BUILDING
INNOVATION
PARTNERSHIP

Mid-Programme Highlights Report

2022

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

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Acknowledgements

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Building Innovation Partnership

Overview

The Building Innovation Partnership (BIP) is an eight-year applied research and innovation programme funded by Industry and the MBIE Science Partnerships Scheme. The purpose of this industry-led programme is to deliver information and solutions to improve the resilience, sustainability and cost-efficiency of horizontal and vertical infrastructure. High level outcomes include:

- New decision-making tools that improve infrastructure planning, design, construction and management.
- New technologies and design solutions that improve resilience and affordability of buildings.
- Stronger building industry through greater use of digital technologies and procurement practices that improve collaboration and productivity.
- Advanced design and operational strategies and emissions verification methods that support the construction of buildings and horizontal infrastructure that meet greenhouse gas emissions targets, and improve resilience to climate change.

The programme is delivered over four themes as shown in Figure 1 below.

Themes One, Two and Three have been operating since August 2018 and Theme Four began early in 2022.

The Partnership is hosted by the Department of Civil and Natural Resources Engineering at the University of Canterbury and there is a strong collaboration with the Civil Engineering Department at the University of Auckland. Oversight and strategic direction of the BIP programme is provided by an advisory board of industry and academic leaders.

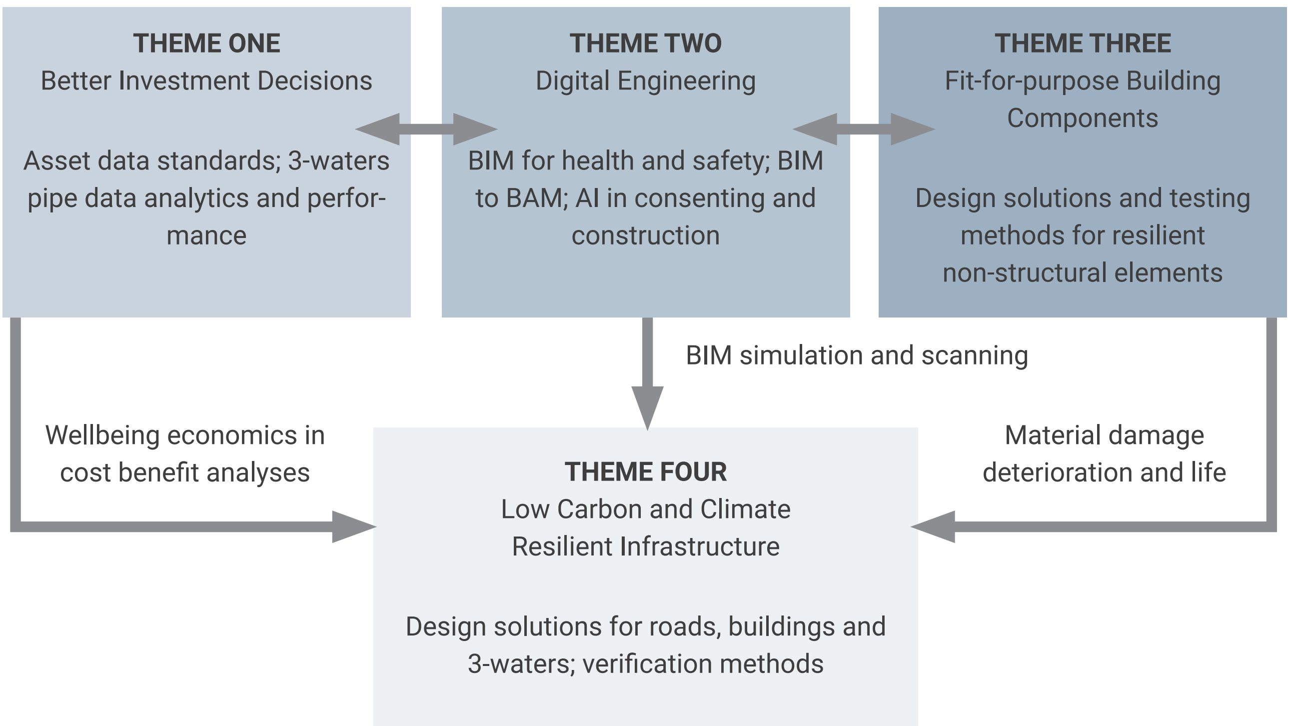

Figure 1:Overview of BIP themes

Advisory Board

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Researcher Associates

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Theme One Researcher

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Theme Two Researcher

Muhammad Rashid,
Theme Three Researcher

Funding

The BIP programme is funded by industry partners on a project-by-project basis. Every $6 of industry funding may be supported by another $4 from the MBIE Science Partnerships Scheme. This funding is available if the Advisory Board approve, and certain criteria are met. These criteria include:

- Does the project fit into one or more of the BIP themes?
- Does the project provide 'industry good'?
- Do the funders represent a broad range of industry?
- Will the output be publicly available?

Highlights

Several research outputs are already in use in industry. These include:

- A national view of three waters pipe assets based on a national data standard. This has led to councils adopting standardised and automated validation tools for as-built data; automated data quality checking; and large-scale analytics to predict the useful life of the assets. These outputs are being used to assist the development of the standards and processes for the four new water entities as part of the three waters reform.
- The creation of a tool for standardising asset information procurement across all infrastructure classes. This has been tested in a KiwiRail procurement process.
- Some key industry papers and presentations that are helping shape New Zealand's approach to the digital revolution that is changing the way that infrastructure is planned, designed, and operated.

Looking ahead

The programme has four more years to run, and, in this time, focus will be on ensuring the latest BIP research is implemented in industry. Several new projects are being developed that build on the lessons learnt to date. These include: the application of BIM to manage whole-of-life environmental outcomes for large infrastructure projects; a revolutionary framework for determining and specifying the performance of non-structural elements in buildings; assisting the concrete industry to develop its roadmap to zero carbon by 2050; and developing innovative retrofit solutions for earthquake prone buildings.

The following sections highlight a selection of active and delivered projects which reflect the depth and breadth of the BIP research programme.

Theme One – Better Investment Decisions

Introduction

It has been known for some time that New Zealand's three waters infrastructure is under immense pressure. This has been the impetus for the Government's three waters reform programme. Regardless of the final structure of these reforms, there are some fundamental concepts that can be harnessed to optimise the vast amount of investment that is going to be needed over the coming years. One of the most important of these is making the best use of data. To this end the Building Innovation Partnership is working with a number of councils across NZ to help standardise asset data; assess and improve data quality; provide data analytics; and develop frameworks and tools to help three waters professionals to make optimised decisions based on those data.

This programme for three waters has several research strands that are linked to a broader strategy of developing data driven insights into NZ infrastructure, leading to better investment in, and use of infrastructure assets. The broader strategy incorporates the use of Digital Engineering (DE) to improve outcome quality whilst managing cost and risk. The research strands include the following projects:

National Pipe Data Portal (NPDP)

Purpose

The New Zealand Government launched its three waters reform programme in July 2020 to improve delivery arrangements for three waters services, currently the responsibility of 67 different city and district councils. This programme has highlighted the poor quality and availability of data on New Zealand's three waters assets and the difficulties this causes infrastructure decision-makers. The National Pipe Data Portal (NPDP) project focuses on infrastructure metadata standards and data quality assessment tools, to improve the transfer of infrastructure asset data within and between organisations. This project is seen as the first step towards the development of national infrastructure dashboards and Artificial Intelligence (AI) enabled digital twins of infrastructure systems.

From the outset, the BIP programme has understood that fragmentation of infrastructure asset data and management systems is a major stumbling block for advancing asset management practices at the national level. Therefore, an early objective of this project has been the development of a common three waters asset data standard, published in the form of a Code of Practice (CoP). The next step was to develop an Infrastructure Model (IM) that maps different infrastructure data to common data standards. Creating a National Pipe Data Portal allows the federated data to be displayed and combined into a single dataset, all mapped to the common three waters asset data standard. Figure 2 shows a graphical representation of the data mapping process.

Findings

Currently 32 councils' pipes, chambers and valves data for their three waters asset (drinking water, stormwater and wastewater) have been mapped to the CoP, as shown in Figure 3. These data can be seen in an integrated geospatial view, which can be analysed as a single dataset.

Development and implementation of Three Waters Asset Data Standards for As-built Data (the Code of Practice or CoP)

Derived initially from the New Zealand Asset Metadata Standard considerable work has been done to develop a workable and tested national metadata standard to describe as-built data for pipes, valves and chambers. The CoP describes a minimal viable standard for the collection of as-built data. The CoP is available in a range of formats to enable any user or software provider to incorporate the CoP into their system either fully or partially as required. For example, the CoP has been taken up by local company 12d NZ Ltd and it has been encoded into its survey software to enable automated validation of as-built data. This is now used by Queenstown Lakes District Council (QLDC) as a standard as-built ingestion process. This is saving significant time and effort for both the surveyors and council staff. At the same time it is ensuring better quality data is delivered to QLDC's asset management system.

BIP is also collaborating with Waka Kotahi on its Asset Management Data Standard (AMDS). The AMDS team have recently released the Drainage System Data Schema This schema has been developed with significant input from the CoP development team to ensure that three waters and road data schemas are consistent and interoperable. This will be key as we develop the National Digital Infrastructure Model (NDIM). The NDIM will be an essential component of managing New Zealand's infrastructure data in an interoperable and re-useable manner.

The development of the CoP is ongoing. The current focus is on extending it to include a nationally consistent condition schema, integrating with the National Forward Works Viewer and developing high level analytic systems.

Process of creating a data dictionary

From Figure 2, it is clear the key component in the data transformation is mapping the data through a translation dictionary. Each council has their own way of defining assets at asset definition level, attribute level and attribute value level. Therefore, it has been necessary to create the dictionaries at those individual level. With the addition of every new council, the dictionary has grown to allow the translation of subsequent councils' data to be a largely automated process.

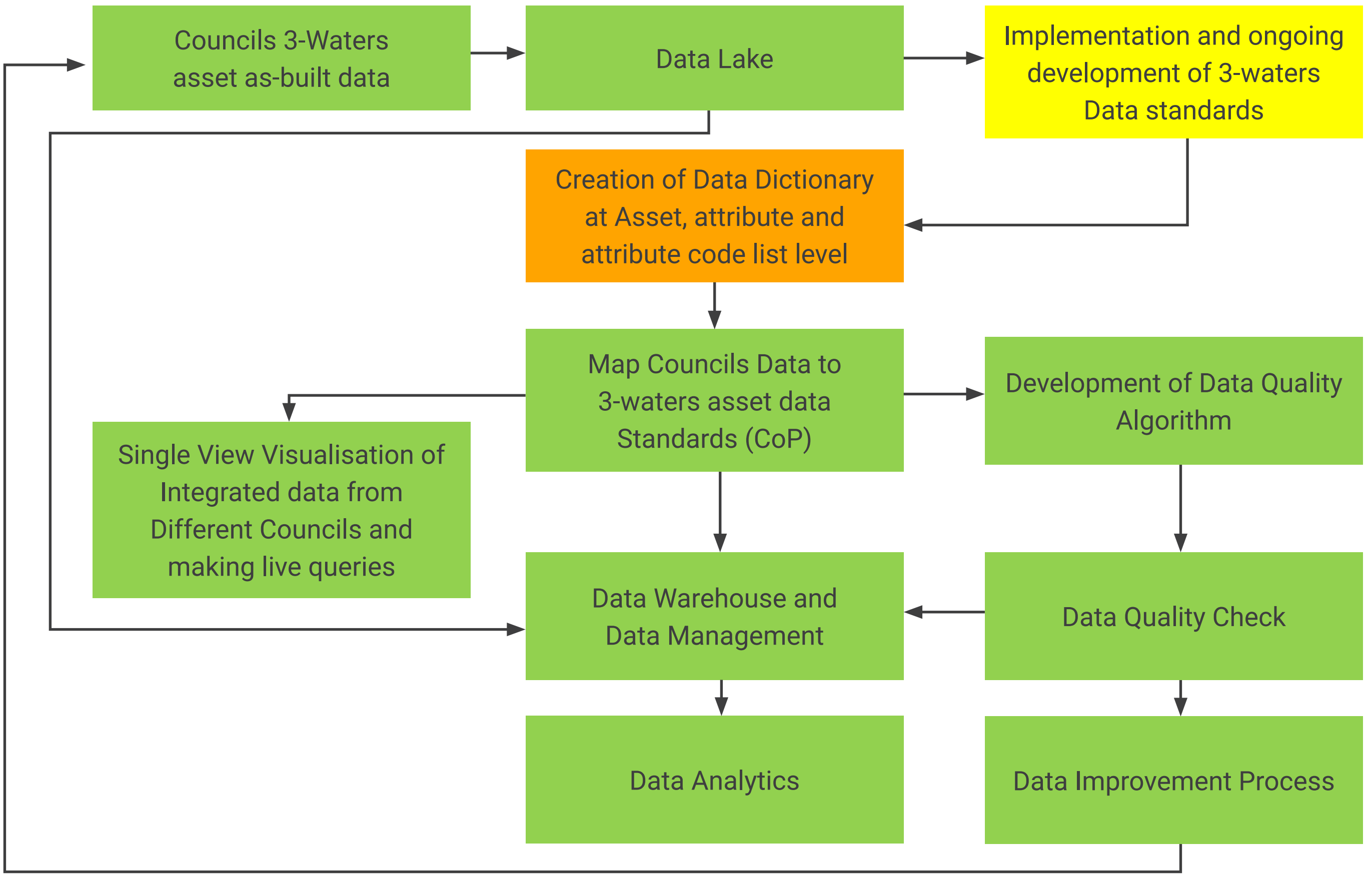

Figure 2: Flowchart showing developement and implementation CoP and data mapping process.

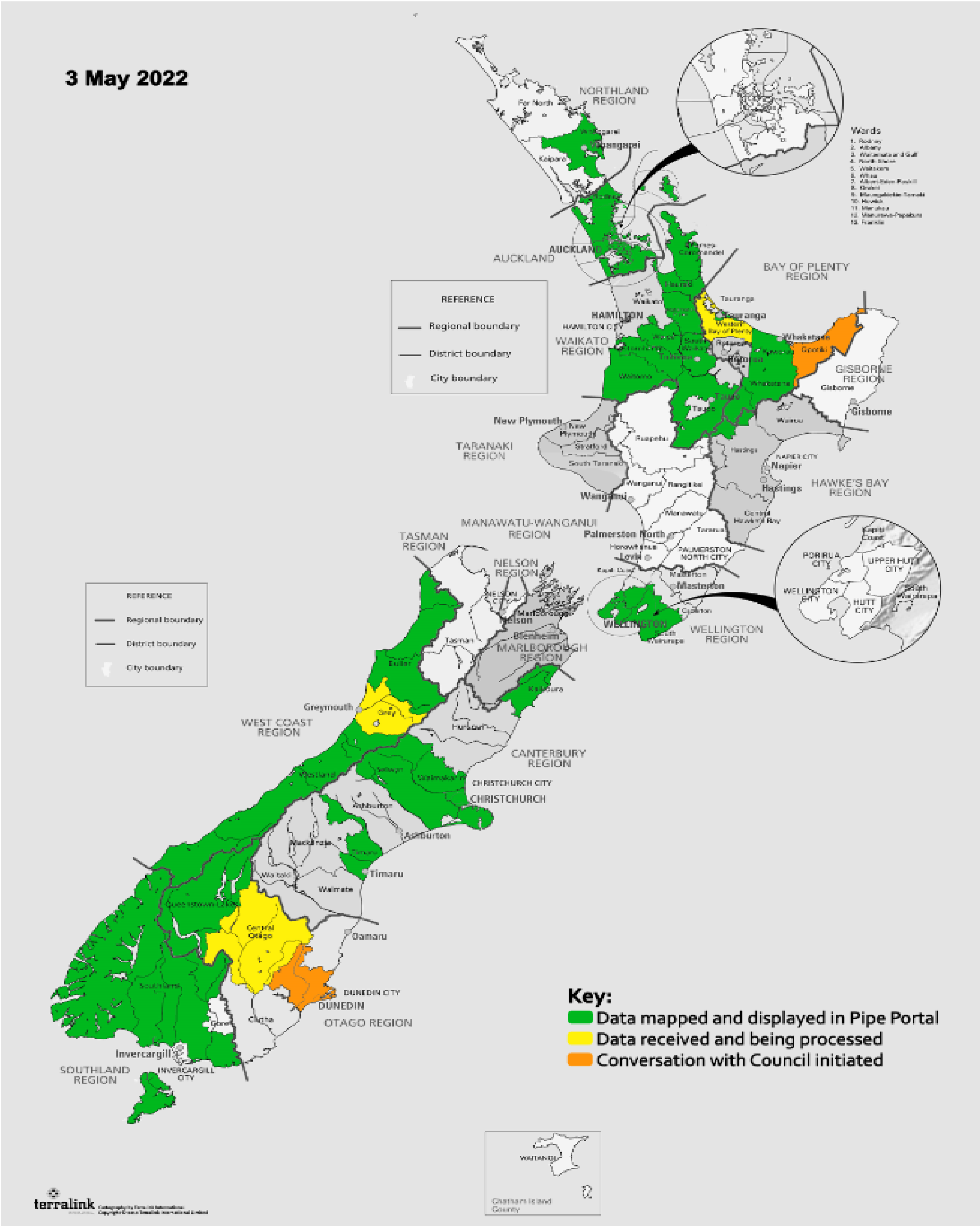

Figure 3: Council engagement map showing number of Councils approached so far and have mapped their as-built data to the three waters standards (CoP).

Integrated Data View Visualisation

Figure 4: Integreated geospatial views of different councils' data mapped to the CoP

As shown in Figure 2, once the data coming from different councils have been mapped to the CoP, we can view them as an integrated data view using geo-spatial software. Figure 4 shows an example of an integrated view of different councils from New Zea land. As shown in Figure 5, we can also create live queries and look for specific information about any individual asset and associated attributes and their values.

Figure 5: Geospatial view of a single council's three waters data to create live query

Implementing the Data Quality Assessment Tool

The Data Quality Assessment Tool has been developed in conjunction with the Waikato's Regional Asset Technical Accord (RATA). Working with nine of RATA's water authorities, BIP has developed a data quality framework and metrics that allow councils to compare their asset data quality and highlight where there are opportunities for data improvement. The metrics and associated tool are based on the CoP. The tool has been successfully applied to several other councils around the country. A shared cost model with the additional leverage of the MBIE funds has allowed this work to be done at minimal cost to any individual council. The NPDP also allows the data quality information to be visualised. This is shown in Figure 6.

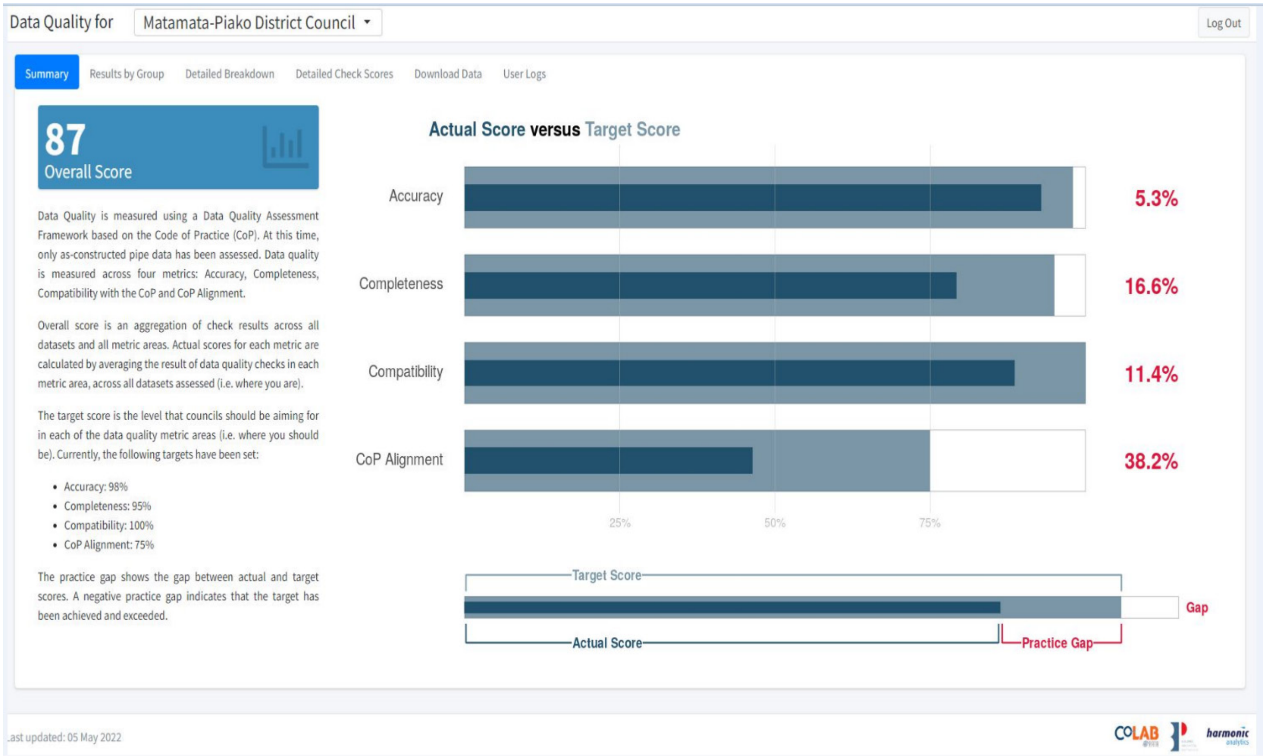

Figure 6: NPDP's Data Quality Dashboard Showing Data Quality Metrics and overall Data Quality Score for a NZ Council

The NPDP is a first step in integrating all New Zealand's infrastructure data into a single National Digital Infrastructure Model. The NDIM will allow a completely different way of planning and managing our national infrastructure with major benefits for our wellbeing, economy and environment.

Analysis of large data sets

The other outcome came from this integrated mapped data is the ability to undertake large data analysis. Figure 7 to Figure 9 show examples of data analysis performed on 32 councils' wastewater pipes data looking at age-based pipe renewal analysis for those pipes.

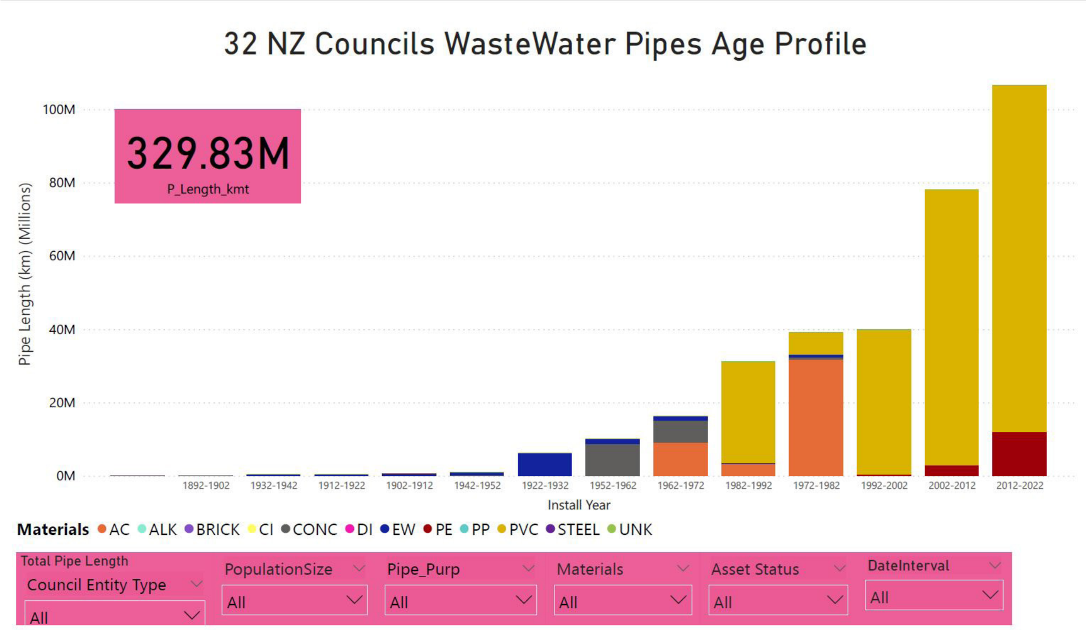

Figure 7: Age based pipe renewal analysis plot for 32 councils' wastewater pipes with different pipe materials.

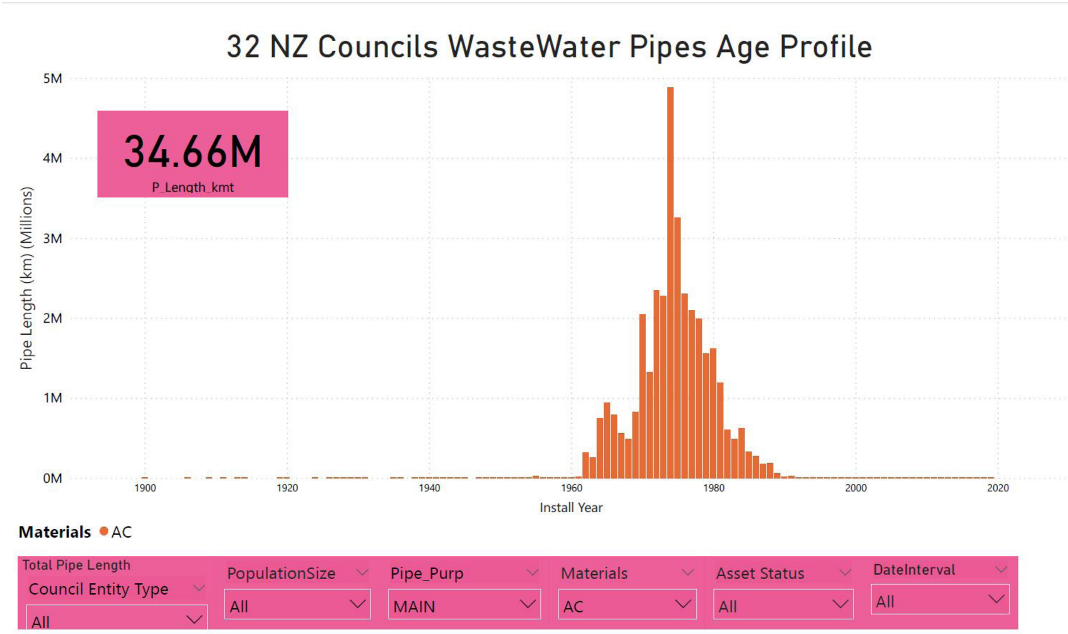

Figure 8: Age based pipe renewal analysis plot for 32 councils' wastewater pipes with Asbestos Cement (AC) Pipe material.

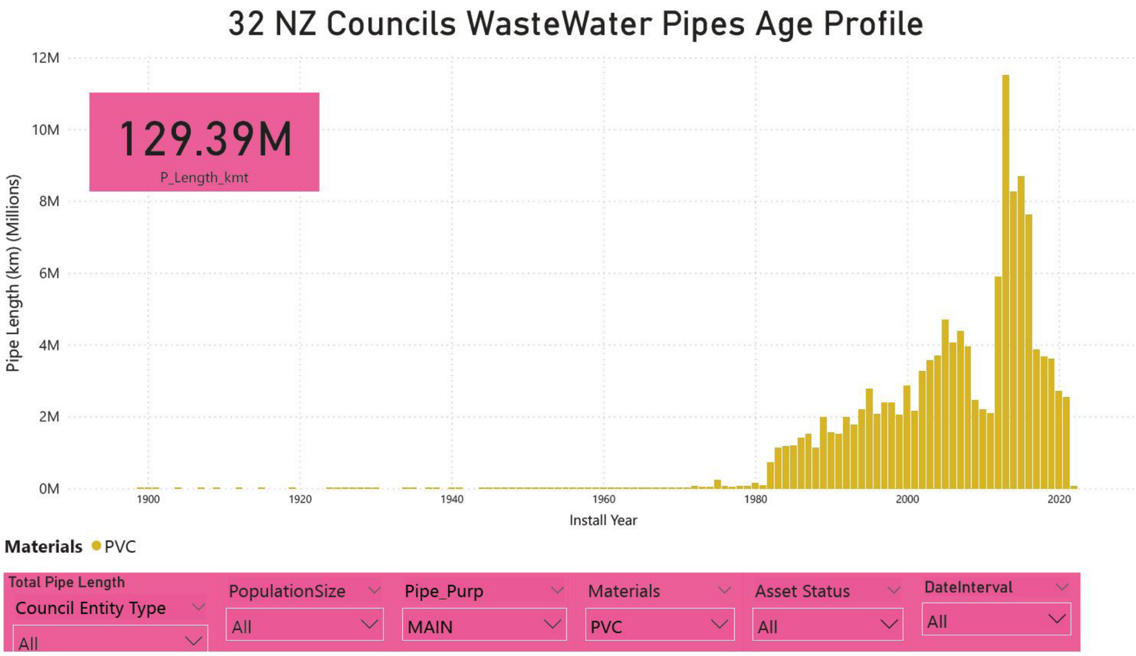

Figure 9: Age based pipe renewal analysis plot for 32 councils' wastewater pipes with Polyvinyl Chloride (PVC) Pipe material.

Benefits to Industry

The success of the NPDP with the RATA councils has resulted in its uptake by 23 other councils throughout New Zealand. There has been a realisation that the benefits of evidence-based decision-making can be unlocked by having multiple datasets expressed and integrated according to well-defined data standards.

Data quality has proven to be as important as having the data in the same format. Any analytics across aggregated datasets need to be conscious of the data quality prior to combining datasets. The data quality tool has been invaluable in understanding dataset's qualities and has driven a strong process of improving data quality.

The CoP and associated processes are being integrated into the Department of Internal Affair's activities to build the underpinning data infrastructure for the proposed four new water entities.

Some of the benefits of the research include:

- Better data and consequent information on which to base investment decisions and other asset management process such as valuation. This will revolutionise the way that investment decisions are made in the three waters sector in NZ with benefits in the order of tens of millions of dollars per annum.
- Consistent data across the country to understand risk and investment profiles leads to more accurate insurance estimates. This should save millions of dollars of premiums and, in the event of a disaster, ensure better coverage for assets.
- Providing a larger data set to allow advanced analytics such as pipe break deterioration models on network level thus reducing the risk of catastrophic failures leading to reduced business, environmental and social interruption.
- Benchmarking of pipe performance relative to other councils thus lifting councils' performance in collecting, analysing and using data leading to better optimised networks and rates spend.

Research Team

Dr Theuns Hennings and Greg Preston lead this project. Research Engineer Dr Purvi Pancholy and geospatial software technician Rachel Buer, carry out the research work for this project. The RATA team comprise: Rachel Casey, Emma Good, and representatives from nine local councils. Data analytics support is provided by Harmonic Analytics Ltd.

Outputs

Developed three waters asset data standards (CoP) and other technical reports on this project are available for public access on the BIP website.

Developing the Holistic Decision-making Framework for Three Waters

Purpose: Development of a performance measurement framework using the NZ Living Standards Framework

Water infrastructure worldwide is facing a number of pressures, including increasing demand due to population growth and urbanisation, increasing legislative requirements, climate change, and ageing infrastructure. Making infrastructure investment decisions has become more complex and fraught with wider implications to society beyond just simple delivery outputs. A three waters wellbeing performance monitoring and investment framework is needed now more than ever to help decision-makers better understand the performance of their three waters infrastructure. This is particularly in relation to providing appropriate services that support community wellbeing.

Current performance and decision-making frameworks and assessment tools rely heavily on economic analysis. Frameworks that utilise sustainable, and wellbeing variables tend to be limited in scope and focus on macro, policy, and micro, infrastructure, level performance. This project works to understand the problem created by a lack of a holistic investment decision-making model that considers social, environmental, economic and infrastructure variables. This lack can lead to investment decisions that are unable to deliver sustainable intergenerational wellbeing. New Zealand Treasury has undertaken significant work to develop macro-level wellbeing frameworks that support policy setting at the national level. Developing a novel meso-level wellbeing performance framework and a suite of indicators that will integrate with macro and micro levels will provide a valuable resource for decision-makers when considering performance and investments in the three waters infrastructure.

Benefits

The research will help decision-makers better understand the impact of their decisions on intergenerational wellbeing. To achieve this, the initial objectives were to:

- Integrate with the New Zealand Living Standards Framework and United Nations Sustainable Development Goals (macro-level).
- Demonstrate the development of a three waters wellbeing performance framework and conceptual model that could be adopted at a regional, district, or city council level (Meso level).
- Identify initial potential indicators and measures that could be used to understand the performance of the wellbeing three waters framework.
- Explore the availability of data and fitness of the data for the performance framework utilising a sample taken from Statistics New Zealand and the Waikato region.
- Identify future development potential, which includes finding the impact of investment in three-waters on the community's wellbeing and conducting a performance analysis.

Findings

In Phase 1 of this research project has successfully developed a wellbeing performance framework and conceptual model and identified the potential usefulness for three waters infrastructure asset managers and owners. The fitness assessment has also been completed with the Stats NZ and Waikato Regional Council questionnaire. This has provided an initial indication that a wide range of data sets are available to test the performance framework and conceptual model (See Figure 10 and Figure 11). The range of data identified in the case study indicates that the data available has the potential to provide an appropriate range of indicators and measures covering the natural, social-cultural, human, and economic capitals but there is a lack of available data for infrastructure.

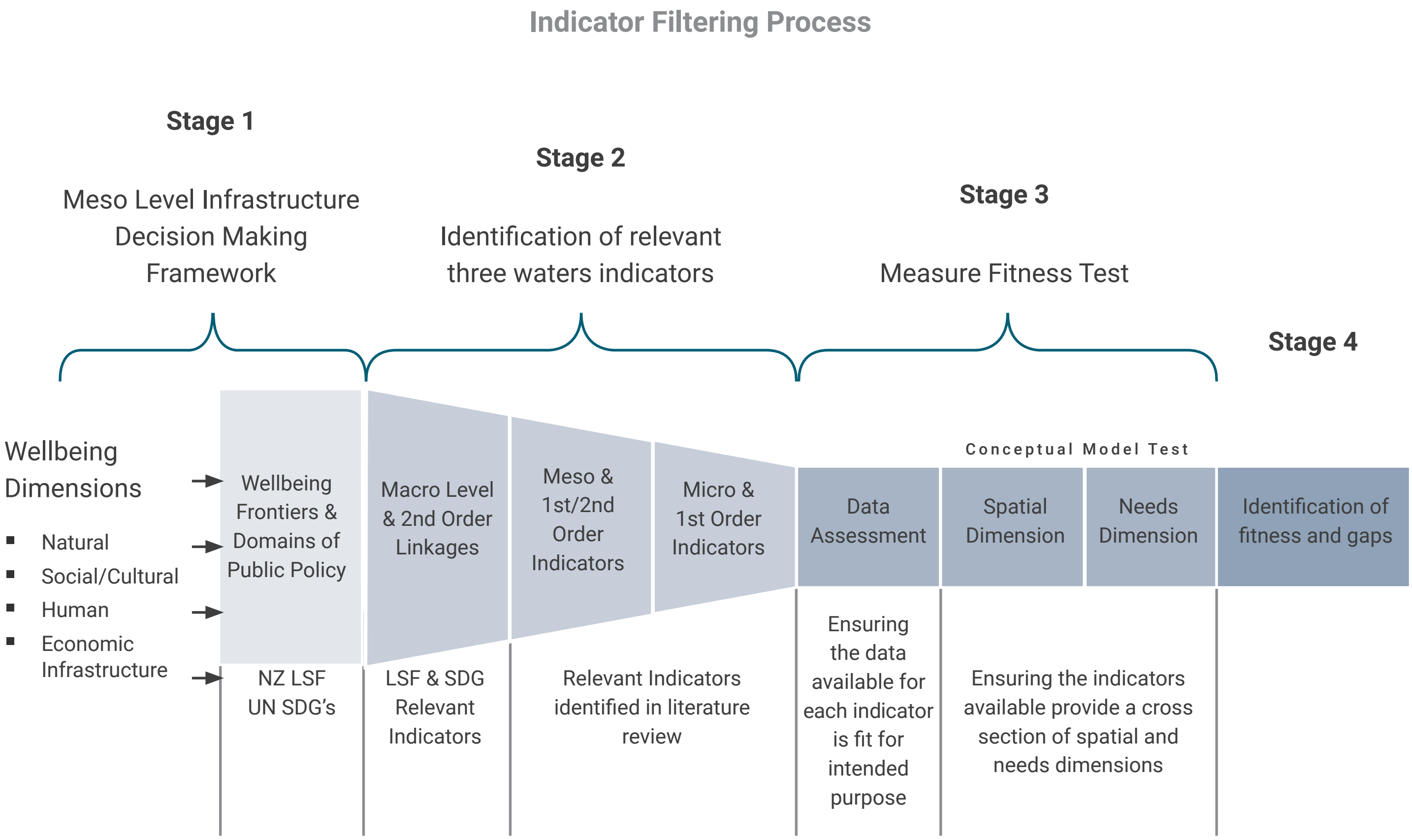

Figure 10: Filtering Process used to Determine Performance Measures

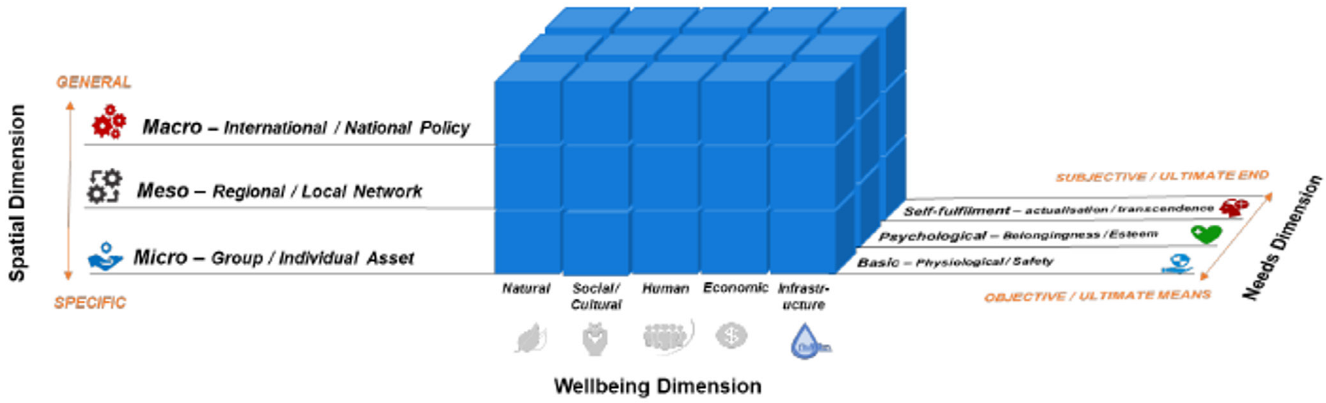

Figure 11: Conceptual Model showing Breakdown of Spatial, Needs and Wellbeing Dimensions.

The fitness assessment was designed to provide an initial test of the performance framework using the conceptual model. The fitness assessment criteria utilised was assessed through the lens of the conceptual models intended use and focused on the data's availability, measure relevance, and how the measure data would potentially work if used in the conceptual model.

Next Steps

The next phase of this project is being undertaken as part of a PhD study. The scope of this study will include:

- Identifying wellbeing outcomes and key performance indicators/measures at the decision-making levels. These will include assessments of council long term plans; government infrastructure strategies; Treasury's living standard framework and interviews/survey of Māori decision-making.
- End-user engagement to test research findings and define outcomes desired from each wellbeing and infrastructure class.
- Defining and aligning benefits, key results areas, performance indicators, and measures for each wellbeing capitals.
- Validating benefits, key results area, performance indicators, and measures with end-users -survey.
- Confirming and collect data for testing.
- Reviewing other decision-making models to see how data is analysed and displayed
- Exploring how this can all be shared in appropriate digital formats including dashboard and digital twins.
- Developing case studies by testing the model's outcome against a completed three waters project.

Outcomes

Recent thinking in investment analysis is shifting towards understanding the community wellbeing outcomes of different investment scenarios. Before such a decision-making becomes possible, the first step is to develop a performance measurement framework applicable at a regional/meso level. Therefore, this work will provide the framework and tools for local and regional councils; elected members; water authorities; and communities to make the best investment choices for their circumstance. The framework will inform officers of local authorities and their communities.

Research Team

Dr Theuns Hennings led the project. PhD student, Erik Barnes and Research Engineer, Dr Purvi Pancholy carried out the out the research work for this project.

Outputs and Impacts

Currently, the framework has been developed as part of a Master's thesis recently published from the University of Auckland. The new research is not far enough developed to know what the final output format will be, but this is likely to be in the form of a digital tool.

Working with Waikato Regional Council, the plan is to embed the framework into everyday decision-making such that the research starts to change behaviour within the next cycle of Councils' Long-Term Plans. In addition, efforts will be made to engage with the Department of Internal Affairs' Three Waters Transformation Team so that lessons from the framework are included into the long-term decision-making of the proposed three waters entities.

Towards a National Digital Twin for Flood Resilience in New Zealand

Purpose of project

Flood inundation is a frequent, widespread, and impactful hazard, which regularly causes damage to housing and infrastructure along with disruption to communities and businesses. Further, flood risk is expected to increase in future due to climate change. To manage this risk, it is essential that we become more efficient at flood risk management. However, the computational modelling and scenario assessment required for such flood risk management and mitigation requires substantial amounts of spatial data related to infrastructure and the environment, making it challenging and expensive. This is particularly a problem for smaller regions or communities where the costs of such analysis may be prohibitive. In this project, we are developing and testing a prototype "flood resilience digital twin", which comprises of three-waters, flood mitigation and other infrastructure, high-resolution topography, and land cover, which we are building with the aim of facilitating flood risk assessments to be completed more rapidly and at lower cost. The digital twin is initially being developed for the town of Kaiapoi in Canterbury and once completed, follow-on work will enable further development and deployment nationwide, including as part of the NIWA-led national flood hazard assessment programme, "Reducing flood inundation hazard and risk across Aotearoa-New Zealand".

A key objective is to enable the automation of flood risk assessment, such that multiple scenarios can be assessed rapidly, such as when given updated information. The digital twin we envisage can bring together and processes the data needed for flood risk assessment and use these for scenario. The digital twin can then analyse the impact of these scenarios and update them given new information. Such a digital twin would enable flood risk assessments to be completed more rapidly and at lower cost, and will facilitate detailed, standardised risk assessments at the national scale.

Findings

The project is halfway through its life and several key data capture and management processes have been automated. Two industry workshops have taken place which have provide very valuable insight into the priorities for development. In the near-term further development is required to:

- include additional dynamic data such as weather data from models or RADAR.
- manage multiple flood scenarios, including standardised scenarios for risk assessment.
- connect the digital twin to the RiskScape hazard assessment software.
- implement a basic front-end for communication of results and control of the digital twin analysis.
- design and implement an API which allows the digital twin to be connected to other existing systems.

In the medium to long-term, we hope to continue to develop the digital twin to include other flood model codes, particularly those which incorporate storm water drainage in urban areas.

Benefits to Industry

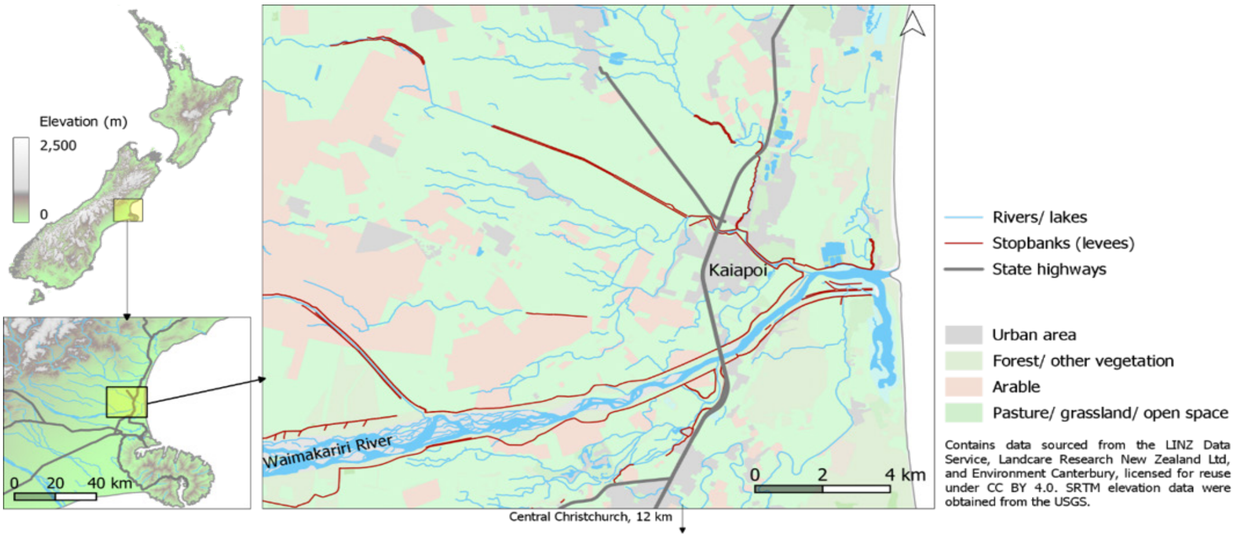

Figure 12: Kaiapoi location and situation to the north of the lower Waimakariri River. The town is protected from flooding by a stopbank (levee) system and pumping station

Whilst still in early development, there are multiple benefits to this work including:

- Rapid generation of multiple hazard scenarios
- Fast assessment of likely inundation for planning for, and responding to, emergencies
- Testing and developing councils' spatial plans

Research Team

The research team includes representatives from:

- Geospatial Research Institute (GRI)
- Building Innovation Partnership, (BIP)
- National Institute of Water and Atmospheric Research (NIWA)
- Land Information New Zealand (LINZ)

The project is funded by FronterSI and the Building Innovation Partnership, with in-kind support from LINZ and NIWA.

Additional resources and researchers are coming onboard from the Engineering Lifelines community to expand the functionality of the model. This will be for automating the process of re-routing traffic in a flood emergency.

Outputs

All software we are developing is available under open-source licencing. The code base for the flood resilience digital twin is available on Github:

https://github.com/GeospatialResearch/Digital-Twins

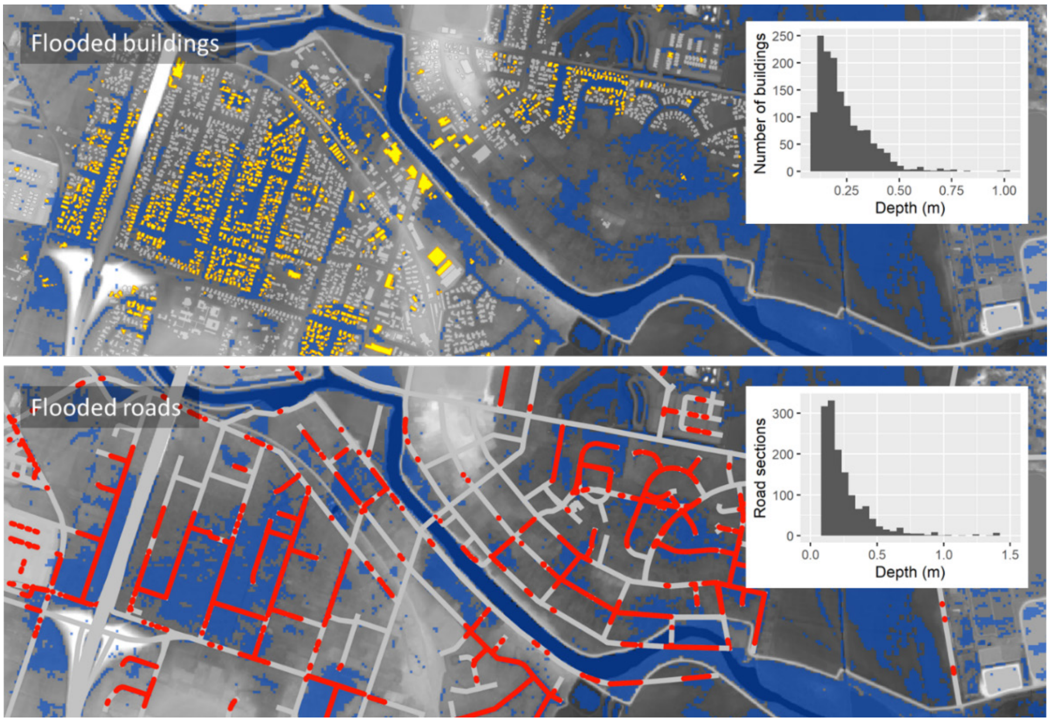

Figure 13: Example analysis within the digital twin, intersecting a model realisation with spatial data for infrastructure.

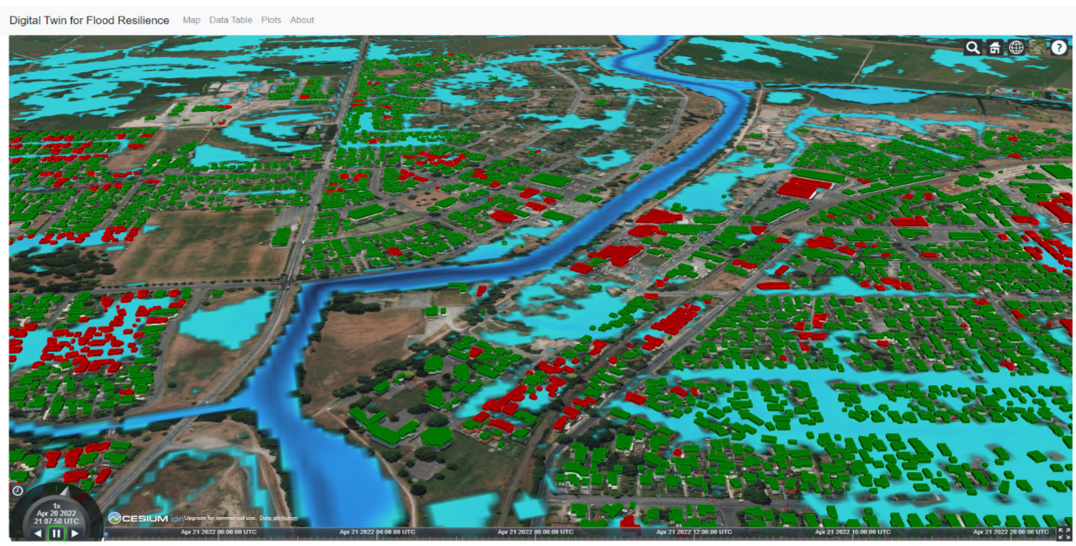

Figure 14: Example analysis within the digital twin, intersecting a model realisation with spatial data for infrastructure.

Theme Two – Digital Engineering (DE)

Introduction

Digital Engineering (DE) is a broad term that captures all aspects of the application of data, digital technologies and processes throughout the whole lifecycle of a construction or infrastructure project. This encompasses planning and design, construction, through to operations and maintenance, and all the way to renewal or retirement. The purpose of Theme Two is to assist industry with the uptake and effective use of DE, whether this is through improved processes in Building Information Modelling (BIM), the application of new techniques in digital consenting or the uptake of technologies such as Digital Twins (DT), Artificial Intelligence (AI), robotics, etc.

As far as possible, researchers work alongside live projects to maximise the impact on the project. Lessons are then shared more broadly with industry. The following are a selection of the active projects.

BIMSafe – Health & Safety through Building Information Modelling (BIM)

Introduction

The BIMSafe NZ Project is a three-year collaboration between the Canterbury Safety Charter's (CSC) Professional Services Working Group (PSWG) and the Building Innovation Partnership (BIP). The goal of the project is to change behaviour in the New Zealand construction industry in the way Health and Safety risks are identified, communicated, and managed throughout a facility's lifecycle.

The project is funded by an ACC Injury Prevention Grant with co-funding from MBIE through the BIP and significant in-kind contributions from industry members of the project team. The project is governed by a Steering Group, comprising the CEO of Construction Health and Safety New Zealand (CHASNZ) and the Board Chairs of both BIP and CSC. An advisory group with members from BIP, PSWG, and industry provide support and guidance to the project.

BIMSafe processes

The project has three workstreams.

1. Development of Best Practice Guidelines for the New Zealand Construction Industry
2. Case Study Project (new ACC building in Dunedin)
3. Knowledge Transfer and Extension Plan

Figure 15 shows an overview of how the process of research flows into application within industry.

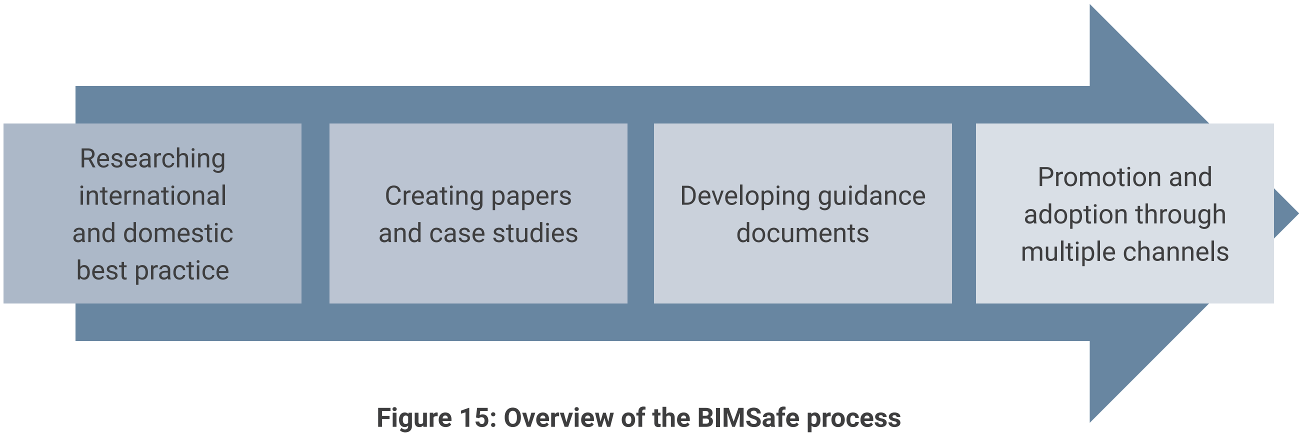

Figure 15: Overview of the BIMSafe process

Outputs and outcomes

The outcome we are seeking is a reduction in accident and injury rates through a greater understanding, communication, and mitigation of risk. This is achieved by utilizing the collaboration and visualization capability of Building Information Modelling (BIM).

To this effect, the project has a range of outputs for clients, managers, supervisors and workers. These include:

- Research papers providing an overview on BIM for health and safety in:
  - Design
  - Construction
  - Civil works
  - Structural works
  - Sub-trades
  - Procurement
- Best practice guidelines for the above
- Case studies
  - Print
  - Video
- Workshops and roadshows
- Social media outputs

Across all outputs, there is strong emphasis on visualisation to ensure that there is maximum uptake by parts of the industry that have lower literacy levels. The project is being tracked throughout its three-year life to measure and assess the uptake and benefits. It is understood that this project is the beginning of an ongoing process of using BIM and other technologies to improve Health and Safety outcomes.

The project will be tested in a real-world environment, specifically the construction of the new ACC building in Dunedin, owned by Ngāi Tahu. Whilst still in the early phases, the project is already having an impact on decision-making on how BIM can be leveraged in construction. This is the way that BIM is procured to reflect the Health and Safety outcomes expected on the case study project. The project is progressing well with a broad interest and engagement across industry.

More information can be found here: https://bim-safe.nz/

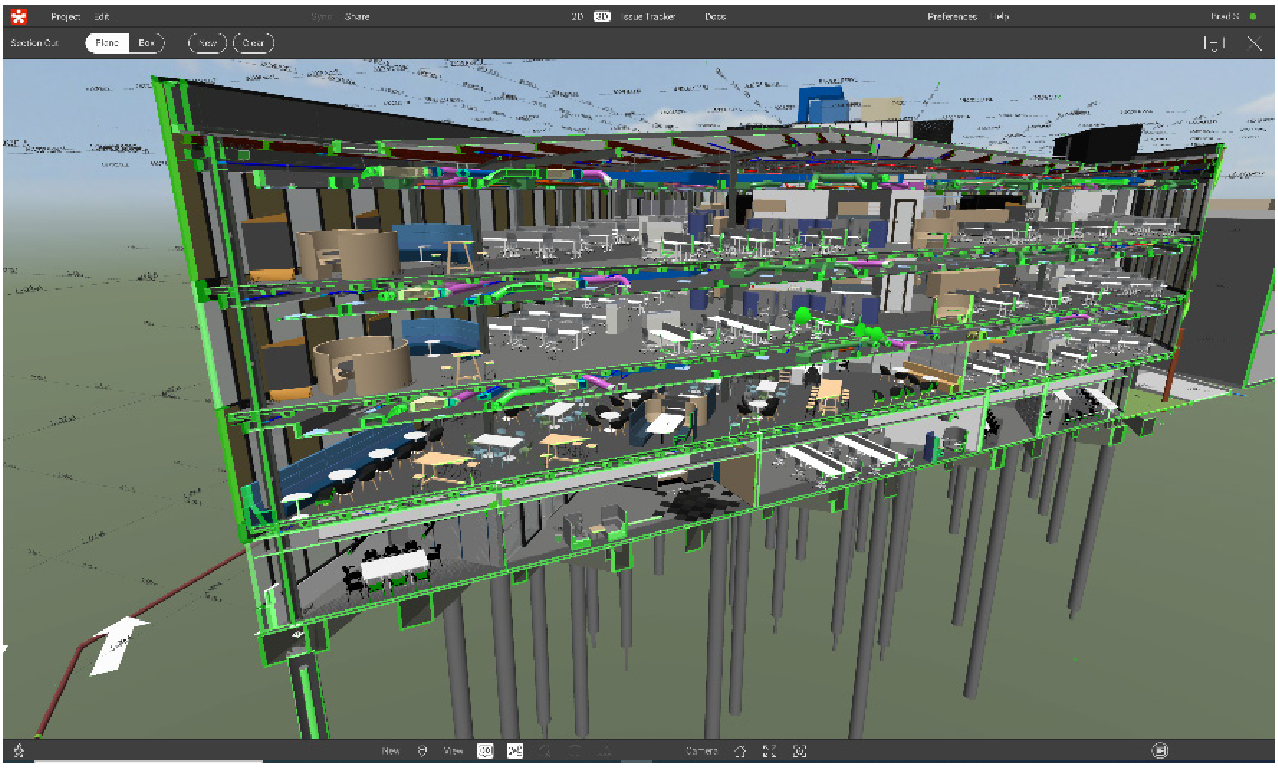

Figure 16: BIM model of case study building

Image courtesy of Warren and Mahoney and Ngai-Tahu

BIM SAFE NZ
Safety Through Technology

Managing whole-of-life building information

Managing information over the whole-of-life of a building is a difficult process. However, this process is essential if we are to plan, design, construct, operate and dispose of a building in a safe, environmentally conscious and cost-effective manner. This also applies to other infrastructure such as roads and pipes, etc.

The lifetime management of building information has been coined the 'golden thread'[1]. A protype Asset Information Specification (AIS) tool has been developed to assist all people along the golden thread to clearly specify their data requirements. This means building data can be:

- Specified to the appropriate Level of Information (LOI)
- Delivered by the right person at the right time
- Quality assured
- Re-used as required

How the AIS Tool simplifies the application of ISO 19650

ISO 19650 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling is the international standard for managing building information (ISO Technical Committee ISO/TC 59/SC 13 , 2022). This standard is becoming the de-facto standard for BIM in New Zealand.

The standard defines several documents that are required for the process to be effective. The standard does not define how these documents should be developed nor how practically the data requirements should be defined. To fill this gap the AIS tool creates a simple interface and procedure so that a user can easily specify what data is required, by whom, and when. The complexity of the ISO process is encoded into the tool so that the user only has to focus on their information needs. This is important as data requirements can often run to several thousand lines long. In addition, the tool will allow the data requirements to be directly uploaded as a template into standard BIM software (e.g., Revit). This greatly reduces cost and risk whilst increasing the quality of the outcome.

Procurement of building information

The AIS tool provides a means of developing standard procurement documentation for building information. Often building information needed by asset managers and other building professionals is poorly defined. When fully developed the AIS tool will allow the capture and analysis of the information needs of a wide range of building and infrastructure owners. It will also allow the development of standardised data specifications for a range of different building types which can then be pre-populated into BIM software. This will streamline the information procurement process and allow clients to understand the cost of procuring non-standard data.

[1] Building Regulations Advisory Committee . (2021, June). *Building Regulations Advisory Committee: golden thread report.* Retrieved from Gov.UK: https://www.gov.uk/government/publications/building-regulations-advisory-committee-golden-thread-report/building-regulations-advisory-committee-golden-thread-report

Components of the AIS

There are several parts to the AIS which link aspects of the process documents outlined in ISO 19650. These documents define the informational needs and are the:

- Organisational Information Requirements (OIR), *the Why*
- Asset Informational Requirements (AIR), *the What*
- Exchange Information Requirements (EIR), *the Who and When*

In addition, the AIS links the informational requirements to a preferred classification system such as Uniclass as in Figure 17. Uniclass is a way to organize everything required for built environment assets and provide a logical code for each general item, which can be used by anyone to identify and refer to it (NBS, 2022). The use of a classification system is essential for the whole-of-life management of assets and systems. The AIS could be configured to any classification system such as Omniclass or the New Zealand Asset Metadata Standard (NZAMS).

Some aspects of the AIS will only have to be filled in once such as the OIR. Others may need to be adjusted according to the scale and complexity of a project. Either way, the saving in time and cost will be significant.

Property	3 WATERS COP EQUIVALENT	PR - Products	PR_65 - Services and process distribution products	Pr_65_52 - Pipe, tube and fitting products	Pr_65_52_01 - Access and inspection chambers and gullies	Pr_65_52_01_01 - Access and inspection chambers
AssemblyPlace	Construction Method					X
SerialNumber	Manufacturing Serial Number for the Asset					
ExpectedLife	Design Life		X			

Figure 17: AIR, linking asset property to Uniclass classification

Benefits of the AIS

There are many benefits to the full development and use of the AIS. These include:

1. Standardised procurement of asset information through a machine-readable format.
1. Easily replicable process between projects.
2. Reduced risk of duplicate data and double handling.
3. A very explicit set of information requirements.
4. Allowing the automatic population of requirements in design software, improving quality and consistency and reduces risk for human error.
5. Automated schema generation to reduce design costs.

Next steps

The AIS is currently in protype as a very large spreadsheet. It was developed and tested alongside real projects including a design for a new build at the University of Canterbury and a KiwiRail re-development. However, it is not fully populated with all the data schemas and classification tables necessary for use across the whole of the infrastructure sector. For full development, the tool needs to be rebuilt on a (cloud-based) database with a web-based interface. The best commercial model to enable this is currently being explored.

Artificial Intelligence (AI) approaches to Code Compliance Checking

Whenever a building is constructed, altered, or demolished, a building consent is required. In New Zealand, there are over 600 codes and standards to be considered when consenting. Conventionally, getting building consent is a manual process. The authorities use checklists to ensure that all relevant requirements are fulfilled. This process can require multiple iterations until all obligations are met, consuming a significant amount of money and time. In the last 50 years, much commercial and academic effort has been applied to automating the compliance checking process. Automated Code Compliance Checking (ACCC) enables architects and project managers to precheck their design for compliance, helps consenting authorities avoid repetitive tasks, ensures consistency, and prevents errors. Most ACCC tools face two main challenges, firstly the Building Information Model does not provide sufficient compliance information of the necessary quality level. Secondly the normative requirements, distributed over numerous codes and standards, need to be computerised and maintained to circumvent the limitation of hard-coded and potentially outdated subsets of applicable rules.

Regulatory documents are typically authored in natural language, intended for human interpretation. The manual translation of all building-related standards, each containing hundreds of rules, is costly and time-consuming. Previous experience in NZ shows that conversion costs around $10,000 per code or standard, which is a daunting $6 million to complete, as well as the time for experts to make the conversion (estimated at one month per code or standard). Due to the high complexity and domain-specific terminology, it is hard to ensure the quality and consistency of human encoded translations. Since standards are frequently amended, it is a complex chore to keep a digital version up to date especially without direct connection to the original text. Developing AI techniques, especially in the realm of Natural Language Processing (NLP), provides an opportunity to both automate the interpretation of published codes and standards, and also to check building designs are code-compliant prior to submittal.

Natural Language Processing approaches to Codes

The research in this PhD project was launched with a systematic literature review of Natural Language Processing (NLP) approaches to building code interpretation. The 41 articles identified for review identified a wide range of NLP processes that needed to be supported to enable code compliance checking (see Figure 18) with varying research input to the different processes. Before 2010, NLP was mostly used for similarity-based regulation clause retrieval. Regulations were usually transformed manually, and the research focussed on practical representation formats. Over time, the technologies progressed from feature-based algorithms to ontologies to machine and deep learning.

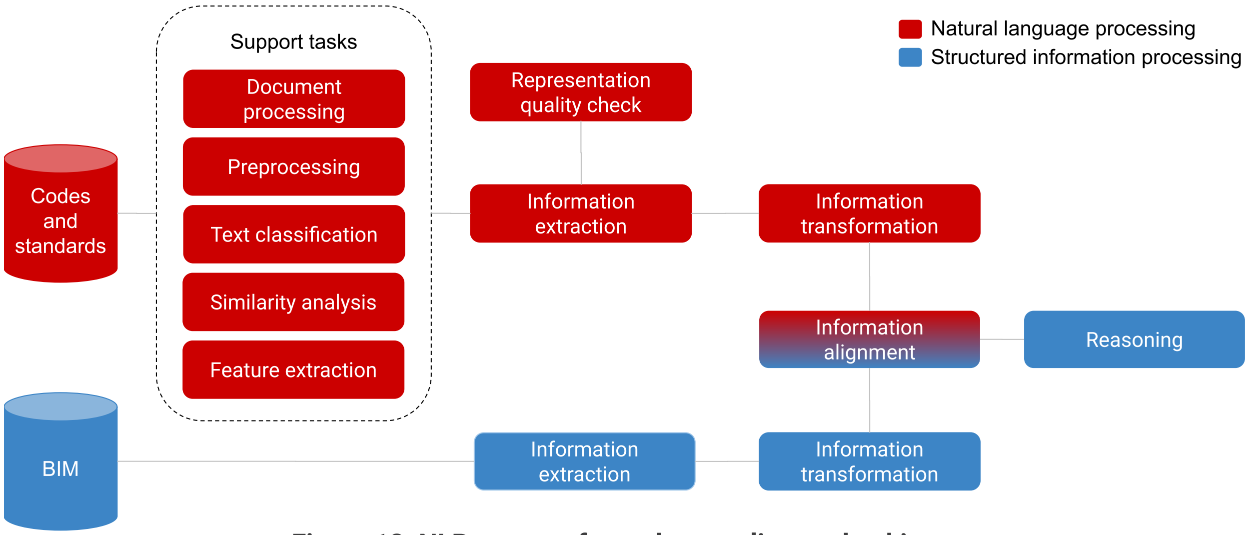

Figure 18: NLP process for code compliance checking

The literature review identified eight gaps in the research, summarised as:

1. Insufficient regulation context considered in extraction.
2. No public datasets to test with.
3. No agreement on the complete representation requirements.
4. Inability to enable scalable information extraction with sufficient performance.
5. Inability to enable scalable information alignment with sufficient performance.
6. Inability to expand beyond handling quantitative textual requirements.
7. Inability to incorporate complex requirements (e.g., performance-based specification).
8. No standard or rigorous approach to quality assurance of translated codes.

Investigating Neural Semantic Parsing

Following the literature review, a new approach was taken to tackling the problem. This involved a training dataset of sixteen NZ Acceptable Solutions, covering the code categories of ‘Stability’, ‘Protection from Fire’, ‘Access’, ‘Moisture’, and ‘Services and Facilities’. These had been manually translated into LegalRuleML (LRML, a computable representation of rules in the legal domain) in a previous National Science Challenge project led by CAS Ltd. The initial translation work on the original LRML datasets showed that transformer-based tools can translate codes into LRML achieving around 47% accuracy.

This level of accuracy is obviously insufficient to rely on a simple automated translation, but it did highlight several approaches to explore to develop more accurate translations. From the original explorations and a focus on error sources it was possible to see that the training was being affected by:

1. Inconsistent LRML encoding by different human translators in the original data.
1. Complex LRML expressions trying to include programming instructions.
2. Non-correspondence between regulatory statements and LRML rules.
3. Implicit encoded knowledge from the human translators.

A range of experiments were run to improve performance, focussing on increasing the consistency and alignment between regulatory statements and LRML rules. With these enhancements the accuracy has been improved to 80.5% for some of the Acceptable Solutions. This is a remarkable improvement over the standard approaches with raw LRML datasets (47% accuracy) and gives us inspiration that our next steps will lead to a usable partially automated translation system for codes and standards.

Next steps

The research project will now focus on a range of methods that could boost the accuracy even further. These include:

- bringing more construction domain knowledge into the transformer systems.
- testing more sophisticated model architectures, training procedures and decoding strategies.
- looking at the performance with international codes and standards included in the training dataset.

Alongside this work we are still seeking to work with Standards NZ and MBIE to develop a quality assurance process that could be applied to determine the acceptability of translated codes and standards.

Theme Three – Fit for Purpose Building Components

Introduction

The recent seismic events in New Zealand resulted in a paradigm shift in how we define the performance of buildings in earthquakes. The definition of performance has changed from a sole focus on the structure (beams, columns, slabs, braces etc.) to a holistic approach that defines performance considering the building as a facility or asset in a society. The focus in design and decision-making processes is shifting from just ensuring life-safety to also maintaining post-earthquake functionality, limiting financial losses and controlling business disruption. Such paradigm shift requires that all constituent elements of a facility be designed to align their performances with the performance target of the facility.

Considering this shift, Theme Three was designed to understand, develop and advance whole-of-building approaches to seismic resilience. The current focus of this theme is non-structural elements (NSEs) in buildings. NSEs are components of, and systems within, a building facility that render the facility liveable and functional during different environmental conditions. A major objective is to refine existing procedures and develop new ones to improve the design, selection and procurement of NSEs. Toward this aim, multiple projects have been launched and completed as discussed below..

Strategic review of design and construction of non-structural elements

Purpose of project

The purpose of this project was to identify the major issues related to the design, selection and procurement of NSEs in New Zealand. The need for this work was identified by the observation that most buildings in the Canterbury and Kaikōura earthquakes performed as our Codes intended them to, i.e., to safeguard lives. Many buildings had minor structural damage but were unable to be reused and re-occupied due to damage and failure of NSEs. In these instances, damage to NSEs caused major disruptions to businesses and our communities.

This project focused on the challenges that the construction industry is currently facing. Additionally, vision for the future and changes that need to be embraced to ensure buildings meet the expectations of asset owners, tenants and our communities were identified and discussed.

Findings

The research showed clear connection between the issues causing pain in the industry with significant damage and poor performance of NSEs in recent seismic events. It also highlighted the future risk of extensive damage to NSEs in New Zealand's wider building stock when subjected to more frequent earthquake events (those events notionally above a moderate earthquake). It was identified that the industry is challenged at its heart by risk avoidance. Contracts and procurement methodologies transfer risk from the asset owner to the construction team. There appears to be a lack of appreciation by asset owners and project managers of the value of collectively managing the risk and responsibility for the design, coordination and construction of NSEs and their seismic restraints.

The procurement models push consultants and contractors to find ways to reduce their costs, which in many cases, results in an inferior outcome for the building owner. One method used by the industry to reduce costs is the use of product substitutions. Product substitutions do not always go through an approval process and can result in inferior products installed that are not identified due to a lack of independent review of NSEs installations. Currently, the design, coordination and construction of NSEs and their seismic restraints rely, in the most part, on self-regulation of the industry. This research indicates that self-regulation is not working, and the industry is falling well short of the seismic performance expected of NSEs in our building stock.

Benefits to industry

The project brought to light major issues in need of solution that the industry is currently facing. The research team believes that solutions to these issues will benefit the industry by increasing productivity. Further, costs and waste will decrease due to avoidance of rework, which currently plagues the industry. A majority from the industry accepted the identified issues as genuine but not everyone in the industry agreed. The research team has been exploring other approaches to ensure that the viewpoints from the entire industry are captured.

Research team

The project was led by Jan Stanway from WSP with a research team that involved industry professionals and academics.

Outputs

The white paper discussing the findings of this project is available for public access on the BIP website. One of the recommendations, the need for a national test facility and qualification framework for NSEs in New Zealand, is discussed in the next section.

Strategic Case for National Testing Facilities for Non-Structural Elements in New Zealand

Purpose of project

The purpose of this project was to scope the need for a multi-functional national testing facility in New Zealand for seismic qualification of NSEs. This study was based on consultation with industry professionals. It followed the strategic white paper produced by BIP on NSEs (as per the previous section). The white paper recommended the development of a high-performance testing facility to provide an investigative platform for commercial and research purposes. This was the hypothesis that was tested.

Methodology

Twenty-four building professionals from New Zealand with different expertise were consulted to test the assumption that New Zealand should invest in a testing platform. The consulted professionals included structural engineers, fire engineers, mechanical engineers, electrical engineers, architects, technical advisors, product manufacturers, managing directors of major suppliers in the country, academics and building control officials.

Findings

The study found that there is insufficient knowledge to develop a business case for investment in a commercial testing facility at this time. There was a range of views among the participants on the establishment of a national testing facility as the first major step toward improvement of seismic design practices. The discussion around the need for a test facility seemed premature as several participants cited non-structural testing not being an industry-wide requirement (due to lack of regulation). The participants identified the inconsistent procedures for seismic qualification of NSEs as more pressing problems. Based on this reasoning, the commercial viability of such a facility was questioned, particularly by suppliers. It was found that at times building projects require test facilities and associated guidance, but this need seems to be limited to specific projects. However, the limited number of test facilities in New Zealand does cause significant increased risk and cost to these projects. Test facilities are available in New Zealand with varying capabilities and capacities but have not always been found adequate resulting in the need to send components overseas for testing.

The major finding from this study was the need for a national seismic qualification framework. This was based on unanimous support from the participants. A seismic qualification framework formally defines the processes related to achieving performance requirements that building components or systems needs to adhere to. The framework is proposed to be a guidance document for the characterization, specification and quality assurance of NSEs. The findings also suggested that the development and implementation of the framework may create the impetus for a dedicated test facility if the existing test facilities are deemed inadequate. It was recommended that the proposal for a commercial national testing facility should be reconsidered once this framework has been developed and adopted within the industry. It was also identified that further research and supporting capability is needed to develop the framework.

Benefits to industry

The project identified that it is unlikely to see major changes in the design practices until a framework has been developed and adopted. Accordingly, the first major step towards improvement of seismic design practices for NSEs should be to develop and implement a national seismic qualification framework.

Outputs and next steps

The project report is available for public access on the BIP website. The project is being followed by another long-term study on the development of a national seismic qualification framework for NSEs in New Zealand.

Seismic performance characterization of non-structural elements through experimental testing

Purpose

This project focused on design of NSEs. The aim was to refine existing approaches and develop new solutions where needed. Research work has shown that the seismic design provisions in New Zealand standards for NSEs are empirical and are mostly stipulated without any technical basis. Secondly, it was identified that the traditional manner in which some NSEs are connected to building floors makes the elements vulnerable to seismic damage. Considering these issues, experimental studies were undertaken to address the following.

1. To investigate the validity of design procedures in New Zealand Standards for NSEs and recommend improvements.
2. To evaluate the seismic performance of traditional and low-damage designs for different n NSEs.

Methodology

Fire sprinkler piping, cladding and partition walls were tested under seismic loads.

Sprinkler systems

Fire sprinkler systems were tested under seismic loading on a shake table to test the validity of the design provisions in the New Zealand Standard on Automatic Fire Sprinkler Systems (NZS 4541). The tests resulted in the recommendation of improvements to NZS 4541 with regard to seismic design. A simple yet reliable seismic design procedure was developed for use in the industry. This procedure has considerable engineering merit over the existing design provisions in NZS 4541.

Figure 19: Test setup for shake table testing of sprinkler systems.

Cladding systems

The work on claddings resulted in the development of a novel rocking system. Seismic tests were conducted on a sub-assembly of panels to study their in-plane, out-of-plane and bi-directional performances. The test results showed that the system worked and had low-damage characteristics. This means that the panels were able to sustain large seismic movements without notable damage. These low-damage connections can be designed for different levels of seismic movements and are thus suitable for different conditions.

Partition walls

The traditional designs for partition walls are very susceptible to damage. A new low-damage solution was developed and tested for partition walls. This system was tested in planar, tee and corner configurations. Minimal damage was observed at high seismic movements. This is a significant improvement over the traditional practices that can lead to significant losses even in low-to-moderate earthquakes.

Benefits to industry

The major industry outcomes from this project are design procedures and detailing guidelines for sprinkler systems, cladding and partition walls. These outcomes will improve the reliability of design and construction practices for NSEs in maintaining post-earthquake functionality, prevention of injuries by ensuring proper stability in earthquakes and controlling financial losses due to damage. These outcomes have been communicated to the industry through ongoing meetings and workshops. The eventual aim is to see these improvements realised in the Building Code.

Future work

As each NSE is an essential part of a network that delivers a function, it is important to test these elements in an interactive manner. The next avenue for experimental studies on NSEs is to bring different elements together and test them to see if the network itself continues to function.

Outputs

The research articles published on the experimental work can be found on the BIP website.

Research team

Prof. Rajesh P. Dhakal led the project. PhD students, Muhammad Rashid and Jitendra Bhatta, carried out the experimental work as part of their PhDs. Prof. Timothy J. Sullivan co-supervised the students.

Acknowledgement

The research team is grateful to Shanon Saxon (FFP Canterbury), Stephen Ridder (AON NZ) and Tom Carpenter (FM Global) for providing advice and feedback on different aspects of the experiments on sprinkler systems. Further, the team from Lanyon and LeCompte Construction (Christchurch) is thanked for sponsoring the precast concrete panels and their steel connections.

Theme Four – Low Carbon and Climate Resilient Infrastructure (started 2022)

Introduction

This research theme was established in response to repeated calls from industry leaders, during a 2021 review of the BIP programme, to support the transition to zero carbon construction in New Zealand.

The aim of this research is to determine infrastructure material, design and operational strategies, and to develop emissions verification methods, that support the construction of infrastructure that meet greenhouse gas emissions targets.

This research also seeks to improve the resilience of infrastructure to climate change.

Pathways to net-zero carbon buildings and communities

Purpose of project

The purpose of this project is to evaluate the impacts of five strategies for reducing carbon emissions from residential buildings and private communities:

- Decarbonisation of the electricity grid
- Electrification of building space and water heating
- Building efficiency improvements to reduce energy demand
- Digitalisation of buildings and electricity grids to improve energy management
- Electrification of vehicles

These strategies can be combined in different ways to form many potential pathways for achieving low carbon buildings and communities. The primary aim of this research is to identify and characterise 'best' pathways and technologies for reducing carbon emissions from buildings and communities. A secondary aim is to develop systems analysis methodologies suitable for assessing emission reductions associated with individual buildings and communities.

Benefits to industry

Information from this research will improve the capability of designers to reduce the carbon footprint of buildings and will underpin the future development of building regulations covering carbon emissions – performance objectives, acceptable solutions and verification methods.

Research team

The project is led by Professor Larry Bellamy from the University of Canterbury with a research team including industry professionals, academics and a PhD student.

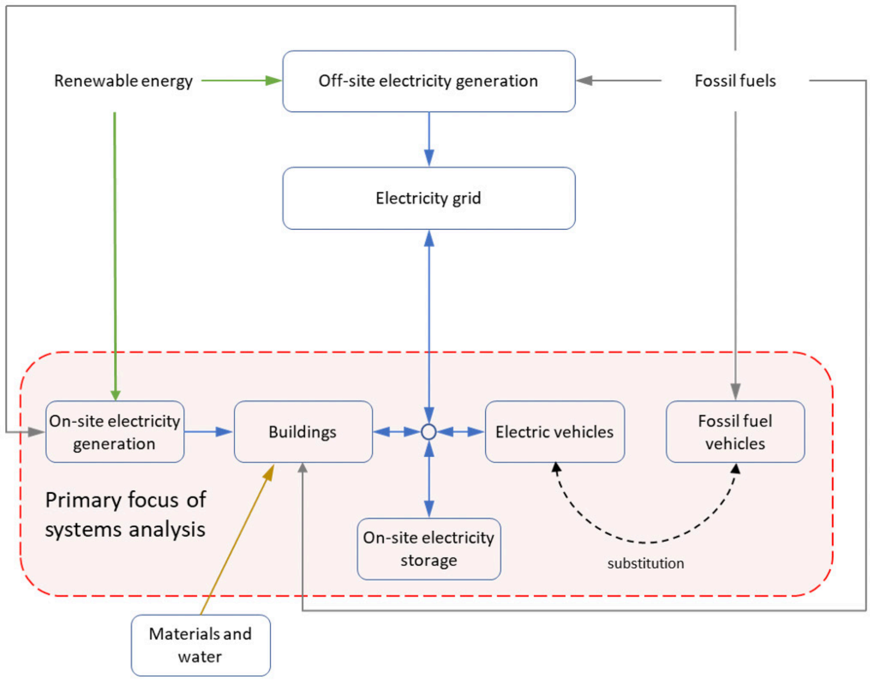

Figure 24: System map of building and community carbon emissions systems analysis

Net-zero carbon concrete 2050

Purpose of project

The aim of this project is to deliver a comprehensive roadmap to net-zero carbon concrete for the New Zealand construction industry, based on an evaluation of the environmental and economic impacts of various strategies. It is the first stage of a series of projects in an integrated programme of work that defines the roadmap for reaching net-zero carbon concrete and then support its implementation.

The roadmap will be informed by global and country roadmaps, modified to suit the particular needs and context of New Zealand.

This project brings together the collective wisdom of the full concrete industry through a set of workshops, supported by information and modelling analyses provided by the research community. It will identify the key strategies that will reduce CO2 emissions by 25% by 2025, 30% by 2030 and down to net-zero by 2050. It will also identify the key challenges that will need to be addressed to reach these targets.

Subsequent projects in Stages 2 and 3 of this programme will support the implementation of strategies by addressing key challenges and barriers, and assessing progress in reducing carbon emissions against the Roadmap targets.

Benefits to industry

This work will make a significant impact on the whole-of-life carbon emissions from concrete construction in New Zealand. The Roadmap will define the barriers, measures and monitoring requirements to assess impacts on CO2 emissions, which will inform the following stages:

Stage 2 - Addressing Barriers

Stage 3 - Measuring Performance

Research team

The project is co-led by Professor Larry Bellamy from the University of Canterbury and Rob Gaimster from ConcreteNZ, with a research team including industry professionals and consultants.

How to get involved

This report highlights several of the main projects currently underway or recently delivered by the BIP programme. However, projects are continually being introduced and developed. The Building Innovation Partnership is keen to explore projects that benefit New Zealand industry and that meet BIP's criteria: These criteria include:

- Does the project fit into one or more of the BIP themes?
- Does the project provide 'industry good'?
- Do the funders reflect a broad range of industry representation?
- Will the output be publicly available?

If you want to get involved with any of the projects highlighted in this report or have a project that you wish to pursue, please contact:

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BUILDING INNOVATION PARTNERSHIP

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