Demonstrative Research on Practical Use of BIM for Building Data Connectivity

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Abstract

Median house prices in New Zealand are continuously growing, and the current housing shortage has seriously tainted housing affordability for local kiwis. The New Zealand government has tried several methods to lower the current house price; however, the shortage of houses challenge has not yet been resolved due to the low productive performance in the current New Zealand construction industry. The low productivity of the New Zealand residential construction industry is mainly due to the out-of-date construction method, low data connectivity within the industry and the current building material shortage.

This research aimed to resolve the New Zealand housing shortage challenge and reduce the influence of the construction industry on our environment by demonstrating the practical use of BIM for improving data connectivity. A case study to examine the relatively new prefabrication technology against the widely used traditional construction method has been conducted in this research, while an environmental impact calculator protocol to support the sustainable material selection process during the design phase of the construction lifecycle has been developed. A standardized material passport generation protocol has also been designed and developed, and a demonstration of using the Cloud BIM platform in residential houses has been conducted.

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1. Introduction

1.1 Background

According to Kiwi bank economists, the current National house shortage in New Zealand hits 130,000. The current housing shortage has seriously tainted housing affordability for local kiwis. Median house prices in New Zealand are continuously growing. The NZ government has tried several methods to lower the current house price, including an initiative of building 1,000 homes in 2019 and 10,000 in the next ten years under the Kiwi Build scheme; however, the plan was withdrawn after a year due to the low productive performance in current New Zealand construction industry. (Darlow, Rotimi et al. 2021). The low productivity of the New Zealand residential construction industry is mainly due to the out-of-date construction method, low data connectivity within the industry and the current building material shortage.

Compared with other industries in New Zealand, the construction industry is rather traditional in practice due to a considerable lag in technological aspects such as automation and digital innovation (Darlow, Rotimi et al. 2021). Today, the majority of the residential houses are built using the traditional on-site construction method that kiwis have been using all the time. It is expensive and has an extended construction period as well as many other issues such as work progress being weather dependent, high complexity and high cost of managing construction sites and workers wasting costly building materials (Brown, Sharma et al. 2020). The out of date construction methodology limits the productivity of the New Zealand residential construction industry, and the relatively new concept of prefabricated houses resolved all the above issues while enabling similarly designed homes to be built faster and cheaper, which reduced the stress of New Zealand's housing shortage (Chen and Samarasinghe 2020).

Also, in recent years, construction companies have been confronted with significant digital transformation problems. Due to its vast volume, various data, and intensive administration, the traditional building industry has been unable to meet the criteria of modern architecture for the production and living of the more scientific and digital human civilisation (He, Yan et al. 2020). Good planning and design and clear construction standards that reflect environmental goals help ensure the building sector's long-term viability (Soonsawad, Martinez et al. 2022). Therefore, improving data connectivity will be a crucial challenge to improving the New Zealand building industry's productivity.

However, technologies that enable better data connectivity within the industry, such as the Building Information Modelling (BIM), is not widely implemented within the New Zealand residential construction industry. BIM is defined as an intelligent 3D model-based process and a digital representation of the physical and functional characteristics of a facility or place. It integrates and analyses the information among the planning, design, procurement, construction and maintenance stages in the project life cycle and provides spatial models (3D), optimized schedule (4D), cost-saving options (5D) and project lifecycle information (6D) to AEC (Architecture, Engineering and Construction) professionals, assisting them in project implementation and management by utilizing the BIM's features, such as interoperability, visualization and coordination (Bryde, Broquetas et al. 2013). It is worth studying that if the better implementation of technologies like BIM, which improves the data connectivity within the construction industry, it will lead to an improvement in the productivity in the New Zealand residential housing construction industry.

Meanwhile, the current material shortage also limits the productivity of New Zealand's residential construction. In recent years, material shortages hampered activity in the construction industry, demanding materials such as lumber, steel and concrete, which had previously been booming. As material costs continue to rise, there are concerns about the impact supply chain stress will have on margins and project viability (Wescoe 2021).

Furthermore, reducing greenhouse gas emissions is arguably the most critical environmental issue facing the global community in the modern world. While the construction industry accounts for around 35 per cent of the world's energy demand and 38 per cent of the greenhouse gas emissions(Fuller and Crawford 2011), the construction industry must start acting now on making more sustainable construction decisions.

1.2 Objectives

With the current house shortage in New Zealand, I felt responsible for applying my research and critical thinking skills to help resolve part of that problem.

This research aims to define the research gaps in the current New Zealand residential housing construction methodology and demonstrate the practical use of BIM in improving data connectivity within the construction industry and hence contributes toward solving the house shortage challenge.

1.3 Thesis outline

This thesis is divided into six parts and is organized as follows:

Chapter one presents a general introduction and the main objectives of this research.

Chapter two presents a comprehensive literature review on the New Zealand residential construction industry. Section 2.2.1 examines the literature outlining the New Zealand construction methods and demonstrates the potential new technology that can benefit the New Zealand residential housing industry. Section 2.2.2 dived into literature about the limited degree of information exchange for the New Zealand residential construction industry and presented a better way for the building material procurement process as well as provided a comprehensive study on Building Information Modelling (BIM) tools. Section 2.2.3 studied the material shortage challenge faced by the New Zealand building industry and tried to seek a solution to release this burden. In contrast, section 2.2.4 examines the environmental impact caused by the construction industry.

Chapter 3 explains the development methodology for demonstrating the use of new technology like BIM on New Zealand residential houses to improve data connectivity. A case study to gain more insight into the New Zealand construction industry by comparing traditional and prefabricated construction methods has been conducted in section 3.2.1. An environmental impact calculator protocol which utilizes BIM technology to support the material selection process has been developed in section 3.2.2. Meanwhile, with the use of BIM technology, a standardized material passport generation protocol has also been developed in section 3.2.3 to release the industry from material shortage burden as well as reduce the environmental impact due to construction material waste. Lastly, in section 3.2.4, a demonstration of using Cloud BIM for a residential house has been conducted to showcase the direct benefits of BIM.

Chapter 4 discuss the case study and developed tools and protocols on the economic, environmental, and social aspects and their limitations.

Chapter 5 provides a general conclusion of this research, while chapter 6 suggests some future works that could be done to make this research more complete.

2. Literature review

2.1 Literature review methodology

A literature review is an essential feature of my master's research. The breadth and depth of the existing work body can be understood by reviewing relevant literature, and gaps in further exploration can be identified. By summarizing, analyzing, and synthesizing a group of related literature, a specific hypothesis and/or new theories can be developed. The validity and quality of existing work against a criterion to reveal weaknesses, inconsistencies, and contradictions can also be evaluated. For my research topic, a systematic literature review has been conducted, which reduces the bias that would result from cherry-picking studies in a non-systematic way. After following steps from "Guidance on Conducting a Systematic Literature Review(Y. (Xiao and Watson 2019)

The method can be repeated as follows:

2.1.1 Inclusion criterion

Only studies that provide in-depth thinking in the construction industry have been included. Only studies written in English were included.

2.1.2 Literature identification

The literature search was started by using the keywords "Construction", "Residential", "Data", and "efficiency". The preliminary relevance was determined by the title. If the content seemed to discuss the relevant area from the title, its full reference would be obtained from my Endnote library, including author, year, title, and abstract, for further evaluation. Scopus, a frequently used database by engineering researchers, has been used. Because technological advancement changes methods used in construction, my research is only interested in publications within recent years. I limit the publication date to 2016 and 2021 (articles published in the past five years) so that the output will be more up to date. In total, 266 articles were listed in the search.

2.1.3 Screening for inclusion

After screening the relevance of papers to my research topic through their titles, abstracts of the 135 studies were read to decide their relevance to the research topic further. A total of 64 studies were deemed relevant, and we obtained the full-text article for quality assessment

2.1.4 Quality and eligibility assessment

Full-text articles have been skimmed through further to evaluate the quality and eligibility of the studies. Journal articles and books published by reputable publishers were deemed high-quality research and, therefore, included in the review. Most online presentations are excluded from the review because of the lack of a peer-review process. Only high-quality reports with well-cited references were included.

Overall, 64 of the initial search were included in the next stage of full-text analysis.

While this research is conducted for the New Zealand construction industry, more publications on the New Zealand construction sector were later analyzed.   Statistics, news and reports from authorities have also been studied.

As previously discussed in the research objectives, the goal of this research is to improve data connectivity within the construction industry and hence contributes toward solving the house shortage challenge

Several reasons for New Zealand's low productive performance in the construction industry have been summarized by reviewing relevant literature.

2.2 Literature review findings

2.2.1 Out of date construction methods

2.2.1.1 Prefabrication technology

Prefabrication is also known as offsite construction, which is an approach that shifts the bulk of onsite building works to a remote location where the environment is controlled (Jiang, Mao et al. 2018).

Back in 1830, the first prefabricated iron-framed house was built in England. However, not until after World War II that the idea of off-site manufacturing houses in the factory was realized on a larger scale. Following World war II, while the international community needed to rebuild the vast areas of destruction while lacking materials and labour resources, the construction practice shifted from traditional construction to offsite prefabrication (Moradibistouni and Gjerde 2017). The pre-fabrication industry started in New Zealand in 1833 when kits and pre-cut frames for the early settlers' houses were imported from the UK, US and Australia. During the colonization period, settler numbers boosted, leading the construction industry to be developed and expand rapidly to meet the needs. Not until the final decade of the 19th century did the New Zealand Railways Department become the first prefabrication housing producer in the country, where elements were manufactured in a factory away from the final location and were sole and carried as a kit to be assembled later (Brown, Sharma et al. 2020).

After years of development, different types of prefabrication have been classified in different ways, including by materials and by degree of prefabrication (the most popular method). Based on the degree of prefabrication, this method has been divided into five subcategories which can be seen in figure 1.

Component base prefabrication

The lowest level of prefabrication is creating components out of materials to reduce the number of pieces and increase the speed of assembly. Examples include cut framing, built-up windows and kit set housing assembled onsite like a jigsaw.

Panelized prefabrication

Premanufactured wall, floor and roof panels. Panels can be open (being framed, clad on one side and sometimes insulated) or closed (with plumbing and electricity conduits, insulation installed, clad on both sides and windows in place). This is essentially an assembly of 2D “face “elements. Usually with 60% prefabricated and 40% on-site job.

Volume/Modular prefabrication

Premanufactured structural boxes or modules are erected offsite and brought together onsite to form a complete building. This assembly of 3D “volume” units appears to be the fastest construction approach; typically, the onsite activities are seen only by the public.

Hybrid prefabrication

Used in combination with another or with traditional construction methods. Normally consist of 60% modular, 20% panelized and 20% site built. Examples include modules interspersed with panels. Typically involve some onsite construction as well as assembly of prefabricated sections.

Complete building prefabrication

In the highest degree of prefabrication, whole buildings are constructed offsite and carried to the site, also known as transportable buildings. Normally 95% of factory construction and 5% of site work will be classified in this category.

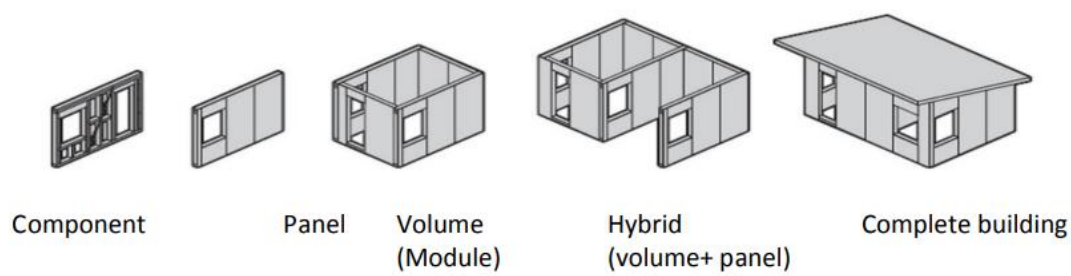


Figure 1 Different types of Prefabrication

(JC Burgess 2013, Moradibistouni and Gjerde 2017)

Being the fifth-largest industry in New Zealand, the construction industry is responsible for

- 40 per cent of New Zealand’s energy consumption
- 40 per cent of the waste generated in New Zealand

- 35 per cent of carbon dioxide (CO_2) emissions in New Zealand, and
- 40 per cent of the raw materials used in New Zealand

This suggests that shifting construction methods towards pre-fabrication will enable the country to benefit from the recognized advantages directly and move forward (JC Burgess 2013).

The majority of prefabrication manufacturers in New Zealand, 64 per cent, provide components or panels with the least amount of prefabrication, while just 8 per cent offer the most prefabrication, entire buildings.(Moradibistouni and Gjerde 2017)

In 2015, New Zealand's first automated pre-fabrication manufacturing factory started, with only 100 houses delivered a year due to non-fully automated processes (Wasim, Han et al. 2020). “Fletchers”, a prominent player in the New Zealand construction industry, has recently established the country's largest offsite manufacturing facility “, Clever Core”, which is expected to deliver 500 houses per year. However the factory is also not as fully automated as other pre-fabrication houses providers in New Zealand; it mainly moves onsite construction tasks to a controlled environment without implementing new technological tools or automation (Darlow, Rotimi et al. 2021).

In the past few years, legislation and government regulations have been developed to make prefabrication more mainstream and serve as a forerunner to increased acceptance of prefabrication. The use of prefabrication has been accelerated thanks to government intervention by introducing numerous policies. The most significant stumbling block has been the protracted wait for design approvals for prefabricated houses. The New Zealand government's MultiProof project, which began in 2010, expedited the consenting process for multiple-use building designs, resulting in faster building consent for conventional prefabrication designs (Brown, Sharma et al. 2020). By constructing more prefabricated apartments, townhouses, and high rises, prefabrication can be used to reduce excessive housing demand.

The prefab industry in New Zealand is indeed gradually evolving. In 2019, around 10 per cent of the construction projects were carried out offsite (Nadkarni 2019). However, compared to other countries where up to 80 per cent of their new builds are constructed off-site, 10 per cent is relatively low. The main reason might be as one-third of the country’s construction businesses are small to medium-sized enterprises (SMEs) with up to 19 employees, the adoption of innovation in the NZ construction industry is limited due to general resistance to change and the financial outlay requirements (Ministry of Business 2021). However, studies suggested that prefab construction does not only save the construction cost in general, but it also offers a more reliable upfront cost, total investment outlay and overall returns on investments from a long-term perspective. Prefab also supports better compliance with the Building Codes, quicker building consents/permits processing, and fewer building inspections (Darlow, Rotimi et al. 2021).

Economic benefits

Prefabricated construction accounts for 17 per cent of all building work in New Zealand in terms of value in 2015(Shahzad, Mbachu et al. 2015). According to current thinking, prefabrication can help the country save money by reducing direct and indirect costs during the construction, use, and demolition/recycling stages of the building lifespan. (Brown, Sharma et al. 2020) It has been shown that the use of prefab resulted in 34 per cent and 19 per cent average reductions in the construction completion times and costs, respectively. This also translated to an overall seven per cent average improvement in the productivity outcomes in the building projects. Twenty per cent cost-saving and 50 per cent time saving 11.1percent productivity improvement were shown for case studies in Prefab houses. The savings come from a decrease in building defects and workplace injuries and a decline in the number of changes to work in progress, faster construction, lower financing costs, and better quality. Furthermore, with construction demand in New Zealand increasing at a pace of 10 per cent each year, the recognized benefit of more incredible construction speed would provide the country with a better chance of fulfilling government housing numbers and quality requirements (Shahzad, Mbachu et al. 2015, Brown, Sharma et al. 2020).

Social benefits

Meanwhile, the benefits of prefab construction also include enhancing the quality of construction while onsite health and safety risk can be reduced (Brown, Sharma et al. 2020). With its unique construction method within a controlled environment, prefabrication can be regarded as a manufacturing activity rather than a building and construction activity(Chen and Samarasinghe 2020). As prefabricated wall frames (91 per cent of all walls) and roof trusses are the most frequent prefabricated elements in residential buildings (95 per cent), factory-based construction is 75 per cent less dangerous than site-based construction, with 75 per cent fewer deaths. Prefabrication lowers the rate of human error, which is the leading cause of building problems(Nadkarni 2019, Brown, Sharma et al. 2020).

However, the lack of innovation in prefabrication construction compared to innovative manufacturing methodologies available around the world, innovation in the prefab construction method is one of the significant impediments to prefabrication adoption in New Zealand. (Chen and Samarasinghe 2020).

Environmental benefits

Prefabrication can significantly minimize waste (40%), environmental impacts (30%–70%), and CO2 emissions (35%) while also utilising energy (55%), water (30%), and raw material (40%) resources more efficiently. Considering future energy resource constraints, rising environmental challenges, and continued population increase, the benefits of prefabrication can propel the country forwards(Moradibistouni and Gjerde 2017, Darlow, Rotimi et al. 2021).

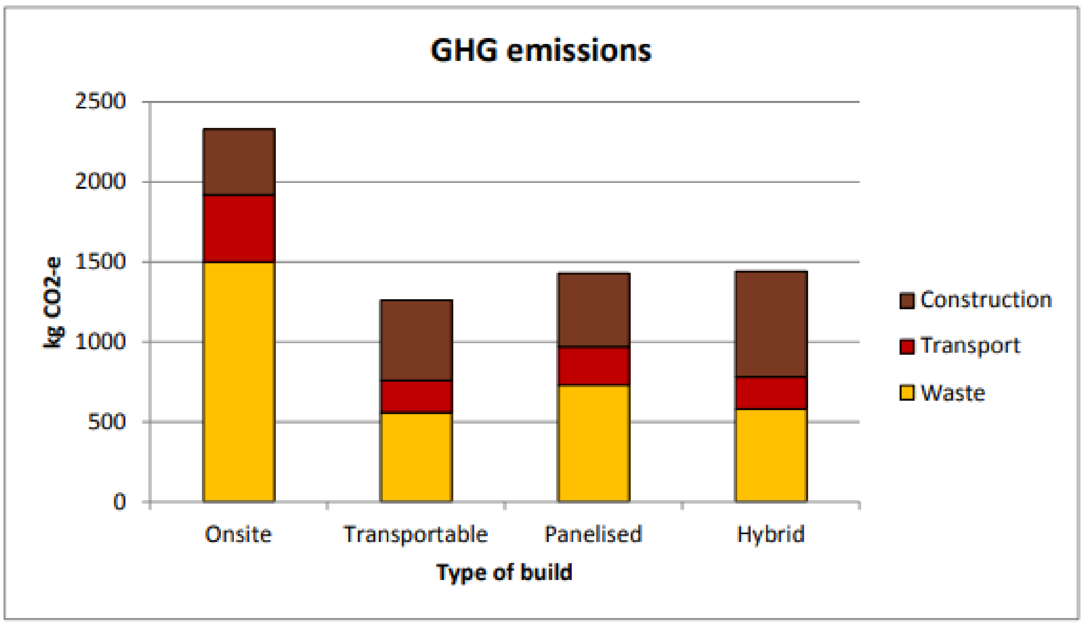


Figure 2 GHG emissions resulting from different construction methods

Burgess conducted a case study in 2013 to compare the GHG emissions resulting from the construction of a 120m2 house between onsite building and prefab construction. The results indicated that the GHG emissions from onsite construction are almost double the GHG emitted from a Transportable prefab constructed house. The comparison can be seen in figure 2 (JC Burgess 2013)

Limitations

Limitation of Prefab technologies includes design drawings used for prefab construction that needs to be more detailed than the conventional drawings used for onsite construction. Connections and locations need to be detailed more vividly as an interface between two components needs to be adequately designed to ensure proper locking. In contrast, BIM needs to be used to provide the level of detail and coordination required for offsite automated construction (Chen and

Samarasinghe 2020). Designers also need to be trained to design that the technology available in the factory has been utilised. Meanwhile, the transportation of components and modules needs to be taken into account during the design stage. The size specifications of manufactured components need to account for local legislative limits. Otherwise, they may not be able to be transported from the factory to the site(Wasim, Han et al. 2020).

Meanwhile, even though contemporary prefabricated housing has grown in popularity in New Zealand since 2008, it was mainly a design alternative for holiday homes or second homes(Sooriyamudalige, Domingo et al. 2020). Prefabricated design and construction are stereotyped as bland and uncompromising and have a long history of negative connotations. Due to mass production, many people believe that prefabrication lacks differentiation to client needs. Although it is an important technique to solve housing affordability problems and accessibility of architectural design to a broader audience, prefabrication has variable degrees of popularity in the building industry. Prefabrication can be more desirable if the design is more flexible(Chen and Samarasinghe 2020). New Zealand now has a minimal number of suitable designs and products; to meet the expanding housing need, a more incredible selection of offsite alternatives is required(Sooriyamudalige, Domingo et al. 2020). The local market has a small number of enterprises that offer state of the art, desired prefabricated homes. The challenge for new and developing businesses is to deliver a viable prefabricated model for New Zealand

Also, replacing traditional methods with prefabrication will almost certainly necessitate a shift in stakeholders' and users' perceptions of prefabrication and the removal of deep-seated institutional impediments. Stakeholders, including builders, manufacturers, financiers, regulators, and designers, will need to work together to achieve this (Chen and Samarasinghe 2020). However, unlike countries such as Japan, Germany, China, and the United States, where there is a demand for a large number of housing units, the high upfront investment cost of improving the automation process in Prefab limited New Zealand companies from making a move, necessitating innovation and further research within the Prefab industry (Moradibistouni and Gjerde 2017).

While there are numerous benefits listed above for prefabricated construction, a research gap has also been presented in New Zealand; there have not yet been any case studies comparing similar residential houses construction involving traditional construction managers and prefabricated companies.

2.2.2 The limited degree of information exchange

2.2.2.1 Procurement process

Currently, the New Zealand construction industry is mainly using the traditional procurement system with a fragmented supply chain. Studies suggest that there is an opportunity to improve the supply chain management system by allowing parties to gain insights into others' thinking and material-related decision making (Samarasinghe, Askarinejad et al. 2020). Suitable materials management processes rely on the collaborative efforts of the whole project team in any project. In the construction industry, particularly, the roles of the contractor, clients and suppliers should be linked when essential purchases of material decisions have been made(Samarasinghe, Askarinejad et al. 2020). The study suggests that while no clear relationship is shown in the seasonal pattern on construction cost throughout the year, one of the most critical risks affecting the current construction project profit is the high-cost variation in building supply. Meanwhile, due to the inconsistency of building material delivery resulting in delays, contractors also suffer from insufficient cash flow, reducing the potential for more similar construction projects (Zhao, Mbachu et al. 2019).

Since the procurement decisions now in New Zealand tend to be made by single parties rather than been made collaboratively, it can be improved by elevating the overall supply chain performance and enabling the whole project team to find building materials that are right for houses in New Zealand, which consequently can improve the industry performance (Samarasinghe, Askarinejad et al. 2020).

2.2.2.2 Building Information Modelling (BIM) in Architecture, Engineering and Construction (AEC)

BIM became a game-changer in the AEC industry. It plays a significant role in reshuffling the traditional AEC industry and reaching better performance by enabling various information to be integrated and recognised as a collaboration process in the project lifecycle(Santos, Costa et al. 2019). Generally, a project life cycle can be divided into five main phases: the Design, planning, procurement, construction, and maintenance phases. It has been considered a powerful tool to deliver benefits in the AEC industry by improving project quality, data-sharing capability, and construction efficiency (Blanco & Chen, 2014). However, BIM has been criticized as a standalone system framework that restricts project stakeholders' access to a standard set of data or information. The emerging cloud-BIM technology is considered an enabling tool that can deal with the standalone nature of traditional

BIM. It can lead to higher levels of cooperation and collaboration and hence provide an effective real-time communication platform for project team members. (Azhar 2011, Gao, Wu et al. 2019)

Currently, BIM can be involved in the project lifecycle as follows,

Planning:

As the first phase of the project life cycle, BIM enables options analysis for the project, including cost estimations, phase planning, site analysis and existing conditions modelling. While BIM is under implementation, scheduling (4D) and estimating (5D) are involved to ensure the construction can be built in time and estimate the cost of project options (Bryde, Broquetas et al. 2013). By comparing different build options based on costs, schedule and appearance, the owner can choose the preferred options and develop the further construction sequence to complete the project on time and within budget. They are taking an educational facility project at Savannah State University as an example. BIM was used to select the best from three options by analysing BIM-based cost estimates. The owner saves approximately $1,995,000 during the planning phase, while this economic decision was made quickly and definitively (Azhar 2011).

Design:

BIM can play a significant role in the design phase as it enables the physical and functional features of the construction to be demonstrated digitally. With the aid of BIM, architects and engineers will be able to conduct the project design more conveniently by integrating multiple data sets into a single model. BIM can provide a wide range of analyses, such as architecture design, structure, lighting, and energy, to analyse the building performance. Meanwhile, BIM can provide accurate 2D drawings, 3D exterior and interior models, and fabrication drawings in the design phase (Afsari 2012). Taking Wellness Center Building at Auburn University as an example, BIM was used for site coordination, constructability simulation and other analysis like Health & Safety risks in the design phase. The project reached an anticipated outcome by implementing BIM as it is a data-rich project. The increased accessibility to all stakeholders in the design phase gave it a big win. (Salman, Khalfan et al. 2012)

Procurement:

In this phase, BIM enables efficient communications among all stakeholders in the project. With the aid of BIM, all information related to the project can be stored, and the construction can be demonstrated in a digital 3D model (Aibinu and Papadonikolaki 2016). All stakeholders can access the data throughout the whole design process. BIM can remove the unnecessary procedures in project delivery through appropriate applications(Aibinu and Papadonikolaki 2016), which can be seen as a revolutionary tool in the AEC industry to represent and share relevant building information. In this phase, the strong coordination provided by BIM can develop a collaborative working environment where contractors and suppliers can be engaged in the design stage and eliminate reciprocal dependencies among stakeholders in the project to enhance the project organization and coordination. A good example showcasing the use of BIM in the procurement stage can be "Mall of Egypt", where the Design and Build was the project delivery method with the aid of BIM. BIM adoption optimised this process by explaining the design proposal using 3D visualization and real-time simulations, enabling stakeholders to make better procurement decisions (Amin and Abanda 2020).

Construction :

For the construction phase, BIM takes responsibility for reaching a goal of less rework, fewer errors, lower cost and schedule risk. Through visualization and optimization of BIM, stakeholders can receive visual feedback on the clash detection, construction simulation and potential risk analysis by 3D control and planning, and make changes with potential risks in advance by reasonable construction arrangement to ensure the construction deadline can be met, as well as to reduce the construction cost and guarantee the construction quality (Gao, Wu et al. 2019). An excellent example to demonstrate the use of BIM in the construction phase can be the implementation of BIM in the Aquarium Hilton Garden Inn. The project utilised the clash detection function in BIM and spotted 55 clashes in advance of actual construction, which avoided a cost of over $200,000 (Azhar 2011).

Maintenance :

The maintenance phase seems to be the most extended phase throughout a complete project life cycle, with a wide range of asset management involved. BIM can store and utilize the information that includes data from the post-construction phase and even life data collected during operation in a 3D model for stakeholders such as the facility manager in this phase to conduct the required maintenance more efficiently (Lin 2011). By utilizing BIM in the maintenance phase, facility managers can better estimate the operation schedule and other details needed to monitor the maintenance progress. A good example demonstrating the use of BIM in the maintenance phase can be the work conducted at Northumbria University; BIM was used to improve the performance of space management. As a result, an efficiency increase in operation execution order was achieved as BIM enables an integrated information utilization and visual environment representation (Guillen, Crespo et al. 2016)

Benefits and barriers to fully implementing BIM

First and foremost, in most circumstances, the primary benefit of using BIM is cost savings and control (Bryde, Broquetas et al. 2013). Traditionally, computers count quantities, and those drawings' information must be manually entered with low precision. When dealing with many drawings and data, a quantity surveyor's knowledge and ability are crucial. However, with the use of BIM, the system may save all relevant information about the building design, timing, and cost using BIM. As a result, the estimated cost can be calculated more precisely, lowering the cost of corrections.

Meanwhile, stakeholders can analyse the technical and economic indicators of different schemes and select a suitable investment scheme using the findings of cost analysis and description in the BIM model. On the other side, most of the time, the physical conflict of building components isn't discovered until after the project has progressed (Azhar 2011). BIM enables these conflicts to be identified and optimised as a solution, resulting in fewer engineering changes and cost savings for later stages. For example, BIM was used to tackle challenges in the Shanghai Tower project due to its complexity and construction difficulties. The BIM team used Autodesk Revit system software to create a three-dimensional model based on the project's construction design documents. The incomplete and unclear aspects of each speciality's original design were checked through modelling work and submitted to the design consultant team to improve, saving money on mistakes(Gao, Wu et al. 2019).

The second factor that affects project success is scheduling. According to a poll of BIM practitioners, scheduling is one of the most apparent benefits of BIM (Farnsworth, Beveridge et al., 2014). A fourth dimension, time, can be added to the 3D model to create a 4D model. As a result, the tasks and times associated with them will be linked to the 3D model, resulting in a visual project timeline. People can check and optimize the project schedule using the information recorded in the BIM system by reviewing the time, task arrangement, and duration. It will significantly reduce the likelihood of any project delays.

Furthermore, BIM may be used to manage risk systematically, and other BIM-based techniques can assess the likelihood of future risk occurrence. BIM will track the project in real-time and analyses potential hazards in the operation and maintenance process, allowing operators to foresee and evaluate risks and steer them towards successful risk management. By enhancing risk management through BIM, a project can be completed successfully and on time (Azhar 2011, Zou, Kiviniemi et al. 2017). A case study of the Mansion on Peachtree hotel in Atlanta can be employed to demonstrate the advantages. This project had to be completed ahead of schedule, and it had challenges with preliminary design and frequent scope changes from the client. The difficulty of assuring quality, risk reduction, and meeting deadlines with an unfinished and uncoordinated design was noted as a concern during the planning stage. The project team introduced BIM to this project. The project team was able to complete the project on time thanks to the use of BIM.(Bryde, Broquetas et al. 2013)

Finally, BIM can dramatically improve project quality (Dubas and Paslawski 2017). Key stakeholders like architects and owners have traditionally discussed architectural design possibilities through design drawings, which can lead to a communication and knowledge gap. Meanwhile, architects' and civil engineers' content work is separated. As a result, disputes over drawings are common. However, with the use of BIM, architects, civil engineers, and owners, on the other hand, can communicate on the same platform, using the same model and similar language. Parties will collaborate as a team with solid communication, resulting in dramatically improved project quality (Farnsworth, Beveridge et al. 2014). Taking the Hangzhou Olympic and International Expo centre project as an example, the structure and the architectural design must be consistent because of the complex terrain of the Qiantang River. The whole project covers an area of 400,000 m2, giving the necessity of using BIM. ProjectWise creates a shared data environment so that separate teams in the project can share engineering data. This interoperable method offers flexibility for designers, construction companies and owners and improves communication. The quality of this project has been fully guaranteed(Gao, Wu et al. 2019).

However, the value of building information modelling (BIM) has been questioned more and more. According to many architectural professionals, BIM software has a negative return on investment(Azhar 2011). On the other hand, BIM's value as a carrier is reflected in essential point simulation, collision assessment, visual presentation and information deconstruction and rebuilding. There are two critical reasons for the difficulties in achieving BIM’s full value. Firstly, some business owners do not value the use of modern technologies when it comes to boosting management. They concentrate on long-term traditional development techniques, including land acquisition and financing. Second, the deployment of BIM is ineffective, making it challenging to improve ROI (return on investment). BIM's worth is reflected not just in critical point simulation, collision inspection, and visual presentation. This model's potential usefulness is mainly based on its ability to deconstruct and recreate information and a corporate collaboration involving data(Farnsworth, Beveridge et al. 2014, Fedorik, Heikkilä et al. 2017). As a result, a research gap has been shown that it's critical to investigate how BIM can handle the integration of diverse professional models, actualise cross-departmental collaboration, accelerate information flow across all building stages, and demonstrate its potential to improve data connectivity. BIM's worth can then be revealed, and the construction industry's digital transition can be accelerated by completely integrating BIM with intelligent construction.

2.2.3 Building material shortage

Developers worldwide that require construction work done nowadays will need to pay more while expecting inevitable delays. Prices of building materials have boosted up to the new peak in history, and the demand is not slowing down(Amman 2021). A study in the UK suggested that from the beginning of 2021 to the end of the year, material prices grew by 15 per cent in general. Sawn timber prices, for example, increased by 23 per cent in July alone and are up 63 per cent from last year. According to UK government data, major construction materials' costs, such as the plywood costs, increased by 80 per cent in 2021, while structural steel prices have increased by 65 per cent, and concrete reinforcing bars have increased by 60 per cent (Fahy 2021). With the continuously increasing cost of construction materials, many suppliers are reluctant to distribute their supply under the assumption that the price will rise even more. By withholding their current supply, they can make more out of the same stock they currently have (Amman 2021). A shortage of material will inevitably lead to a higher demand which not only causes the price bump but also lead to the fact that material supply delay is becoming more and more common; a standard three day delivery from the supplier in 2020 now can easily get delayed from three to five weeks in the US (Amman 2021).

Similar to the rest of the world, the construction industry in New Zealand is experiencing an even more significant increase in cost and shipping delays for construction materials (Pennington 2021). There are three main reasons New Zealand developers suffer more from the material shortage and delays. First, our local supply cannot meet the increasing demands of our local construction projects.

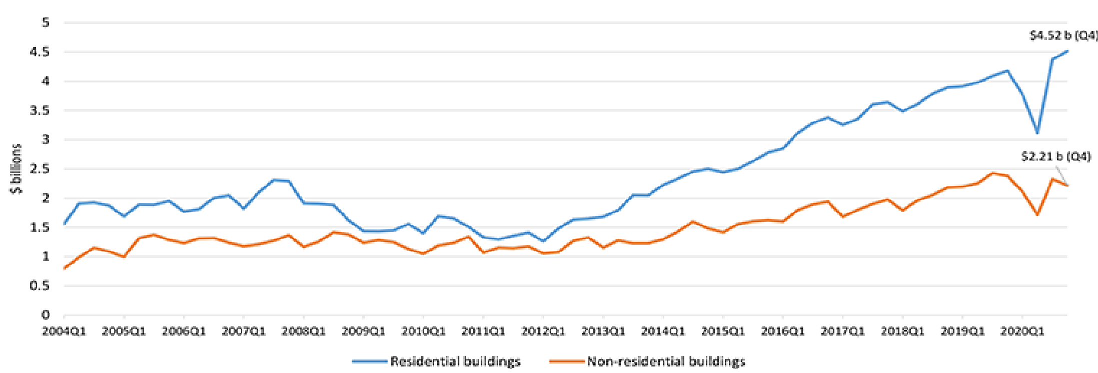


Figure 3 Quarterly value of building work put in place (March 2004 to December 2020)

(Ministry of Business 2021)

As shown in figure 3 from the New Zealand Ministry of Business, Innovation & Employment (MBIE), the quarterly value of building work for residential and non-residential has gone up significantly. Especially for the residential category, the quarterly value of building work has gone from around NZD 1.5 billion in 2011 to around NZD 4.5 billion in 2021. Within the ten years, the residential building work value has almost tripled, indicating the need for raw materials would also be bumped up the same way. According to the MBIE from a Stats NZ's Business Operation Survey in 2020, 56 per cent of construction businesses experienced production disruption from New Zealand domestic suppliers (Ministry of Business 2021). The production rate to meet up with the boosting demand for building materials is lacking, but the local delivery is also unable to meet the desired speed. According to MBIE, in 2020, 63 per cent of construction businesses experienced delivery disruption from a domestic supplier. Another reason for the material shortage and delays being more severe than the rest of the world is our geographical disadvantage of being far away for many materials suppliers. Thirty-eight per cent of New Zealand local construction businesses reported that they had experienced delivery disruption from international raw material suppliers. (Ministry of Business 2021, Pennington 2021)

While the delays in getting products are causing difficulties for builders to manage on-site workflows, the increase in procurement cost has also resulted in the increased price of completed houses for Kiwis (Pennington 2021).

Therefore, a research gap has been shown that with the current New Zealand construction industry, work needs to be done to improve the situation and release the sector from the material shortage and delay burden.

2.2.4 Environmental impacts on the construction industry

Meanwhile, reducing greenhouse gas emissions is arguably the most critical environmental issue facing the global community in the modern world. With 50 per cent of raw materials coming from the soil, the construction industry consumes half of our primary resources. The construction and operation of buildings and other constructed assets account for 35 per cent of the world's energy demand and 38 per cent of the glasshouse gas emissions(Fuller and Crawford 2011). In New Zealand, buildings and their construction account for as much as 20 per cent of our emissions(NZGBC 2022). Hence, a crucial aspect here is reducing the number of resources needed in the construction industry, including everything from buildings to infrastructure. At the same time, size, style, and location are the three principal factors that determine the residential sector's emissions (Fuller and Crawford 2011, Beetz 2021). However, materials with high embedded greenhouse gas emissions, such as cement, concrete, and steel, also account for a significant portion of national material demand. Their performance is more aligned with modern construction requirements (Soonsawad, Martinez et al. 2022). The materials and energy needed to create, operate, and replace the necessary infrastructure to support a growing population will put additional strain on the environment and make climate change mitigation and adaptation efforts more difficult (Fuller and Crawford 2011). Meanwhile, from an economic perspective, the construction industry is one of the most fragmented, decentralized, and diverse, employing about 3 million people in around 800,000 businesses. (Beetz 2021).

In both New Zealand and Australia, efforts such as the Green Star criteria update in 2020 have been made to reduce greenhouse gas emissions from building activities (Soonsawad, Martinez et al. 2022). Greenstar was created by Green Building Council Australia and adapted for New Zealand. Australasia's largest voluntary and truly holistic sustainability rating system for buildings, fit-outs and communities. Their ratings are available for every commercial building type, from hospitals, and schools, to office buildings, shopping centres, and industrial warehouses. Residential houses are covered by their Homestar ratings. Green Star assesses the critical elements of a project's sustainability across key categories. Each category includes a benchmark for a lower-carbon, healthy project. Points will then be awarded for successfully meeting these criteria. The total number of accredited points decides the building’s/house’s final Green Star rating. Buildings with a high Green Star rating are more valuable from a financial perspective for sale or rent and more sustainable environmentally, motivating the developers to aim for higher Green Star ratings in New Zealand and Australia (NZGBC 2022). Green Building rating tools used in the EU and China Green Building Council’s Three Star rating tool used in China and LEED

(Leadership in Energy and Environmental Design) used in US and Canada are similar rating systems used in other countries.

However, initiatives to reduce the environmental impact of construction materials have been scarce, and more environmentally friendly construction technologies are required to meet the emission reduction targets (Soonsawad, Martinez et al., 2022). The potential to save energy and contribute to a decrease in the sector's carbon footprint can be viewed from different perspectives: the synergetic effects of enhancing vertical and horizontal integration of construction processes and material re-use and circular economy (Beetz 2021, Soonsawad, Martinez et al. 2022)

Therefore, it is critical that the construction industry start acting now to make more sustainable construction decisions.

Material passport and circular economy

While New Zealand is experiencing a construction raw material shortage causing delays, construction waste is also a critical issue (Domingo and Batty 2021). As the construction industry is currently responsible for up to 50% of landfill waste in New Zealand, New Zealand is ranked at the higher end of the scale internationally, providing the industry is an obvious target for change. A survey conducted by the Ministry for the Environment ranked waste as one of the three most pressing challenges facing NZ during the next 20 years. (Domingo and Batty 2021). The wide range of trades and sub-domains in the construction industry and the diversity of its products, which range from residential buildings to tunnels and bridges, results in a large amount of data being transferred in transient processes without making any use of the data. At the same time, the construction industry as a whole is lagging in terms of productivity and digitalization (Beetz 2021).

While the improvement of the design validation process may play an essential role in construction management(Domingo and Batty 2021), with the increasing environmental impact of construction waste and shortage in raw material, the potential of a circular economy has been raised (Gepts, Meex et al. 2019)

When comparing the repairment of an old building with constructing a new one, the study suggested that demolishing a well-performing building made no sense in terms of life cycle performance. In contrast, in the case of poor-performing buildings, replacement by an efficient new design might be the better solution. (Schwartz, Raslan et al. 2022). The main reason for this difference is associated with the embodied greenhouse gas emissions due to the replacement of existing materials that need to be transported to landfills and the embodied greenhouse gas emission required for the actual construction. This embodied greenhouse gas is significantly lower in refurbishments, as building foundations and structures e highly greenhouse gas-intensive elements need to be procured in a replacement scenario. (Schwartz, Raslan et al. 2022)

While construction is one of the most significant greenhouse gas emitters, due to the enormous number of carbon-intensive materials used in constructed infrastructure, it will take great effort to improve its environmental and climate performance. However, in the spirit of developing a more circular economy of the built environment, this might be achieved by more flexible use of existing buildings, increases in overall construction lifetime, increasing use of recycled materials, the substitution of emission-intensive materials with low-carbon and renewable resources, and increased use of renewable energy during construction material extraction and processing could all assist in lowering the built environment's greenhouse gas footprint (Giesekam, Barrett et al. 2016). Also, developing technologies that provide spatially explicit information about the present and future building material demand and encouraging the interchange of information about low carbon materials and best practices will enable a reduction in greenhouse gas emissions from the construction sector (Soonsawad, Martinez et al. 2022). Also, because of the better control and environmental evaluation that can be carried out on these items from their manufacture until the end of their useful life, using prefabricated and industrialized products and systems can help to limit their environmentally detrimental impacts (Ramos-Carranza, Añón-Abajas et al. 2021). Moreover, policies that encourage building reuse, repair, and refurbishment and an emphasis on green sourcing of building materials and the improvement of secondary material markets can all help create a circular economy of built infrastructure. (Milios 2018, Soonsawad, Martinez et al. 2022). Potential adoption barriers, such as perceptions of high cost, low availability of products, industrial culture, and unclear division of responsibilities for environmental impacts, should be factored into strategies to encourage the use of alternative construction materials. Some of these obstacles could be overcome by the early involvement of relevant stakeholders and the establishment of precise and reliable embodied carbon benchmark data in construction materials. (Giesekam, Barrett et al. 2016, Soonsawad, Martinez et al. 2022)

To this end, several studies have looked at building material stocks and demand at various spatiotemporal scales.

Table 1 Study on building material stocks

Model	Use	Article	Reference
Regression model	Estimate floor space for eight residential and service building types and a global building material database to calculate the total demand and potential to recycle construction material by 2050.	Modelling global material stocks and flows for residential and service sector buildings towards 2050.	(Deetman, Marinova et al. 2020)
Material Input Stock and Output model	Estimate the amount of 11 types of building materials used to build up or renew in-use buildings from 1900 to 2010.	Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use	(Krausmann, Wiedenhofer et al. 2017)
Dynamic material stock and flows model	Model growth, demolition, and maintenance rates of buildings to estimate changes in non-metallic minerals use in 72 residential building types from 2004 to 2009 in the European Union. This model was used to project material demand, waste, and recycling flows to 2020.	Maintenance and Expansion: Modeling Material Stocks and Flows for Residential Buildings and Transportation Networks in the EU25.	(Wiedenhofer, Steinberger et al. 2015)
Top-down material stocks model	Based on historical material flow data to estimate national changes in material stocks. The model investigated per capita material stock changes and material efficiency and saturation in Japan and the United States. Also used in China to project steel and cement demand and CO2 emission	Accounting for the Material Stock of Nations	(Fishman, Schandl et al. 2014)
LCA model	BIM and LCA integration. Enables quick data extraction on building's environmental impact.	A BIM-based LCA tool for sustainable building design	(Kamari, Kotula et al. 2022)

		during the early design stage	
Material input stock model	CO_2NSTRUCT provides values embodied greenhouse gas and energy for some construction materials. Embodied energy is supplied as a total divided into energy from non-renewable and renewable sources.	CO_2NSTRUCT	BRANZ
Hera carbon calculator	Contains valuable information about carbon emissions for steel elements but do not include other building elements.	HERA's steel product carbon offset program – Hōtaka Whakakore Puhanga Waro (mo te Hua Rino)	HERA

By studying the above models, a research gap has been presented. While the current models did present benefits to keeping track of the material stock and the environmental impact, it is either complicated to use or too specific to certain houses it studies. A more general, user-friendly calculator for New Zealand designers to use for supporting material used decisions in early design stages is needed.

2.3 Identified research gaps

1. Case studies comparing similar residential houses constructed with different construction methods from technical experts in the industry to provide a more insightful overview needs to be conducted.
2. Demonstration of how BIM can handle the integration of diverse professional models, actualise cross-departmental collaboration, accelerate information flow across all building stages, and demonstrate its potential to improve data connectivity.
3. Investigate technology that can improve the current situation and release the construction industry from the material shortage and delay the burden
4. A more general, user-friendly environmental impact calculator for New Zealand construction industry players to use for supporting material used decisions in early design stages.

3. Methodology and its implementation

3.1 General methodology development

This research project aims to look at how new technologies like BIM can benefit the New Zealand residential housing sector by increasing data connectivity and identify the potential methodology to release the burden of our critical housing shortage challenge and reduce environmental impact. Therefore, while the research gaps have been identified in previous Literature Review session, a development methodology has been designed to mainly focus on demonstrating the practical use of Building Information Management (BIM) software in the residential housing sector of the New Zealand construction industry as well as providing a case study where prefabricated construction technology is used.

The primary approach encourages the construction industry to increase productivity by combining technologies, human capital skills, and procedures to create more value with little new capital or staffing overall. It's about how the industry alters procedures and employs new technologies to improve data connectivity and increase productivity.

Productivity benefits can spread across industries and produce network effects when a common standard is implemented. By addressing information asymmetry and encouraging innovation and competition, common standards also help to prevent market failure. Therefore, the general approach here is to improve data connectivity by utilizing BIM data in various stages of a complete construction cycle to demonstrate the benefits of using a common data format throughout the construction cycle.

The methodology can be split into different steps to enhance the overall construction process.

Firstly, as a research gap of case studies comparing similar residential houses constructed with different construction methods from technical experts in the industry to provide a more insightful overview has been identified, residential developers within the New Zealand construction market should be approached. Ideally, technical experts within the company should be invited for interviews and interview questions should be designed prior to the interview. For a comprehensive comparison between traditional construction and prefabricated construction, a case study should be designed so more quantifiable results can be obtained from the invited technical experts. Hence, a more insightful overview of the construction industry in New Zealand can be observed.

Secondly is to improve the decision-making process of material used in the first phase of the construction lifecycle - the design phase.

A commitment to use resources is what a decision is defined. Human beings engage in one of the most basic yet complex psychological processes: decision-making. Formulating an exact description for decision making can be challenging because people are responsible for a wide range of duties and make a wide range of decisions every day. A decision, according to Jonassen, is an ill-structured problem in which one must weigh many options before choosing one (Jonassen 2012).

Therefore, the first step in enhancing the decision-making process is to present as much information as possible for each design option by improving the data connectivity. The architects can then weigh them against one another.

In my research project, a research gap has been identified: a more general, user-friendly environmental impact calculator for players in the New Zealand construction industry to use for supporting material used decisions in early design stages.

In order for the architects to do so, a comprehensive database of materials should be chosen, which architects can refer to while selecting materials. Meanwhile, an automating process tool should also be developed to display the environmental impact of architects' chosen design. While this tool/protocol aims to calculate and display the environmental impact embodied in different construction materials, it is also critical that the generated information from inputted designs will not be easily accessible to other users. Therefore, to avoid having a general tool or product developed and shared with the public and the other users, a standard protocol that can transfer the developed tool to the user's individual database is proposed as a requirement of the developed product.

To develop an environmental impact calculation tool, a general platform that is easily accessible for everyone to transfer the developed tool to the user's individual database needs to be found. Meanwhile, the goal of this development is to turn technical data into a working prototype that exhibits the solution. A tangible, functional prototype needs to be developed as the product. Because nothing works the first time perfectly, the step of the development process is more iterative than the others. It is made up of the iterative cycle, which includes design, testing, debugging, and redesign. The cycle should repeat until a developed product that can be used and duplicated by users into their own database is developed.

Therefore, the critical process of developing the tool/protocol to support material selection process decision making includes the following, as shown in figure 4.

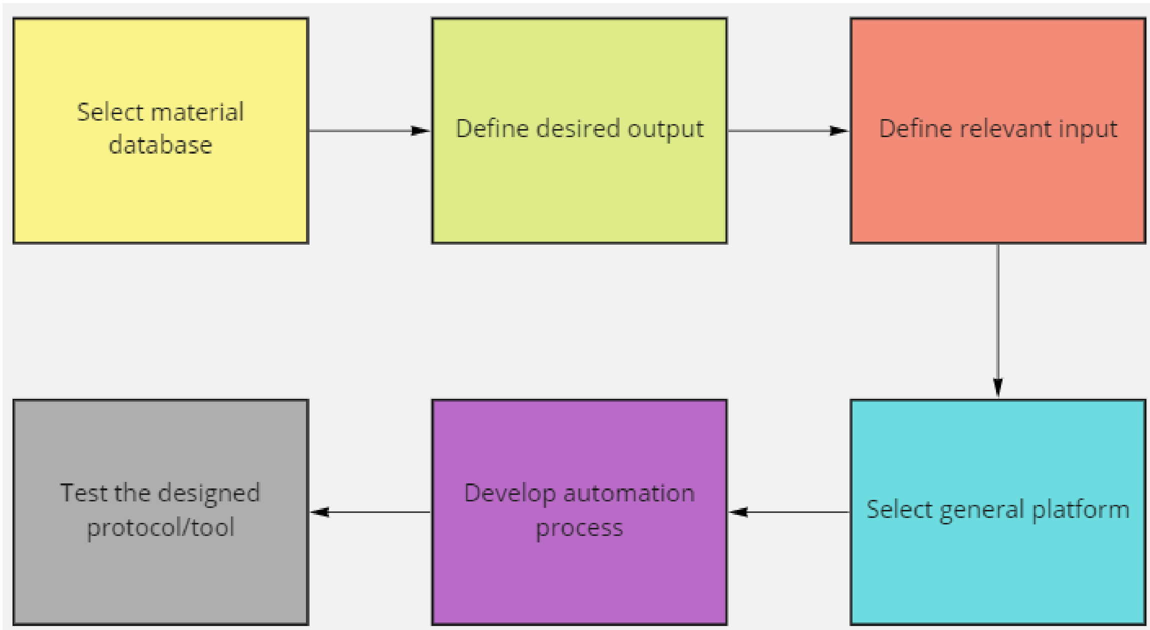


Figure 4 Process of developing an environmental impact calculator protocol

1. A comprehensive database of materials should be chosen that architects can refer to while selecting materials
2. Define the desired output relevant to the decision-making process, i.e., Embodied CO2 for materials, Embodied Energy of materials etc.
3. Define relevant data to input into the tool, i.e., Material type, quantities, appropriate measurements
4. Select a general platform where the tool can be developed. The protocol to develop the tool can easily be replicated and easily transferred to users' individual databases to provide better information security.
5. Developed the automation process for the tool to process input and generate the desired output
6. Test the design protocol and ensure its viability and feasibility for users.

Thirdly, the general improvement of the construction process is the development of a tool to reduce environmental impact while releasing the burden of material shortage. This lies in the design stage preferably as well. However, this tool's benefits will ideally be throughout the construction cycle, mainly at the end of the construction cycle.

Engineers/architects have always been taught to utilize optimization processes to reduce material usage, improve the efficiency of specified systems, and, as a result, reduce the negative environmental impacts. A new technique known as 'healthy sustainability' has recently arisen, with the goal of having positive rather than negative environmental impacts. A structure whose elements can be reused in the same or other project or product at any moment during its operational service or at the end of its life is an example of implementing a healthy sustainability strategy. Reusing structural elements not only has the ability to cut embodied energy by a significant amount, but it also tackles resource constraints and provides a cost-effective option for construction value chains, governments, and end-user advantages.

In order to do so, the concept of generating the material passport that has been discussed in the Literature review session is proposed. A standardized material passport protocol for the New Zealand construction industry should be developed to improve the data connectivity within the industry. The material passport is a digital report containing circular economy relevant data that is entered into and extracted from a centralized database in the form of reports customized to the needs of diverse users. A large amount of detailed data requires digital solutions to collect, process, store and utilize information. This tool enables recycling, reuse and recovery of waste construction materials as well as contains practical solutions that help reduce greenhouse gas emissions.

Therefore, a centralized database should be first developed or found if available, and the developed tool shall also not be easily accessible to other users. Hence, instead of having a general tool or product developed and shared with other users, a standard protocol to easily transfer the developed tool to the user's individual database is also proposed as a requirement of the developed product.

The designed tool from the developed protocol needs to provide reliable and standardized information on material flow and material compositions. The availability of material composition is a core aspect of a functioning circular economy. The information should be able to be updated when changes are made to the building or its components.

To develop a standardized material passport database for a house/building, a general platform that is easily accessible for everyone to transfer the developed tool to the user's individual database needs to be found. Meanwhile, the goal of this development is to turn technical data into a working prototype that exhibits the solution. A tangible, functional prototype needs to be developed as the product. Because nothing works the first time perfectly, the step of the development process is more iterative than the others. It is made up of the iterative cycle, which includes design, testing, debugging, and redesign. The cycle should repeat until a developed product that can be used and duplicated by users into their own database is developed.

Therefore, the critical process for developing a standardized material passport database for a house/building is shown in figure 5.

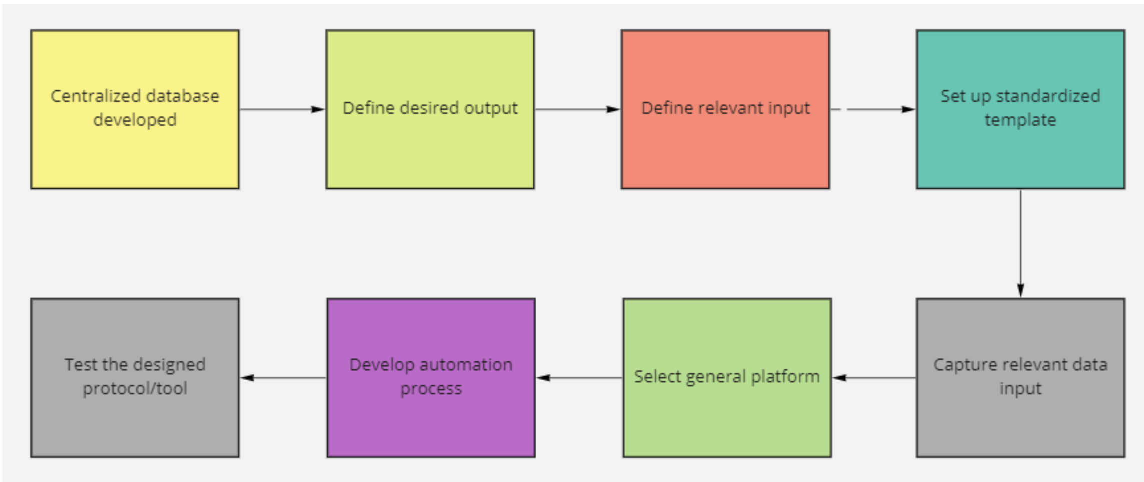


Figure 5 Process of developing a standardized material passport database

1. A centralized database should be first developed or found if available
2. Defined the desired output, i.e. QR codes/ links representing generated material passports for each material to be used in the construction process.
3. Define relevant input, i.e., Manufacturing data, pricing data etc.
4. Set up a standardized template to ensure consistency and readability.
5. Capture relevant data input, the designed tool from the developed protocol should include a standardized methodology to capture relevant input data for the material passport
6. Select a general platform where the tool from the developed protocol to be developed can easily be replicated and can be easily transferred to users' individual databases to provide better information security.
7. Developed the automation process for the tool to process input and generate the desired output
8. Test the design protocol and ensure its viability and feasibility for users.

Lastly, to investigate how BIM can improve data connectivity and handle the integration of diverse professional models, actualize cross-departmental collaboration, and accelerate information flow across all building stages. An overall demonstration of using data extracted from BIM needs to be implemented. BIM's worth can then be demonstrated, and the construction industry's digital transition can be accelerated by completely integrating BIM with intelligent construction. Architects, engineers, and contractors now may view their 3D models anywhere with cloud-based BIM. By storing BIM data in the cloud, stakeholders may upload and access the most recent version of their models, allowing them to collaborate from a single point of truth which significantly improves data connectivity within the construction industry.

While many available Cloud BIM platforms enable the above requirement, the implementation should make the comparison between different products and select a suitable one for a case study demonstration. While the above two steps also lie in the construction cycle of residential houses, to complete the circle of the development methodology for my research, it is also critical to involve the tools/protocol designed earlier in this final phase where a viable demonstration can be implemented.

3.2 Methodology implementation

3.2.1 Prefabricated construction method case study

While a research gap has been identified that case studies comparing similar residential houses constructed with different construction methods from technical expertise in the industry to provide a more insightful overview of the current New Zealand construction industry, several companies were approached, and only a few have responded.

3.1.1.1 Case study and interview with CLOT Homes

Company background

CLOT Homes was founded in 2007 and reformed in 2020. It is a subsidiary firm under LEFON Group and has 13 years of building construction experience. It is a current member of the New Zealand Master builder association. Their business expertise includes Design Build, project management, main contracting, and House land packages.

Interview

The interviewee is the site manager of CLOT home, managing three residential projects with over 100 house subdivisions and 43 houses under construction. Interview was conducted on the 19th July 2021 online, interview questions were designed prior to the interview and were mainly for gaining a more realistic understanding of the current construction method used by the New Zealand building industry.

Key points discussed during the interview can be summarized as follows:

- The pandemic highlighted the weaknesses of global supply systems in the second half of 2020. As global manufacturing began and supplies recovered, supply issues were expected to stabilize in 2021. However, supply constraints caused by the pandemic continue to affect crucial resources such as lumber, paint & coatings, aluminium, steel, and cement, among others. While New Zealand is located relatively far away from the prominent manufacturer and the building material supplies depend intensely on importing, the material shortage is a primary challenge for the New Zealand industry. Meanwhile, in his opinion, the economic crisis caused by the pandemic reminds New Zealanders of the importance of owning assets, and people want to purchase their homes instead of renting more than ever, especially with the low house loan interest offered by the New Zealand bank, the housing demand in New Zealand are current sitting high. It has been suggested that major cities like

Auckland will likely have higher density housing (smaller land hence lower land cost) to reduce the overall house price. However, as material prices are boosting up and supply delays become more and more common in New Zealand, many developers are unable to survive in the industry due to the unexpected long investment turnover period while the house price is boosting up. Hence, the material shortage problem is a crucial challenge needed to be solved to reduce the construction industry burden.

- BIM technology is not being used in the traditional construction method, which is used by the majority of the residential housing developers in New Zealand. While New Zealand houses are relatively simple in structural design and are mainly simple one-story, two-story, and maximum three-story wood framing houses, architects generally produce 2D drawings for the construction team. However, framing materials can now be ordered as pre-cut, reducing the expected material waste. Also, since with residential houses, the layout of HVAC, drainage and other services generally do not need to be coordinated during the design stage as there is enough room for all services designed to fit in residential houses in New Zealand, he suggests that the developers do not feel the need to implement BIM and pay for its expensive fees and the extra training/hiring for the team. However, he admitted that he also believes that New Zealand's traditional construction method is outdated and needs a change. He suggested that it will need to be when the construction industry sees the economic benefits of implementing new technology then the technology will be better adopted by the industry.

- Environmental impact from the construction industry concerns the developers. However, their priority remains economic benefit over environmental concerns as they are already carrying enough burden with the long investment turnover period.

- The current New Zealand construction industry has already progressed from building everything on site traditionally to having a small portion of the building material "prefabricated". Currently, for the majority of the developers, they have chosen to partner with a pre-cut timber framing manufacturer to have house framing pre-made and sent to the site for assembly, which is at the beginning of the component-based prefabricated level prefabrication.

3.1.1.2 Case study and interview with Bauing Group

Company background

Shenzhen Bauing Construction Group Co., Ltd. ("the Company"), a subsidiary of Shenzhen Bauing Construction Holding Group Co., Ltd. ("the Group"), was incorporated in April 1994 with a registered capital of RMB680 million. The Bauing Group is one of the most qualified companies in China's construction and design industry. Interior design, curtain wall and steel structure engineering, integrated artificial intelligence engineering, fire control building engineering, electromechanical installation, security solutions, metal window and door installation, conference construction, and medical devices are among the services it offers; it also provides integrated design, construction, and installation, as well as management services to its clients.

The company is China's largest integrated design firm. It has been nominated for Top 10 of China's 100 Enterprises in construction and design and China's 100 Developing Enterprises in Construction. The group's business network encompasses mainland China as well as the globe. The group is present in all the five regions of China, focusing on public culture projects, sports site construction, luxury hotel construction, transportation stations construction, hospital design and decoration, and luxury residence decoration. The group also has a business presence in more than 20 countries and regions, including Europe, Southeastern Asia, Mid-Asia, West Africa, Australia and New Zealand.

Interview

The interview was held with the New Zealand office, initiated in 2019. The New Zealand office mainly focuses on delivering residential housing design and construction work and the newly developed Prefabricated modular construction housing services.

The interviewee is the Modular project manager of Bauing Group New Zealand office. He is now expanding their New Zealand market for modular residential house construction. Interview was conducted on the 2nd of August 2021.

Key points discussed during the interview can be summarized as follows:

- Bauing New Zealand remain positive on the modular technology will slowly expand in New Zealand construction industry as it solved many of the challenges faced by the traditional construction method that the industry is currently using, such as extensive construction period, being weather dependent, high labour cost and unnecessary construction material waste. However, challenges remain as people still have a strong bias thinking modular houses are cheap and of poor quality. However, this is not true as the quality of modular homes has moved miles in recent years, the design and material used currently are incredible, and the modular houses are also built to government building codes. They are relatively cheaper and quicker than the traditionally constructed houses because they are built/manufactured in a controlled environment and a factory process with less unnecessary waste on both labour and material. Meanwhile, as government regulations and insurance policies on modular houses are still not as mature as the regulation on traditionally built houses, homebuyers are expected to remain in doubt about this new technology. However, these challenges will slowly be resolved with time, and the New Zealand construction industry can better realize the benefits of modular construction.

- BIM technology is being used by Bauing, New Zealand, as they have developed their own piece of software to use with BIM to design modular homes. As shown in Figures 6,7, and 8, their software enables the designers to transfer an architectural BIM model into a modular design model for manufacturing and building. However, he suggested that with some smaller modular housing developers, as their modular designs are limited and relatively similar, their design methods remain 2D, and BIM technology is currently not fully utilized by the modular construction industry in New Zealand.

Figure 6 Architecture design of a residential house

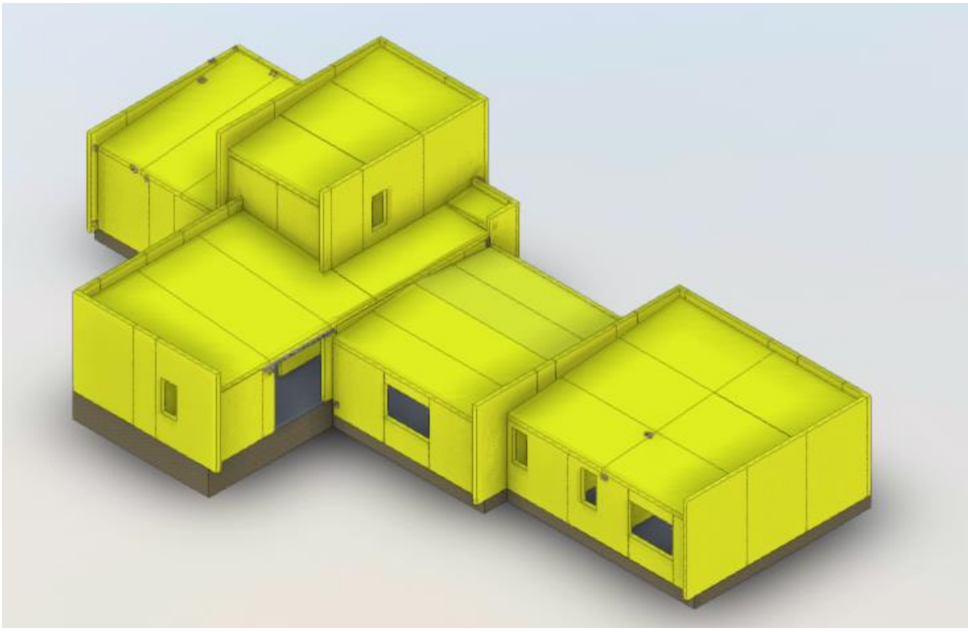


Figure 7 Transferred modular design

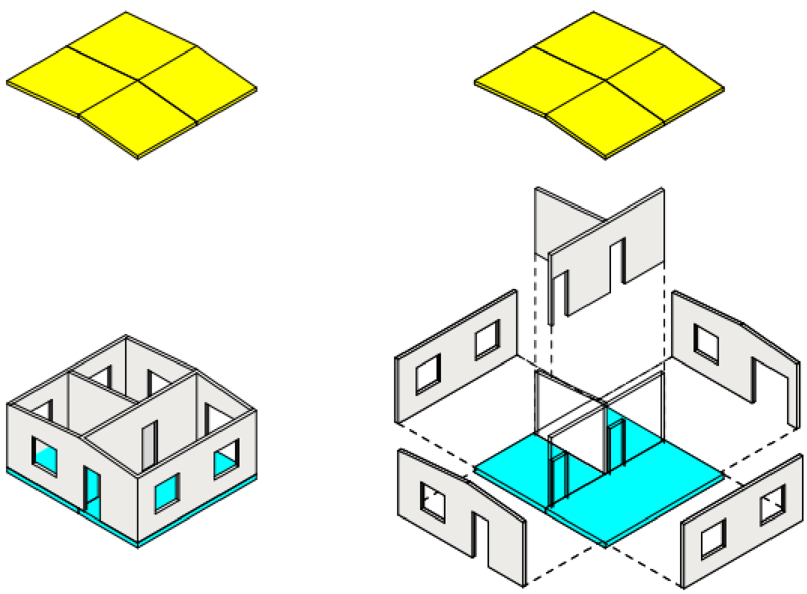


Figure 8 Modular design concepts

3.1.1.3 Construction time & cost comparison from case studies

Cost comparison

After showing the CLOT Homes site manager the BIM model of a two-story residential house so that he has a visualization, he suggested that the construction price for a residential house like in figure 9 will be around NZD$3000+gst per m2.

Figure 9 Two-story residential house BIM model

After visualization of the BIM model, the modular project manager suggested that the cost for building a model shown in figure 9 as a modular home will be around NZD$2500 per m2 and transportation NZD$50,000 from the oversea manufacturing factory to New Zealand as they found it is cheaper to manufacture overseas and transport the modular to New Zealand for installation.

Hence, a cost summary table can be found in table 2. (Both cost and time provided are based on the information given by the interviewees on 19th July and 2nd August 2021 and may no longer be valid now)

Table 2 Cost summary table

	Traditional construction	Pre-fabricated construction		
	$3000+gst	$2500		Area(m2)
Cost per m2	$ 3,450.00	$ 2,500.00		279
Total construction cost	$ 962,550.00	$ 697,500.00		
Transportation cost	N/A	$ 50,000.00		
Total cost	$ 962,550.00	$ 747,500.00		
Cost comparison		77.66%		

As a result, while the land cost will be the same, having the house constructed using the prefabricated technology based on the price two industry experts provided is only 77.66% of having it built using the traditional construction method.

Timeline comparison

After examining the BIM model of an ordinary two-story residential house shown in figure 9, the site manager from CLOT Homes has provided a guided timeline to construct the house using the traditional construction method, as shown in table 3. In contrast, the Modular project manager from Bauing group, New Zealand, has provided a guided timeline to construct the house using the modular construction method, as shown in table 4.

Meanwhile, according to the information provided by CLOT Homes and Bauing Group New Zealand, a comparison timeline can be shown in figure 10 and 11.

While using the prefabricated construction method theoretically should take 106 days to construct, the modules can be manufactured off-site, which can be in parallel with the earthwork construction on-site. Hence, it again reduced the construction period of a prefabricated construction house to only 81 days.

As can be seen from the timeline comparison, the difference in construction time between the traditional construction method and the prefabricated construction method is significant.

Table 3 Suggesting timeline for traditional construction method

Name	Duration
Excavation and earthwork	5 days
Private drainage and Underslab plumbing	5 days
Foundation	15 days
Ground floor framing	3 days
Steel beams	2 days
Scaffolding	2 days
Joist	5 days
Midfloor	3 days
First-floor framing	5 days
Safety nets	1 day
Truss	3 days
Fascia and gutter	2 days
Roofing	5 days
Building paper	2 days
Aluminium Joinery	5 days
Stairs	1 day
Wall underlay and cavity batten	10 days
Penetration	2 days
Cladding (Brick veneer & weatherboard)	20 days

Exterior Painting	7 days
Downpipe	1 day
Scaffolding Dismantle	2 days
Preline	3 days
Interior door	2 days
Insulation	1 days
Interior wall	5 days
All in one	2 days
Interior plastering	10 days
Painting	7 days
Waterproofing	7 days
Tilling	5 days
Kitchen and Wardrobe	4 days
Lighting	2 days
Plumbing	3 days
Skirting	1 day
Carpet	1 day
Driveway	7 days
Garden deck fence paving	10 days
Pergola	2 days
TOTAL	**178 days**

Table 4 Suggested timeline for modular construction

Name	**Duration**
Excavation and earthwork	5 days
Private Drainage and Under-slab Plumbing	5 days
Foundation	15 days
Building Modulars off-site (Parallel)	~~21 days~~
Transport to the site (Parallel)	~~4 days~~
Installing Modules	30 days
Lighting	2 days
Plumbing	3 days
Skirting	1 days
Carpet	1 day
Driveway	7 days
Garden desk paving	10 days
Pergola	2 days
TOTAL	**81 days**

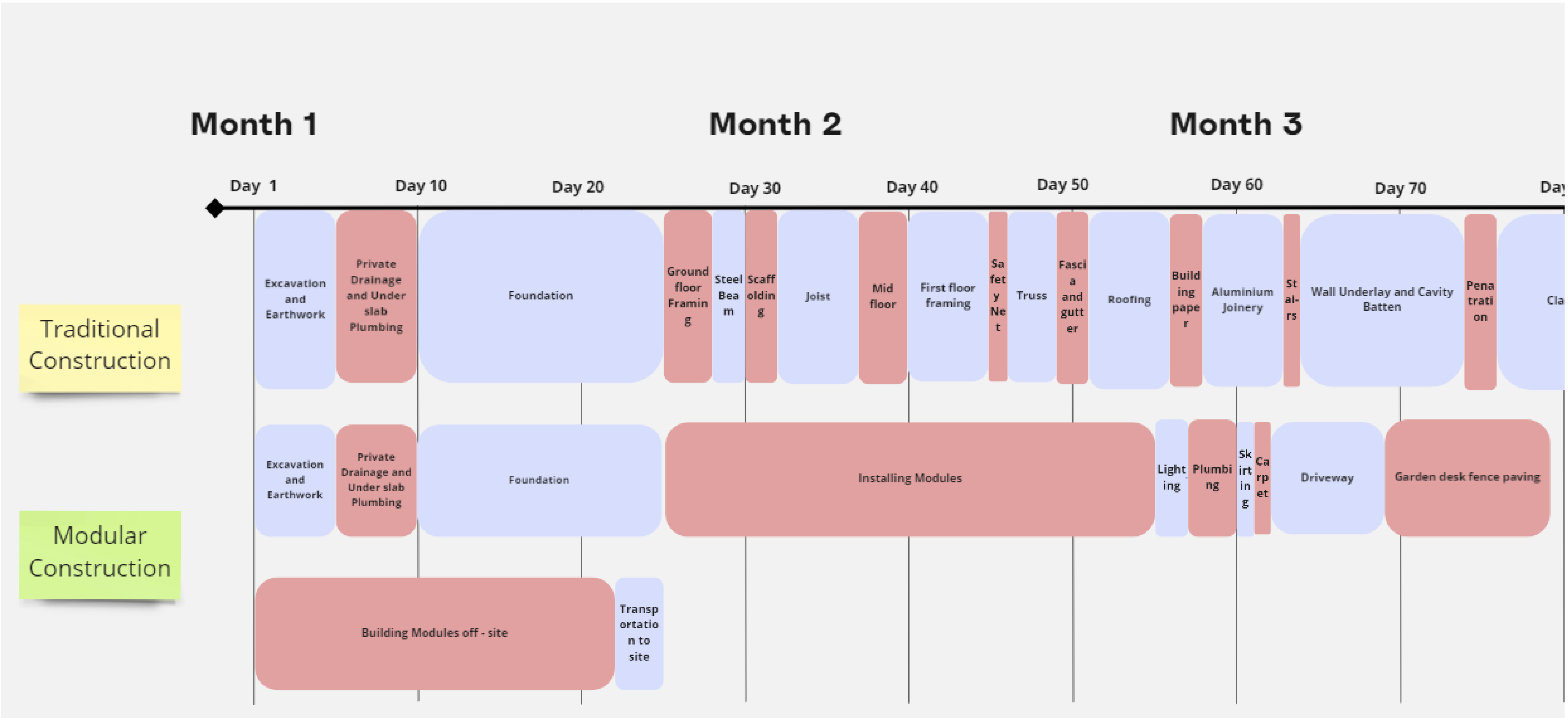


Figure 10 Comparison timeline

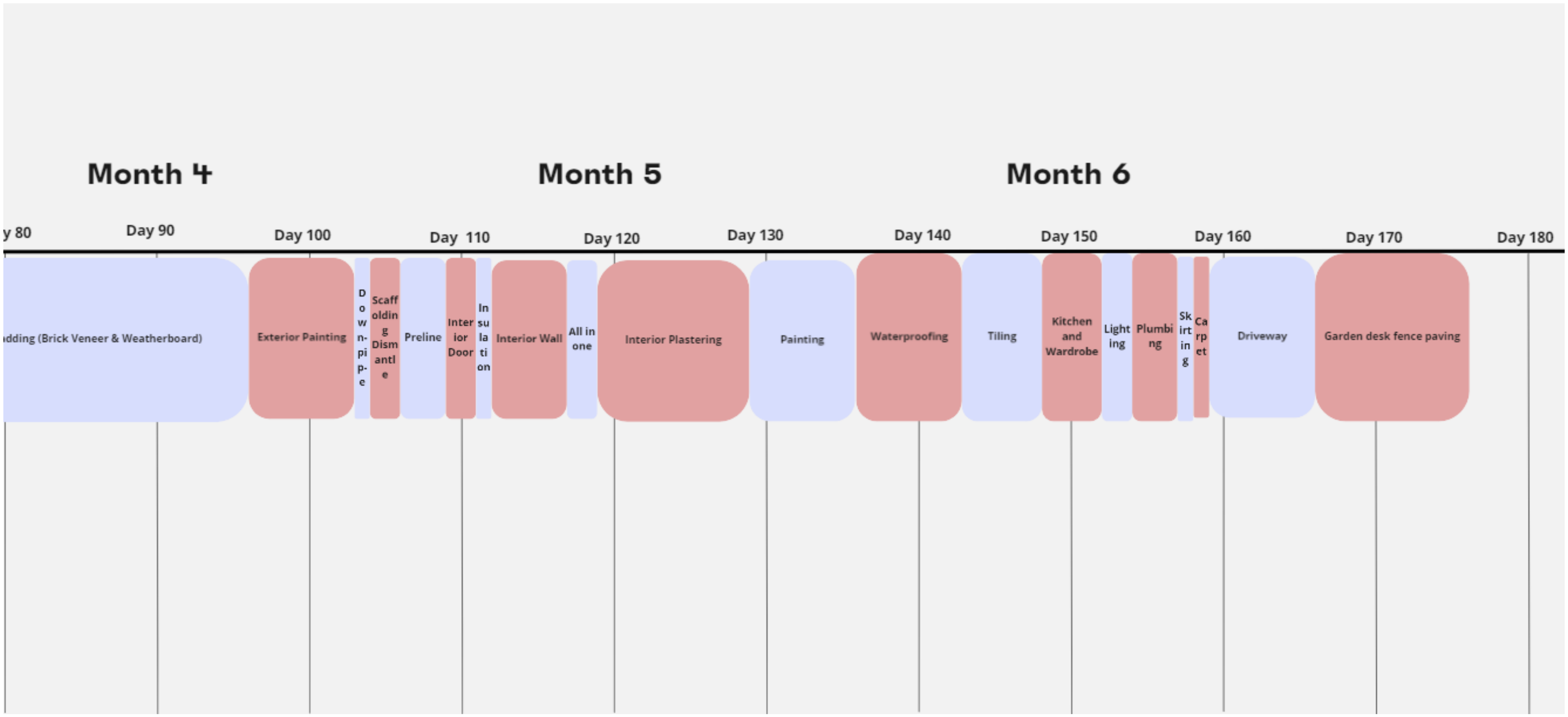


Figure 11 Comparison timeline continues

3.2.2 Environmental impact calculator

As identified in the Literature review section, there is a need to improve the environmental impact of the construction industry in New Zealand. The methodology section above suggested the development of an environmental impact calculator protocol that enables users to use it as an environmental impact calculator as well as to design a functional environmental impact calculator of their own following the developed protocol to ensure the confidentially of architectural designs. By implementing BIM technology to improve data connectivity which enables this tool, designers can now compare building materials used in designs and support them with better sustainability design decision making, which contributes to a greener environment.

The development process can be seen in the following sections.

3.2.2.1 Select material database

A comprehensive database of materials should be chosen that architects can refer to while selecting materials. While numerous material databases of environmental impact data are available, few of the most well-known ones have been selected to compare, as shown in table 5.

One of the databases for comparison is the well-known environmental impact for building materials database the UKComDat, similar to EUComDat (material database for European Union), ITComDat (material database for Italy), which are material databases for each region, it provides data sets to be utilized in building environmental performance assessments and follow international standards and norms. It was created in response to the necessity for buildings' environmental performance to be quantifiable. There is roughly 350 construction products' environmental impact information in the UKCoMDat database, extending much beyond embodied energy and carbon indicators. Concrete – Complementary British Standard to BS EN 206 contains many concrete datasets, with roughly 19 categories described by Concrete – Complementary British Standard to BS EN 206. UKCoMDat is the UK's first and only database covering a wide range of environmental indicators. It allows for the accurate computation of building life cycle assessments (LCAs) required by internationally recognized green building certification schemes such as LEED, BREEAM, DGNB, HQE, and others utilizing locally manufactured and/or sold construction materials. UKCoMDat comprises 24 environmental impact indicators at each stage of the product's life cycle, in addition to embodied energy and carbon. Foreign specialists have independently verified the vast majority of the data sets.

Table 5 Material database comparison

Database	Organization	Advantages	Disadvantages
UKCoMDat	UK The Ecolabel Centre	• Includes around 350 building products in the database. Very comprehensive • Multiple environmental indicators • Been used for green building certification schemes such as LEED, BREEAM, DGNB, HQE	• Many materials in the database are produced in the UK, which will be less relevant to the New Zealand building industry • Some materials used in the New Zealand housing construction cannot be found in the database
mindful MATERIALS	Illinois Green & Building Green	• Been used for green building certification schemes such as LEED v4, WELL Building Standard • Cloud-based database • Material manufacture has been included in the database design process	• Some materials used in the New Zealand housing construction cannot be found in the database
CO_2NSTRUCT	BRANZ	• Multiple environmental indicators • New Zealand's local database consists of materials been used in the New Zealand building industry	• Less comprehensive as materials are categorized based on the Revit material database, branding information is not included.

However, as this material database aims to provide building material environmental impact data for the UK construction industry, even though it contains roughly 350 materials, many materials in the database are produced in the UK, which will be less relevant to the New Zealand building industry. Also, materials used in the New Zealand housing construction cannot be found in the database, which means the database is not ideal for this research.

The mindful MATERIALS database aggregates building material sustainability information while aiming to minimize redundant effort on the part of both manufacturers and designers. It acted as an agnostic product certification library while having manufacturers on board in the database design phase; mindful Materials enable manufacturers to showcase product transparency and optimization information and industry professionals to search for a multitude of relevant products. However, since some key market players in the New Zealand building materials manufacturing industry are not included in this database, environmental impact information for some materials used in the New Zealand construction industry cannot be found. Hence, the mindful MATERIAL database is not ideal for this research.

As discussed above, it became clear that a local material environmental dataset is ideal for this research as it will be more specific to the New Zealand construction industry. A database that is backed by a reliable and trustworthy organization is needed. Building Research Association of New Zealand which is commonly known as BRANZ, is a well know non-profit research organization dedicated to enhancing the performance of the New Zealand building system with an objective, evidence-based approach. They turn intelligent research into reliable, accessible, and practical knowledge for other researchers. BRANZ constantly partners with other research organizations and conducts studies to better understand the issues affecting the building and construction industry in New Zealand. BRANZ always pushes the industry to think of new and better ways to put their study discoveries into practical and usable knowledge.

When BRANZ commissions research, it has been demanded that it concentrate on how it will benefit people across the building industry in New Zealand. Their goal is to urge the industry to keep New Zealand communities' ever-changing requirements at the forefront of their decision-making. Among the companies and organizations in the structural systems in New Zealand, BRANZ plays a unique leadership role. They encourage difficult dialogues and collaborate with system actors to address the building system's potential pitfalls. They work together to find answers to issues including homelessness, housing shortages, mental health, and climate change. Hence, the information and values provided by their database are relatively trustworthy, reliable, and more specific to the New Zealand construction industry. The CO_2NSTRUCT database BRANZ provided for all users contains environmental data, including the embodied carbon and energy values for building materials. Even though it is less comprehensive than the other two databases, as materials are categorized based on the Revit material database, branding information is not included. Still, it meets the requirement of this research by enabling embodied carbon and energy values for building materials to be calculated based on material type, resulting in the CO_2NSTRUCT database being selected as the final database to support the development of the environmental impact calculator.

3.2.2.2 Define desire output

Building materials manufacturing consumes a large amount of energy and produces many glasshouse gas (GHG) emissions, accounting for around a quarter of all human CO2 emissions. It generates significant amounts of waste both during manufacture and at the end of its useful life. More efficient material use could help achieve various environmental and economic benefits. Material efficiency comprises developing specialized techniques, financial models, consumer preferences, and legislative instruments that would significantly reduce the number of new materials needed to supply well-being. Despite the fact that many opportunities exist, material efficiency is not utilized to its full potential in real-life practices.

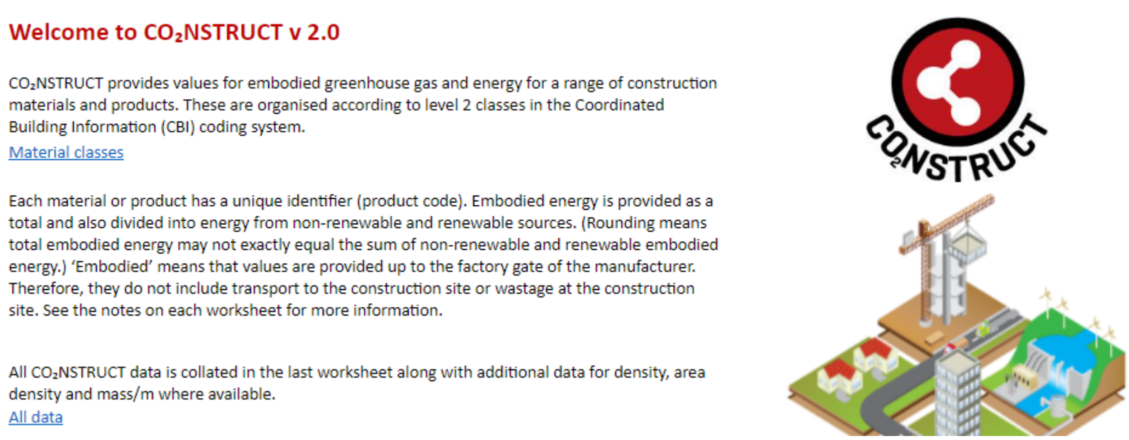


Figure 12 CO2NSTRUCT Database

The CO_2NSTRUCT database BRANZ shown in figure 12 provided for all users contains environmental data, including the embodied carbon and energy values for building materials, including concrete, glass, timber and metals, as well as products such as bathroom and kitchen fittings and lifts. Embodied carbon is the amount of greenhouse gases, expressed as carbon dioxide equivalents, required to produce a material. Embodied energy is the amount of energy consumed to extract, refine, process, transport and fabricate material or product (including buildings). This is provided as a total divided into energy from non-renewable and renewable sources. Renewable resources are energy sources that can be naturally replenish themselves overtime such as wind, solar trees etc., whereas non-renewable will be gone forever once used, such as coal and fuel (Nicolson and Nixon 2012). For this research, the amount of energy required to produce material and the greenhouse gas emissions are the two critical factors in determining the environmental impact of building material. These two factors can be found in the chosen CO2NSTRUCT database. These two factors will be the key output from the developed environmental impact calculator. At the same time, total embodied carbon and embodied energy for the whole house will also be included to give the user an overview of the entire design.

3.2.2.3 Define relevant input

To obtain desired output values for construction materials, the material code from Revit must be inputted to find embodied CO2 and energy values for a specific material. The material quantity, volume, and density will also be needed to calculate the embodied CO2 and energy. As all materials embodied carbon is calculated based on Kg CO2 equivalent per kg of material (each quantity), a simple equation, as shown in equation 1, can be applied to obtain the embodied CO2 equivalent for each specific item needed for a specific design.

Equation 1 Embodied CO2 eq per item

$$Embodied\ CO2\ eq\ per\ item\ \ (kg) = Volume\ (m3) \times Density\ \left(\frac{kg}{m3}\right) \times Embodied\ CO2\ eq$$

A similar approach can be taken for the calculation of the embodied energy, as shown in equation 2

Equation 2 Embodied Energy per item

$$Embodied\ Energy\ per\ item\ \ (MJ) = Volume\ (m3) \times Density\ \left(\frac{kg}{m3}\right) \times Embodied\ Energy$$

However, individually calculating embodied CO2 and energy per material/item can be time-consuming, and it is a repeatable task that should be reduced in the modern technology world. Using an excel sheet to automate the calculation using the above formulas will be less time consuming and more ideal for designers to use this tool to optimize their design decision making process instead of giving them extra time-consuming tasks like manually calculating embodied CO2 and energy for each material that use each time they alter their design. However, obtaining a list of materials used in a housing design is relatively complicated with 2D architecture design. Each item used will need to be manually entered into a list for further calculations.

However, while this research focuses on applying BIM technology in the construction process for residential houses to improve data connectivity, with the use of BIM, a material takes off list can be generated and exported as an excel spreadsheet for users to obtain all materials used for a specific architecture design. This again showcases how technology like BIM helps with information management of construction materials in the building process. It will be harder to obtain the desired information in the design with traditional construction methods.

Family	Family and Type	Material: LCAQuick Materia	Material: LCAQuick Material Name/Des	Material: LCAQuick	Count	Material: Area	Material: Volume
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_13_1	Insulation, polystyrene extruded (XPS)	Volume dependent	1	2.127593	0.171317
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_52_37_1_1	Plasterboard (GIB® standard 10 mm)	Volume dependent	1	2.16899	0.021982
Basic Wall	Basic Wall: Brick Cavity Wall	PR_20_93_52_15	Brick, clay	Volume dependent	1	3.092941	0.216506
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_51_89_1_3_5	Steel, primary (galvanised finish, coating	Area dependent, to	1	3.092941	0.278365
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_13_1	Insulation, polystyrene extruded (XPS)	Volume dependent	1	3.092941	0.247435
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_52_37_1_1	Plasterboard (GIB® standard 10 mm)	Volume dependent	1	3.092941	0.030929
Basic Wall	Basic Wall: Brick Cavity Wall	PR_20_93_52_15	Brick, clay	Volume dependent	1	4.793213	0.327638
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_51_89_1_3_5	Steel, primary (galvanised finish, coating	Area dependent, to	1	5.176799	0.453843
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_13_1	Insulation, polystyrene extruded (XPS)	Volume dependent	1	5.019877	0.391689
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_52_37_1_1	Plasterboard (GIB® standard 10 mm)	Volume dependent	1	5.194234	0.051289
Basic Wall	Basic Wall: Brick Cavity Wall	PR_20_93_52_15	Brick, clay	Volume dependent	1	6.762128	0.470406
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_51_89_1_3_5	Steel, primary (galvanised finish, coating	Area dependent, to	1	7.02637	0.627509
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_13_1	Insulation, polystyrene extruded (XPS)	Volume dependent	1	6.918271	0.549618
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_52_37_1_1	Plasterboard (GIB® standard 10 mm)	Volume dependent	1	7.038381	0.070324
Basic Wall	Basic Wall: Brick Cavity Wall	PR_20_93_52_15	Brick, clay	Volume dependent	1	1.777151	0.124401
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_51_89_1_3_5	Steel, primary (galvanised finish, coating	Area dependent, to	1	1.777151	0.159944
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_13_1	Insulation, polystyrene extruded (XPS)	Volume dependent	1	1.777151	0.142172
Basic Wall	Basic Wall: Brick Cavity Wall	PR_25_71_52_37_1_1	Plasterboard (GIB® standard 10 mm)	Volume dependent	1	1.777151	0.017772

Figure 13 Snip of BIM model Takesoff list

Therefore, with an export list of material taken off from BIM, all desired input can be imported to the calculation. Embodied CO2 eq and energy can be generated in the calculator.

3.2.2.4 Select general platform

To develop an environmental impact calculation tool/protocol, a general platform that is easily accessible for everyone to transfer the developed tool to the user's individual database needs to be found. As the complete item list from the architecture housing designs will need to be imported to the calculator, the goal is for this research to provide a guidance protocol for each user to use the designed product and also have the option to transfer this product to their own workspace so that the confidentially of the architecture design can be ensured.

Compared to other coding platforms, Google Workspace provides several developer products and tools that can integrate services with Google Workspace or expand Google Workspace programs like Gmail, Drive, and Chat. Each Workspace app or integration has its own Google Cloud project where APIs, authentication, and deployments are configured. Therefore, instead of having the environmental impact calculator developed as a web app or piece of software, an easily accessible calculator developed in the google workplace platform will be ideal as google is a commonly used platform and supports the calculation spreadsheet to be read performed relevant calculations. Users can easily access the developed environmental impact calculator to obtain environmental impact data as well as transfer this tool to their own google workplace following the designed protocol.

3.2.2.5 Develop automation process

While by export the material takes off the list and performing the calculation on an excel spreadsheet calculator using the CO2NSTRUCT database values enables a relatively straightforward calculation of embodied CO2 and energy for a housing design which helps with the material selection decision making process for architects, it still requires a large number of manual tasks such as downloads the CO2NSTRUCT database, export material lists, and import in formulas and performs the calculation. These manual tasks can be easily replaced by a simple automation process in google's workplace.

The primary approach to coding this automation process is to embed the CO2NSTRUCT database in the background while enabling automatic upload, download, and file conversion of the generated material takesoff list. The code can also allow matching materials between the uploaded list and the embedded database, allow material data extraction, and perform calculations. An effort has been made to minimize changes to the designed code to ensure an easy transfer for users.

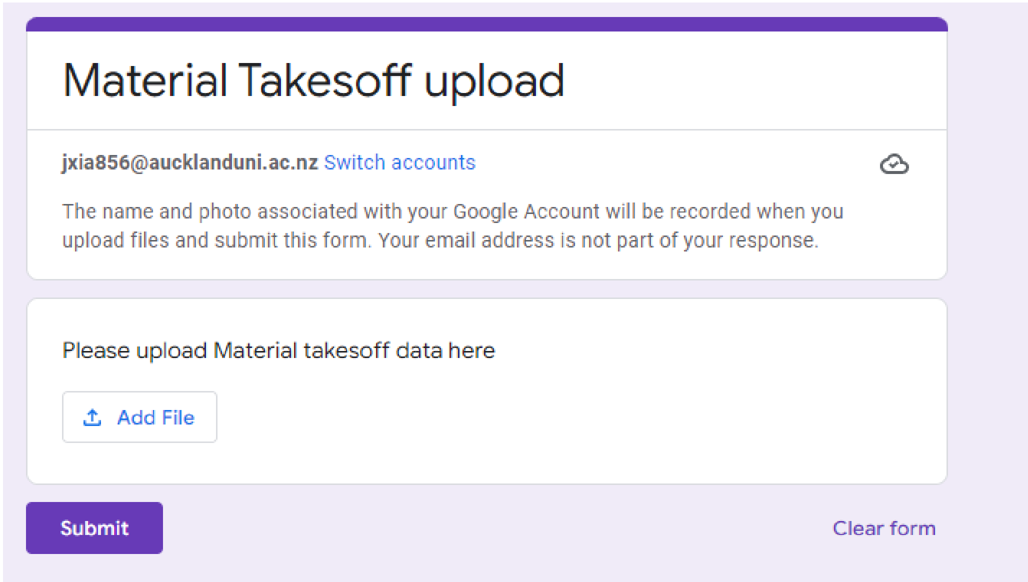


Figure 14 Material takesoff upload form

With the developed tool based on the designed protocol, the users only need to export the material list from BIM and import it into a google form, as shown in figure 14. The result sheet will be available after the background calculation is completed.

If the user decides to transfer this tool to their own work to ensure data confidentially, they just simply need to follow the protocol as follows.

1. Set up a working folder in google drive
2. Download the BRANZ CO2NSTRUCT database and import it into the set-up folder
3. Open the App script in the BRANZ CO2NSTRUCT database spreadsheet as shown in figure 15

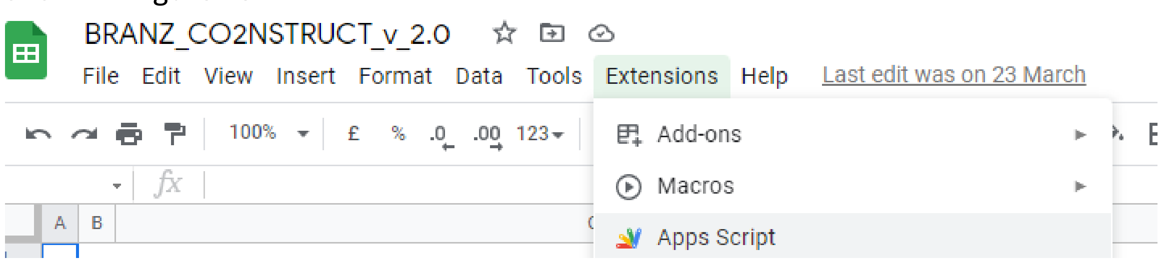


Figure 15 App Script pathin BRANZ database

4. Copy and paste code in Appendix A into the script where the folder name needs to be updated on how the user named their folder. The code will automatically try to find the uploaded material takesoff list and work out all file conversions once uploaded in later stages.

5. Create a new google form and set up a question that enables file upload, as shown in figure 16.
6. Open the response tab for the created google form and open the extension App script tab
7. Copy and paste the code in Appendix B into the script, and the code will automatically seek environmental impact values from the database and perform all calculations while completing the file conversion and generate a link with results when the material takes off list has been uploaded
8. Open the form and upload the Material takesoff list to the google form
9. The calculated embodied CO2 and energy results will automatically be generated in the background, and a result link will display in the response google sheet

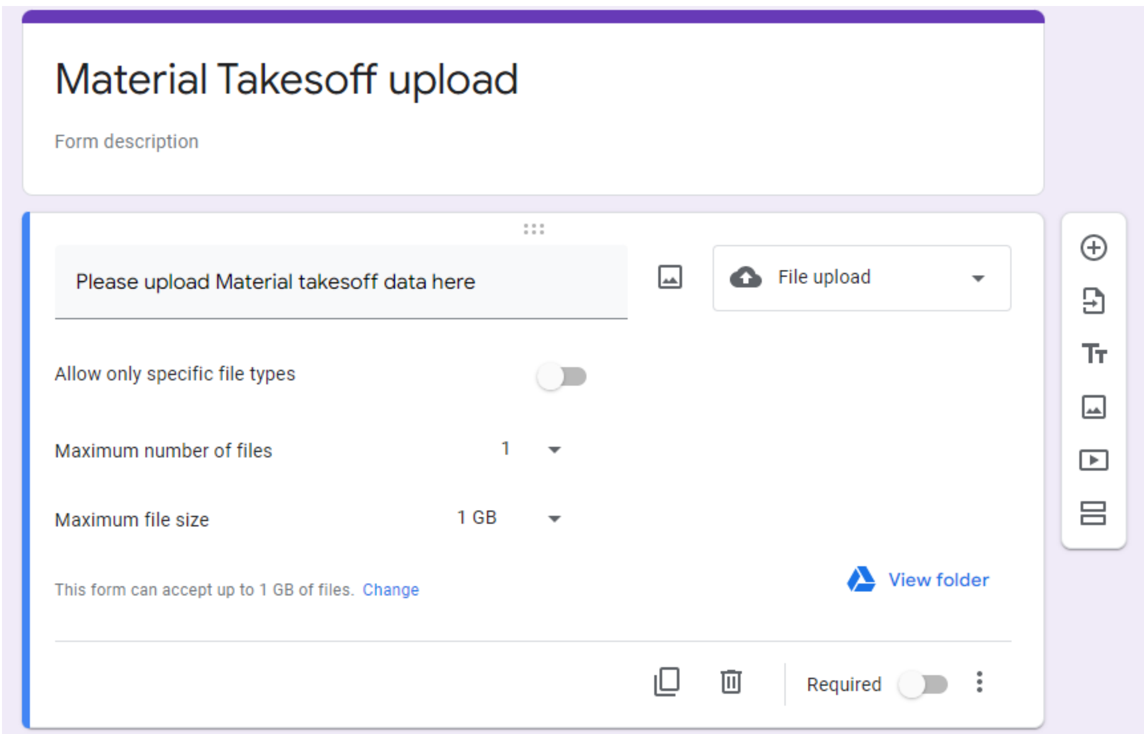


Figure 16 Material Takesoff upload form set up

3.2.2.6 Test designed tool/ protocol

This development aims to turn technical data into a working prototype that exhibits the solution. A tangible, functional prototype has been developed as the designed tool. Because nothing works the first time perfectly, the step of the development process is more iterative than the others. It is made up of the iterative cycle, which includes design, testing, debugging, and redesign. The cycle should repeat until a developed product that can be used and duplicated by users into their own database is developed.

The working prototype can be seen as follows,

As shown in figure 17, a folder has been set up in a personal google drive while the BRANZ CON2NSTRUCT database has been uploaded. A material takes off upload form has also been set up.

After uploading the material takesoff list generated by Revit into the google form, the calculation begins in the background, and after around 20 mins, the generated result sheet will be saved in the folder, and a link will appear in the form response google sheet

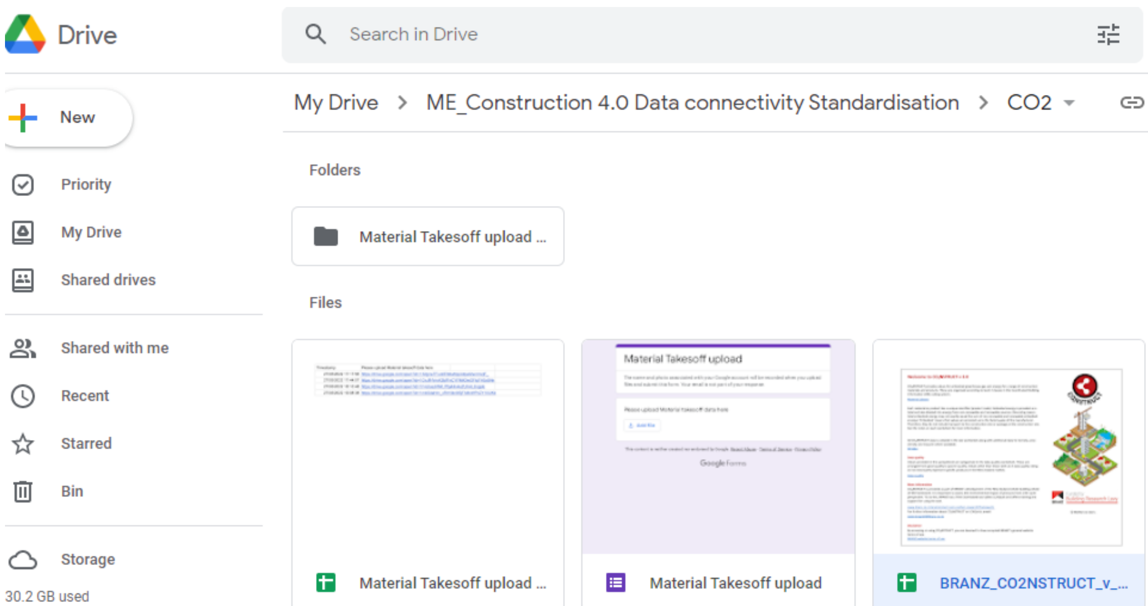


Figure 17 Folder set up for Environmental calculator protocol

This designed environmental impact calculator will ensure the embodied CO2 and energy for materials from each uploaded architecture design material takesoff list to be calculated and generated the resulting list as shown in figure 18.

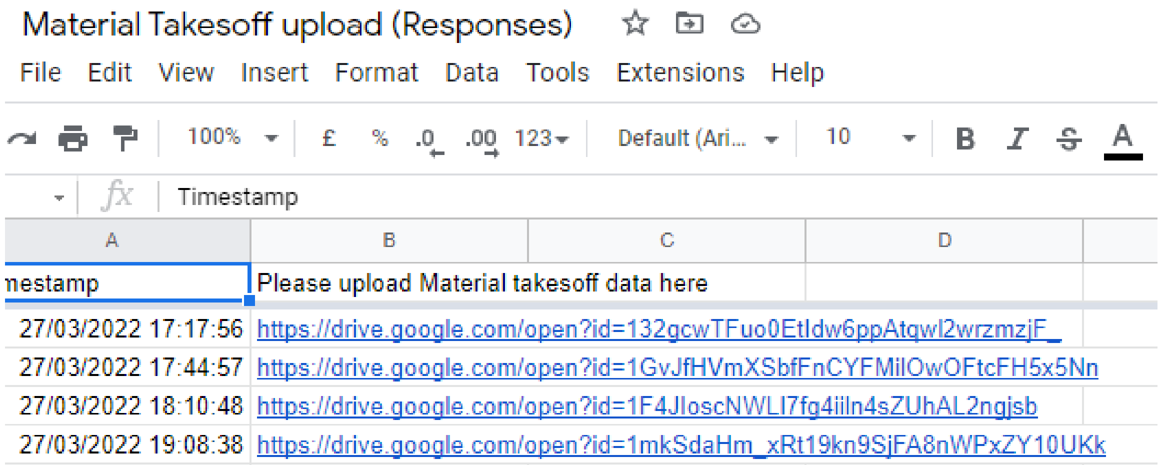
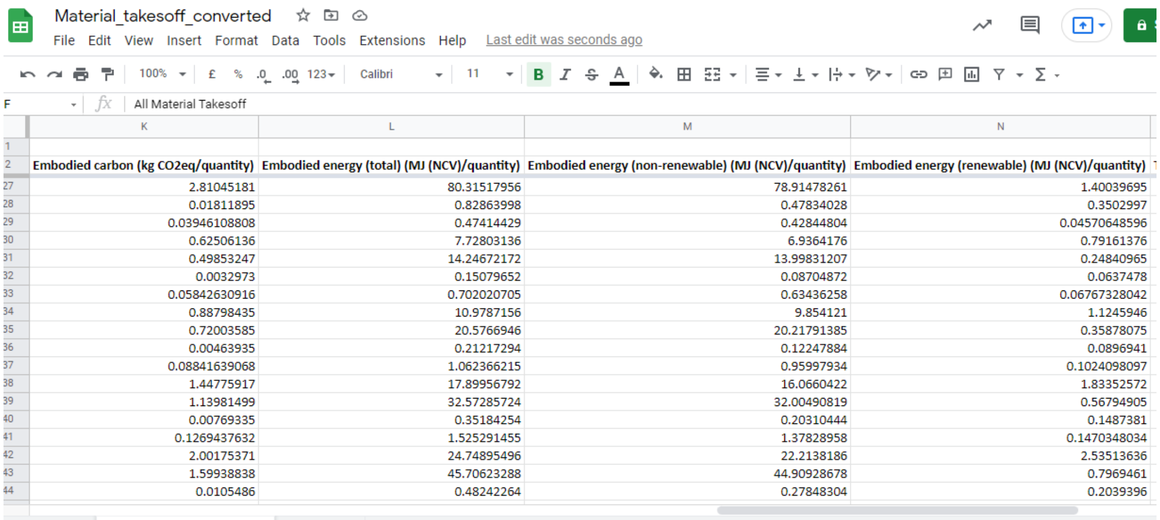


Figure 18 Material Takesoff upload history

After opening up the resulting sheet from the response google sheet, the embodied CO2 and energy will display alongside each material, and the total embodied carbon and energy for the whole design, as shown in Figures 19 and 20.



	K	L	M	N
2	Embodied carbon (kg CO2eq/quantity)	Embodied energy (total) (MJ (NCV)/quantity)	Embodied energy (non-renewable) (MJ (NCV)/quantity)	Embodied energy (renewable) (MJ (NCV)/quantity)
27	2.81045181	80.31517956	78.91478261	1.40039695
28	0.01811895	0.82863998	0.47834028	0.3502997
29	0.03946108808	0.47414429	0.42844804	0.04570648596
30	0.62506136	7.72803136	6.9364176	0.79161376
31	0.49853247	14.24672172	13.99831207	0.24840965
32	0.0032973	0.15079652	0.08704872	0.0637478
33	0.05842630916	0.702020705	0.63436258	0.06767328042
34	0.88798435	10.9787156	9.854121	1.1245946
35	0.72003585	20.5766946	20.21791385	0.35878075
36	0.00463935	0.21217294	0.12247884	0.0896941
37	0.08841639068	1.062366215	0.95997934	0.1024098097
38	1.44775917	17.89956792	16.0660422	1.83352572
39	1.13981499	32.57285724	32.00490819	0.56794905
40	0.00769335	0.35184254	0.20310444	0.1487381
41	0.1269437632	1.525291455	1.37828958	0.1470348034
42	2.00175371	24.74895496	22.2138186	2.53513636
43	1.59938838	45.70623288	44.90928678	0.7969461
44	0.0105486	0.48242264	0.27848304	0.2039396

Figure 19 Environmental calculator results for each component

Total Embodied carbon	Total Embodied energy (total)	Total Embodied energy (non-renewable)	Total Embodied energy (renewable)
271.2262901	4766.482668	4043.329161	723.1539005

Figure 20 Environmental calculator results Total

After testing out the designed protocol, it has been proven that an environmental impact calculator design protocol has been developed utilizing the improved data connectivity feature of BIM technology. Users can use this tool as an environmental impact calculator as well as follow the developed protocol to design a functional environmental impact calculator of their own to ensure the confidentially of architectural designs.

3.2.3 Material passport

As identified in the Literature review section, there is a need to improve the current situation and release the construction industry from the material shortage and delay burden. The methodology section above suggests a material passport standardization protocol should be designed to enable the circular economy of building materials.

Ideally, a material passport should be created at the design phase and updated during the construction process. However, alternative types of analyses, such as 3D scanning, can also be used to develop it for already existing structures.

The availability and relevancy of the data, particularly about a component's use history and reuse potential, aids reuse, recycling, and biodegradation should be included. It is also critical when selecting components that can be reused in the future. As a result, materials passports are being developed as a tool to incentivize innovative product design and the deployment of circular business models.

Given that there is no material passport standardization in New Zealand, this research aims to develop the standardization of material passports in New Zealand using New Zealand manufacturing information by improving data connectivity through utilising BIM technology. The implementation of the development process can be found in the following sessions.

3.2.3.1 Develop a Centralized database

A centralized database (abbreviated as CDB sometimes) is a database that is stored, maintained, and accessed from a single location. This is usually a mainframe computer or a central computer or database system, such as a desktop or server CPU. A centralized database is typically utilized by an organization (e.g., a business) or an institution (e.g. a university.) Users gain access to a centralized database via a computer network that allows them to connect to the central CPU, maintaining the database.

To develop a material passport standardization tool, a centralized database that is easily accessible for everyone to transfer the developed material passport generator to the user’s individual database needs to be created or selected if it is currently available. As the complete item list from the architecture housing designs will need to be imported to generate a material passport for each item, the goal is for this research to provide a guidance protocol to transfer this material passport generator to their own workspace so that the confidentially of the architecture design can be ensured.

Instead of developing a centralized database, Google workplace is again chosen to be the general platform to develop the material passport generator protocol and store the material passports, as google is a commonly used platform. The workplace owner can easily manage access to Google workplace. It is also a cloud-based database where users from all parties can access it from anywhere.

3.2.3.2 Define desired output

The desired output for a material passport standardization protocol should include a well-set template that applies to all construction materials. Ideally, a unique link that directs to each component's material passport should be generated as each component should have its own material passport for the future use.

3.2.3.3 Define relevant input

The digital material circularity passport will provide potential reuse/repurposing options on a component level. Thus, it will improve end-of-life information. The development of digital material passports will provide reliable and standardized information on material follows. Assessment of material flow and stock will provide reliable material flow models. The flow models will offer end-of-life routes to construction waste. Hence, the data involved will be relatively complicated.

Ideally, a components bank should start with a small collection of data that offers demonstrable value and utility across the industry (including government) and can be quickly expanded if needed. The information set can then be expanded by adding supplemental data, such as proprietary data or industry technical standards, by-product data solution providers or data aggregators. In recognition of the worldwide nature of many products, international technical standards should be adopted unless there is a compelling need to utilize or develop a New Zealand standard. However, as a starting point, only the data values considered critical for a building material component will be included in this research.

The following are some of the main reasons for starting with a relatively small dataset:

• Feasibility - the fundamental data suggested is easily accessible, and its application would quickly offer value to all stakeholders.

• Technical standards are dynamic in nature, and developing and incorporating them into digital templates might take a long time.

• Data management - simplifies the data input, validation, and synchronization processes by first limiting the dataset to static attributes.

Metadata is a collection of information that describes and characterizes other data. Metadata for a building product could include information about its unique identifier, which unlocks additional key contextual details so that the reader or a digital system consuming data understands what the product is and what it does. In this case, it will be the unique product code obtained from the BIM model.

While this research focuses on applying BIM technology in the construction process for residential houses to improve data connectivity, with BIM, a material takes off list can be generated and exported as an excel spreadsheet for users to obtain all materials used for a specific purpose architecture design. This again showcases how technology like BIM helps with information management of construction materials in the building process. It will be harder to obtain the desired information in the design with traditional construction methods.

Commercial assurance features like product specification and supplier are crucial in guiding construction design and procurement decisions. Therefore, obtaining manufacturing information and pricing information is also important for the material passport for potential maintenance or replacement. These data sets can be easily found in the material passports.

Meanwhile, as the tracking of each component is also critical in the whole building process, providing RFID and a barcode representing the unique link of the material passport will help track and manage components. Tracking information should also be included in the material passport template.

Hence, the material passport template will consist of three major parts – Product information, pricing information and Tracking info.

After examining the feasibility of the relevant data from Product information, pricing information and Tracking information, the following product information is considered critical and must be included in the material passport,

- Product name – enable the user to identify the product
- Product description – enable the user to identify the product
- Status – enable the user to update the status when needed
- Family – enable the user to identify the product
- Volume – enable the user to determine sizes
- Count – enable the user to determine the quantity
- CO2 emission -– enable the user to determine the environmental impact
- Weight – enable the user to determine the weight

while LCAQuick Unit quantity requirement, density and product image URL are less critical and can be included if they can be easily found and imported to the database.

The following pricing information is considered critical and must be included in the material passport,

- Item number – allow the user to identify the product in the suppliers' system
- Supplier – allow the user to identify the supplier
- Length – allows the user to identify the unit length for purchasing the component from the supplier
- Unit Price – allow the user to identify the value of the component
- Quotation date – allow the user to identify the value of the component at a specific time as the building material price are constantly changing
- Quotation number – allow the user to chase back the quotation from the supplier for potential budgeting purposes

while the price per length (unit price per item can be for a channel that is 6m long selling for $480 per unit, however for more accurate cost estimation, price per length i.e. $80 per meter can be used in a material passport) , quotation expiry date, sales, payment terms, supplier location, supplier region, supplier website, product specification and contact number are less critical and can be included if they can be easily found and imported to the database.

As tracking will only be allocated after the supplier has manufactured the component, RFID and barcode are considered less critical at this stage for the material passport.

All critical data should be clearly distinguishable from the less critical ones

3.2.3.4 Set up standardized template

Structured data has clearly established relationships between standardized data points and is contained in a pre-specified model or template. Structured data is much easier for 'big data' or machine learning algorithms to consume, whereas unstructured data comes in various formats, which makes it more difficult. Unstructured data is also difficult to validate by its very nature, even if machine learning may be used. When structured and interoperable data can be shared throughout an industry ecosystem, it aids in the development of the information infrastructure required to enable innovation and increase productivity.

Currently, the construction industries have virtual pools of 'unstructured data' that may be data-rich. Still, they are information-poor in the sense that they lack the ability to turn data into useful information that can be used to automate processes.

According to extensive literature research and input from construction industry stakeholders, this business is plagued by time-consuming information searches and high rework costs. It is a major contributor because unstructured data is not easily accessible, searchable, or exchangeable between manufacturers, suppliers, and trading partners or between these companies and regulatory bodies. Hence, a standardized template needs to be designed.

According to the relevant input defined in the previous stage, a material template has been designed and stored in the centralized database, as shown in Appendix C.

3.2.3.5 Develop automation process

The key idea about the material passport generation in this research is to have the material list generated from the BIM model and the manufacturing information for each component combined into a metadata material passport for components with a standard format to ensure consistency and readability as shown in figure 21. However, while the material list can be easily exported from BIM and the manufacturing data can also be easily inputted by suppliers or inputted based on the information suppliers provide, combining and transferring the data from different formats into one standardised material passport will be a time-consuming task. Hence an automation process for this repetitive task is needed.

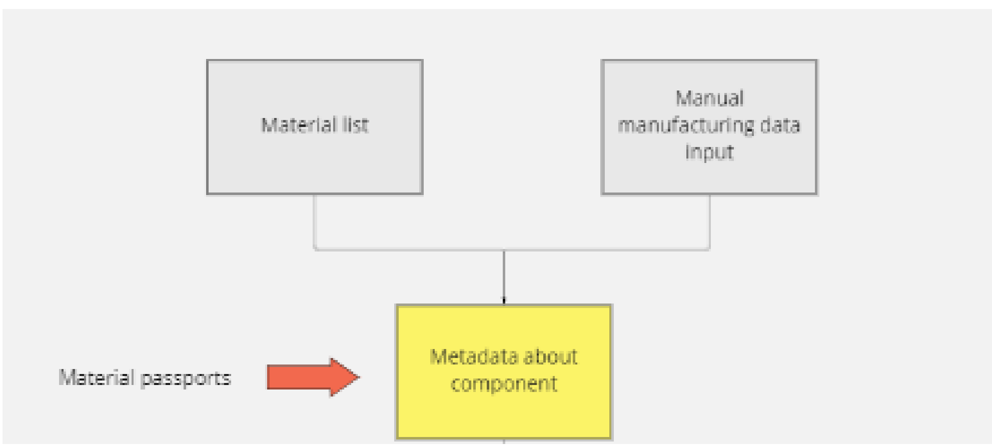


Figure 21 Material passport development process

The main approach for coding this automation process is to embed the designed material passport template in the centralized database and autofill components' information into their individual material passport. It automatically generates a unique link that directs to each component's material passports. These material passports can be securely stored in the centralized database, and the user can easily manage access. At the same time, this database can also be easily transferred to the property's next owner (this building material bank).

This developed protocol to generate material passports for building components can be easily transferred to their own workspace to ensure data confidentially,

Users simply need to follow the protocol as follows.

1. Set up a working folder in personal/organization google drive
2. Export the material list from the BIM model or manually create a material list
3. Upload the material passport template from Appendix C into the working folder
4. Obtain manufacturing /pricing information and input into the material list
5. Copy and paste code in Appendix D into the script where the folder location needs to be updated based on how the user set up the folder. The code will automatically try to find the uploaded material list with all information

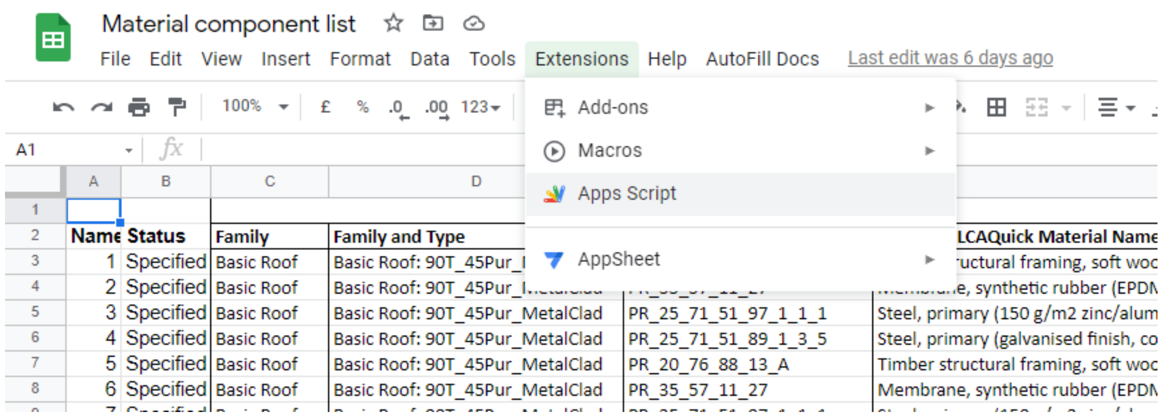
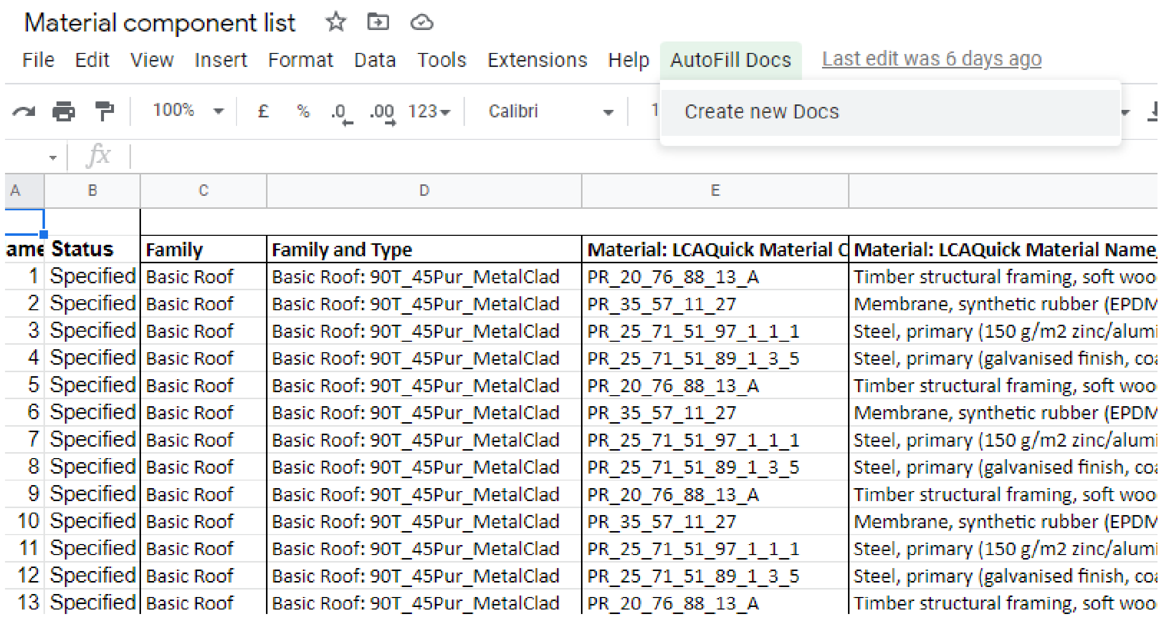


Figure 22 Material component list

6. Click the new tab “AutoFill Docs” to generate material passports for each individual component in both Doc format and PDF format, as shown in figure 23. Generated material passports will be located in a dedicated folder within the database.



ame	Status	Family	Family and Type	Material: LCAQuick Material C	Material: LCAQuick Material Name
1	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_20_76_88_13_A	Timber structural framing, soft woo
2	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_35_57_11_27	Membrane, synthetic rubber (EPDM
3	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_25_71_51_97_1_1_1	Steel, primary (150 g/m2 zinc/alumi
4	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_25_71_51_89_1_3_5	Steel, primary (galvanised finish, co
5	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_20_76_88_13_A	Timber structural framing, soft woo
6	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_35_57_11_27	Membrane, synthetic rubber (EPDM
7	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_25_71_51_97_1_1_1	Steel, primary (150 g/m2 zinc/alumi
8	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_25_71_51_89_1_3_5	Steel, primary (galvanised finish, co
9	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_20_76_88_13_A	Timber structural framing, soft woo
10	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_35_57_11_27	Membrane, synthetic rubber (EPDM
11	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_25_71_51_97_1_1_1	Steel, primary (150 g/m2 zinc/alumi
12	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_25_71_51_89_1_3_5	Steel, primary (galvanised finish, co
13	Specified	Basic Roof	Basic Roof: 90T_45Pur_MetalClad	PR_20_76_88_13_A	Timber structural framing, soft woo

Figure 23 AutoFill Docs function

3.2.3.6 Test the designed protocol/tool

Steel reuse and repurposing can save up to 96% of the carbon emissions compared to primary steel production (Smeets and Drewniok 2019). In contrast, recycling has the potential to save up to 60% environmental impact of new steel. Thus, a much more sustainable option would be to increase domestic re-use and repurposing of steel. Hence, steel components have been selected to reduce the run time for generating material passports for testing the protocol. Steel takes off list has been generated as shown in figure 24.

Name	Status	Family	Category	Material: LCAQuick Material Cc
381	Specified	PFC-Parallel Flange Channel	PFC-Parallel Flange Channel: 150 PFC Beam- 150x90x24PFC	PR_20_76_51_12_1_7_4_1_1
384	Specified	PFC-Parallel Flange Channel	PFC-Parallel Flange Channel: 150 PFC Beam- 150x90x24PFC	PR_20_76_51_12_1_7_4_1_1
385	Specified	PFC-Parallel Flange Channel	PFC-Parallel Flange Channel: 150 PFC Beam- 150x90x24PFC	PR_20_76_51_12_1_7_4_1_1
386	Specified	PFC-Parallel Flange Channel	PFC-Parallel Flange Channel: 150 PFC Beam- 150x90x24PFC	PR_20_76_51_12_1_7_4_1_1
387	Specified	PFC-Parallel Flange Channel	PFC-Parallel Flange Channel: 150 PFC Beam- 150x90x24PFC	PR_20_76_51_12_1_7_4_1_1
382	Specified	PFC-Parallel Flange Channel	PFC-Parallel Flange Channel: 200 PFC Column- 200x75x23PFC	PR_20_76_51_12_1_7_6_1_1
383	Specified	PFC-Parallel Flange Channel	PFC-Parallel Flange Channel: 200 PFC Column- 200x75x23PFC	PR_20_76_51_12_1_7_6_1_1

All Material Takesoff | Steel takesoff | Sheet1 | Sheet2

Figure 24 Steel component takesoff list

Components were then categorized, and pricing information was obtained from suppliers, as shown in Appendix E.

This pricing information was then imported into the component list, where the code was set up in the background. Once the “AutoFill Docs” tab was clicked, the material passports generation started. The generated material passports have all been saved in the dedicated folder in PDF and Doc format. The link direct to the doc file is listed alongside other material data in the component list shown in figure 25. Users can either access the material datasheet from the component list or directly find it in the centralized database.

An example of the component material passport can be found below in figure 26.

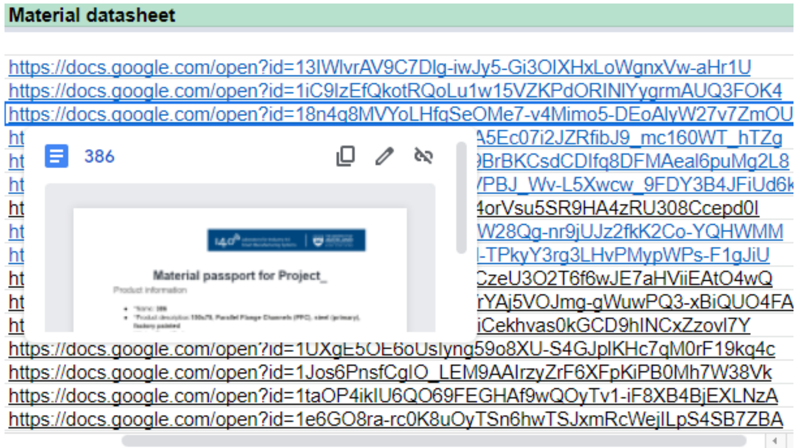
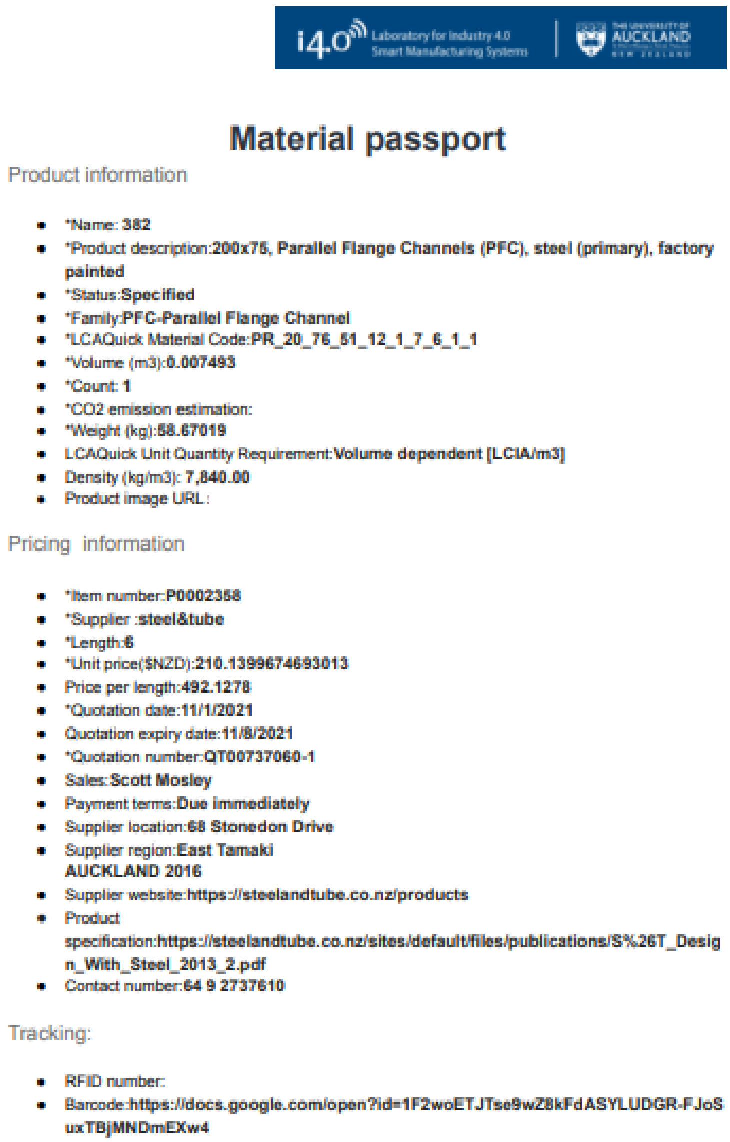


Figure 25 Generated material passport links



Material passport

Product information

- *Name: **382**
- *Product description:**200x75, Parallel Flange Channels (PFC), steel (primary), factory painted**
- *Status:**Specified**
- *Family:**PFC-Parallel Flange Channel**
- *LCAQuick Material Code:**PR_20_76_51_12_1_7_6_1_1**
- *Volume (m3):**0.007493**
- *Count: **1**
- *CO2 emission estimation:
- *Weight (kg):**58.67019**
- LCAQuick Unit Quantity Requirement:**Volume dependent [LCIA/m3]**
- Density (kg/m3): **7,840.00**
- Product image URL:

Pricing information

- *Item number:**P0002358**
- *Supplier :**steel&tube**
- *Length:**6**
- *Unit price($NZD):**210.1399674693013**
- Price per length:**492.1278**
- *Quotation date:**11/1/2021**
- Quotation expiry date:**11/8/2021**
- *Quotation number:**QT00737060-1**
- Sales:**Scott Mosley**
- Payment terms:**Due immediately**
- Supplier location:**68 Stonedon Drive**
- Supplier region:**East Tamaki AUCKLAND 2016**
- Supplier website:**https://steelandtube.co.nz/products**
- Product specification:**https://steelandtube.co.nz/sites/default/files/publications/S%26T_Design_With_Steel_2013_2.pdf**
- Contact number:**64 9 2737610**

Tracking:

- RFID number:
- Barcode:**https://docs.google.com/open?id=1F2woETJTse9wZ8kFdASYLUDGR-FJoSuxTBjMNDmEXw4**

Figure 26 Material passport example

3.2.4 Demonstrative use of Cloud BIM in residential houses

To investigate how BIM can handle the integration of diverse professional models, actualize cross-departmental collaboration, and accelerate information flow across all building stages. An overall demonstration of using data extracted from BIM needs to be implemented. BIM's worth can then be demonstrated, and the construction industry's digital transition can be accelerated by completely integrating BIM with intelligent construction. Architects, engineers, and contractors now may view their 3D models anywhere with cloud-based BIM. By storing BIM data in the cloud, stakeholders may upload and access the most recent version of their models, allowing them to collaborate from a single point of truth. While many available Cloud BIM platforms enable the above requirement, the implementation should make a comparison between different products and select a suitable one for a case study demonstration.

3.2.4.1 Existing most used cloud BIM platforms comparison

Revizto

Revizto is cloud-based visual collaboration software for architects, engineers and contractors to communicate their design within the project team in a navigable 3D environment. Revizto uses gaming technology and cloud solutions to bring together multiple BIM and CAD data in one unified 3D environment to track all project concerns. The Revizto platform is user-friendly, simple to understand, and adaptable to BIM processes. BIM deployment is expedited using Revizto, allowing AEC teams to communicate in a common language and share a single window into all project data.

Figure 27 Revizto Model viewing

Revizto, as shown in figure 27, is a platform that converts Autodesk Revit BIMs and Trimble SketchUp models into interactive 3D environments with collaboration features and issue tracking and also is a cross-platform application that runs on 64-bit Windows, Mac OS X, iOS, and Android platforms, as well as in most recent web browsers that support the Unity plugin. Revizto integrates BIM intelligence and makes it immediately accessible and actionable for the entire project team. Project team members can identify and manage model-based issues in 3D space and 2D sheets, including addressing clash groups, using Revizto's powerful Issue Tracker preconfigured workflows. Anyone can utilise Revizto based on project requirements because it gives uniform access to a project's data for both 2D and 3D workflows.

Autodesk construction cloud

Another Cloud BIM collaborative platform that the construction industry has used is the Autodesk construction cloud, shown in figure 28.

Figure 28 Autodesk Construction Cloud Model viewing

Autodesk Construction Cloud brings together some of the most industry sophisticated range of construction management software packages from the widely used Autodesk, supporting workflows throughout all construction phases—from design to planning and operations. The breadth of workflows covered, the depth of capabilities in each software package, and the data communication between those products are awe-inspiring.

Cloud BIM Platform comparison

Table 6 Cloud BIM platform comparison

	Autodesk Construction Cloud	**Revizto**
Company	Autodesk funded in 1982	Revizto funded in 2010
Price	Starting from $49/month	Starting from $600/year
Pricing model	Per feature	Per feature
Best for	1-1000+users	2-1000+users
Features	✓ Accounting Integration ✓ Budget Tracking/Job Costing ✓ CRM ✓ Change Order Management ✓ Commercial ✓ Contract/License Management ✓ Contractor Management ✓ Equipment Tracking ✓ Estimating ✓ Incident Reporting ✓ Mobile Access ✓ Offline Access ✓ RFI & Submittals ✓ Residential ✓ Subcontractor Management	~~Accounting Integration~~ ~~Budget Tracking/Job Costing~~ ~~CRM~~ ~~Change Order Management~~ ~~Commercial~~ ✓ Contract/License Management ~~Contractor Management~~ ~~Equipment Tracking~~ ~~Estimating~~ ~~Incident Reporting~~ ✓ Mobile Access ✓ Offline Access ✓ RFI & Submittals ~~Residential~~ ~~Subcontractor Management~~
Deployment	✓ Cloud, SaaS, Web-Based ~~Desktop - Mac~~ ✓ Desktop - Windows ~~Desktop - Linux~~ ~~Desktop - Chromebook~~ ~~On-Premise - Windows~~ ~~On-Premise - Linux~~ ✓ Mobile - Android ✓ Mobile - iPhone ✓ Mobile - iPad	✓ Cloud, SaaS, Web-Based ✓ Desktop - Mac ✓ Desktop - Windows ~~Desktop - Linux~~ ~~Desktop - Chromebook~~ ~~On-Premise - Windows~~ ~~On-Premise - Linux~~ ✓ Mobile - Android ~~Mobile - iPhone~~ ✓ Mobile - iPad

Overall, as shown in table 6, Autodesk Construction Cloud provides more features for the free trial and has specific features for residential housing.

Hence, It has been selected for this research's demonstration to assess BIM's worth in the New Zealand residential housing construction industry.

3.2.4.2 Demonstration of Cloud BIM use in residential houses

While Autodesk Construction Cloud has been selected as the cloud BIM platform for this research, a residential project has been initiated, as shown in figure 29.

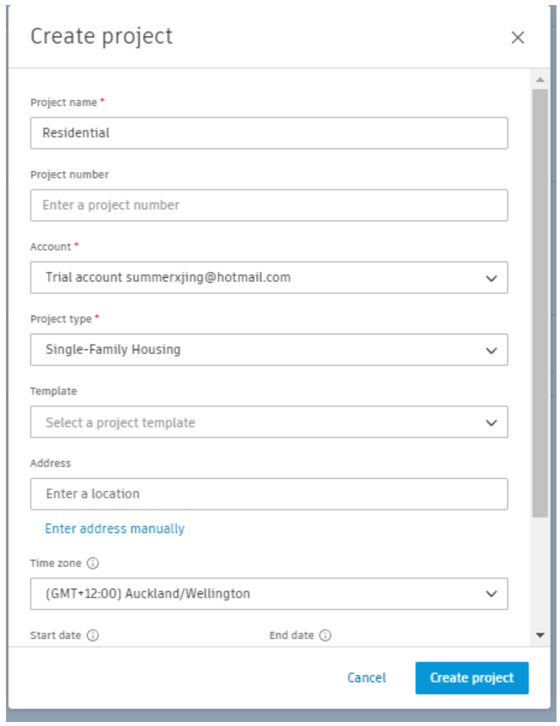


Figure 29 Project creating Construction Cloud

Meanwhile, as shown in figure 30, access levels within the project space can be easily managed with the construction cloud to prevent confidential information from being accessed and ensure designers, engineers and contractors with the right access level can access the information required on all platforms any time.

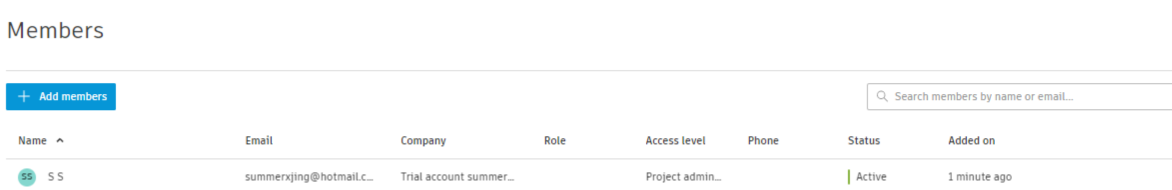


Figure 30 Access management Construction Cloud

There are seven key features embedded in the construction cloud enabling information management throughout the complete construction lifecycle as shown in figure 31.

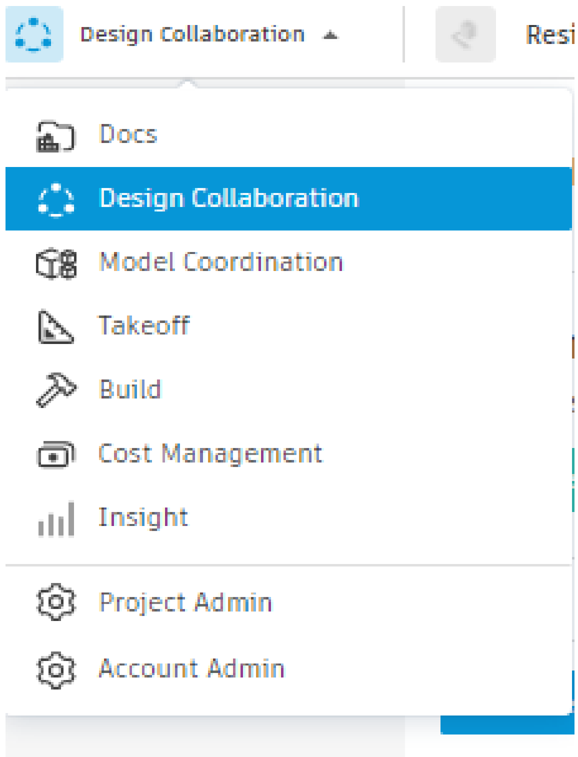


Figure 31 Construction Cloud key features

During the Design phase, the Design Collaboration and Model Coordination features, as shown in figures 32 and 33, allow the project team members to collaborate on coordinated, shared design. Design files from different parties can be uploaded and merged into one complete design; clashes can be identified, as well as issues can be initiated and assigned to the dedicated project team member to be resolved while coordinating documents can be securely stored within the project.

During the planning phase, the takesoff feature in figure 34 allows accurate takeoffs to be created to improve design quality and constructibility. Takeoff packages can be easily created to keep the components list organized, and inventory can also be easily managed. Meanwhile, the components' takesoff can also be visualised, and each component's detail can be found with the takesoff feature (figure 35 & figure 36). Hence, the preconstruction teams can execute design intent, bid competitively, mitigate financial risks, and remain profitable by streamlining coordination, model conditioning, quantification, bid management, and qualification.

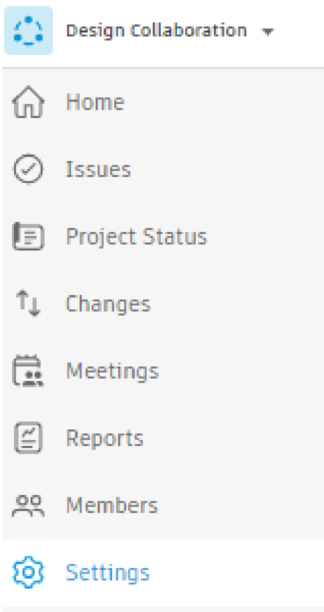


Figure 32 Design collaboration

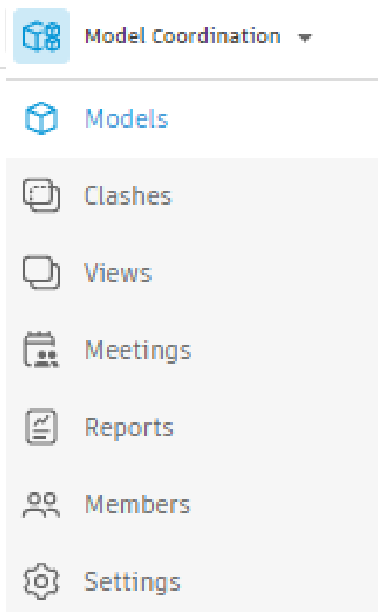


Figure 33 Model Coordination

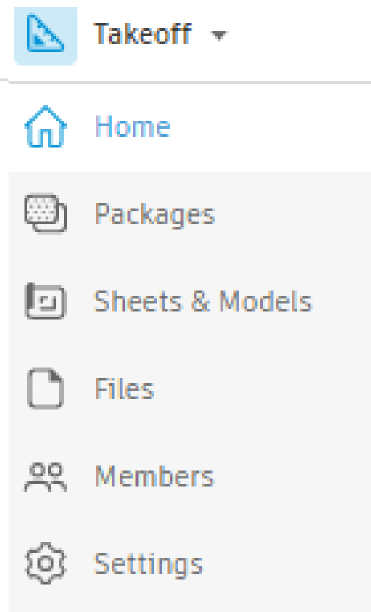


Figure 34 Takesoff

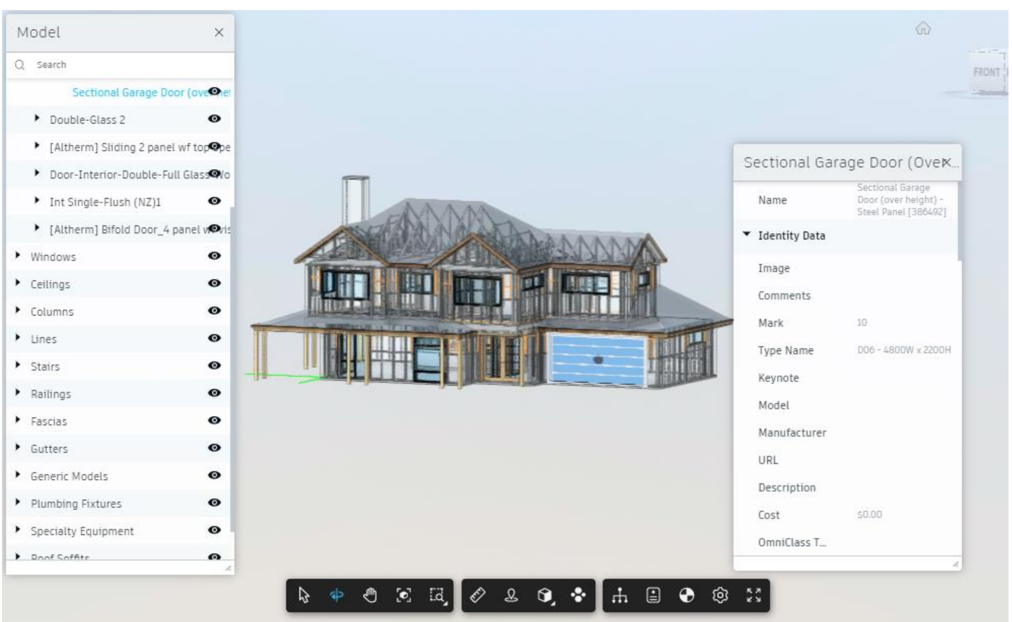


Figure 35 Takesoff model complete view

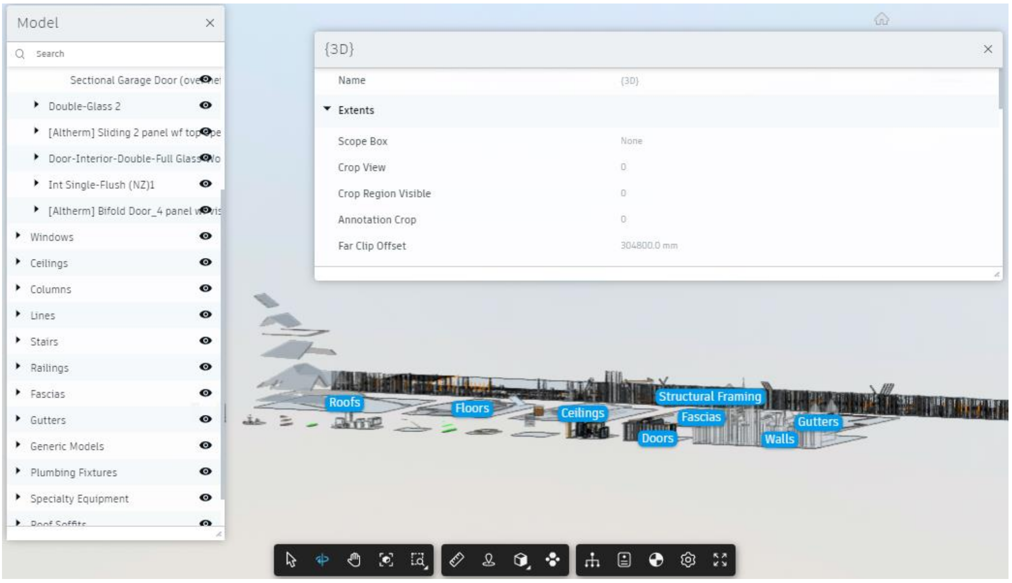


Figure 36 Takesoff model material grouped view

With the Build feature and the cost management feature shown in Figures 37 and 38, Issues and RFIs can be connected between designers' drawings and the construction sites during the build phase. Assets can be easily managed as well as cost and budgeting of this project can be organized and shared with relevant parties.

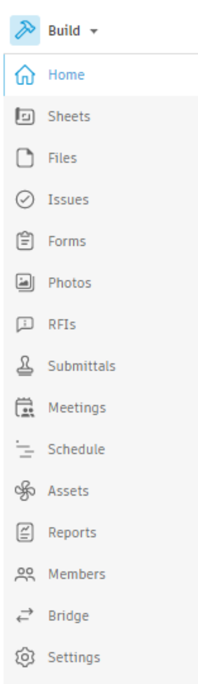


Figure 37 Construction Cloud Build feature

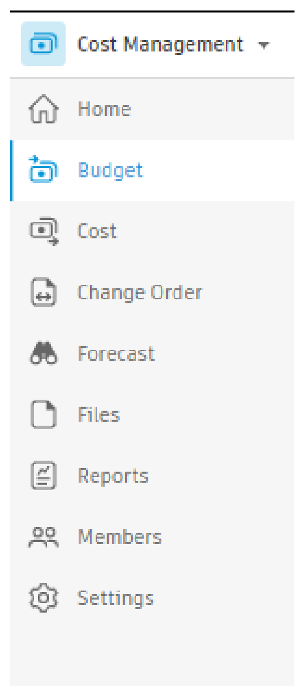


Figure 38 Cost management

During the operation phase, BIM asset data created throughout the lifecycle can then be used for model viewing and allow the maintenance schedule to be organized. With all project work recorded in this common data platform, the owner gains control over the project status and problems. When the ownership gets transferred, all data can be easily handover to the next owner for future use.

Overall, the benefits of using cloud BIM to coordinate construction projects include

1. Coordination and clash detection to reduce future rework
2. Operational and asset data hand over
3. Model development
4. Model visualization
5. Coordinate subcontractor using BIM during the pre-construction and construction phase to reduce cost and overall schedule
6. The design model can be used for creating construction documentation to reduce on-site complication

3.2.4.3 Connect with material passport

As shown in figure 39, while assets for the construction project can be easily managed, the material passport can also be uploaded into the construction cloud for future reuse and recycling. The link generated from the material passport generation protocol that leads to individual components material passport is shown and can be opened and updated directly from the construction cloud.

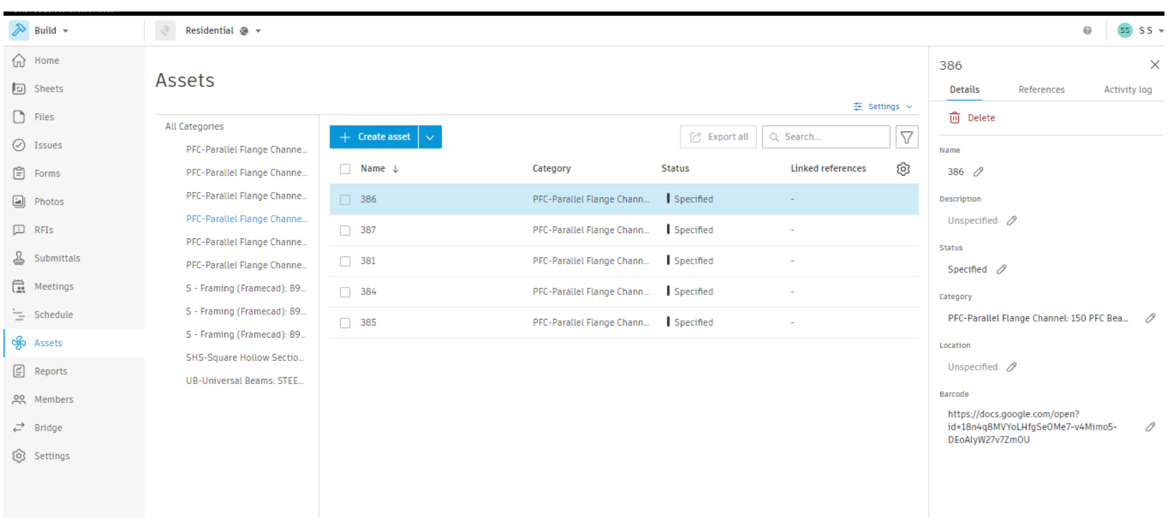


Figure 39 Asset management

A standardised material flow has been mapped by improving the data connectivity using BIM technology. As shown in figure 40, the material passports for each component can now be extracted for checking during general maintenance and updated and used during the design, construction, and maintenance/demolition phases within the Cloud BIM database. When the ownership gets transferred, with the BIM model and other data imported during the construction lifecycle, the material passports can be safely transferred to the next owner and act as a content bank for potential recycling or reuse based on the components 'condition.

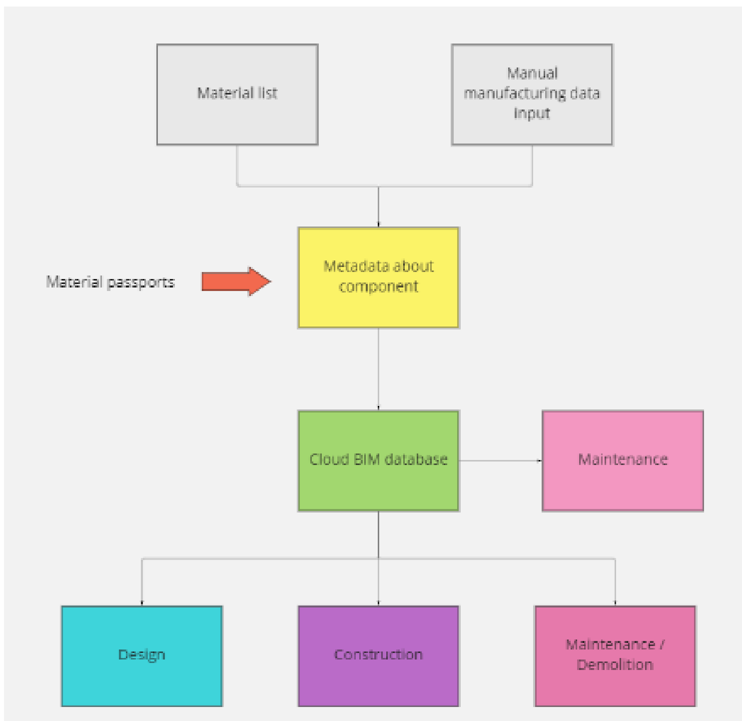


Figure 40 Material Passport with Cloud BIM model

4. Discussion

While Bauing Group New Zealand claimed to be optimistic that modular technology can slowly expand in the construction industry during the interview, as mentioned by the site manager from CLOT Homes, the current New Zealand construction industry has already progressed from building everything on site traditionally to having a small portion of the building material “prefabricated”. Currently, most developers have chosen to partner with a pre-cut timber framing manufacturer to have house framing pre-made and sent to the site for assembly, which is at the beginning of the component-based prefabricated level of prefabrication. This shows a sign that while developers see benefits from using technologies like prefabricated framing components, their resistance to changing their construction method will be hugely reduced. The benefits that prefabricated technology brings are significant as it solves many challenges faced by the traditional construction method that the industry is currently using, such as extensive construction period, being weather dependent, high labour cost and unnecessary construction material waste, as the comparisons shown in this research in section 3.1.1.3, the same architecture designed two-story residential house with two different construction method, the prefabricated method will reduce the cost by $215,000 (22.3%) and reduce construction period by 97 days (54.5%). As the building process will mainly be off-site in a controlled environment, labour safety can also be ensured while less material waste will incur. However, it is expected that Bauing Group has put in a lot of investment and effort to develop their software, enabling them to transfer the BIM model to their prefabricated designs easily. Also, with extra investment into hiring BIM managers and designers and the time and cost to train existing labour to install modular houses, the profit margin for the developers currently using traditional construction methods will be significantly reduced.

Meanwhile, as people still have a strong bias thinking modular houses are cheap and of poor quality and the government regulations and insurance policies on modular houses are still not as mature as the regulation on traditionally built houses, it is expected that homebuyers and developers remain in doubt about this new technology. Therefore, New Zealand is still mainly dependent on the traditional construction method. However, with new technologies becoming more common in the industry and government regulations becoming more apparent, it is expected that developers and the government can seek benefits from hugely implementing the prefabricated technology in the New Zealand residential construction industry.

On the other hand, as mentioned by the site manager from CLOT Homes, currently, the environmental impact of the construction industry does concern the developers.

However, developers' priority remains to gain economic benefit by treating environmental concerns as they are already carrying enough burden with the long investment turnover period. Therefore, a free tool such as the environmental calculator protocol developed in this research in section 3.2.2 will be an excellent way for the residential housing sector to start revising their material choice when designing new houses. This free protocol is easy to access and transferable to the user's individual workspace to ensure the confidentially of the designs. While through using this tool, there will be no direct financial benefits in the short term, as climate change and environmental sustainability are becoming more and more critical in today's society, employees are now looking for employers that think and act sustainably, customers and buyers nowadays prefer carbon-neutral brands and businesses and governments around the world are introducing climate regulations to enforce sustainable decisions are made by local businesses. Hence, long term wise, start acting on reducing environmental impact by selecting more environmentally friendly using the developed environmental calculator protocol will be a good start for the New Zealand residential housing construction industry players. While more developers are starting to act on developing more sustainable housing, New Zealand's carbon-neutral goal can be achieved sooner and eventually reach carbon-zero.

Meanwhile, as mentioned by the site manager from CLOT Homes, due to the worldwide construction material shortage, material prices are boosting, and supply delays are becoming more and more common in New Zealand, many developers are unable to survive in the industry due to the unexpected long investment turnover period while the house price is boosting up. The material shortage problem is a critical challenge that needs to be solved to reduce the burden on the construction industry. With the use of material passports, every residential house can be treated as a material bank when they are planning to be demolished. It is also helping to reduce environmental impact due to construction material waste which is 40 per cent of the waste generated in New Zealand and 35 per cent of carbon dioxide (CO_2) emissions in New Zealand, as discussed in section 2.2.1.1. Materials passports designed in section3.2.3 are electronic and interoperable data sets that aggregate materials' properties, allowing suppliers, designers, and users to assign the maximum possible value to them and lead toward the material circular economy. Ideally, material passports could be designed for a product (a wall, a stairwell), a component (a column, a beam), or a specific substance (wood, steel). It should contain multiple layers of data with characteristics from various fields. This allows future designers to reuse the materials when they become "trash" following the demolition or renovation of a given structure. As a result, a structure might be considered a “bank” or "store" of still-usable materials. Using a material passport with the help of BIM technology, as shown in section 3.2.4.3, the traceability of construction material has been enabled. It is possible to see where resources are situated in the building and which can be reused. This makes it simple and accessible for designers to use these materials in future projects.

The materials passport specifies the material value of three potential processes as follows,

Recovery – Optimal recovery of the value of the already used material by burning it and generating energy from the produced heat during the burning process. When the materials in a structure are identified, stakeholders know what materials are present, their quantities, and where.

Recycle – A process of transforming waste material back into new valuable materials, Steel for example can be recycled indefinitely without a reduction in material quality. While recycling materials that are of poorer quality and functionality than the original is called downcycling. Concrete, for example, will be employed in asphalt infrastructure, and windows will be used in fiberglass manufacturing. A material passport provides designers with information about building elements, allowing them to utilize them in projects that serve their primary purpose. After then, the remaining value can also be identified and utilized.

Reuse – Using a material again for its original or another purpose without applying any complicated treatment or processing it. Raw-material construction consumes energy and depletes natural resources. This exploitation is reduced by installing material passports, which allows for the reuse of building materials. Steel beams, for example, can be reused directly for structural support given that the steel condition still meets the standard as manufacturing information should be ideally stored in the material passport for reference.

Therefore, with a standardized material passports generation protocol designed in section 3.2.2, material passports can be easily generated, securely stored and handover when ownership gets transferred.   At the same time, relevant stakeholders can access the generated material passports when needed and import updates to the centralized database for each component. Data connectivity has been dramatically improved. Building material recovery, recycling and reuse are now enabled, leading a release to the material shortage and critical material waste challenges faced by the New Zealand construction industry. However, this process will take some time for the industry to accept and adopt, and the significant benefits will only show at the last stage of the housing lifecycle.

Also, with the demonstration of using a Cloud BIM platform for a residential house, benefits from cloud BIM to coordinate projects have been presented.

Cloud BIM enables easy coordination and clash detection between different designers working on other project parts. Significant rework costs can be reduced by spotting clashes at the early stage of the construction process. However, since New Zealand houses are relatively simple in structural design and are mainly simple one-story, two-story, and maximum three-story wood framing houses, architects generally only need to produce 2D drawings for the construction team. Also, since with the majority of the residential houses, the layout of HVAC, drainage and other services generally do not need to be coordinated during the design stage as there is enough room for all services designed to fit in residential houses in New Zealand, developers do not feel the need to implement BIM and pay for its expensive fees and the extra training/hiring for the team. On the other hand, while higher density housing is in need for the major cities like Auckland in New Zealand, the easy coordination and clash detection feature from BIM will become more and more in demand for the New Zealand residential housing developers.

Cloud BIM also enables operational and asset data seamlessly handed over when ownership of property gets transferred; this is not achievable from the traditional construction method as data will be lost throughout the year, and even though design drawings of the property are well kept, the remaining value of it is limited. However, with Cloud BIM and the valuable data, it collects throughout the construction lifecycle, data is sorted and connected into useful information that can be easily understood and utilised by people with no technical experience in the construction industry.

Meanwhile, the Cloud BIM platforms enable access to the project at any time from anywhere as well as enabling the coordination of subcontractors by allowing schedule organization all in one platform with easy access to model visualization.

With Cloud BIM, numerous benefits have not yet been fully discovered. With better adoption of BIM in the New Zealand construction industry, better data connectivity of the residential building construction industry can be achieved, and a network effect will be expected. A network effect occurs when a new service user influences the service's value to others. 'Network effects are a sort of externality in which the number of customers and/or producers using the same (or compatible) technology directly impacts their utility and/or earnings. In a nutshell, network effects are created by raising the adoption rate (popularity) of a product or service (Newton 2011). When a network effect exists, the value of a product or service rises in proportion to the number of other people who use it. Consider public transportation or a telephone system where the quantity of users is essential. With better adoption of BIM in the New Zealand construction industry, more BIM-related technology such as the developed protocols of environmental calculator and material passport generator in this research can be developed. In contrast, more data can be captured, stored securely, and turned into useful information utilized during the construction lifecycle.

As a result, it is expected that enterprises can compete on a fair playing field to provide digital applications.

However, while this research aims to showcase the benefits of improving data connectivity through BIM technology to the New Zealand residential construction industry, the designed environmental calculator protocol and the material passport generator protocol can only be used in conjunction with BIM technology. As discussed in the interviews with CLOT Homes and Bauing Group New Zealand, BIM technology is currently not being used in the traditional construction method, which is used by the majority of the residential housing developers in New Zealand, nor with some smaller modular housing developers, as their modular designs are limited and relatively similar to one another, their design methods remain 2D. This suggests that BIM adoption in New Zealand residential construction may still take some time as its benefits will slowly be realized by the developers. More studies studying BIM use should be done like this research to present the benefits and limitations of implementing this technology.

5. Conclusion

In conclusion, to release the New Zealand housing shortage challenge and reduce the influence of the construction industry on our environment by improving the data connectivity using BIM, a case study to examine the prefabrication technology has been conducted in this research, while an environmental impact calculator protocol to support material selection process during the design phase of the construction lifecycle has been developed in this research. A standardized material passport generation protocol has also been designed and developed, and a demonstration of using the Cloud BIM platform in residential houses has been conducted in this research.

Based on the case study and interview conducted in this research, the prefabricated method will reduce the cost by $215,000 (22.3%) and reduce the construction period by 97 days (54.5%). As the building process will mainly be off-site in a controlled environment, labour safety can also be ensured while less material waste will incur. It can be expected that while developers and the government can seek benefits from hugely implementing the prefabricated technology in the New Zealand residential construction industry, prefabrication technology will be more common in the New Zealand residential construction industry. By conducting this case study, industry insights into current challenges and potential opportunities of the New Zealand residential housing industry have been revealed and discussed. This research's practicability in real-world scenarios has been improved.

Meanwhile, with the environmental impact calculator protocol being developed, users can easily use this developed tool to support their material selection process or transfer this tool to their individual workspace to ensure data security. It is suggested that the New Zealand residential housing construction industry players start acting on reducing environmental impact by selecting more environmentally friendly materials using the developed environmental calculator protocol will be a good start. It allows a more sustainable decision making during the first phase of the construction life cycle. By developing this tool/protocol, the potential benefits it brings to the environment showcase the advantage of improving data connectivity by using BIM technology in the New Zealand residential housing industry.

In addition, with a standardized material passports generation protocol designed in this research, material passports for every single component of a residential property can now be easily generated, securely stored and handover when ownership gets transferred. At the same time, relevant stakeholders can access the generated material passports when needed and import updates to the centralized database for each component. Building material recovery, recycling and reuse are now enabled, leading a release to the material shortage and critical material waste challenges faced by the New Zealand construction industry.

Furthermore, by conducting a demonstration of using the Cloud BIM platform in residential houses, benefits from using cloud BIM have been identified and summarized as follows,

1. Coordination and clash detection to reduce future rework
2. Operational and asset data seamlessly hand over
3. Model development coordination between different designers
4. Model visualization and easy access for all relevant stakeholders
5. Coordinate subcontractor using BIM during the pre-construction and construction phase to reduce cost and overall schedule
6. The design model can be used for creating construction documentation to reduce on-site complication

Again, these benefits showcase the potential of improving data connectivity using BIM technology in the construction industry. Meanwhile, the designed material passport protocol has also been implemented in conjunction with the demonstration of using Cloud BIM. It is suggested that more benefits of implementing BIM have not yet been revealed. More similar tools that provide benefits to the industry can be designed as a network effect for increasing the adoption of BIM in the New Zealand residential industry.

Overall, the landscape of the construction industry is changing rapidly as engineering firms, contractors, and other value chain participants discover the benefits of connected construction technologies and progressively adopt them. Technologies like BIM and Cloud BIM can help put assets, people, processes, and job sites onto one platform, allowing everyone and everything to work smarter. They can also help reduce downtime, improve asset utilisation and efficiency, and gain greater visibility into operations. Meanwhile, emerging technologies like material passport generation, environmental impact calculator, as well as the data and advanced analytics that these new capabilities might enable are at the heart of the linked building. Developing data, analytics, and user-based insights capabilities could be crucial as the construction sector evolves toward linked construction. I would expect that in the near future, linked construction will almost certainly be a catch-all term for substantial digital expenditures aimed at connecting, integrating, and automating activities, as well as bringing the entire value chain onto a secure, intelligent infrastructure.

6. Future Work

Initially, it was planned for this research that with the generation of the digital material passport process, a physical tracking protocol of building components would be developed, and a case study monitoring the complete lifecycle of building components of a residential house would be conducted.

Ideally, after the building components have been manufactured, the generated link associated with each component's material passport, as shown in section 3.2.3, will be transformed into unique QR codes and stuck onto each physical component so that smartphones can scan it. RFIDs can also be allocated to individual components so that the transportation and installation of the components can all be monitored and tracked.

Therefore, the material passport protocol can be more complete as a real-life case study of a complete lifecycle of building materials has been conducted. However, due to the COVID restrictions and lockdowns during this research, the physical tracking of actual building components cannot be achieved. Still, it should be done in the future to ensure the completeness of the standardized material passport protocol.

Meanwhile, due to the time constraint for this research, the proposed environmental calculator protocol excludes information such as sustainability scenarios and carbon sequestration which can be conduct in future work.

Appendices

Appendix A Environmental calculator code A

```
function myFunction() {

  const folders = DriveApp.getFoldersByName("CO2");

  let e1, e2;

  // Find e1 and e2 files in the Project folder
  let fileIterator = folders.next().getFiles();
  while (fileIterator.hasNext()) {
    file = fileIterator.next()
    if (file.getName() == "BRANZ_CO2NSTRUCT_v_2.0") {
      e1 = SpreadsheetApp.open(file).getSheetByName("ALL DATA");
    } else if (file.getName() == "All Material Takesoff_") {
      e2 = SpreadsheetApp.open(file).getSheetByName("All Material Takesoff");
    }
    if (e1 != null && e2 != null) {
      continue;
    }
    Logger.log(file);
  }

  const rows = e2.getDataRange().getValues();

  e2.getRange(2, 11).setValue("Embodied carbon (kg CO2eq/quantity)");
  e2.getRange(2, 12).setValue("Embodied energy (total) (MJ (NCV)/quantity)");
  e2.getRange(2, 13).setValue("Embodied energy (non-
renewable) (MJ (NCV)/quantity)");
  e2.getRange(2, 14).setValue("Embodied energy (renewable) (MJ (NCV)/quantity)
");

  e2.getRange(2, 15).setValue("Total Embodied carbon");
  e2.getRange(2, 16).setValue("Total Embodied energy (total)");
  e2.getRange(2, 17).setValue("Total Embodied energy (non-renewable)");
  e2.getRange(2, 18).setValue("Total Embodied energy (renewable)");

  for (let index = 2631; index <= rows.length; index++) {
    try {


      let LCAQuickMaterialCode = rows[index][4];
      let MaterialVolume = rows[index][9];

      let findCode = e1.createTextFinder(LCAQuickMaterialCode).findNext();
```

```
      let row1 = findCode.getRow();
      let col1 = findCode.getColumn();


      let embodiedcarbon = e1.getRange(row1, col1+3).getValue();
      let total = e1.getRange(row1, col1+4).getValue();
      let non_renewable = e1.getRange(row1, col1+5).getValue();
      let renewable = e1.getRange(row1, col1+6).getValue();

      e2.getRange(index + 1, 11).setValue(embodiedcarbon * MaterialVolume);
      e2.getRange(index + 1, 12).setValue(total * MaterialVolume);
      e2.getRange(index + 1, 13).setValue(non_renewable * MaterialVolume);
      e2.getRange(index + 1, 14).setValue(renewable * MaterialVolume);

      Logger.log("Index " + index + " Finished");
    } catch (e) {
      continue;
    }
  }

}
```

Appendix B Environmental calculator code B

```
function myFunction() {

  const folders = DriveApp.getFoldersByName("CO2");

   const resFolder = DriveApp.getFoldersByName("Please upload Material takesof
f data here (File responses)").next();


   let e2File = resFolder.getFiles().next();
   let folderBId = resFolder.getId();

   let e2FileId = e2File.getId();
   var xBlob = e2File.getBlob();
   var newFile = {
     title: 'Material_takesoff_converted',
     parents: [{ id: folderBId }] //  Added
   };
   file = Drive.Files.insert(newFile, xBlob, {
     convert: true
   });
   Drive.Files.remove(e2FileId);

   let newe2File = DriveApp.getFolderById(folderBId).getFiles().next();

   let e2 = SpreadsheetApp.open(newe2File).getSheetByName("All Material Takeso
ff");


   let e1
   Logger.log(e2);

   // Find e1 in the Project folder
   let fileIterator = folders.next().getFiles();
   while (fileIterator.hasNext()) {
     file = fileIterator.next()
     if (file.getName() == "BRANZ_CO2NSTRUCT_v_2.0") {
      e1 = SpreadsheetApp.open(file).getSheetByName("ALL DATA");
     }
     Logger.log(file);
   }

  const rows = e2.getDataRange().getValues();

  e2.getRange(2, 11).setValue("Embodied carbon (kg CO2eq/quantity)");
  e2.getRange(2, 12).setValue("Embodied energy (total) (MJ (NCV)/quantity)");
```

```
  e2.getRange(2, 13).setValue("Embodied energy (non-
renewable) (MJ (NCV)/quantity)");
  e2.getRange(2, 14).setValue("Embodied energy (renewable) (MJ (NCV)/quantity)
");

  e2.getRange(2, 15).setValue("Total Embodied carbon");
  e2.getRange(2, 16).setValue("Total Embodied energy (total)");
  e2.getRange(2, 17).setValue("Total Embodied energy (non-renewable)");
  e2.getRange(2, 18).setValue("Total Embodied energy (renewable)");

  let sum1 = 0
  let sum2 = 0
  let sum3 = 0
  let sum4 = 0

  Logger.log(rows);

  rows.forEach((row, index) => {

    try {


      let LCAQuickMaterialCode = row[4];
      let MaterialVolume = row[9];

      let findCode = e1.createTextFinder(LCAQuickMaterialCode).findNext();

      let row1 = findCode.getRow();
      let col1 = findCode.getColumn();


      let embodiedcarbon = e1.getRange(row1, col1 + 3).getValue();
      let total = e1.getRange(row1, col1 + 4).getValue();
      let non_renewable = e1.getRange(row1, col1 + 5).getValue();
      let renewable = e1.getRange(row1, col1 + 6).getValue();

      e2.getRange(index + 1, 11).setValue(embodiedcarbon * MaterialVolume);
      e2.getRange(index + 1, 12).setValue(total * MaterialVolume);
      e2.getRange(index + 1, 13).setValue(non_renewable * MaterialVolume);
      e2.getRange(index + 1, 14).setValue(renewable * MaterialVolume);

      sum1 += embodiedcarbon * MaterialVolume;
      sum2 += total * MaterialVolume
      sum3 += non_renewable * MaterialVolume
      sum4 += renewable * MaterialVolume

      Logger.log("Index " + index + " Finished" + " " + sum1);
    } catch (e) {
```

```
      return;
    }


  })

  e2.getRange(3, 15).setValue(sum1);
  e2.getRange(3, 16).setValue(sum2);
  e2.getRange(3, 17).setValue(sum3);
  e2.getRange(3, 18).setValue(sum4);

}
```

Appendix C Material passport template

Material passport

Product information

- *Name: **{{Name}}**
- *Product description:**{{Material: LCAQuick Material Name/Descriptions}}**
- *Status:**{{Status}}**
- *Family:**{{Family}}**
- *LCAQuick Material Code:**{{Material: LCAQuick Material Code}}**
- *Volume (m3):**{{Material: Volume}}**
- *Count: **{{Count}}**
- *CO2 emission estimation:
- *Weight (kg):**{{Weight}}**
- LCAQuick Unit Quantity Requirement:**{{Material: LCAQuick Unit Quantity Requirement}}**
- Density (kg/m3): **{{Density}}**
- Product image URL： **{{Product image URL}}**

Pricing information

- *Item number:**{{Item number}}**
- *Supplier :**{{Supplier}}**
- *Length:**{{Length}}**
- *Unit price($NZD):**{{Price}}**
- Price per length:**{{Price per length}}**
- *Quotation date:**{{Quotation date}}**
- Quotation expiry date:**{{Quotation expiry date}}**
- *Quotation number:**{{Quotation number}}**
- Sales:**{{Sales}}**
- Payment terms:**{{Payment terms}}**
- Supplier location:**{{Supplier location}}**
- Supplier region:**{{Supplier region}}**
- Supplier website:**{{Supplier website}}**
- Product specification:**{{Product specification}}**
- Contact number:**{{Contact number}}**

Tracking:

- RFID number:**{{RFID number}}**
- Barcode:**{{Barcode}}**

Appendix D Material passport code

```
const onOpen = () => {
  const UI = SpreadsheetApp.getUi();
  const menu = UI.createMenu("AutoFill Docs");
  menu.addItem("Create new Docs", 'createNewGoogleDocs');
  menu.addToUi();

}


const createNewGoogleDocs = () => {

  // https://docs.google.com/document/d/1KJDBKM10T4uvAiQiS7sR4639xLzAfNB64xlZd
8xCTD0/edit
  const googleDocTem = DriveApp.getFileById('1KJDBKM10T4uvAiQiS7sR4639xLzAfNB6
4xlZd8xCTD0');

  // https://drive.google.com/drive/u/0/folders/1BKdZNrj3ieVWcklFKWuRltsZQS3wG
YOU
  const destinationFolder = DriveApp.getFolderById("1BKdZNrj3ieVWcklFKWuRltsZQ
S3wGYOU");

  // https://drive.google.com/drive/u/0/folders/1iBpO7vfHh7bpUOB5hinhw8u8OS1W1
ouC
  const pdfFolder = DriveApp.getFolderById("1iBpO7vfHh7bpUOB5hinhw8u8OS1W1ouC"
);

  const sheet = SpreadsheetApp.getActiveSpreadsheet().getSheetByName("Steel ta
kesoff");

  const rows = sheet.getDataRange().getValues();
  rows.forEach((row, index) => {
    if (index === 0 || index === 1) {
      return;
    }
    if (row[33]) {
      return;
    }

    const copy = googleDocTem.makeCopy(`${row[0]}`, destinationFolder);
    const doc = DocumentApp.openById(copy.getId());

    const body = doc.getBody();

    // const date = new Data();

    body.replaceText('{{Name}}', row[0]);
```

```
    body.replaceText('{{Status}}', row[1]);
    body.replaceText('{{Family}}', row[2]);
    body.replaceText('{{Category}}', row[3]);
    body.replaceText('{{Material: LCAQuick Material Code}}', row[4]);
    body.replaceText('{{Material: LCAQuick Material Name/Descriptions}}', row[
5]);
    body.replaceText('{{Material: LCAQuick Unit Quantity Requirement}}', row[6
]);
    body.replaceText('{{Count}}', row[7]);
    body.replaceText('{{Material: Area}}', row[8]);
    body.replaceText('{{Material: Volume}}', row[9]);
    body.replaceText('{{Weight}}', row[10]);
    body.replaceText('{{Price}}', row[11]);
    body.replaceText('{{Item number}}', row[12]);
    body.replaceText('{{Supplier}}', row[13]);
    body.replaceText('{{Supplier website}}', row[14]);
    body.replaceText('{{Product image URL}}', row[15]);
    body.replaceText('{{Length}}', row[16]);
    body.replaceText('{{Unit Price}}', row[17]);
    body.replaceText('{{Price per length}}', row[18]);
    body.replaceText('{{Mass per meter}}', row[19]);
     body.replaceText('{{Density}}', row[20]);
    body.replaceText('{{Quotation date }}', row[21]);
    body.replaceText('{{Quotation expiry date }}', row[22]);
    body.replaceText('{{Quotation number}}', row[23]);
    body.replaceText('{{Sales }}', row[24]);
    body.replaceText('{{Payment terms}}', row[25]);
    body.replaceText('{{Supplier location }}', row[26]);
    body.replaceText('{{Supplier region}}', row[27]);
    body.replaceText('{{Contact number }}', row[28]);
    body.replaceText('{{Product specification }}', row[29]);
    body.replaceText('{{RFID number}}', row[30]);
    body.replaceText('{{Barcode}}', row[31]);


    doc.saveAndClose();

    const pdf = doc.getAs(MimeType.PDF);
    const pdfFile = pdfFolder.createFile(pdf).setName(row[0] + " " + row[1]+ "
 " + row[2]);

    const url = pdfFile.getUrl();
    sheet.getRange(index + 1,32 ).setValue(url);

    // Logger.log(row)
  })
```

```
  // Logger.log(rows);
}
```

Appendix E Quotation from supplier Steel&Tube

steel&tube

QUOTATION

68 Stonedon Drive
East Tamaki
AUCKLAND 2013

Phone +64 9 2737610
Fax +64 9 2731470

Quotation To	Delivery Address		
Cash Trade SH-AKL Auckland - 68 Stonedon Drive East Tamaki AUCKLAND 2016	Cash Trade Collection **Collection** East Tamaki AUCKLAND 2016	**Account Number**	2004213
		Quotation No	QT00737060-1
		Quotation Date	1/11/2021
		Quote Expiration	8/11/2021
		Customer Ref	Summer Material Stock Check
		ETD	2/11/2021
		Payment Terms	Due Immediately
		Sales Person	Scott Mosley
		Project ID	
		Page	1 of 1

Item Number	Description	Width	Length	Quantity		Unit Price		Amount
P0002358	200mm x 75mm Channel G300 AS/NZS 3679		6.000	1.00	ea	82.0213	m	492.13
P0001701	180mm x 75mm Channel G300 AS/NZS 3679		6.000	1.00	ea	74.8240	m	448.94
P0008174	150mm x 75mm Channel G300 AS/NZS 3679		6.000	1.00	ea	63.3693	m	380.22
P0035317	100mm x 45mm Joist G300		9.000	1.00	ea	542.8925	ea	542.89
P0061331	75mm x 75mm x 5mm Mill Finish C350L0 NZS SHS AS/NZS 1163		8.000	1.00	ea	44.3417	m	354.73
P0035871	200mm x 25kg Universal Beam G300 AS/NZS 3679		6.000	1.00	ea	89.7864	m	538.72

Subtotal	2,757.63
Total Charges	0.00
Net amount	2,757.63
GST	413.64
Total (NZD)	3,171.27

____

Steel & Tube Signature

Bank Account: ANZ Bank A/C 01-0607-0023700-00
Please use **QT00737060-1** as your reference

____

Customer Signature

I accept this Quotation in accordance with its Terms

A 2% credit card surcharge will apply if paying by credit card

All orders are subject to additional shipping and handling charges, which may not be displayed on this Quotation. For more information about these

Appendix F Quotation from supplier Steelhaus

Thanks for your enquiry, at this stage we can only price the 0.95 and 0.75mm, we are unable to price for the 1.15mm

89 S41-095-500 (400pc), - $15,920.00 +GST ($7.96/m)

89 S41-075-500 (947pc). - $31,582.45 +GST ($6.67/m)

Please contact me if you have any questions.

Kind Regards,

Michaela Thompson

Office Manager

P: 09 972 2124 I M: 027 333 0188 I 12 Hautu Drive, Wiri

STEELHAUS
Creative I Strong I Cost Effective

EZYJOIST™
STEEL FLOOR JOIST SYSTEM

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