Scanning
2 – Additive Manufacturing
3 – AI/KBS/ML
4 – Immersive Reality
5 – Autonomous construction equipment and robotics
6 – BDA
7 – Blockchain
8 – BMS/BAS
9 – Computer vision
10 – Digital Twin
11 – Generative/Parametric design
12 – integrated BIM
13 – Prefab building components
14 – real-time mobile collaboration
15 – Simulation
16 – UAV (drones)
17 – ubiquitous connectivity and tracking
18 – Wireless monitoring/Internet of Things (IoT)

Perceived cost savings

Low High

In contrast to Figure 18 and Figure 19, despite there being several use cases during the construction phase for the technologies, more than expected have plotted in the lower left quadrants of Figure 20 and Figure 21. In particular, additive manufacturing (2), immersive reality (4), and simulation (15) all scored lower than BMS/BAS (8) which could be considered of lesser use during the construction phase than those three technologies.

This could partially be due to a lack of awareness however, as Figure 13 shows, the respondents had a similar level of awareness of immersive reality and simulation as they did of BMS/BAS. It could also be due to the low response of contractors and sub-contractors to the survey (Figure 3). Where technologies could prove useful for construction activities include:

- Using BIM and immersive reality on site to verify that the as-built reflects the design,
- Simulating site works as part of health and safety preparation (delivery schedules, traffic management etc.),
- Using a combination of 3D scanning, autonomous construction equipment and computer vision to mark out the site prior to the commencement of construction.

The following sections for the façade and external envelope (Section 5.1), consenting (Section 5.2) and scheduled maintenance (Section 5.3) discuss the processes undertaken during the construction phase, highlighting where technology could be used to better manage quality, cost and risk.

5.1 Façade and External Building Envelope

As a synthesis of building elements, the façade nowadays is an important building element in terms of performance and architectural design. Façade parameters such as complexity, materials and finishes, performance, magnitude, and location of the project can account for anything between 20% and 30% of the total construction costs [49].

Specific requirements of applied products and aspects relating to every building activity have to be addressed and met in façade manufacturing, which could include Design for Manufacturing (DfM) but also economic aspects (i.e., market demand and market acceptance), or legal aspects (such building codes and liabilities which are regulated by BCAs).

Monitoring the installation is also an important activity as building envelopes can be difficult to accurately predict and require a significant amount of coordination between many parties.

Industry considers:

Using BIM and immersive reality to verify the design on site will be the next big thing to progress. We have seen lots of vendors developing site-based AR for both set out and checking.

5.1.1 Current industry position

Several façade geometry strategies are benefiting from additive manufacturing. Although some products allow for 'true freeform' (i.e. double curved surfaces) like fabrics and membranes, these often do not meet building construction requirements [50]. The use of additive manufacturing can overcome these issues by developing elements such as 3D printed glass [51], or freeform dome structures made from contour crafted clay or concrete.

Construction Labs (portable, high-tech production facilities) are being used on complex projects in the UK for the construction of façades and primary structure connections. By using semi-formed materials that are assembled into components on site and data gathered from LiDAR equipped drones, finely tuned parts can be fabricated and customised en masse. This reduces delivery costs and enables a unique level of flexibility.

Modular techniques enable rapid construction of flat-pack buildings, with the exception of intricate façade components. In those cases elements need to be designed and fabricated locally [52] to bring the required finesse. However, as noted in Section 4.1.4, self-assembly can reduce construction time by numbering off-site fabricated pieces.

Wastage is also a big concern in façade production due to variances between standard material sizes and actual usage, with wastage ranging from 15 to 50% [53]. The utilisation of additive manufacturing and modular construction should reduce the degree of wastage.

5.1.2 Vision for the future

Greater flexibility in façade construction is required. Prefabrication doesn't provide the full extensibility needed assemble components where different companies and contractors work on the same project. Additive manufacturing is also being explored for 3D printed parts of non-structural components of the building envelope (capping, end pieces etc.), but with further development of material properties, this could extend to structural applications in the close future [50].

Construction sequencing poses a challenge to full prefabrication as there are times where sequential components need to be added at a later date, in parallel to other contractors and sub-contractors also being on site [52]. This can be overcome with the introduction of cyber-physical systems (CPS) into the façade industry whereby smart machines, production facilities, and building site terminals are capable of autonomously exchanging information, triggering actions, and controlling each other independently [11]. These would provide better coordination and reduce the clash with other parties on site.

The use of BIM-based design delivery could aid in the production of 3D-fabrication models through transfer of accurate façade information from the design model to the tools directly used for fabrication. This workflow would not only improve the building quality, but also reduce wastage in time and materials from the traditional design to fabrication methodology [43].

Industry says:

As mentioned in Section 4.1.1, weathertightness is a big concern within NZ and so the use of tools such as Construction Labs to verify that the interconnected parts and façade systems meet the design brief and codes and standards would be valuable.

5.1.3 How do we get there?

New processes, innovative management tools, and new IT are needed to integrate the currently isolated design, fabrication and installation processes into a single environment. This in turn will improve collaboration efficiency and reduce the waste that typically arises during construction.

5.1.4 Implications

BIM-based building lifecycle management can help to process the as-built data of the façade fabrication quickly to determine the cleaning, repair and maintenance requirements (see Section 6.1.2). Similarly, it can help integrate human resources, processes and BMS/BAS that are related to the façade and external building envelope. Facilities managers would be able to review the rationality, correctness, consistency, and completeness of BIM models (both in terms of geometry and information) provided by the project team and integrate this information into their systems. Whilst this would greatly reduce the risks for assets in the whole lifecycle, as discussed in Section 4.1.4, a lack of data exchange standards and poor procurement methods will hinder the ability to achieve this, if the right data aren't specified during the design phase.

CASE STUDY

Planning for maintenance with advanced construction techniques

When considering the future ongoing maintenance of the façade, Newtecnic has used a Construction Lab on Saudi Arabia's new city-wide transport system featuring six new metro lines, 85 stations and over 100 miles of track. It's been designed for a future where digital technologies will play an increasingly important role, as the system has been engineered to make it suitable for future robot access, movement and operation. This means robots referencing the building's 3D cloud-hosted Digital Twin, in conjunction with GPS, can calculate routes and locations on the building's façade. While robots will do the heavy lifting, replacing and carrying away of damaged components, airborne drones can be used for inspection and cleaning [51].

Newtecnic have demonstrated that having the foresight to incorporate the means for future technologies to be used in the O&M phase into the design and construction phases, can result in a more efficient maintenance programme of the façade and external envelope.

5.2 Consenting

Consenting at the construction phase is concerned with ensuring the code compliant designs are constructed. For residential construction this is accomplished through inspection at particular milestones. For commercial buildings this is accomplished with engineers' reports and producer statements.

5.2.1 Current industry position

Current approaches are very human and paper-centric with physical inspections a requirement. The Artisan tool from BRANZ [44] has recently been launched and allows for electronic submission of photos from site to check milestone construction points matching consented requirements for residential builds.

5.2.2 Vision for the future

Residential building inspections by Territorial Authorities (TAs) could be automatically driven by the output of the automated consenting process, and tools further developed to support this process. For commercial buildings, the engineers' reports and producer statements could also be driven and checked through the output of the automated consenting process.

5.2.3 How do we get there?

There are a number of major steps required to reach the described future state. The major ones are as detailed below:

- An interoperability standard is required between the code compliance consent outputs and tools for the inspections and reports required from site,
- Checking tools need to be developed for residential compliance which are driven by the consent requirements. With UAV developments, much of the required photographic documentation could be automated on site, and other photographic documentation sourced from site workers,
- Checking tools need to be developed for commercial building compliance with audits against engineers' reports and producer statements matching the consented requirements.

5.2.4 Implications

Efficiency on site would receive a boost with automation of the inspections and greater certainty during build that construction matches required design parameters from the consents.

5.3 Preventive and Predictive Maintenance

Preventive and predictive maintenance during the construction phase is focused on the successful delivery of asset information prior to commencement of the O&M phase and ensuring that any changes to the design continue to meet the expected operational performance.

5.3.1 Current industry position

Despite technological developments, many buildings still suffer from defects and unacceptable performance caused by inadequate construction, making them vulnerable to increased frequency of planned maintenance during their lifecycle [54]. These defects may be attributed to the use of defective construction materials, poor supervision, non-compliance with specifications and poor quality control on site, which all contribute to higher O&M costs [55].

Common maintenance issues caused during the construction phase include [56]:

- The new plant ‘tossed over the fence’ from the capital construction team,
- The facility being commissioned later than scheduled because of construction delays and an expectation from the asset owner that the O&M personnel will make up lost time,
- The project coming in over budget and at the end of the construction phase, options to facilitate maintenance and reliability (e.g., sensors, IoT, smart technologies) being sacrificed in favour of saved time and cost,
- O&M manuals of as-installed systems and equipment documentation being delivered at handover, long after the asset owner has moved into the building and the O&M personnel are already operating the facility.

5.3.2 Vision for the future

In order to deliver a successful construction phase and to set up a strong O&M phase for planned maintenance, the following should be considered:

- Continued participation from O&M personnel to review installed systems and equipment, including sequencing of installed services,
- The reintroduction of a ‘clerk of works’ (CoW) on the construction site, acting on behalf of the client, verifying the installed equipment,
- Ability for O&M personnel to undertake benchmark testing prior to handover,
- The use of QR and RFID tags on installed equipment that contain product information and O&M manuals to provide confidence to the O&M personnel that the planned maintenance schedule is still as expected,
- 3D scanning tools, IR goggles and frequently updated BIM and 3D environments for the O&M personnel to interrogate in order to ensure that required access for all equipment has been maintained from the design,
- The use of BDA to leverage data and analyse the causes in design change during construction, RFIs, defects lists etc.

5.3.3 How do we get there?

To support efficient planned maintenance, it is important that facility O&M documentation be:

1) Required by the owner,
2) Accurate,
3) Available in a timely fashion.

System-level and manufacturer manuals of as-installed systems and equipment, including as-built drawings, should be available for review by the owner over the course of the construction phase. To efficiently operate a facility, O&M information must be available prior to handover, owner occupancy, and especially before O&M personnel training. Although obtaining O&M documentation may be overseen by the asset owner's representative or building commissioning agent, the effort should be coordinated with and overseen by the asset owner's project manager to ensure it is being accomplished.

The immediate reintroduction of a ‘clerk of works’ could be difficult as the building systems that existed when clerks of works were around were much simpler. It may be more realistic to ensure that the designers are properly trained in site observation and that they have the budget to place the right people on site for the construction phase.

5.3.4 Implications

The O&M team often falls victim to the misconception that they will have to build the maintenance strategies and asset databases as they go following handover, as the budget has not included provision for the engineering or contractor teams to deliver this information. As a result, information sets that had been developed during the design and construction phases are not properly translated into O&M information, and critical aspects of the assets’ histories are lost forever. Therefore, in the event that O&M information is not available prior to handover, owners should revise their procurement specifications to mandate the requirement.

If poor construction is carried out, there are implications for building maintenance i.e., increased degradation of building components leading to an increased frequency in planned maintenance and, therefore, increased costs.

As mentioned in Section 4.3.3, where plant and equipment O&M information had been populated during the design phase, the asset owner and O&M personnel must verify that what has been installed matches the pre-populated information, or update the maintenance schedules accordingly. Using BDA as part of that verification process to track changes and causes, would aid in closing out the feedback loop to both the client and the design team (as discussed in Sections 3.3.2 and 3.3.3).

For a client employed CoW, a lot of the risk that currently sits with the designers and builders will be moved back on to the client.

CASE STUDY

Using BIM to improve construction coordination and risk management

The adoption of BIM, and the capability to exploit its benefits, varies between countries. The Netherlands is at the forefront of using BIM, and it has penetrated into contractor companies as well as the design community. It appears around half of all Dutch contractors use BIM, with the fraction being much higher for larger contractors. This level of adoption far exceeds the uptake of BIM by contractors in the rest of Europe and New Zealand. The requirement to use BIM on nearly all government contracts has driven the uptake of BIM.

Faced with the requirement to have BIM capability in order to operate, Dutch contractors are finding the technology can help to reduce construction risks and inefficiencies. As a risk management tool, BIM is being used to communicate who on the construction site is responsible for what, and the requirements of materials used. The value of BIM to contractors is its ability to reduce inefficiencies due to rework and poor coordination, which can add 10% or more to the cost of construction.

Section 6:
Operate/Maintain Phase

Facilities operations and maintenance (often combined into the term O&M) encompasses a broad spectrum of services, competencies, processes and tools required to assure the built environment will perform the functions for which it was designed and constructed. O&M typically includes the day-to-day activities necessary for the built structure, its systems and equipment, and its occupants and users, to perform their intended function.

Accounting for as much as 80% of a building's lifecycle costs, O&M expenses often reach three times the building's initial construction costs [36, 37]. Significant decrease in anticipated project value traditionally occurs during the handover, commissioning and facility start-up period (usually the first year after commissioning (*Figure 9*) and often results in a period of unstable operations, with significant lost revenue and profit opportunities due to unexpected and extended downtime. Similarly, actual O&M costs are typically one to two percent higher than the expected total O&M costs from the initial business case [56]. These higher costs do not include the operability value destroyed because of poor design choices, unprepared operators and maintainers, outdated maintenance strategies and a lack of necessary documentation.

Common causes for the additional costs include:

- The O&M team not given the opportunity to contribute to the design or selection of equipment, with choices based on lowest initial cost and not on total lifecycle cost or reliability and maintainability. Also, no consideration given to installed equipment in other buildings, resulting in a lack of standardisation, the need to overstock spare parts, and time and resource requirements for the O&M team to become familiar with new equipment,
- Voluminous O&M documentation is delivered coincident with commissioning in disparate formats that are usually inconsistent and not readily transferable into the asset management system. Also, it is often hardcopy only, and largely focussed on time-based preventive maintenance with heavy reliance on parts replacements, and little use of predictive maintenance or condition-monitoring technologies,
- O&M data not being loaded into the asset management system and linked with asset and spare parts data or maintenance procedures,
- Predictive maintenance baseline assessments not carried out to ensure proper installation and readiness of equipment, prior to releasing the contractor(s), leaving the O&M team to fix the mistakes. Combined with the first year of operations generally comprising significant unexpected downtime due to the O&M team trying to reactively understand the new equipment.

Building maintenance 30 or 40 years ago was not to the level of sophistication it is today. Back then, a system that controlled all the systems in the building was a pretty new thing. Today, buildings are basically computers and maintenance requires a different skill set [57].

How can digital technology be used to overcome these difficulties?

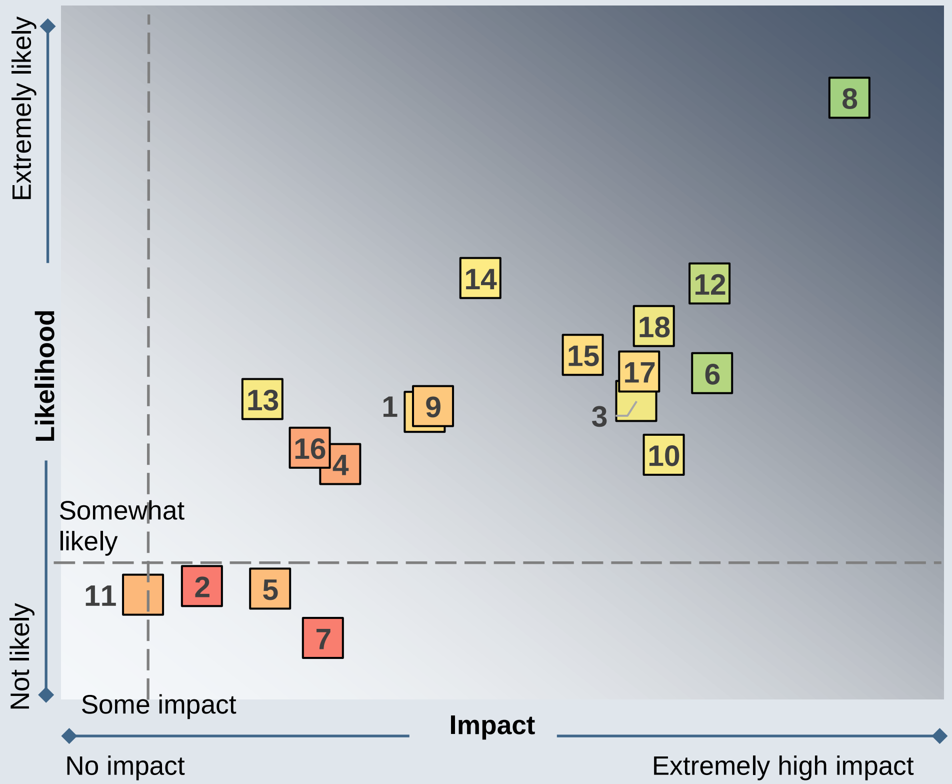


Figure 22: Impact versus likelihood of technologies during O&M

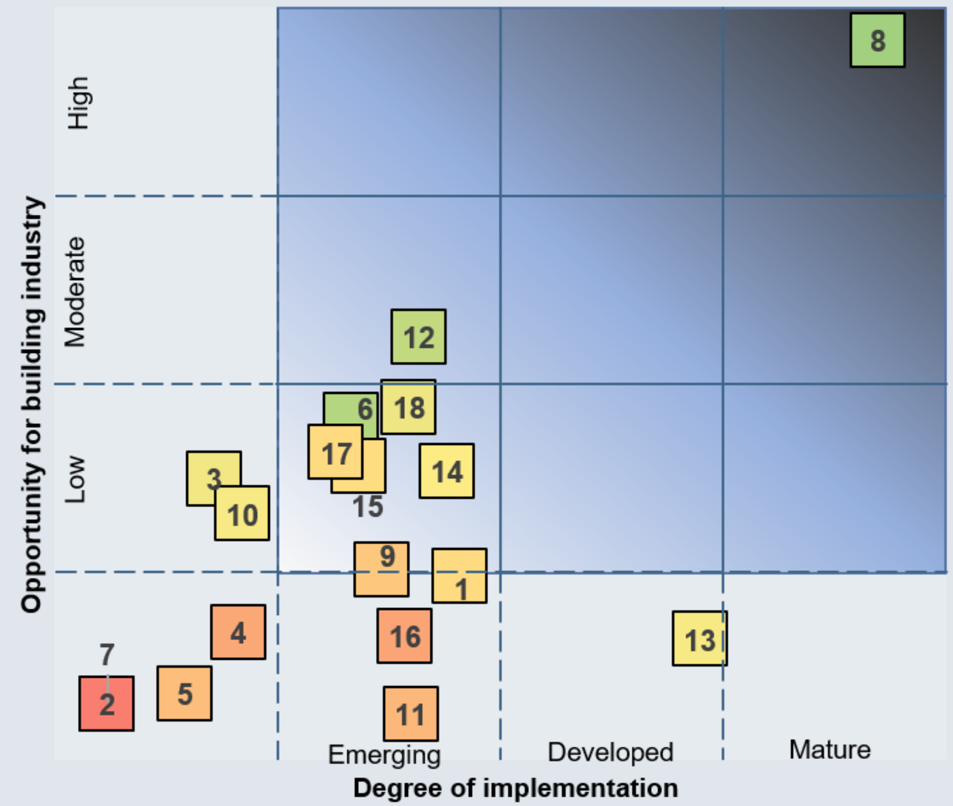


Figure 23: Trend radar of technology usage during O&M

Where:

1 – 3D Scanning
2 – Additive Manufacturing
3 – AI/KBS/ML
4 – Immersive Reality
5 – Autonomous construction equipment and robotics
6 – BDA
7 – Blockchain
8 – BMS/BAS
9 – Computer vision
10 – Digital Twin
11 – Generative/Parametric design
12 – integrated BIM
13 – Prefab building components
14 – real-time mobile collaboration
15 – Simulation
16 – UAV (drones)
17 – ubiquitous connectivity and tracking
18 – Wireless monitoring/Internet of Things (IoT)

Perceived cost savings
Low
High

According to the survey respondents, BMS/BAS (8) and prefabricated building components (13) are currently the most widely used within NZ, with only BMS/BAS considered to provide any real opportunity and cost saving during the O&M phase (Figure 22 and Figure 23)

Respondents consider several of the remaining technologies to be ‘emerging’ and to provide a low-moderate opportunity and cost saving. These include:

- BDA (6),
- Integrated BIM (12),
- Real-time mobile collaboration (14),
- Simulation (15),
- Ubiquitous connectivity and tracking (17),
- Wireless monitoring and the Internet of Things (18).

Similar to the responses in Section 5, Figure 22 and Figure 23 also show technologies that were expected to have scored higher for the O&M phase, that didn’t. Again, immersive reality (4), and Digital Twins (10) both ranked lower than generative and parametric design (11) in their degree of implementation, the latter of which could be considered of lesser value during the O&M phase than the other two. This trend doesn’t appear to be due to levels of awareness as immersive reality and Digital Twins are seemingly more known to the respondents than generative and parametric design (Figure 13).

As speculated in Section 5, the unexpected results could be a result of the low number of responses from asset, facilities, and operations and maintenance management professionals to the survey (6% of the total response as per Figure 3).

Based on the emerging and low to moderate opportunity sectors of Figure 23, processes and technologies in the O&M phase where research providers may want to focus future efforts include:

- Using immersive reality on site combined with integrated as-built BIM to identify equipment and systems hidden by wall and ceiling coverings quickly and accurately,
- Digital Twins as a means of managing an asset,
- Using AI/KBS/ML with wireless monitoring, IoT and BDA for predictive maintenance,
- Ubiquitous connectivity and tracking with BMS and BAS to automate the building based on environmental conditions (e.g., opening and closing shutters based on degree of sunlight).

The following sections discuss the technologies and processes in the O&M phase for the façade and external envelope, consenting, and scheduled maintenance that could better manage quality, cost and risk.

6.1 Façade and External Building Envelope

Periodic maintenance to façades is important, both to prolong the life span of a building and to avoid consequential damage to it. However, façade maintenance should be conducted safely, using reliable equipment, so as not to provide any risk to the users and owners of the building.

6.1.1 Current industry position

Architecture and engineering have lagged behind the revolution in computing power when it comes to the operation and maintenance of buildings. Other technologies such as cell phones are more sophisticated in terms of feedback, operability and flexibility [57].

Recent developments in intelligent façade systems are improving energy efficiency and occupant comfort requirements by integrating technology as part of the function (Figure 24). By combining computation, smart materials (e.g. thermobimetal), and sensors, performance-based responses are programmable to react to changes in weather conditions and undergo self-shading and self-ventilating [38]. Similarly, improved energy-efficient ecological, photoelectric, and intelligent façade panels are gathering momentum [53, 58].

Technology is being integrated into façade function in the following categories [59]:

- Control technologies – predefined and pre-programmed control logics based on user preference,
- Sensing technologies – adaptive façades receiving input from feedback devices such as sensors and programmed systems. This includes ubiquitous systems that analyse data and learn to find the best solution,
- Actuator technologies – devices which convert input energy into a mechanical action utilising external forces to provide motion to the façade mechanisms, based on changes in the physical properties, directions and magnitude of the façade system.

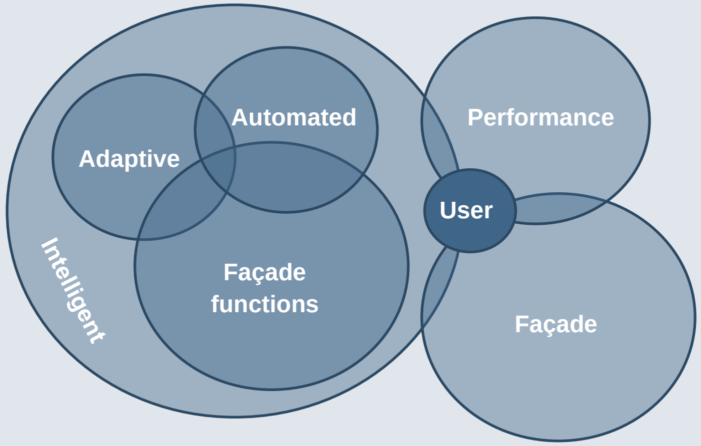


Figure 24: Intelligent façade section [61]

These technologies generally reduce the operations requirement of a building through automated response to user comfort. However, they can increase maintenance costs, as demonstrated by the Institut du Monde Arabe in Paris. Despite providing a means of controlling daylight, the use of mechanical photosensitive panels with 16,000 moving parts culminated in a maintenance regime that could not be sustained and a system that deteriorated after only a few years [57].

Conversely, the Al Bahr Towers in the UAE, and the Swisstech Convention Centre show improvements to intelligent façade systems. The former uses an automated sunscreen façade, responsive to the sun's movements, improving control over energy consumption and glare [60]. The latter has a dual-functional glazing system that provides solar protection whilst producing electricity through translucent panels that adapt to light conditions and maximise power output [61].

For the maintenance of façade and building envelope systems, traditional access solutions for cleaning use scaffolding, suspended platforms and harnesses that have increased risk to human safety. Repetitive processes leading to fatigue and distraction are major concerns with fatal accidents in window washing having been recorded for years [62].

6.1.2 Vision for the future

A fully developed Digital Twin of a building would allow for easy availability and visualisation of live data using wireless monitoring and IoT. Sensors attached to the façade could continually monitor temperature, humidity and air pressure, providing a target-orientated and optimised maintenance management solution. The recording and storing of weather measurement data would provide input into analytics of historical conditions, assisting with forecasting FM activities [63]. The use of AI/KBS/ML with IoT and BMS/BAS, could monitor façade condition, and trigger alerts when its target state drops below a threshold. This would notify staff via real-time mobile collaboration of unplanned maintenance works.

Also, utilising real-time mobile collaboration and immersive reality, smart assistance systems such as cyber glasses, integrated with as-built digital information (BIM, O&M manuals etc.), would negate the review of extensive façade product manuals and undertaking of routine tasks. It would however, enable greater focus on creative, value-added activities [11, 64].

Some of the other emerging technologies identified in Figure 22 and Figure 23 could provide benefit to the façade and external building envelope in the following areas:

- UAV and autonomous construction equipment used for cleaning and surveying buildings during scheduled maintenance [65-67],
- Prefabricated building components and additive manufacturing used to replace out malfunctioning or broken façade elements,
- Wireless monitoring and IoT in energy harvesting (light, heat, solar etc.) linked to BMS/BAS prioritising collected energy (e.g. electricity stored through solar, adjusting façade panels to optimise sunlight into a room before turning on the artificial lighting, or using sensors to monitor heat in a room before turning on the HVAC system) [53],
- Nanotech in self-cleaning claddings that allow the material to repel water, oil and dirt, reducing recurring costs and water usage [53].

6.1.3 How do we get there?

The building envelope is a system of components that must co-operate for multi-functional operability. Many of the examples presented demonstrate single adaptive facade features which are interdependent and mutually exclusive (e.g., sun-shading or energy harvesting). The development and implementation of truly intelligent façade concepts are in their early stages in New Zealand with multi-functionality one of the biggest challenges.

In addition to the development of smart products and augmented operators, intelligent façades need to include networked smart machines in intelligent systems where control and organisation can be defined to benefit building performance. Equally, intelligent systems are intended to make industrial production faster, more efficient and more flexible, ensuring company competitiveness throughout the supply chain.

NZ Experience:

The leaky building history has left designers wary of being too adventurous with façade design and specification. Further consideration needed on how this can be resolved.

6.2 Consenting

There are few consenting impacts in the O&M phase, though significant renovations and eventually some forms of demolition will require consents. The future and requirements for these consents are as specified for the design phase in Section 4.2. Improvements in consenting in previous phases is likely to lead to better information availability for the O&M phase with a richer BIM available at handover.

6.3 Preventive and Predictive Maintenance

The handover of a new or newly renovated facility is celebrated by the project team, occupants, and owners. For those responsible for operating, maintaining and managing that facility, the work is just beginning.

Preventive maintenance refers to tasks, such as inspections and repairs, that are performed according to a predefined schedule. These tasks can include isolated responses to work orders as well as recurring services such as machine lubrication and calibration.

6.3.1 Current industry position

Facility managers have to sift through the asset information and maintenance schedules delivered in boxes of paper documents and unstructured digital folders full of files, only to re-enter that information into their asset management systems. It's reported that this process of transcribing, entering, and validating data can take years [70].

In many cases, the equipment manufacturers issue preventive maintenance recommendations for the equipment, which are used to form the basis of facility maintenance schedules. These typically cover the frequency of maintenance and replacement of parts.

Field personnel need to find these maintenance recommendations to complete jobs. Whether hard-copy or digital, over time such documents are often moved or lost, increasing the cost to complete those tasks and potentially increasing downtime of mission-critical facilities.

During the life of a project, information is collected and recollected, transcribed and then lost, over and over again. When it comes to the tasks themselves, the results of inspections are often limited to using hand-held mobile devices to push notifications to a system, confirming the task was completed. Any task-specific details are recorded in hard-copy, subsequently scanned, and saved in a system as a static record, unable to be analysed for patterns in the frequency of repairs required.

6.3.2 Vision for the future

If one thing is for certain, machines and equipment will break, so operators need to be as prepared as possible. While preventive maintenance of an asset encompasses a variety of activities, there is always a need for information and the ability to assess asset performance and condition. Technologies and processes that have the potential for improving preventive and predictive maintenance tasks include:

- Scanning QR or RFID codes with handheld devices to access the correct plans, drawings and O&M manuals from cloud storage,
- Having an integrated BIM model, filtered specifically for maintenance personnel (e.g. limited to the assets identified as requiring maintenance from a linked COBie output) accessible on a handheld device, or in IR goggles for interrogation [64],
- Online web forms, accessible via handheld devices, to record works undertaken that are subsequently uploaded to the maintenance system,
- Having a Digital Twin of the plant or equipment loaded and accessible in IR goggles for maintenance personnel to practice repairs before physically conducting them,
- The use of robotics to conduct condition surveys of plant and equipment.

The implementation of IoT technologies and BDA in preventive maintenance transitions the regime from one of prevention, to one of prediction. While preventive maintenance is based on optimised timing, planning and workload balance, predictive maintenance brings the additional benefits of data analysis and diagnostics that add flexibility and continuous improvement to the maintenance process (Figure 25).

This combination of performance assessment and digital technologies can allow greater analysis of real-world data and drive further intelligent action. Real-time data gathered from connected smart machines and equipment can improve predictive analysis, thereby allowing unforeseen situations and changing conditions to be identified. At the same time, it can mitigate potential damage, maximise parts' efficiency, and reduce downtime [71].

Data networks can communicate aggregated sensor data from connected machinery to on site or cloud data storage where analytics tools with predictive algorithms can analyse data. The resulting analysis provides insight into performance optimisation, identifies optimum maintenance approaches, and determines when each individual part is likely to fail. This information is then automatically transmitted via data visualisation and collaboration tools, providing workers the ability to perform maintenance on only the parts that need it, when they need it.

According to a recent report [72], predictive maintenance can reduce the planning time by 20–50%, increase equipment uptime and availability by 10–20%, and reduce overall maintenance costs by 5–10%.

6.3.3 How do we get there?

The need for a coherent system to manage building data is enormous, as are the potential benefits. Historical data, lessons learned and the locations of short-term fixes should not be lost with the departure of an employee. Engineering observations can provide a critical benchmark, but only if the report can be found. More reliable identification of trends for prediction and more confident diagnoses can be achieved when information is able to be cross referenced and inter-related. Through inter-linked information, it should be easy to research and analyse the history of conditions, cost or actions taken on any system within a single building, and compare with buildings of similar use or construction types to a component level of detail within a portfolio.

6.3.4 Implications

Adding new smart digital technologies to any work environment can have considerable impacts and challenges such as increased upfront costs, the need for additional technical support, and changing talent requirements (see Section 7). Also, the transition to predictive maintenance cannot be achieved by technology alone; process and organisational change are just as important.

Without the foundational building blocks of process and people (Figure 1), investment in technology is not likely to yield the desired results. Sensors and smart devices are useless unless maintainers know what the reported information means. Similarly (as discussed in Section 3.3.4), having performance data captured and fed back into future project designs and budgets, closes out the feedback loop of a fully operational Digital Twin (Section 2.2). All of this contributing to “starting with the end in mind”, and promoting a whole of life costing approach.

Wider considerations for implementation of smart digital technologies include [72]:

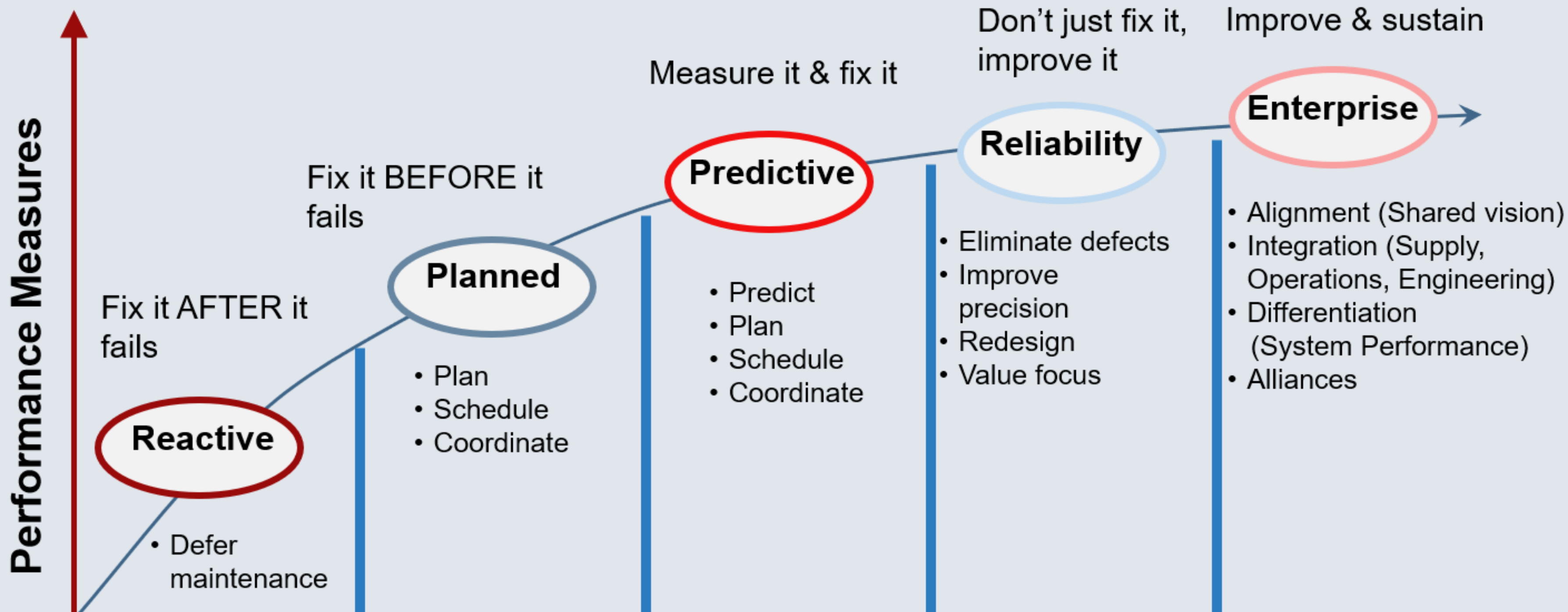
- **Security** – With the advances in IoT and ubiquitous connectivity, there is a growing concern that building systems are a soft vector into a computer network. Asset owners should consider safeguarding access to critical equipment and protect connected assets by adopting a proactive cybersecurity stance,
- **Data management** – Priority should be given to gathering the right data, as it is crucial to enable accurate prediction and pattern identification [73]. This will likely require a major effort in data cleansing and retrospective failure event mapping to carry out effective analysis. With the growing use of IoT sensors and ubiquitous connectivity (e.g., light fittings with sensors tracking people movement, space usage etc.), having the right data is only part of the process. Choosing and maintaining the most appropriate software capable of storing and analysing amassed data from multiple assets and locations, and utilising AI/KBS/ML to forecast failures and outcomes, is key to successful predictive maintenance,
- **Equipment upgrades** – Finding spares and managing inventory for replacement parts for old equipment can be difficult. The cost to upgrade or replace equipment with smart assets may be significant,
- **Technology** – Software, hardware and algorithms focused on predictive maintenance are still in their early stages compared with other approaches to maintenance. It might therefore be advisable to take a pilot approach to predictive maintenance, testing and learning before scaling up,
- **New skills and organisational approaches** – Adapting to predictive maintenance can demand new skills beyond traditional maintenance planning and execution. Organisations may need to augment capabilities with multiple vendors such as data scientists and reliability engineers in order to develop algorithms and predictive models and implement solutions.

CASE STUDY

Digital Twins for improving facility management

DPR Construction is one of the few construction companies to place digital technology and innovation at the centre of their business strategy. They have been using BIM since the 1990s and have progressed to using technologies such as digitally-assisted fabrication and prefabrication, artificial intelligence, robots, laser-scanning, on-site mobile devices and Digital Twins. While Digital Twins are a hot topic in the building industry, they have been used for some time in other industries. Rolls Royce, for example, use Digital Twins for the design and management of their engines.

Helsinki is one of a growing number of cities using Digital Twins for urban design and city management. DPR has ‘discovered’ the value of the as-built building information they hold at the completion of construction projects for the creation of Digital Twins used by facility and asset managers. They have established a facilities management business based on the competitive advantage they have through possessing digital information on buildings they have constructed.



People	"Fire fighting" heroes	Overlapping responsibilities	Role-based training	Defined roles & responsibilities	Cross trained / bench strength
Processes	Limited development	Planning materials & inventory management	Kitting materials & scheduling technicians	Monitoring technician work execution	Total productive maintenance
Systems	CMMS PM management	CMMS planning & inventory management	CMMS scheduling & robust reporting	CMMS automated work generation	CMMS lifecycle cost tracking
Technology	Limited utilisation	Electronic document management systems	Predictive technologies	Mobile handheld devices	Barcoding & RFID utilisation
Governance	Minimal performance tracking	Lagging indicators	Leading & lagging indicators	Continuous improvement efforts	Organisational metrics aligned

Figure 25: Maintenance maturity scale [77]

Section 7: **Recommendations**

To achieve a transformation of the building industry supported by digital innovation and collaboration requires action from all stakeholders. Our ten core recommendations, detailed below, should not be taken as siloed initiatives capable of creating change individually. Rather, they are an interwoven set of initiatives that need to be coordinated and implemented by all in the industry. The call for change is made to government, regulators, clients, educators, companies and individual professionals. Taken together these initiatives will have a profound impact on the productivity and competitiveness of the New Zealand building industry, as has been promised over many years.

7.1 A Digital Transformation Blueprint

There needs to be a clearly articulated vision for a future construction industry that has embraced technology in support of its transformation. Where the government expects productivity improvements it also has a role in projecting its vision of what this transformation would entail.

We recommend that the government commissions and commits to a digital transformation blueprint outlining a clear vision for the future of the construction industry. Internationally, we have seen how this approach motivates and guides the industry towards the government's goals.

In the UK the promotion of 4 levels of BIM capability across the industry (Level 0 through to Level 3) with deadlines to achieve each of the capabilities, has driven a swathe of initiatives that enabled Level 2 to be achieved and Level 3 to be planned for (see the CDBB Level 3 strategic plan).

7.2 Grassroots Initiatives for the Technology Sector

The cluster of technology providers with specific skills in the construction industry is fairly small and the number of technology experts in companies across the industry is likewise small. However, the impact that these specialists can make to the industry is high. In order for them to maximise their impact it will be beneficial to provide further support and development initiatives to grow their capabilities and help them share their experience with the industry.

We recommend that MBIE fund further partnerships to accelerate the use and development of various technologies for the sector. Engagement with NZ Tech, who support technology clusters for various domains (e.g., FinTech, EdTech, BioTech, AI Forum, etc) would provide access to expertise and resources to grow a successful construction technology alliance.

Support and showcasing activities could include a national showcase of technology for the industry, publication of case studies of technology use, forums for individual technological innovations such as the successful BIM forums run in Christchurch, Wellington and Auckland from the BIM Acceleration Committee, etc.

These approaches successfully build a grassroot network of expertise around technologies which the rest of the industry can access and build upon (e.g., in use of drones, VR, AR, AI, BIM, etc). The warts-and-all presentations of technology on particular projects allows the impact of digital technologies to be assessed for building projects and information from case studies is used to inform industry on the value of digital building technologies, and to support their uptake and use.

7.3 Embedding Change

For the majority of technological interventions, a company will require several projects to embed the process change necessary to see continuous success. Study tours to major innovative companies across the world drove home the message that a single success (or failure) with a technology was not a good indicator that a company was in a position to realise continuous success with the technology.

There needs to be support within the organisation to embed the necessary process change into the organisation. This can be supported by guidance notes and case studies from successful uptake in other organisations, but sees a need for industry champions to be pushing the right messages to those undertaking this journey.

7.4 Adapting the Regulatory Framework

The regulatory framework is often reported as being a barrier, or hindrance, to new ways of working in the industry.

We recommend a coordinated approach to adapting the regulatory framework to incentivise investment decisions based on outcomes for the end user. In line with the government's 'Better Rules' initiative and digital transformation strategy our suite of codes and standards should be revisited with a view to digitalisation for automated consenting applications.

This could include revisiting the impact of performance-based codes versus prescriptive specifications which can be automatically checked, and development of digital analogues when codes are modified to support consistency.

7.5 Pervasive Security and Privacy

There are serious security and privacy implications from many of the new technologies which are being investigated for the industry. The industry needs guidance for each of the new technology being incorporated and security and privacy issues need to become a standard consideration for all technological innovations.

For example, IoT sensors and devices embedded in a building are susceptible to hacking and remote control by hostile agents, appropriate security protocols need to be enacted to safeguard these devices. Or when using drones on site there are privacy concerns in regards to the monitoring of personnel across the site, which need to be addressed through policy for projects. Best practice approaches can be developed and shared within the industry to ameliorate these risks.

7.6 Government Uses BIM

Central government could show leadership through procurement rules that incentivise an all-of-government approach to the use of BIM. There is clear evidence on the benefits of this approach within New Zealand as well as internationally, including the UK mandate on use of BIM for government contracts.

New Zealand government could work to gain the same productivity improvements from BIM to ensure value for money across all of its projects. Government departments who are major asset owners could take a BIM positive stance and require BIM for all new build and major renovations in their property portfolios.

7.7 Whole of Industry Approaches

There is great commonality in the issues that face individual organisations in the construction industry when implementing technology supported change. It should be possible to identify whole of industry approaches to develop fixes for these pain points.

This requires a level of coordination which reaches beyond individual organisations and likely draws upon the various professional societies who can coordinate across all professionals in a sector of the industry. Successful approaches to fixing pain points can be identified from case studies, or by a consensus approach across professionals in the industry.

Professional societies are well placed to promote industry-wide approaches and to provide the necessary training to ensure their adoption. These could extend to new ways of contracting to promote a high trust contracting environment and to ensure greater collaboration across the industry.

For all approaches, there is a serious need for accepted industry-wide metrics that reflect the real cost of construction and ownership.

7.8 Educate to Require Best Practice

There is clear best practice in the adoption of individual technological interventions to effect particular process change. However, these best practice approaches are often not widely disseminated or known about in the industry.

There is a role to gather and disseminate this best practice so that clients, including government agencies, are educated to mandate the use of best practice technologies and standards on their projects (e.g., such as requiring as-built BIM models for operations and asset management).

This role could be fulfilled by a Digital Clients Group advocating for digitalisation of vertical infrastructure, comprising Clients and Asset managers from private and public sectors to educate and improve processes throughout the supply chain.

Bodies such as the BIM Acceleration Committee (BAC) and Open Geospatial Consortium (OGC) have identified international and national standards which should be used by the industry across all phases of a project. Government agencies with significant property portfolios should be incentivised to implement these standards for the capture and use of their asset data.

7.9 Data and Process Standards Agreed

There needs to be national agreement and promulgation of a foundation of data standards and processes to allow all in the industry to work collaboratively and with full interoperability. In general, international standards should be utilised where they match NZ's needs as they will be available in the software tools used by the majority in the industry. However, some local adaptation may be necessary to suit bespoke needs of particular players.

Alongside the foundational data standards there needs to be publicised best practice in their use and published templates to lower the barrier to entry to the use of standards. The model established by the BIM Acceleration Committee is exemplary and should be used for the wider set of standards that would underpin movement to a digital twin ecosystem, IoT 4.0 (Internet of Things) and cyber-physical systems.

7.10 Training and Skill Development

The majority of the construction workforce needs greater skills in the technology space to understand and manage the impact it will have on their roles and processes within projects.

While many students fresh from tertiary training will have a requisite skillset, further training will ensure that we don't have to wait for generational change to see these skills being utilised throughout companies and projects. Training will need to be applied at all levels in the industry from management and through to the construction site.

International approaches have included upskilling of the whole workforce in countries such as the UK as part of their initiative to reach Level 2 BIM. As an example of the impact of lack of training an analysis of BIM models currently being delivered shows a wide range of quality of models, with many not properly utilising BIM capabilities, and often being developed in the same manner as would be seen with 2D and 3D building models.

If quality BIM models are not being created then the wide range of benefits of a BIM will be unable to be realised on projects.

CASE STUDY

Technology integrated across entire supply chain

Katerra's mission is to transform construction by utilising technology and data to improve processes and coordination across the entire supply chain and the whole lifecycle of buildings. Much has been written about the prospects of this vertically-integrated Silicon Valley start-up. There is speculation that Katerra's expertise in technology and supply chains, combined with its innovative end-to-end approach to building (its service covers design, engineering, materials, products, off-site manufacture and construction) will disrupt the building industry.

It is interesting that Ikea has recently entered the building industry, with a business model similar to Katerra's and ambitions to be a disruptive innovator too. While these companies have not impacted New Zealand yet, it is only a matter of time before a technology-savvy construction company will do so.

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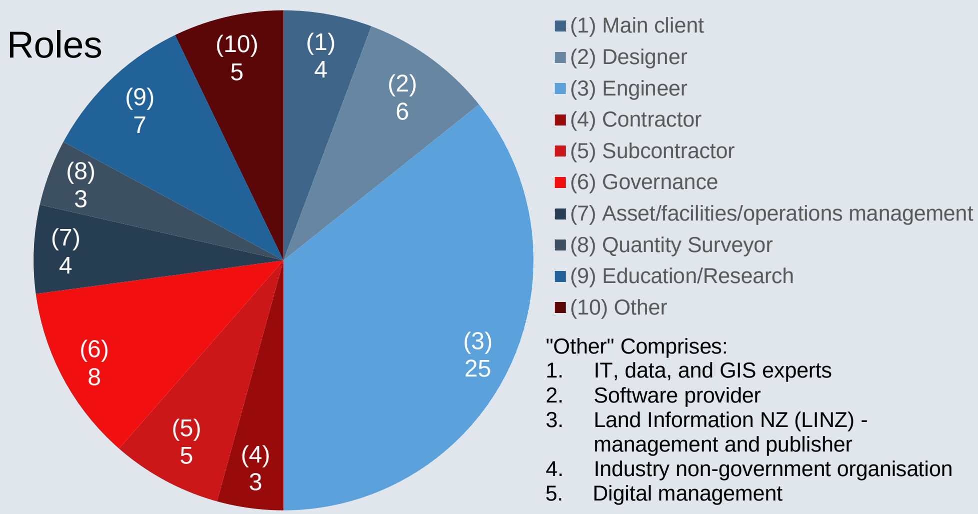
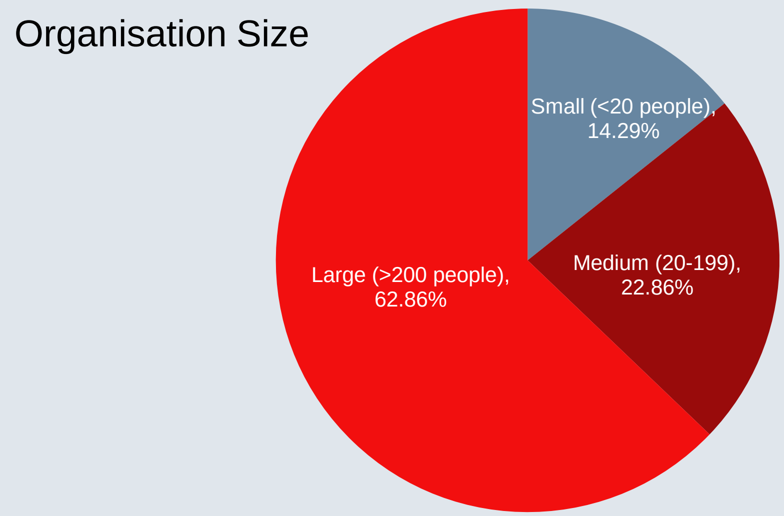
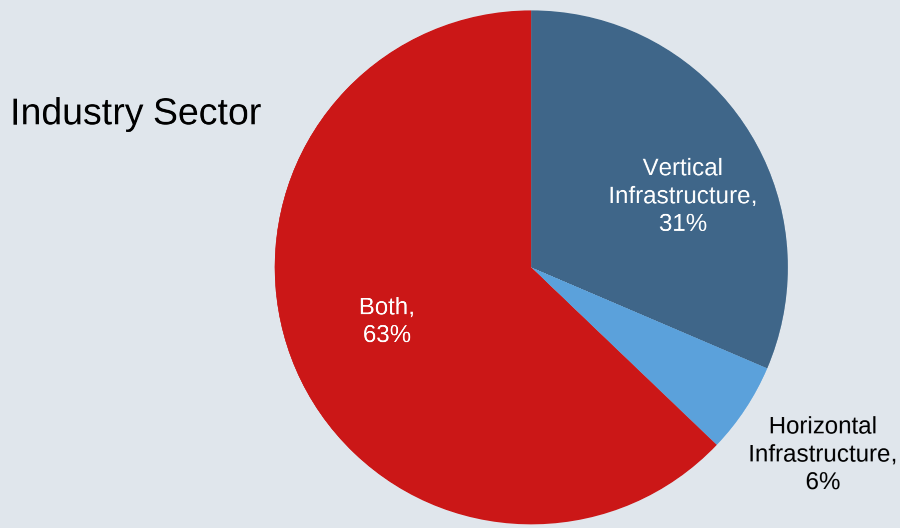
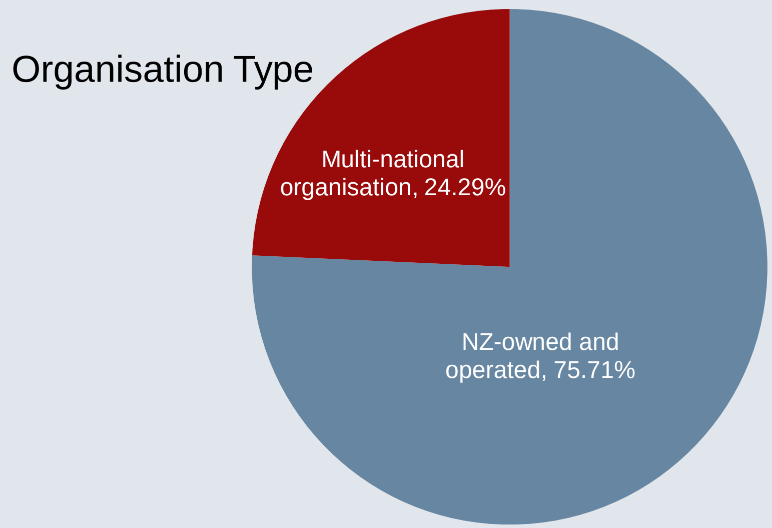
Appendix A:
BIP survey results

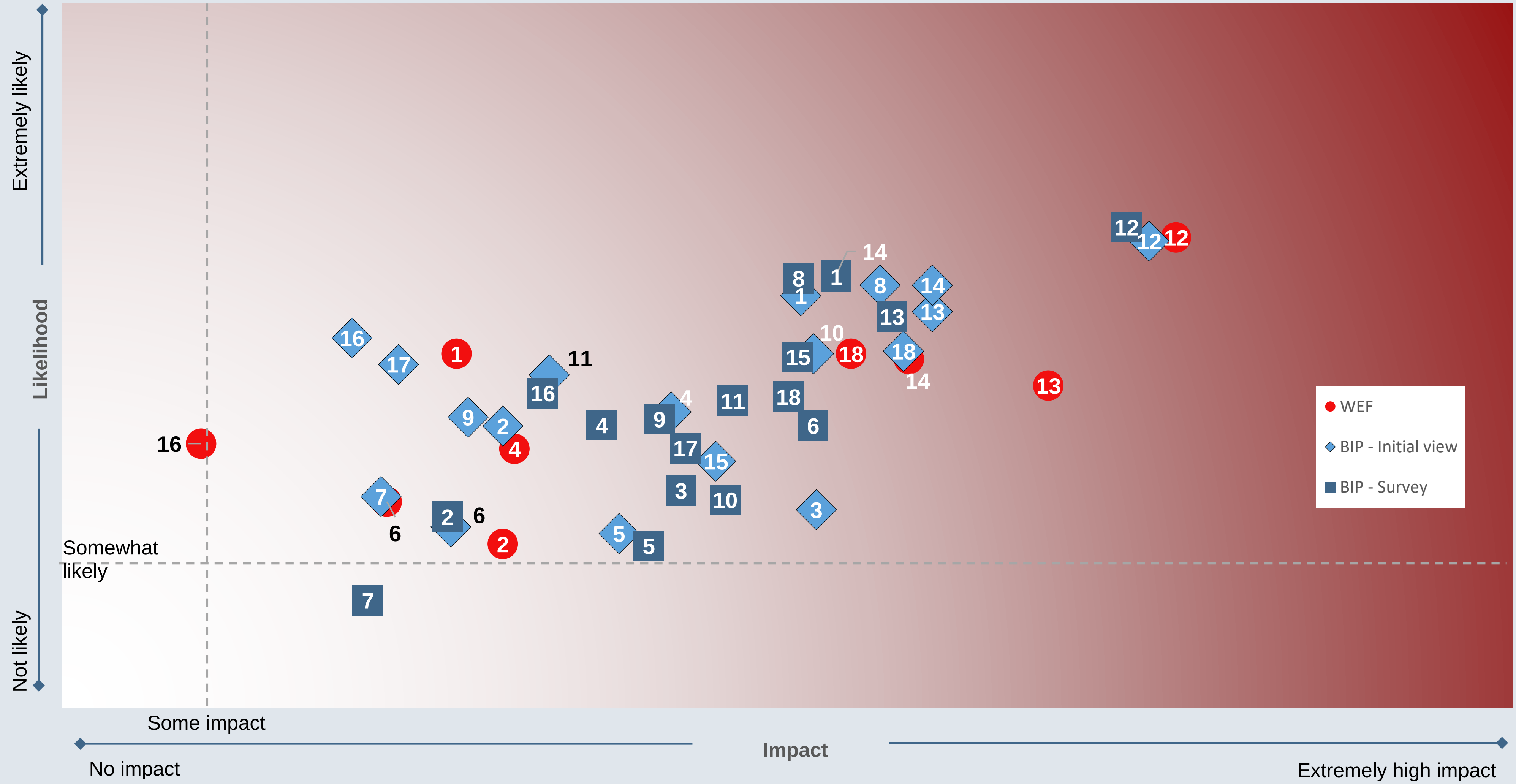
Survey Respondents breakdown





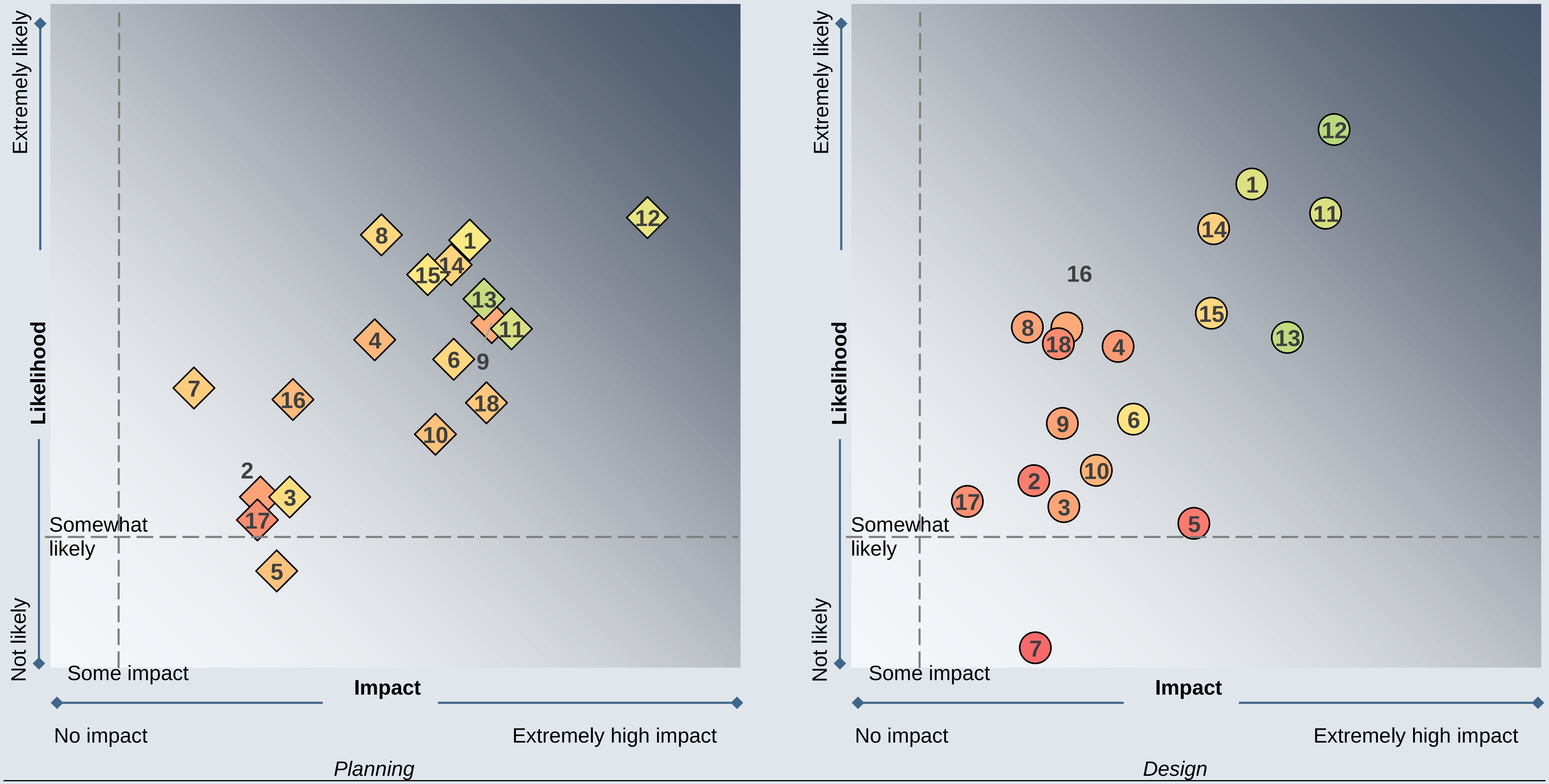






Where:

1 – 3D Scanning
2 – Additive Manufacturing
3 – AI/KBS/ML
4 – Immersive Reality
5 – Autonomous construction equipment and robotics
6 – BDA
7 – Blockchain
8 – BMS/BAS
9 – Computer vision
10 – Digital Twin
11 – Generative/Parametric design
12 – integrated BIM
13 – Prefab building components
14 – real-time mobile collaboration
15 – Simulation
16 – UAV (drones)
17 – ubiquitous connectivity and tracking
18 – Wireless monitoring/Internet of Things (IoT)



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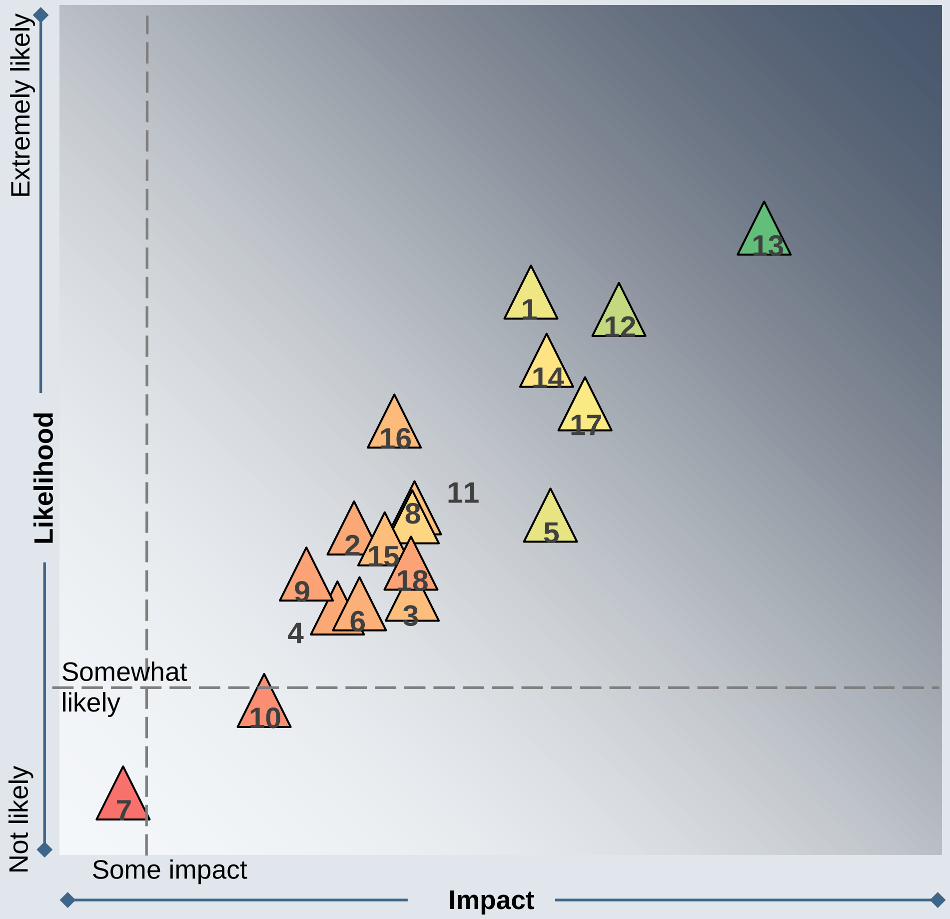
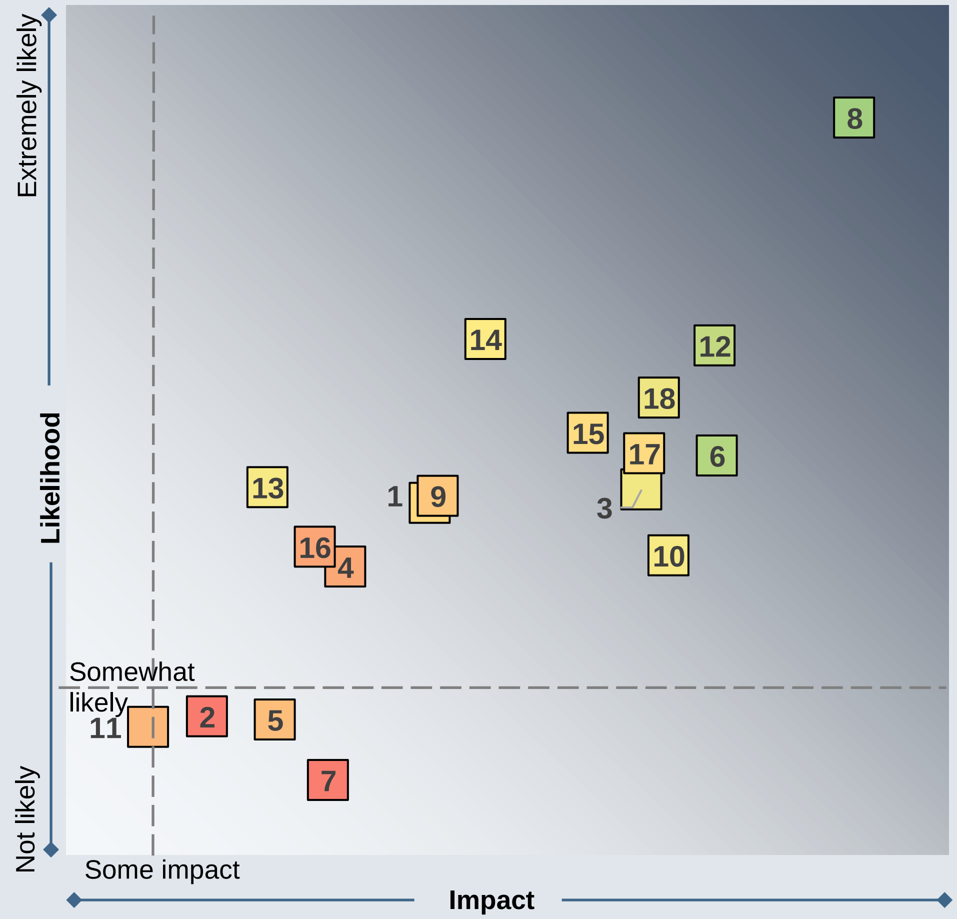
18 – Wireless monitoring/Internet of Things (IoT)

Perceived cost savings

Low High



Construction



Operate and Maintain

Where:

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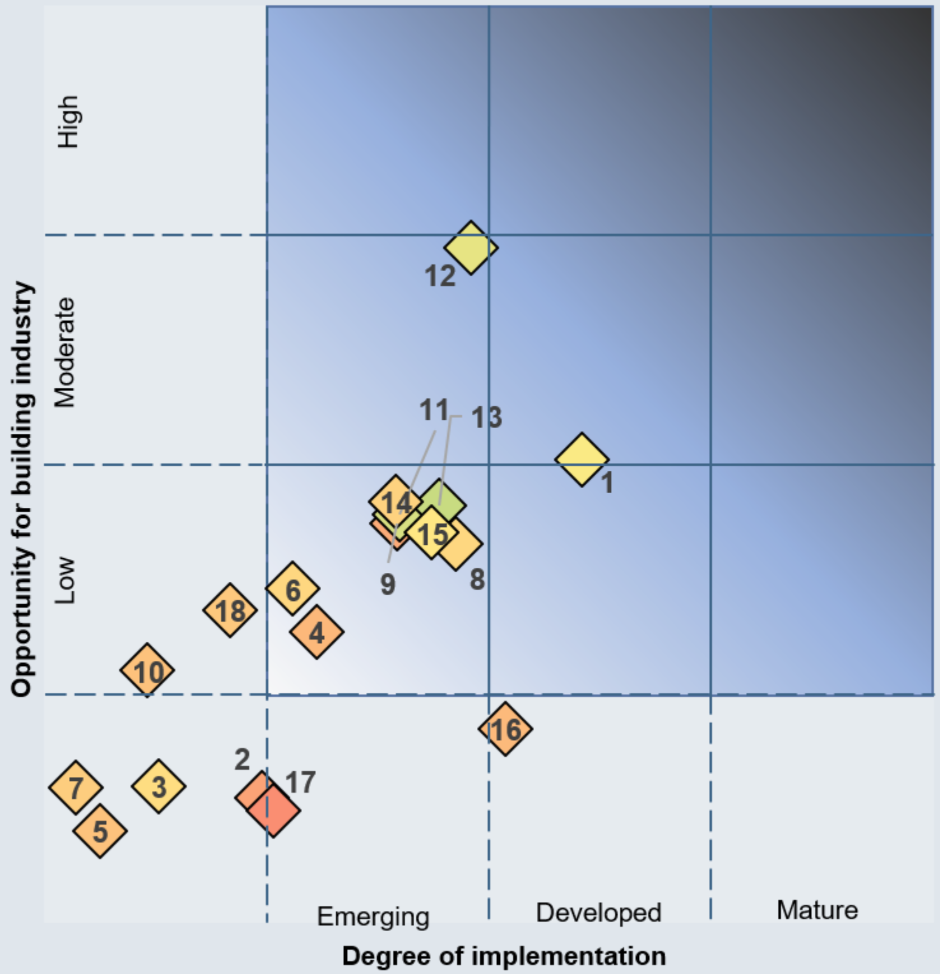
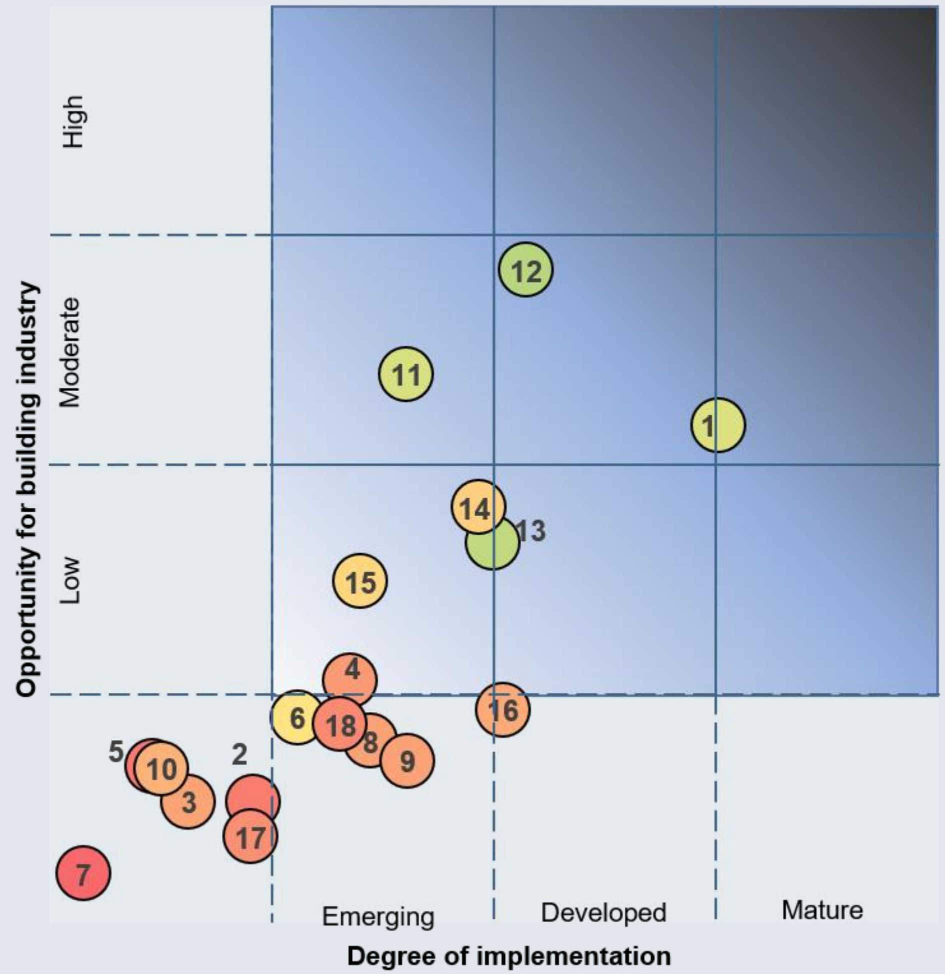
Low High



Planning



Design

Where:

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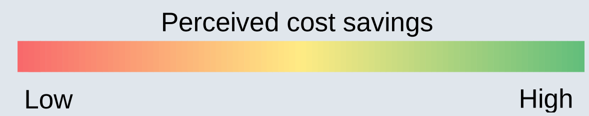
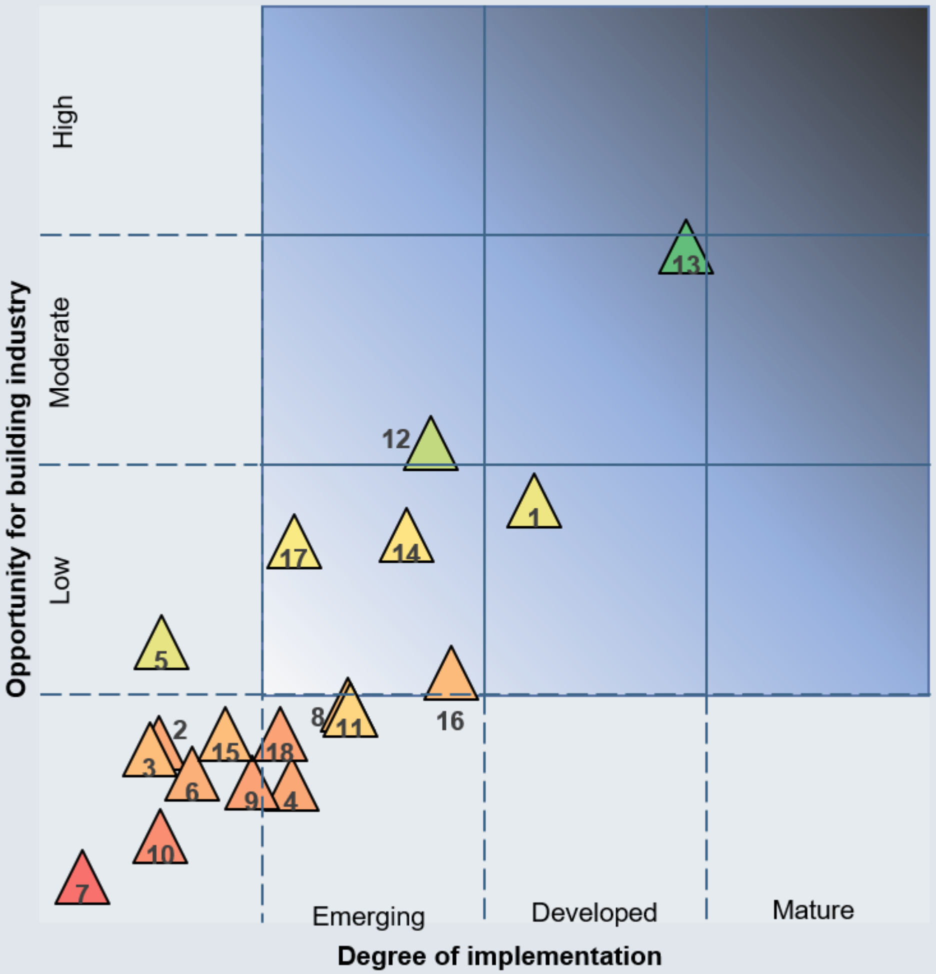
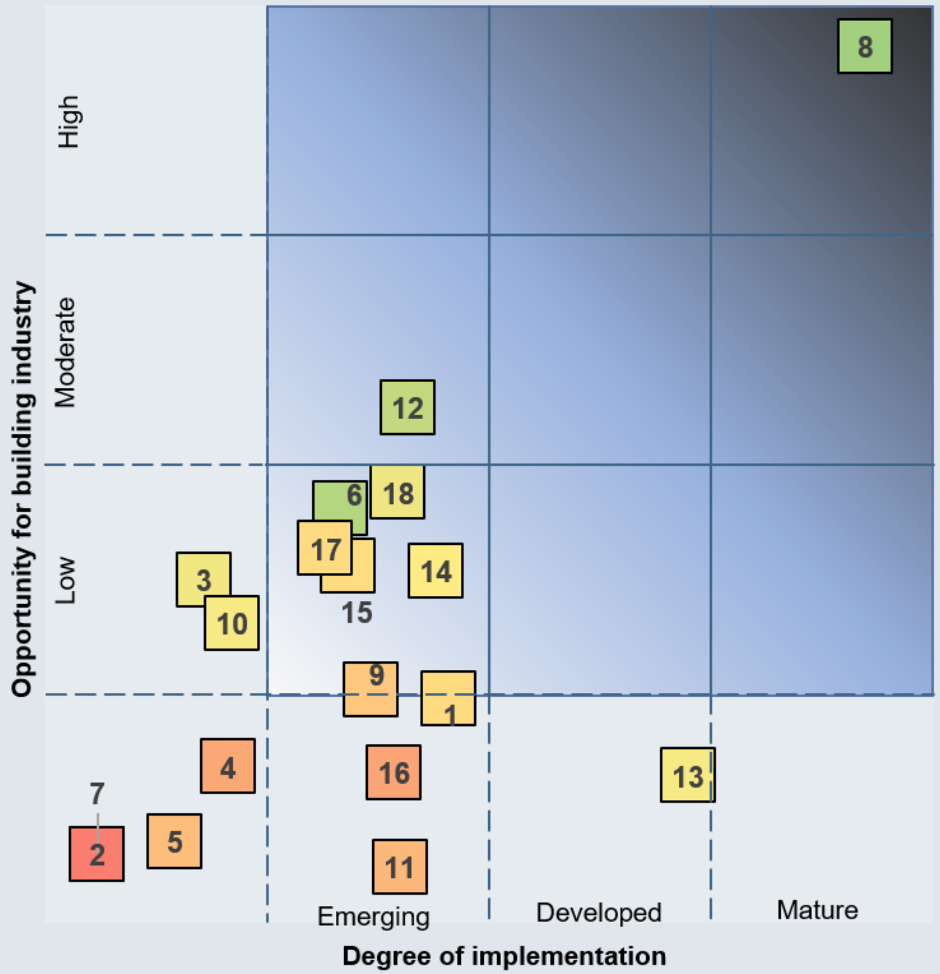




Construction



Operate and Maintain

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Perceived cost savings

Low High

Survey Question responses:

1) What you consider to be the biggest opportunities for the construction industry and its use of digital technologies?

"For clients to realise that the cheapest is not necessarily the best and a slightly more expensive solution now that enables the use of digital technologies will save them significantly in the future such as IoT for predictive asset management. We are currently researching this and consider there is huge potential"

"More input from the government and funding to drive industry change in behaviour and requirements. There are many individuals who want to drive change but lack funding"

"Savings coming from more efficient communication, more coordinated and complete design - leading to reduced RFIs, variations, and workarounds."

"Collaboration to get fully Integrated BIM models with ALL trade information all coordinated. NZ is way behind and with little formal protocols and a lack of training in the industry in this space"

"Establishing a standard and most importantly getting that adopted and used by all parties."

"Interoperability is key to be able to share and manipulate data without having to reinvent or re-establish it for each phase of the construction industry."

"Using information for insight. From planning through to operations, using the full lifecycle of the data being generated, and harnessing ALL the information available, to close the information loop and use insights generated to feed back into more effective and efficient processes."

2) What digital technologies do you consider would have the greatest impact (positive and negative) on your business?

"An overemphasis of the benefits of BIM is creating a serious issue for contractors. –

The standard of documentation and the completeness of the coordination of the various professional disciplines' documentation is declining as the use of BIM increases. Models are incomplete and not current; documentation is incomplete and contradictory.

There is no attention to detail. Clash detection might be achieved but proper coordination so construction can proceed is not.

Serious delays and increased costs arise due to incomplete coordination. Over-reliance on BIM creates delays and increased costs."

"Cloud data and non-graphical data change control systems and repositories, such as BIMserver, but for a wider range of asset classes (all of them, from structural members to boreholes or geological surfaces).

The ability to push and pull information from this source would allow the ability to create IoT systems as well as fabrication component control."

"Establishing a common data environment that allows us to deliver projects using BIM principles, but also to consume and host data that we would otherwise not have licences to access (e.g., Revit or point cloud files)."

"Cloud based Digital Document Control systems have had a negative impact, files are not structured or organised as they were in the past, they are clumsy and time consuming to use, incomplete and contractual disputes are common due to the confusion caused by cloud-based documents.

The benefits of instant communication and sharing of digital information are negated by these problems."

"A common software across all dimensions of BIM"

3) For you/your business, what do you consider to be the biggest roadblocks to technology adoption?

"Need for common standards and methodologies."

"Changing mind-sets and too much technology"

"Unwillingness to change

(which I think in part stems from a fear of not being the 'guru of knowledge'). "

"Limited budgets to innovate and adopt new technology (takes time to implement and upskill)."

"client understanding cost benefits."

"Benefits not being proven or understood. Digital world is a long way from fully integrated digital systems from concept to completion of a project."

- "Learning curve.
- Tight timelines.
- Small budget.
- License costs.
- MONEY"

"Perceived costs

(rather than opportunities to see ROI)."

4) Other comments

"There is a lack of knowledge and protocols with many having their own take on how to address BIM whereas it has been used internationally for many years now. There is no need to re-invent the wheel just need some discipline around the protocols."

"It's disappointing that there is a real attempt from the design stage to coordinate in the BIM construction sector, the basis is there and real-time front-end database from the construction shop drawings that sadly is left as a project deliverable. Not finished off or used effectively in the whole of life of the building."

"With digital technologies incremental change is difficult, because operating both traditional and new ways is very resource consuming and the real benefits of the digital technologies stay hidden. Most often everyone just gets very frustrated when the number of digital technology increases, but there are no clear processes or training how the technology should be used, how to deal with overlapping applications and the overlapping of traditional and emerging."

"I don't have great trust on the NZ construction industry changing any time soon. There is not enough underlying understanding and through that not enough investment in digital technologies. This applies to all players in the industry. As an example, pre-fabrication is not really complicated at all and the benefits are clear, but still for some reason no-one is interested in investing in it."

"We need to demystify Digital Engineering for Clients and provide clear and scalable steps for implementation."

"Central Government (MBIE) needs to raise awareness at mid and lower management levels of the technology components contained in the Construction Accord and 30-year infrastructure strategy"

BUILDING
INNOVATION
PARTNERSHIP