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AFFORDABLE HOME SOLUTIONS.

Z. TAYLOR | 2022

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Budget Builds: Affordable Home Solutions.

by

Zachary Taylor

A thesis submitted to Victoria University of Wellington in partial fulfilment of the requirements for the degree of Master of Architecture (Professional).

Victoria University of Wellington

2022

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The following thesis is part of the Advanced Manufacturing and Prototyping for Design Research Lab. AMPD aims to investigate and define innovative techniques and methods of modern construction applicable to the architecture and construction sector through the use of advanced tools of design, fabrication, and manufacturing. The fourth industrial revolution is core to our research exploring methods of improving information flow from design to fabrication—across the digital continuum—to design architecture that builds wellbeing for people and the planet. We can't keep doing what we have always done—our research questions the status quo by designing and constructing prototypes. You should consider the thesis within the larger body of research that AMPD Research Lab undertakes. Each thesis has focused on an aspect of AMPD's aim.

ampd
Research

Figure 1. buildaBlock concept dwelling (a).

Abstract.

Affordable housing is becoming an increasing issue in New Zealand as current house prices are increasing expeditiously, severely affecting first home buyers with no pre-existing assets. The purpose of this paper is to rethink the way we inhabit homes by examining developing countries approaches of incremental and self-help construction to generate affordable solutions. Although successful incremental designs have been reached in a third world approach, little research shows how these ideas can benefit first home buyers in a first world context with aid from prefabrication. This paper investigates the specific context of New Zealand through a digital and physical experimental approach of design.

The resulting design proposal develops expandable homes that allow inexperienced users access to engage in self-help building methods to achieve cost reductions. Design considerations are influenced by affordability, construction, and income to develop a preliminary understanding on how the combination of incremental and self-help techniques could prove an affordable platform for first home buyers.

Analysis of the developed design highlights that a cost-effective outcome is not possible through standard forms of prefabrication. As the material and manufacturing processes chosen to allow engagement of inexperienced users was not cost-effective, additional research is found to be needed to generate an alternative solution.

Keywords.

First Homes - Modular - Affordability - Expandable -
Incremental Construction - Self-Help

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- Mum and Dad: For the constant support and wisdom.

Terminology.

The following is a list of common words found throughout this dissertation. Each definition has been tailored towards this particular project for greater understanding.

Incremental Construction
The act of partial construction-built overtime through varying stages.

Self-Help
Using one's own efforts and skills to construct, in full or part of, a building without help from professionals.

Modular
Interchangeable pieces or components of a building which can be used in a variety of construction applications.

Prefabricated
(Of a building or piece of furniture) manufactured in sections to enable quick or easy assembly on site.

Median Multiple
The ratio of median house prices to the median gross annual household income.

SIPS Panel
Structurally insulated panels designed as a complete wall system.

DIY Enthusiast
A non-professional with basic knowledge of building methods and techniques.

CNC machine
Computer Numerical Control (CNC) An automated machining tool controlled by means of computer, programmed to follow instructions to cut various sheet materials.

GFA
Gross floor area of a building. Includes all floors.

Contents.

Introduction.

The dream for many New Zealanders is to one day own their own home. Unfortunately, this is becoming more of a dream and less of a reality. Many New Zealanders are finding it harder every day to get onto the property ladder with the ever-increasing house prices that always seem out of reach.

Data supplied by the Real Estate Institute (REINZ), showed that the national median house prices had risen to $780,000 as of February 2021, an increase of 22.8% from the same time last year (REINZ, 2021). The rapid increase in prices can be linked to New Zealand's house shortage based on data supplied between the 2013 and 2018 census. The country's usually resident population count increased by 10.8% while the total number of dwellings only increased 6.2%, suggesting a shortage in housing compared to population growth (StatsNZ 2019; Ninness, 2019). A clear side effect from this data is emerging within the New Zealand population as one in three New Zealanders did not own their own homes and resorted to renting as of 2018 (StatsNZ, 2018). The concurrent data is showing that the current housing methods in New Zealand are no longer suited to the prevailing financial market. There is a need to build new homes at an affordable rate, making it easier for more people to build new, reducing the gap for supply and demand in the property market.

New construction methods need to be researched and brought to practice targeting affordability. Although the likes of prefabrication do offer some cost benefits through standardisation (Lawson, Ogden & Goodie, 2014), these savings are not substantial enough to make it an affordable solution as a one-off product. The best way to identify this issue is by focusing on others who are in a greater financial struggle. Supporting construction methods undertaken in developing countries shows the creative thinking and problem solving that occurs due to lack of financial support, resulting in resourceful outcomes (Turner, 1967). The idea of incremental housing is a construction method in which a house grows overtime based on occupancy needs and budget limitations (UN-habitat, 2005). The main benefit of this method is the initial costs associated with the building, allowing partial completion to reduce upfront construction costs (Mselle & Sanga, 2018). By incorporating aspects of incremental housing with prefabricated means could yield limitless solutions in which housing could be revolutionised within New Zealand's social conventions for first home buyers.

Question.

How can we implement strategies of incremental housing and prefabrication within a first world context to produce affordable homes?

Aims and Objectives.

The aim of this research is to generate an affordable housing solution based on an incremental construction process. This idea is to help first home buyers struggling to obtain a house with the constant increasing house prices by allowing them to start small with the option of gradual extension.

Objectives

1. Take key design strategies from self-help and incremental construction commonly practiced in developing countries.

2. Combine incremental construction with prefabrication to develop a 'clip' together design that can work under the following conditions:

    a. Must be affordable.
    b. Must be simple for inexperienced users.
    c. Quick solution to erect.
    d. Extensions must be available/possible at any given stage of the construction process.

3. Test various solutions, both digitally and physically, to identify key problems.

4. Generate a developed design accompanied by a working scale model of a part section demonstrating the construction process.

5. Generate examples of the final product showing how homes can be constructed in stages using the incremental approach.

Methodology.

Producing a resolved product that implements strategies of incremental housing with prefabricated means will require multiple methodological approaches to conduct this research. The primary approach will be using experimental means through a digital path due to its quick repetition and changeability, allowing for quick iterative designs which can be manipulated based on external data.

A design led methodology allowed for experimentation through exploring solutions and possibilities based on previous findings. This process followed the path of sketch, digital modelling, to physical models which allowed pragmatic testing to occur for issues associated with the designs. This allows greater control and understanding of the implied system to identify faults and successes when developing the final solution.

Secondary data gathering is predominately used to influence the changes through digital experimentation. Collected through quantitative means, such as multiple medians, annual household incomes, and median house prices, allows for accurate data representation linked directly to New Zealand's housing market and demand. These sources are gathered through government official websites, ensuring their reliability, to best inform the design choices through digital means.

Correlation aspects are to be included through land costs, size, and budget of the design while aspects of qualitative approaches are used in cohesion to understand people's needs within the design through an unbiased standpoint supported by the secondary data. Processing of the data was achieved by linking median house prices and the multiple median to achieve an affordable house price figure. This data examined how unaffordable New Zealand housing has become, highlighting the issues for first home buyers with no existing assets.

Existing companies refer to modular construction as expandable or scalable without showing examples of their product being able to expand outside of the design phase. This information is not direct within many of the companies, leading to the conclusion that the term expandable only refers to pre-construction. This highlights the shortcomings of post design expandability to target affordability through reduced initial costs.

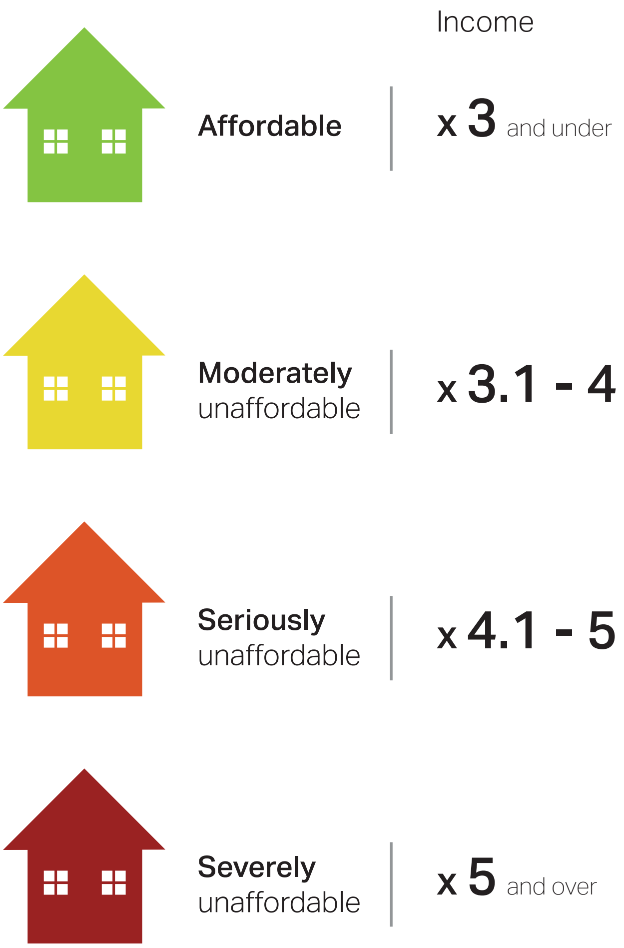
" Cheap does not mean sacrifice.
Cheap means **careful** and
considerate design choices. "

\- Author

1 The Problem.

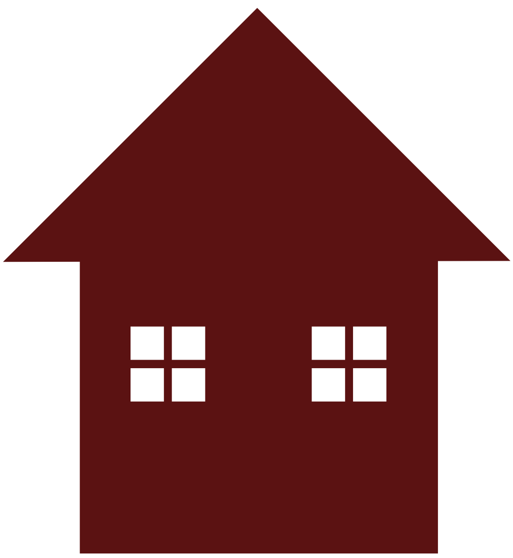
Understanding the issues surrounding housing in New Zealand.

1.1 Median Multiple.



Median multiple refers to the ratio of median house prices to the median gross annual household income and is internationally recognised under Agenda 21, Chapter 7 of the United Nations Framework (Interest.co.nz., 2021).

These figures are based on the average household income where in most cases, both parents within the household work and provide income. Comparing these statistics to those of 1974 shows the alarming increase in house prices. The median multiple in 1974 was a mere 2.6 when the average house price was only $13,000 (StatsNZ, 1974) based on an average $95 weekly wage (New Zealand History, 2018). It would be an assumption to say that most households in the 70's were living off of one income and yet the median multiple was still considered affordable. Even with both two persons working per household in 2021, the median multiple is severely unaffordable at 6.7 in New Zealand (Lynch, 2021).



New Zealand

x 6.7

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Figure 2. Anual median prices changes (REINZ, 2021).

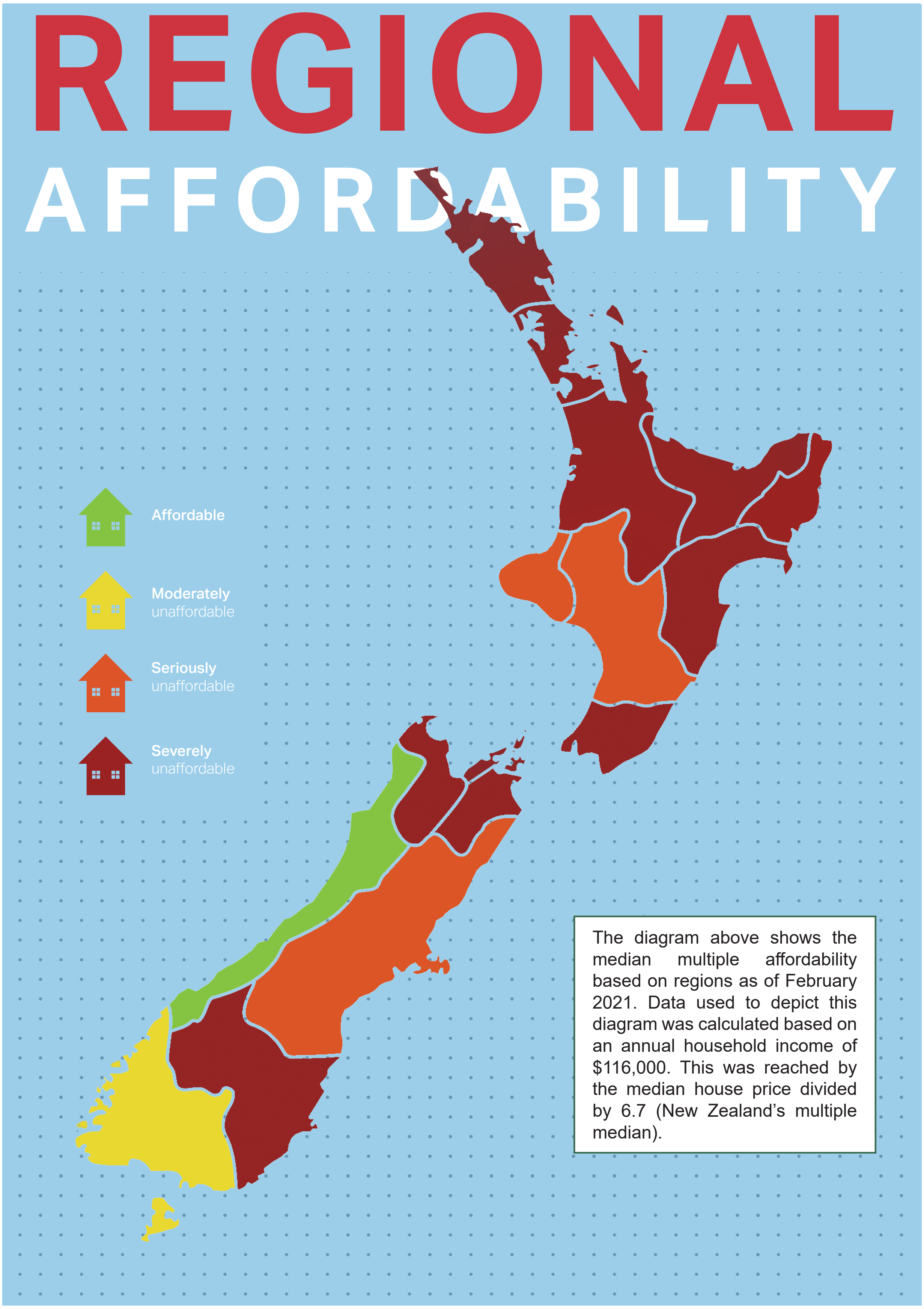


Figure 3. Regional affordability (a).

1.3 Affordable House Price.

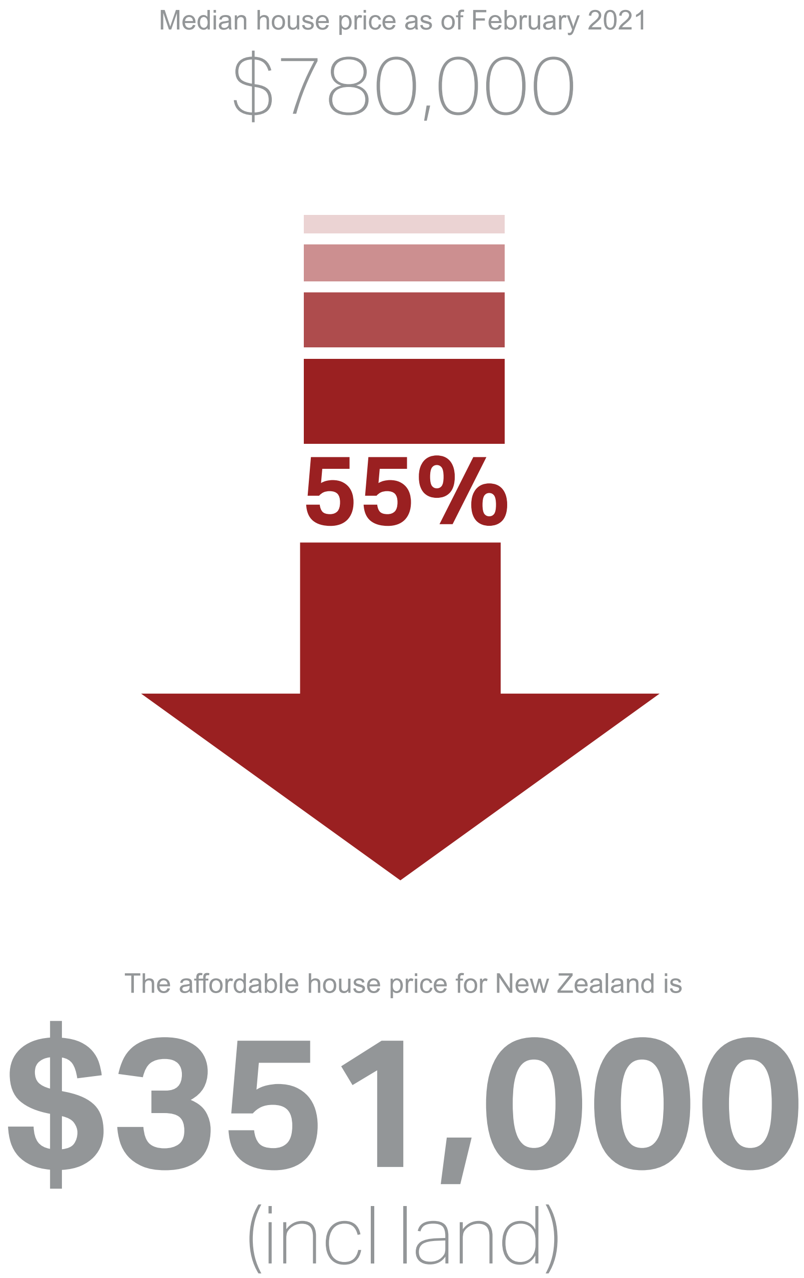


Figure 4. Affordable house price (a)

As mentioned previously, average house prices have risen 22.8% from the same time last year and are now sitting at $780,000 (REINZ, 2021). Based on the median multiple, in order to achieve affordable housing in New Zealand, house prices must drop 55% (Lynch, 2021). In order to achieve an affordable outcome, construction of housing will need to drop drastically as the likelihood of land decreasing in value is minute. It is understood that achieving the “affordable” house price based on New Zealand statistics is very unlikely, however, the aim of this research is to achieve a similar cost with the initial stage of incremental construction.

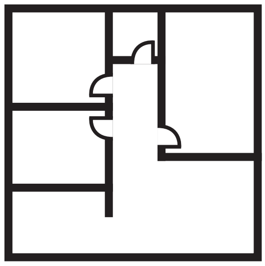
1.4 House Size.

Based on data supplied by StatsNZ, in 1974, the average house size was almost half the size of 2010 where it reached its peak (2020b). Why is this? It could be a number of things

- *Peoples wants vs needs.*
- *Higher expectations in houses*
- *We are more materialistic (we collect more objects).*
- *We spend between 84-100% indoors or at home (Chicca, Vale & Vale, 2018).*

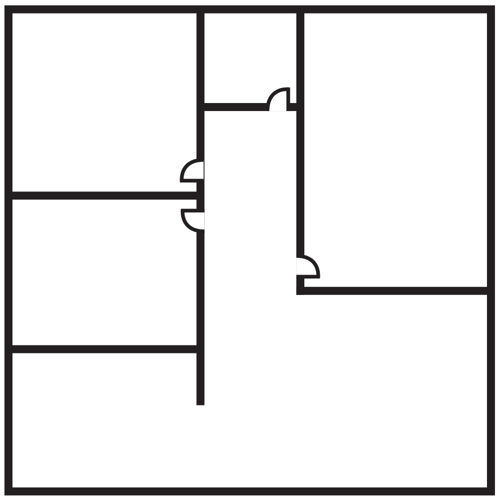
These are all contributing factors as to why houses got larger, but why the sudden shift in houses getting smaller? 200 square metres for an average house occupancy of 2.7 in 2010 is excessive, however, with the average house occupancy unchanged since 2006, floor areas continue to drop (StatsNZ, 2020a). There are multiple reasons for this change, a list below helps understand why the shift in size has occurred.

- *House costs are greater*
- *Land value has increased meaning smaller blocks of land are more appealing.*
- *2019 showed that "over 50 percent of all homes consented in Auckland were multi-unit homes, compared with a low point of about 16 percent in 2010" (StatsNZ, 2020b, para. 7). These "accounted for over 40 percent of all new homes consented in New Zealand in 2019" where the floor area of a multi-unit averaged 100 square metres (StatsNZ, 2020b, para. 6).*



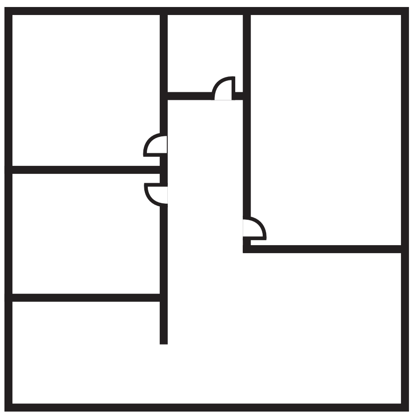
NZ 1974

109m²



NZ 2010

200m²



NZ 2019

158m²

Figure 5. House sizes by year (a).

1.5 **Cost Comparison** New vs Old.

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APOLLO 139

This is the smallest three-bedroom design offered by GJ Gardeners as of May 2021 and is already peaking at the affordable house price limit with a price estimate for Manawatu/Horowhenua of $320,000 - $360,000 (G.J. Gardner Homes, n.d.). On top of this cost is land. A current new subdivision in Levin, down Roslyn Road, has 700 square meter sections available for $330,000 as of May 2021. This would therefore put an estimated total build cost at $670,000.

139m^2

3

2

1

EST $670,000

Figure 6 & 7. Apollo 139 (G.J. Gardner, 2021).

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5 BEECHWOOD AVENUE, LEVIN

$110m^2$

3

1

1

Located in a quiet cul-de-sac, this small three-bedroom home is presented by Wilton & Co who are a local real estate firm in Levin. Partially renovated, this house has new carpet, vinyl wood flooring, and paint. The kitchen and bathroom both appear to be original while the rest of the house presents a modern and fresh feel internally. With one less bathroom over its new counterpart, and seemingly closed in floor plan, enquiry offers are over $589,000, which makes the price difference between old and new only 12% for homes located in the same town.

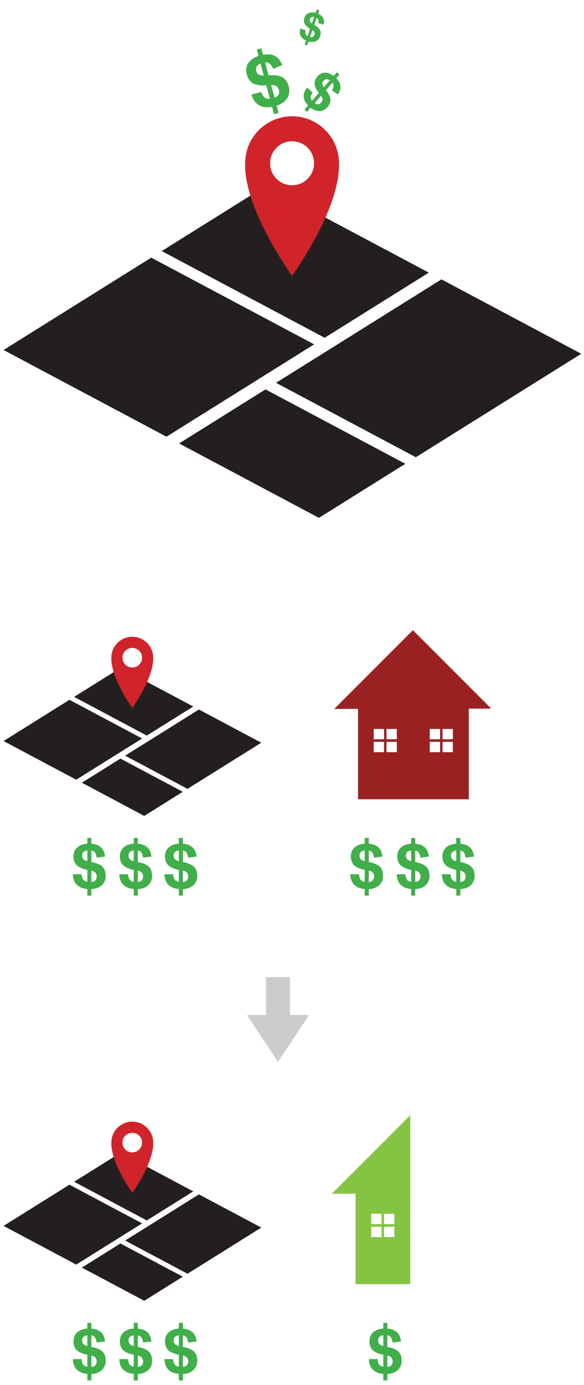
BEO $589,000

Figure 8, 9, & 10. 5 Beechwood Avenue (Wilton & Co Realty, 2021).

1.6 Summary.

What's the underlying issue with current housing construction in New Zealand?

Land value is too high



People are reverting back to building smaller due to price constraints caused by land value. The demand for housing "due to factors such as population growth, availability of mortgage credit, and tax policies that incentivise property investment" have all contributed to the rise in land value (Nunns, 2019).

What can we do about it?

Unfortunately, nothing, land is an uncontrollable variable that will never decrease in value. As a result, house sizes have decreased to cater for the uncontrollable land value. Shown by the new build example for Levin, land price equates for nearly 50% of the total build price. This example was also located in one of the more affordable regions in the north island. If a home such as the Apollo 139 by G.J. Gardeners would be located on a new site in Auckland, based on the median house price of $1.1 million, the land would equate to 70% of the total build cost.

Reducing existing house prices is something that is difficult and implausible. Reducing costs is only possible through new construction as this is the only controllable variable. By decreasing house sizes, the initial costs associated with building new can be diminished, keeping in mind an incremental design approach will accommodate future needs of the home.

Figure 11. Land value assessment (a).

2 Preliminary Research.

Analysing key elements and components
towards developing a solution.

2.1 **Incremental Construction.**

Knowledge from third world country approaches to building can be used to benefit first home buyers in New Zealand. Incremental housing highlights advantages where the self-help process contributes towards affordable approaches. While there has been much research on incremental housing to support low financial groups in third world countries, few researchers have taken these principles to benefit first world problems. In conjunction, the use of modular and incremental architecture has not been explored. This literature review examines how building practices from developing countries can aid in generating accessible housing within first world countries. Additionally, it illustrates how modular construction paired with incremental design can generate cost effective solutions that are not limited to growth.

Self-help and affordability

First developed after the First World War, incremental housing was a response to the severe housing shortage in Europe (Marinovic, 2020). The gradual building process allows for “partial habitation of completed portions of a house under construction” (Mselle & Sanga, 2018), acknowledging cost savings through self-help building and minimum standards (Joon, Lim, Kim & Wang, 2019; UN-habitat, 2005; Bangdome-Dery, Eghan & Afram, 2014). Due to the gradual building process, initial building costs seem cheap in comparison to normal construction but the total costs can be higher by 25% (Alananga, Lucian & Kusiluka, 2015). Although costs are greater, the flexibility of construction costs spread overtime reduces the impact on household's budgets.

Guidance

As this method of construction is not ‘planned’ from the start, many of the additions are poorly implemented into existing designs which are often partly demolished, creating material wastage (Tariq, 2011). It is clear that expertise involvement in incremental housing would generate a more successful outcome due to the low quality and wastage of materials that occurs without supervision in third world countries.

Modular construction

The introduction of modular design through incremental housing would seek to improve standards surrounding the incremental construction approach. Modular construction as a whole is considered a standardised process, praised for having flexible layouts which result in economical construction (Hofman, Voordijk & Halman, 2009; Murtino et al., 2010; Slawik, Bergmann, Buchmeier, & Tinney, 2010). The flexible layouts are explained by Till and Schneider (2005) as soft layouts, where one can design a “structural system that allows changes to be made at a future date”. Although written in theory, this knowledge is not utilized in practice as the term modular architecture is primarily referred to as interchangeable and autonomous within the design phase (Hofman et al., 2009). While modular construction is only flexible with the initial design, first home buyers prepare for future needs through additional rooms which may not be currently required, ultimately paying for space which is not yet inhabited. It has become common understanding that large cost savings are primarily seen by developers and not through one off solutions due to the quantity and repetition involved (Lawson et al., 2014). The lack of examples supporting the ability for additions through prefabrication methods generates uncertainty within this research.

Conclusions

This paper will help contribute towards affordable housing in New Zealand through bridging knowledge between incremental and modular construction to design an affordable solution with growth potential for first world housing solutions. With proper guidance and design, incorporating these ideas with New Zealand building standards can produce affordable housing that is appealing for a first home buyer. This research will ultimately help aid those in financial struggle who are unable to attain their first home within New Zealand’s current housing market.

2.1.1 **Incremental Timeline**

The following diagram is intended to help understand the principles of incremental building. Intended to be completed over a set period of time, the following is an example of how one building may be inhabited over a 15-year timeline.

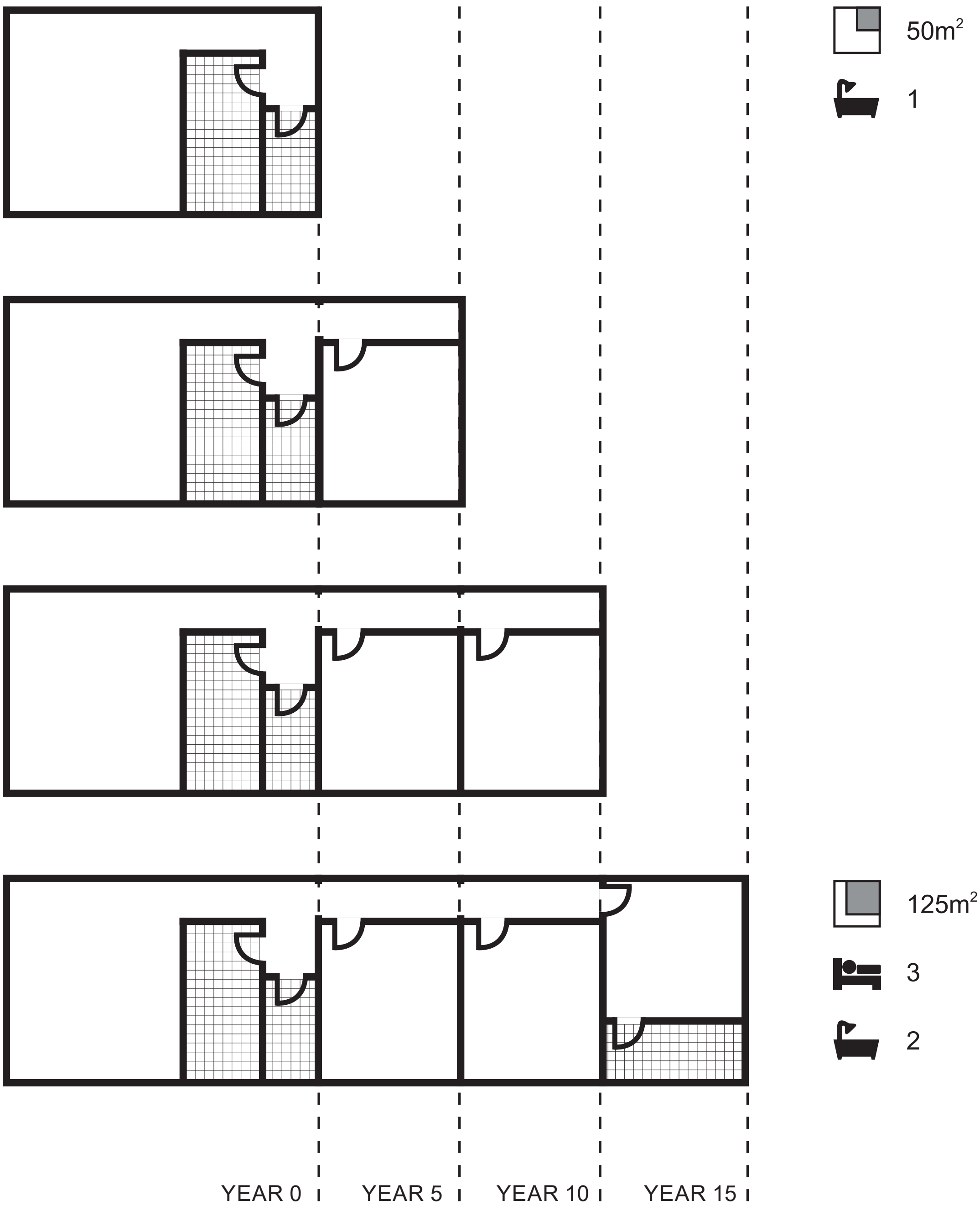


Figure 12. Example of incremental expansion (a).

2.2 **Precedent & Preliminary Studies.**

The following is a collection of precedents locally, and globally, that showcase creative and innovative designs that provide insight towards a solution of creating affordable homes. They include ideas of, but not limited to, rapid construction, incremental construction, minimal tools required, low budget, small footprints, factory built, and click systems.

2.2.1 **PopUp House.**

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Figure 13. Popup house: The affordable passive house (Nillufary, 2014).

PopUp house is a great example of utilizing the self-help approach with prefabricated means. Through its structurally insulated panels and individual timber framing, it proves an easy installation where an example house (figure 13) was fully completed within four days using basic power tools (archello, 2014). Although not directly designed to accommodate expansion, a similar approach could be used to develop and push the idea of self-help incremental construction. This approach appeals because of the simplicity of framework and construction, however, structurally this may not be suitable for New Zealand building standards.

2.2.2 **Villa Verde**

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Figure 14. Villa Verde housing (The Guardian, 2016).

Villa Verde is an example of affordability through means of semi-complete construction. Although government funded, the principle of half building is a similar pursuit to this research. This concept allows for half of the house to be occupied with the option to extend through a predetermined framework at a later date. Alejandro Arvavena used this project as a way to help those under the poverty line, acknowledging the problems and weaknesses of the current situation in Constitución, Chile (Aravena, 2014).

This is a direct response to the lack of budget allowing self-help expansion to occur through the safety net of a predetermined framework. This gives the families a sense of accomplishment and pride for building contributing to their own home. Villa Verde has successfully achieved its intended purpose, it benefits from the use of self-help and incremental construction to a degree. However, it lacks the level of customisation and flexibility that this research is trying to address.

2.2.3 **Vila Matilde.**

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Figure 15 & 16. Vila Matilde House / Terra e Tuma Arquitetos Associados (Archdaily, 2015).

Constrained by the family's finances, Vila Matilde is a low-cost solution on a narrow site in Brazil. The construction method of exposed concrete blocks act as an all-in-one wall solution, once laid the walls are complete, no finishing or future maintenance is required. The smart use of plants in the centred courtyard draws the focus away from the uniform concrete block to create a harmonious balance between structure and landscape through weight, colour, and texture.

Not only does this project meet the affordable outcome set out by the architects, but the building also has the possibility of an extension via the roof to “accommodate future demands of the family” (Archdaily, 2015). The important information from this is the concrete slab ceiling, meaning no foundation work or prepping is required to start the extension for the additional room.

The key points from this project to help benefit this research is that affordable can be beautiful with smart design and the correct balance of materials and textures. There is a level of beauty in seeing the raw, unfinished block work that allows you to see the structure of the building. These values add depth and texture to the build which further eliminates the label of ‘cheap’ associated with Vila Matilde.

2.2.4 **5x4 Artkit.**

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Figure 17. 5x4 House, (Arkit, n.d.).

A response to the extremely small inner-city sites, the 5x4 house developed by Arkit shows how lush small multi storey living can be. Built on a 20 square metre foundation, the four-storey building comprises a garage, 2 bathrooms, kitchen/dining, bedroom and outdoor deck complete with a hot tub. This particular example does not relate to affordability or incremental housing; however, it shows possibilities of how this particular layout could prove beneficial by means of vertical modular extensions. A small footprint would create predictable and repetitive layouts, paired with modular construction, this approach could see affordable outcomes.

2.2.5 **NZSIPS.**

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SMART 100 is the largest kitset house from NZ-SIPS. With a gross internal area of 102 square metres, this basic design is prefabricated in the factory and delivered to site. The overall cost of the kitsets is explained to be around 8-12% more compared to traditional timber framing, however, the construction process of using SIPS panels can erect the house envelope in a matter of days. This process can see savings of around 50% compared to regular timber framed construction (NZSIPS, 2021a).

Although it is fast to erect and has significant savings through labour costs, it is still a complete package with no room for expansion. Even with this kitset being the largest, clients are unable to expand from the 100 square metres that this delivers. Additionally, you are seeing upfront costs of $85,000 just for the panels. This does not include internal framing, external cladding, roofing materials, and window and door joinery. (NZSIPS, 2021b, para. 3).

Learning from SIPS construction, providing a strong framework for clients to build from will be integral to this research. Ensuring a quality and strong frame is in place will be vital to allow safe building practices to occur without the need for professionals.

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Figure 18. (Top) - NZSIPS smart 100 house (NZSIP, n.d. a).
Figure 19. (Bottom) - NZSIP construction make-up (NZSIP, n.d. b).
Figure 20. Right (Top) - Lockwood home (Lockwood, n.d.).
Figure 21. Right (Bottom) - The Lockwood building system (Lockwood, 2018).

2.2.6 **Lockwood.**

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Although Lockwood homes do range upwards of $330,00 for a 3-bedroom home, the main benefit Lockwood has to this project is not the price but instead some key ideas integrated within the system.

In essence, these are a large Lego set which have the potential to be built by non-professionals. The problem demonstrated with Lockwood homes from an incremental approach is the system relies on the interlocking corners. As this can only occur between two staggered pieces, expanding from this approach is not possible. However, Lockwood utilizes steel tie rods for lateral bracing which fixes the roof and walls together. If a wall was designed where expansion can occur, this system could be used in conjunction with the existing tongue and groove locking of the roof in order to extend the roof upon expansion. This will require some disassembling of fascia but otherwise no major demolition would be required.

2.3 **Case Study Review.**

The previous precedents were analysed in terms of their relevance and usefulness towards this research. Each case study was picked because of a distinct feature, helpful in pushing this research forward. Below are the key aspects derived from the precedent study:

- All of the projects have a simplistic approach, no fancy frills, just rudimentary construction.
- Cheap was associated heavier to those homes in developing countries, (Villa Verde and Vila Matilde) but this did not make for a lesser architecture. Due to the tight budget constraints, smart and clever designs were pushed further, stretching the dollar value of these homes.
- Paired with conscious material choices, this further iterates the beauty that can happen with cheaper products.
- The self-help technique proves to be an efficient and affordable means of construction for clients; however, this ability needs to be simplified through its construction method with an appropriate design and construction component to work for New Zealand regulations.
- To meet the goal of an affordable home, the construction has to be easily erectable without the need for specialist tools.

Self-help approach for budget considerations

No specialist components or tools

Affordable does not mean cheap

3 Design Phase 1.

Exploration of initial design considerations.

3.1 **Overview.**

The following are a procurement of initial concepts developed to understand the problem and issues that are faced with incremental construction. Functionality is the main driving factor which will show weak areas where improvements and further development is needed.

The designs revolve around a rating scale of 20. The higher the number, the better the design. Each concept is graded based on a point system, below is a list of scores associated with parameters which were determined based on the aims and objectives set out for this project (see page 2).

Letter	Points	Parameter
a	2	Is it quick to build/simple design?
b	3	Does it employ the self-help technique?
c	3	Is it predicted to be affordable?
d	5	Can you extend the house at any given point?
e	2	Can the house be fully closed while extending?
f	2	Can the roof be easily extended upon incremental construction?
g	1.5	Minimal product wastage.
h	1.5	Insulated/Dry/Watertight.

Rating Scale

The rating scale is shown at the end of each concept. Each of the highlighted letters represents a parameter that the particular concept achieved.

a
b
c
d
e
f
g
h

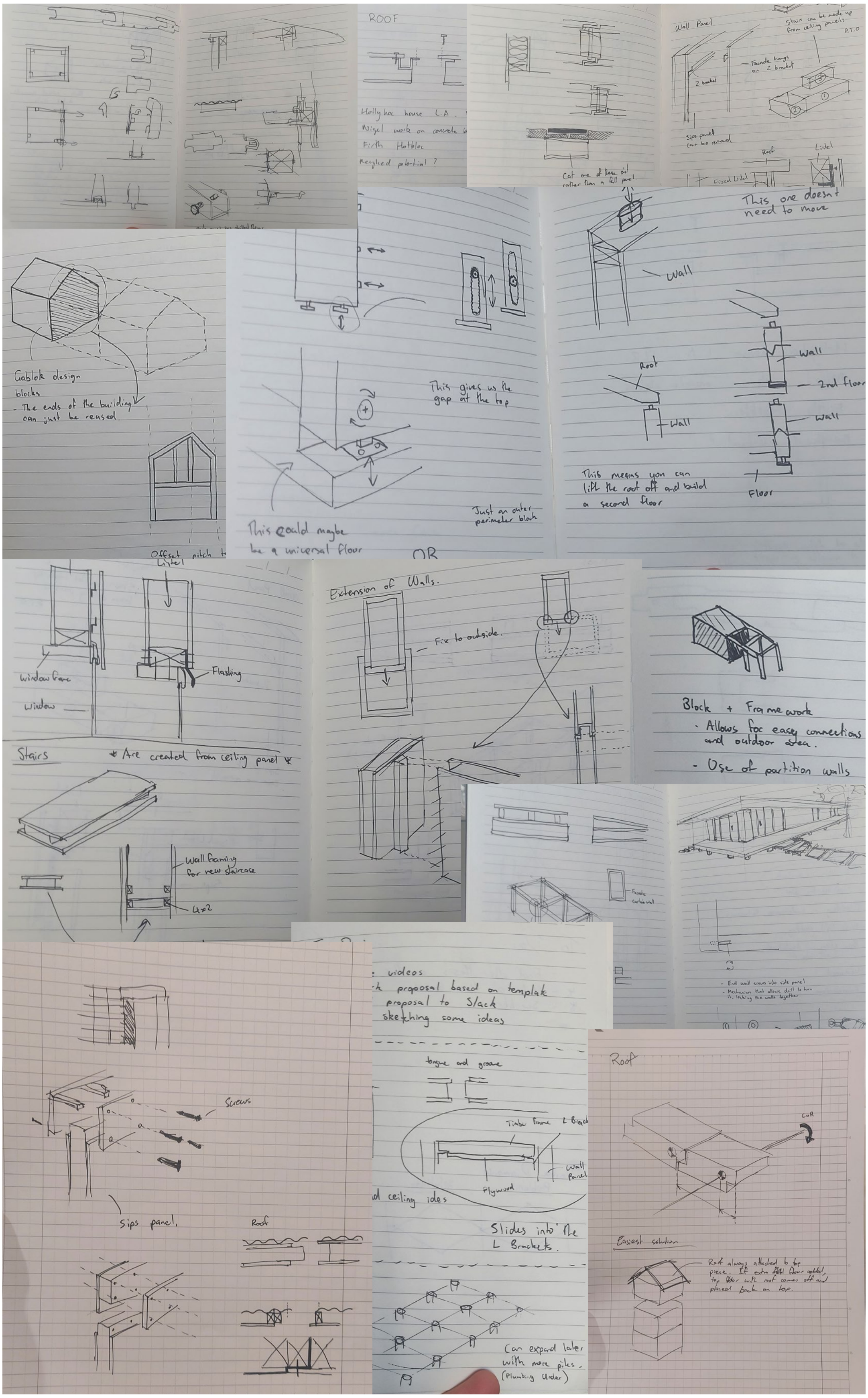


Figure 22. Sketches for potential concept ideas (a).

3.2 Initial Concepts.

3.2.1 Removable SIPS Panel.

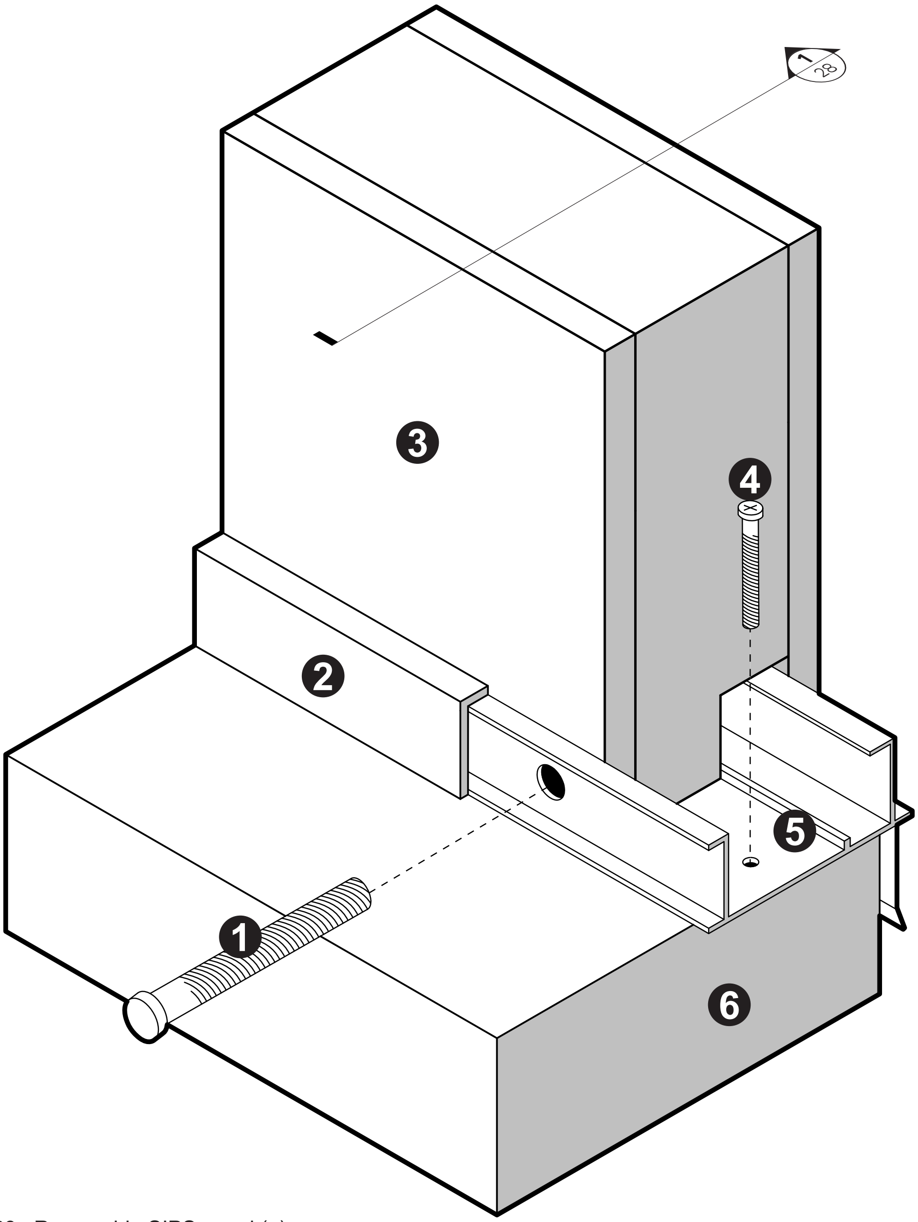


Figure 23. Removable SIPS panel (a).

Utilizing the SIPS panel, slight modifications to the base of the panel were made in order to create a removable wall by lifting it in and out of a specialized track. Additional considerations had to be made for the joining of panels to each other and corners.

1. **Bolt** – Fixes through track and panel
2. **Skirting** – Clips onto the track
3. **SIPS Panel** – Modified bottom
4. **Screw** – Fixes track to foundations
5. **Aluminium Track** – Built in waterproof flashing
6. **Foundation** – Wooden construction, (block appearance for illustrative purposes)

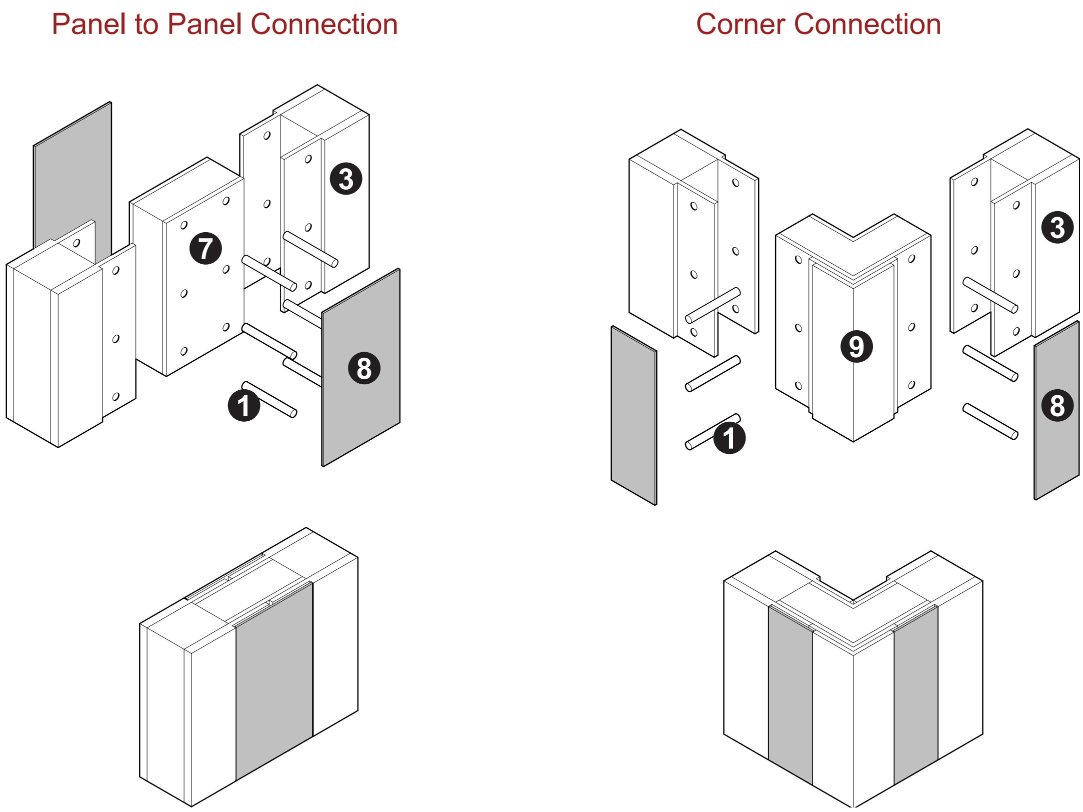


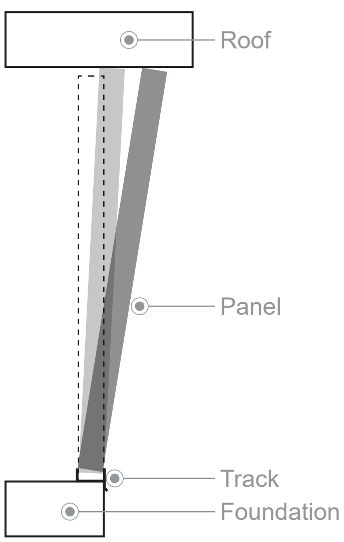
Figure 24. Removable SIPS panel junctions (a).

7 Spline
Locks in SIPS panels

8 Cover Panel
Clips on and off

9 Corner Column
Locks in SIPS panels

Section 1



Highlighting the gap required at roof for panel removal.

Pros

- To remove a wall, only the spline block needs to be cut.
- No glue is needed to support the panels as they bolted together.
- Removable cover panels

Cons

- The corners would be extremely hard to be removable, another solution for the track would need to be made for this to work.
- The walls need a gap to lift out of the track, this results in the structural walls not supporting the roof, eliminating the need for a structural wall.
- It has become very specialised with multiple remaining issues, steering away from the affordable construction that this research

RATING SCALE
11.5

3.2.2 **Removable SIPS Panel 2.0.**

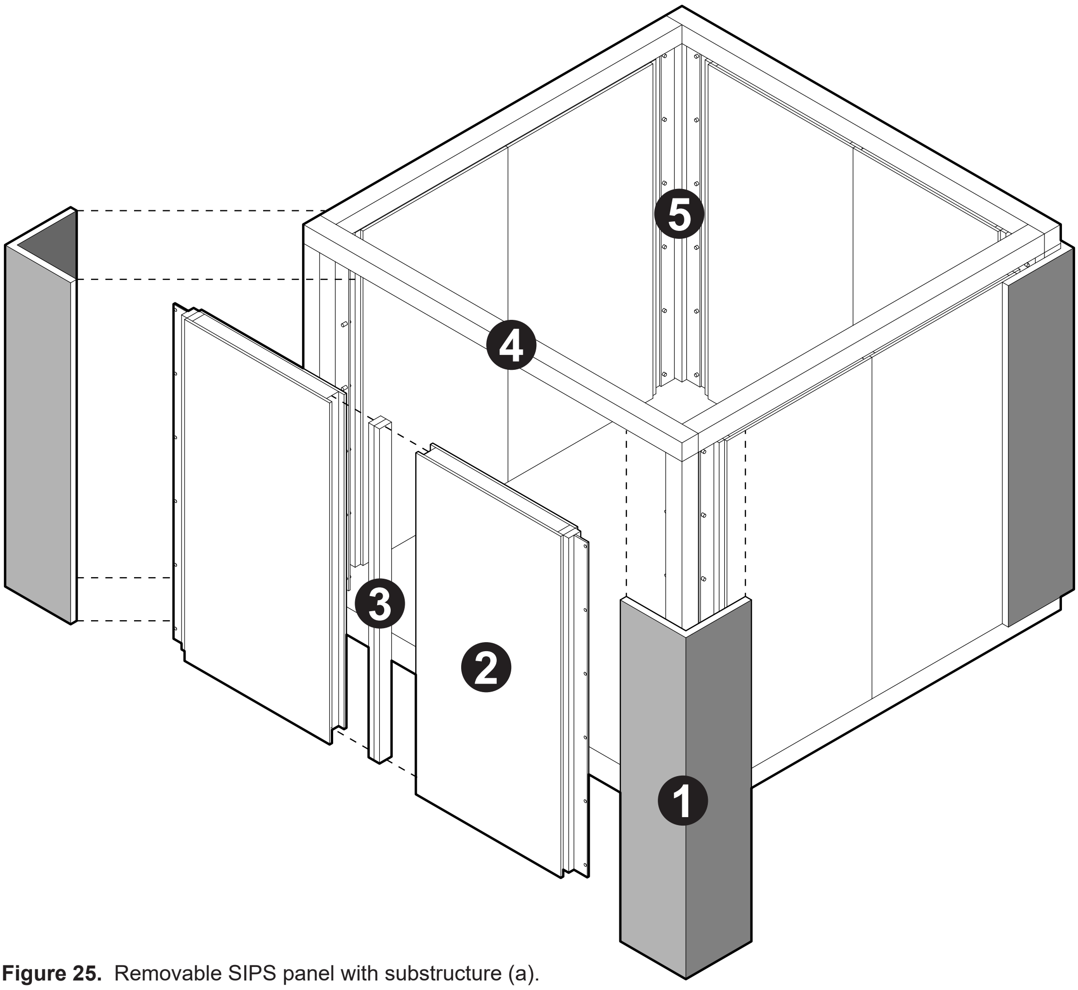


Figure 25. Removable SIPS panel with substructure (a).

Building upon the previous concept, this iteration eliminates the issue of supporting the roof by adding a post and beam structure which the panels are bolted to with steel connections on both the posts and panels. The structure is built on a square grid allowing for expansion as shown in figure 24.

1. Cover Panel
   Clips on and off
2. SIPS Panel
   Modified ends
3. Jointer
   two 4x2 for fixing
4. Structure
   Post and Beam
5. Steel Connections
   Overlapping
6. Bolt
   Fixes between the two steel connections

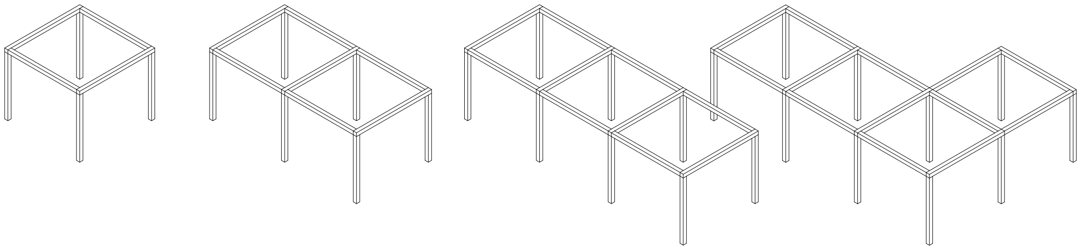


Figure 26. Incremental construction of the post and beam structure (a).

Pros

- Glueless.
- Removable cover panels are used to hide the bolts.
- Potential for incremental construction.

Cons

- Potential for columns to be located in the centre of rooms upon expansion.
- Limited to expansion on the grid
- Consists of two structural elements (expensive).
- Insulating the corners where the steel connections are located.
- Waterproofing the corners.

Note:

As this concept uses two structural elements, the structural wall panel is no longer necessary. This opens up possibilities for different solutions based on a post and beam configuration.

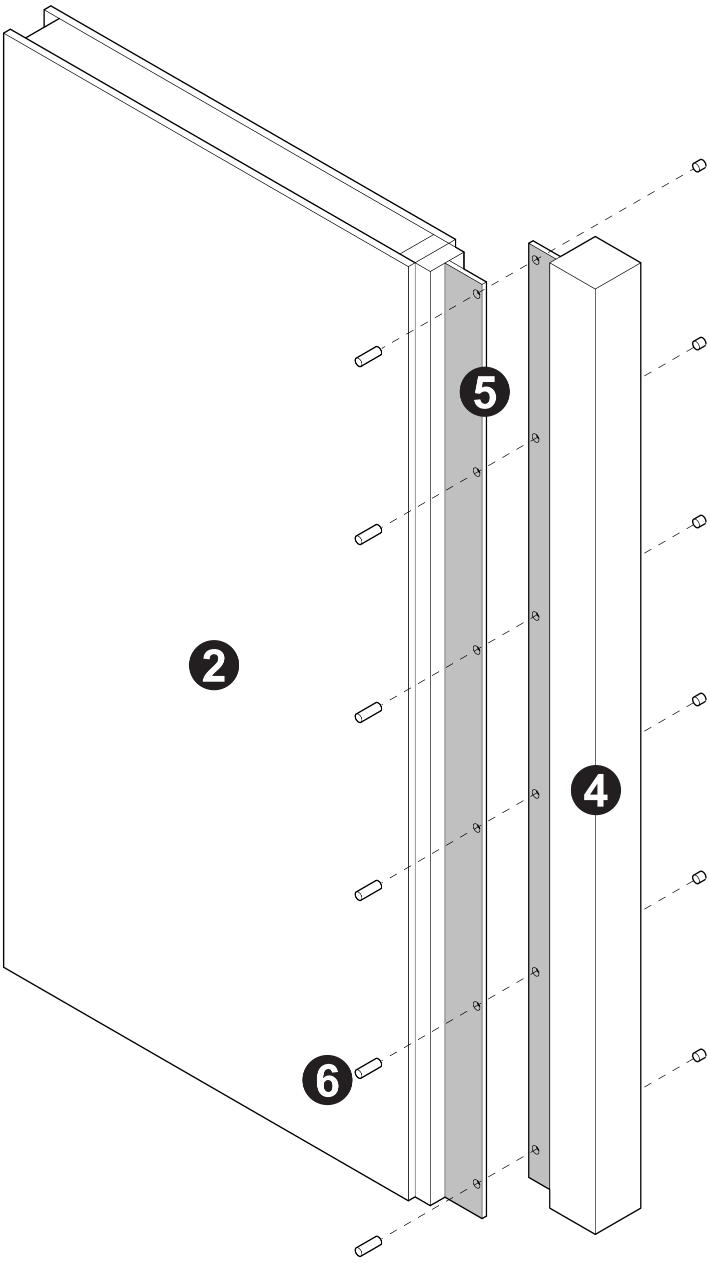


Figure 27. SIPS panel to substructure connection (a).

3.2.3 **Removable SIPS Panel 3.0.**

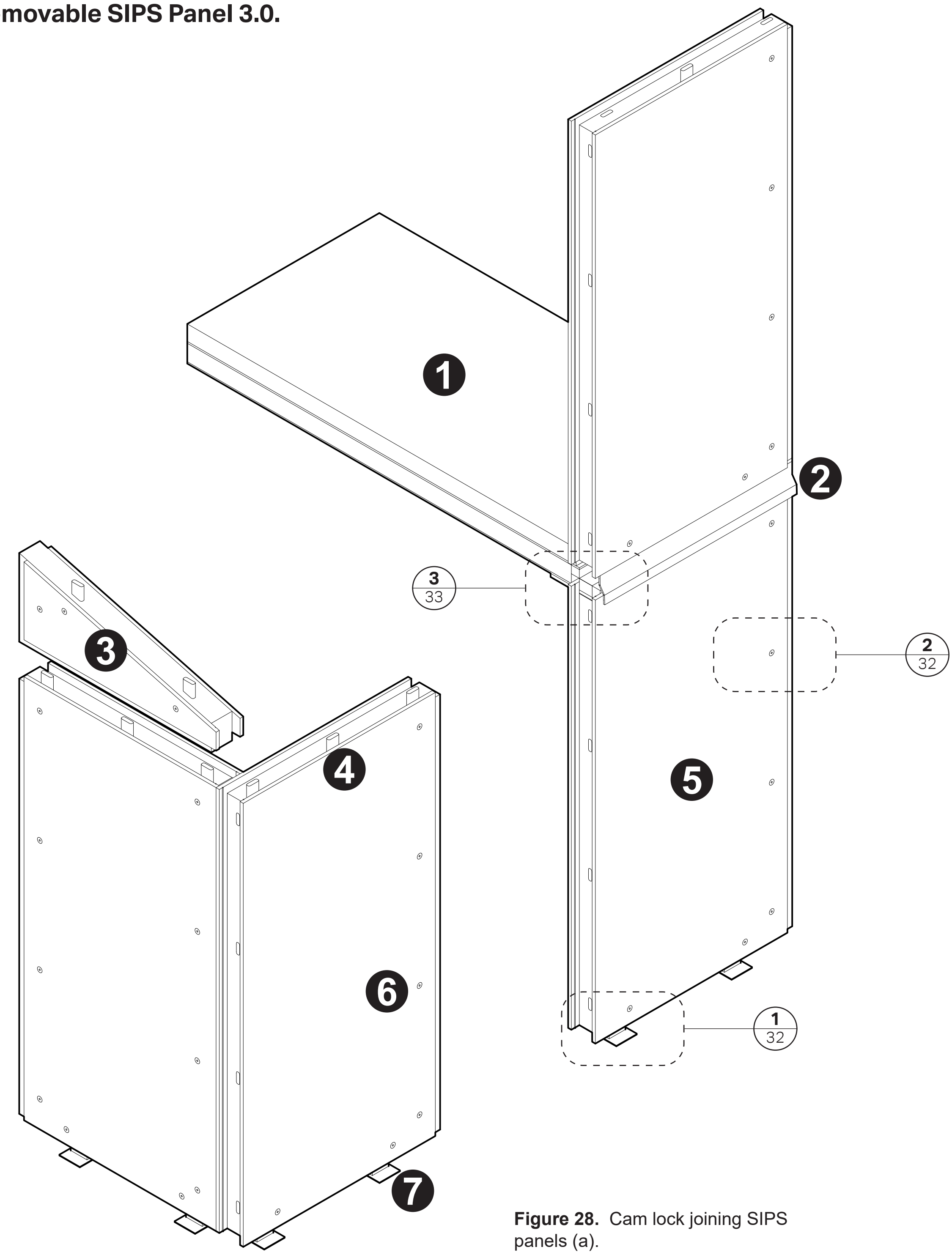
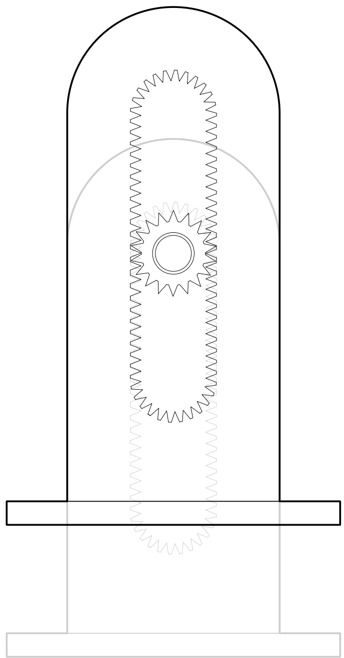


Figure 28. Cam lock joining SIPS panels (a).

This iteration addresses both issues seen in concepts 1 and 2 where the panels were not able to be used as structural components if they were to be removable. Building upon these design issues, the walls remain the structural component, eliminating the need for a sub structure underneath as shown in concept 2 as retractable feet are now in the base of each panel. This allows each panel to be put into place and then lifted up to lock in the supporting floor or roof above, removing the need for a gap as concept 1 had. The action of either removing the roof or propping it up would be required upon removal of the walls.

1. **Floor Panel**
   SIPS construction
2. **Flashing**
   2nd floor waterproofing
3. **Slope Panel**
   Creates fixing point for roof
4. **Pin Connection**
   Cam lock turned to raise a connection point locking panels together
5. **SIPS Panel**
   Modified ends
6. **Cam Locks**
   Joins adjacent panels
7. **Lifting Feet**
   Cam lock turned

Figure 29. Raise and lower feet mechanism (a).



Detail 1 7

Cam lock controlled; the feet are lifted/lowered by a gear mechanism which rotates around a toothed track. Upon being lifted, the base of the foot will require being fixed down with screws to the foundation.

Detail 2 6

Locking the panels together without a permanent solution already partially exists. SIPS already makes a cam lock panel which latches two panels together, however, glue foam is still used for water tightness in their product. A proposed rubber gasket will be used within the tongue and groove portion of each panel ensuring that once locked together, the gasket is firmly squashed.

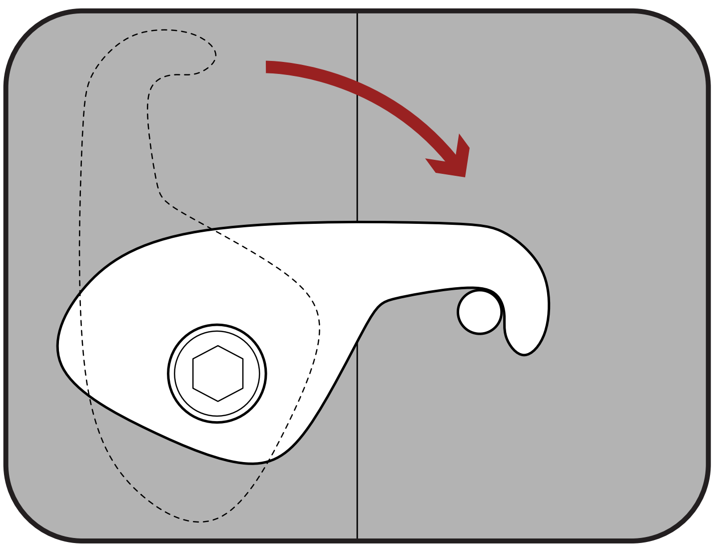


Figure 30. Cam lock control inside SIPS panel (a).

Detail 3

The construction process of the second floor will require the incorporation of a flashing. As the panels lift up and down, this will need to be inserted and fixed once the panels are in their lifted position.

The pin connections as shown are also controlled by a cam lock system. Once rotated, the pins are lifted and slot directly into the floor or roof structure above requiring no screws for locking them together.

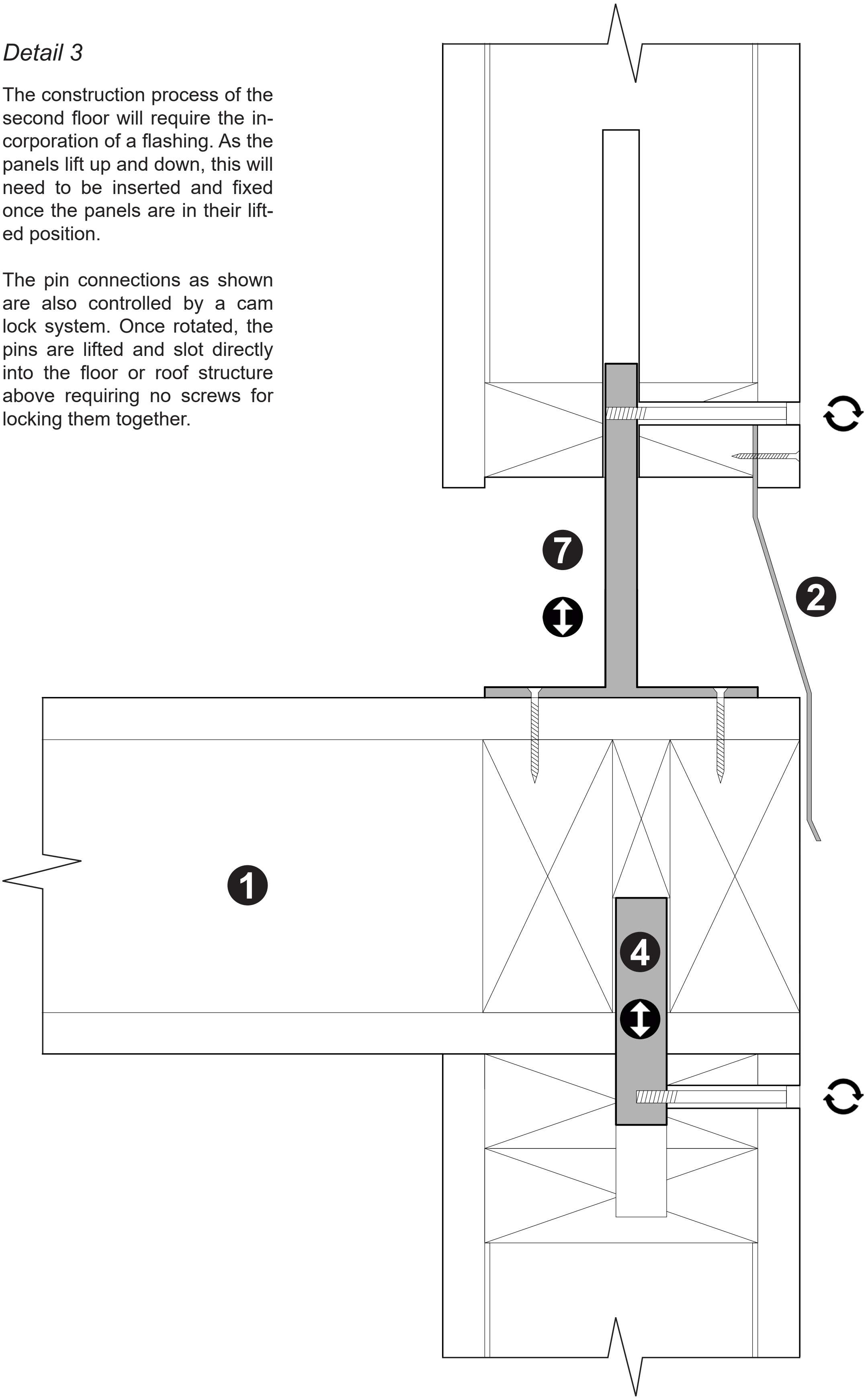


Figure 31. Locking of a second-floor panel into the wall system (a).

Additional panels for windows.

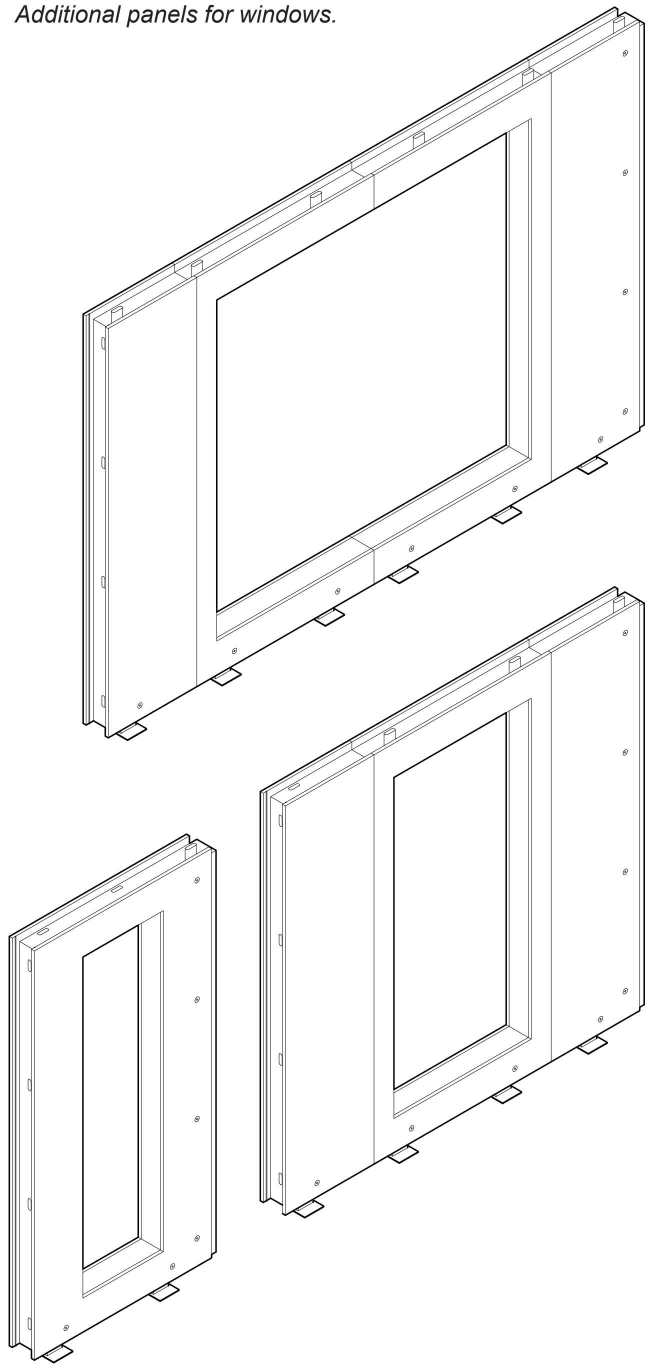


Figure 32. Additional panels for windows (a).

Pros

- Glueless.
- Easy Locking.
- One structural component.
- Incremental construction.
- No gaps (fully insulated).
- Vertical and horizontal extension.

Cons

- Roof needs supporting/removing upon extension.
- It's just modifying an existing product.
- Expansion would require the building to be open to the elements, not usable for the client.

Note:

Although explained that the initial costs seem cheap in comparison to traditional construction, the worry of this concept is that the initial savings will not be great enough to warrant using this approach. As this concept only builds upon an existing construction method, which already shows savings are not substantial enough for an affordable solution, adding these components to it will only increase the price.

RATING SCALE

13

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3.2.4 **Prefabricated Modular Boxes.**

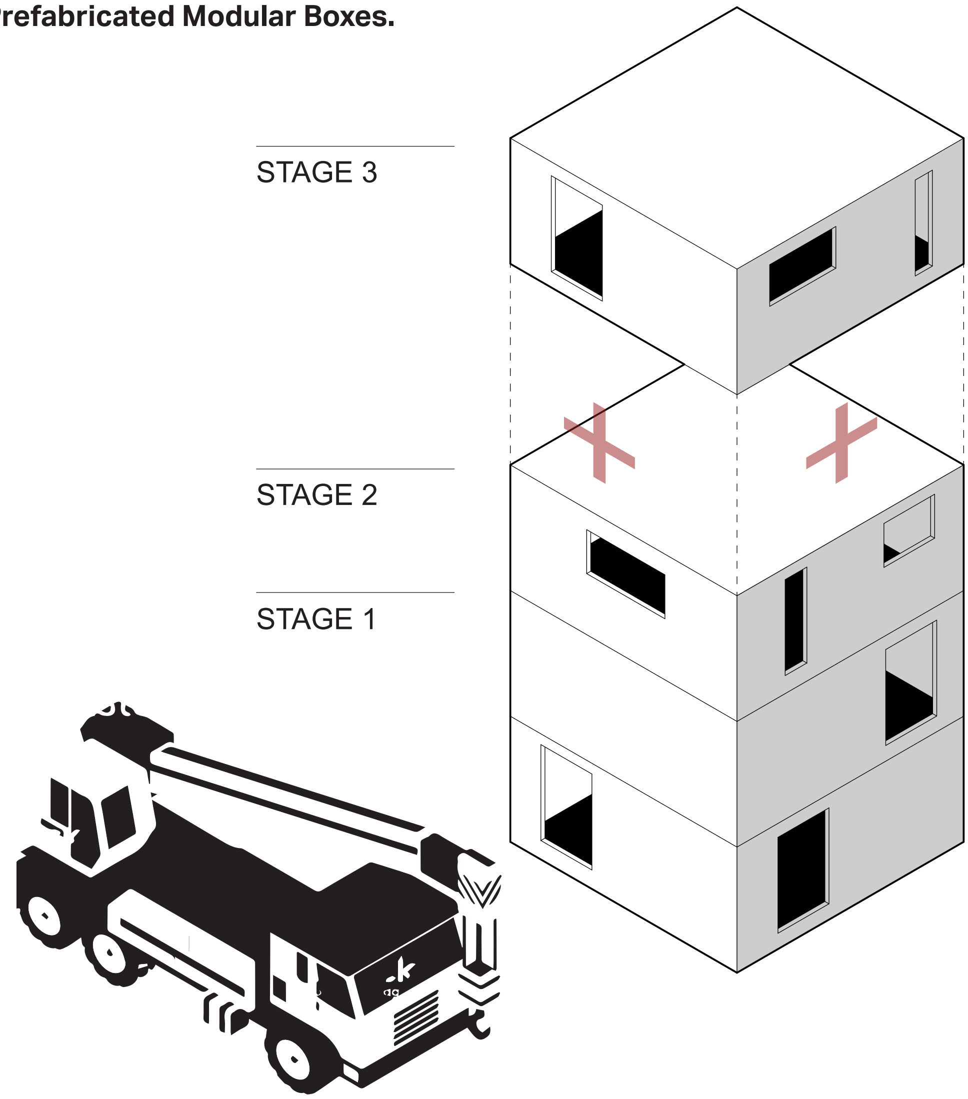


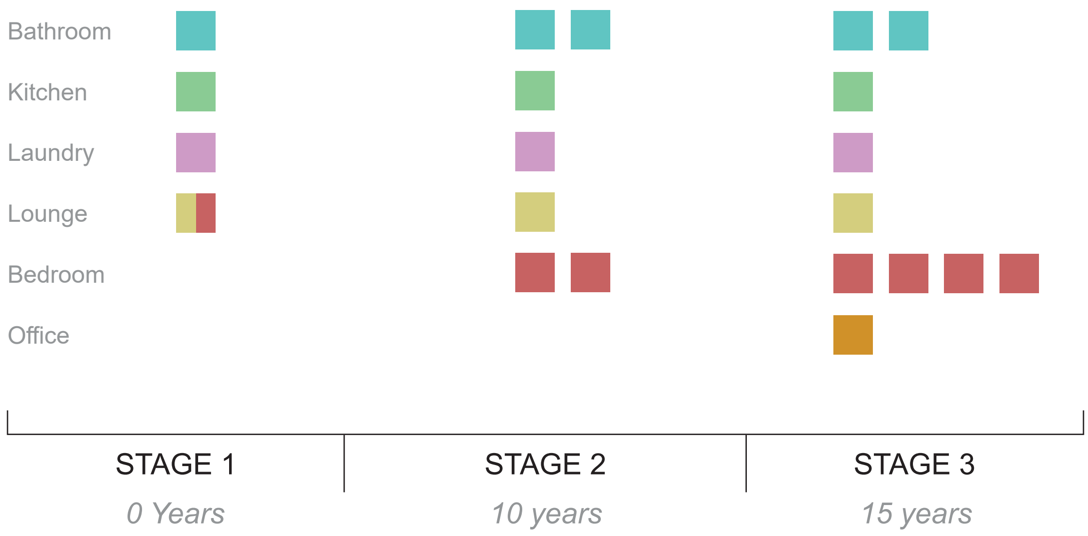
Figure 33. Modulated stacking floors (a).

This concept stems on the idea of stackable floors. Matching the incremental building approach, adding additional floors at any point would be an easy way of deriving simple floor plans that can extend any home.

Further research shows multiple companies such as Hickory Group and Urban Splash are already utilizing a similar construction method which implements stackable modules (Hickory Group, 2013), (Wang, 2016). Although not used in small residential buildings, this method of construction relies heavily on prefabrication and quantity to reduce costs through time saved on site. An example by Hickory Group (2013) shows a 63 module, 7 storey apartment building installed in just 11 days.

The reason this concept is not used for individual housing is that the benefits are primarily seen with quantity. In circumstances for high rise construction, one crane can be used over a period of 11 days to lift 63 modules compared to half a day for one module in a residential house. Using this method for incremental construction means the hire of a crane at each stage of extension, further increasing costs, making it an unviable solution. Additionally, this method also relies heavily on prefabrication, impeding on the self-help technique aimed at reducing costs.

An example of incremental layout through stages of time



Pros

- Incremental construction.
- Simple solution.
- Fast extensions as the extra floor will be fully completed offsite.
- Existing house will be untouched during extension of module.
- Vertical construction allowing for predictable and smaller footprints.
- Foundation fully completed in stage one.

Cons

- Relies solely on Prefabrication.
- Does not utilize self-help practices.

Note:

The affordable letter (c) is highlighted for the idea due to the ease of mass production of prefabricated layouts of the same sizes as well as the incremental approach of stacking.

RATING SCALE 15

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3.3 **Summary.**

The previous set of concepts were initial gatherings of thoughts and ideas put to paper. These allowed for quick testing and extending knowledge towards developing the idea of an expandable home through its construction. The key findings from the initial concept study found that utilizing a SIPS panel construction did not prove a suitable option for expansion due to the structural wall needing to support the roofing structure. This caused issues when designing the removable panels as additional structure was needed, therefore voiding the use of a structural wall panel. Additionally, a larger emphasis on clients using the self-help method would prove to reduce labour costs and the amount of prefabrication required. Many of the designs became too complex and required specialist components, whereas the designs should focus more towards a simplistic approach so a greater scope of users are able to assemble a larger portion of the home.

Moving forward, further research needs to be conducted towards how the envelope of the building will be constructed for mature enthusiasts. This should entail a simplistic approach where clients are able to frame their own homes through prefabricated components. As the frame of the house is vital in supplying a safe platform to build from, a larger focus will be conducted on how an expandable housing frame can be built with minimal building experience through the use of self-help and incremental construction methods.

4 Further Research.

New ideas.

4.1 **Precedents.**

4.1.1 **XFrame.**

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Figure 34. Galloway X-Frame Prototype Frame (XFrame, n.d. a).

Created by Ged Finch, a current Victoria University PhD student, XFrame set out to solve global housing issues. Designed with flat-pack plywood components, XFrame is easily delivered and built on-site without the need for specialist tools, glue, or nails. Composed of only 12 lightweight components, each is adaptable to create floors, walls, roof, and window/door cut-outs while also allowing the incorporation of traditional timber framing where specific dimensions are needed. Due to the limited number of components, XFrame benefits from ease of construction through its self-help approach, transportability, affordability, and reusability due to its simplistic design. This construction method was purposely designed so each component can be repurposed at the end of its intended life as they can be removed without contaminants resulting in a reusable product. This approach is known as a circular economy. Using this approach allows us to reduce the construction waste that is currently making up 50% of landfill waste in New Zealand (Inglis, 2007; REBRI, 2014).

The main drawback to the XFrame system is the complex CNC cutting required for each component. In order to achieve the interlocking pieces, multiple recesses and holes are required from each component, extending the cutting time, therefore increasing the manufacturing costs. As this system has been designed to be reused multiple times, the reusability may outweigh the costs, however, simplifying the cutting process of components could yield beneficial results for a more upfront cost-effective solution.

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Figure 35. (Left) - XFrame locking component and pin (a).
Figure 36. (Right) - X-Frame Series 5 Generic Panel (XFrame, n.d. b).

Pros

- Reusable components.
- Sustainable product.
- Lightweight.
- Strong.
- Glueless.
- Simple construction.
- Self-help.
- Modular.
- Expandable (linear).

Cons

- Requires specific roofing elements for each build.
- Complex structure which could deter some users.
- Complex CNC manufacturing process (Costly).

4.1.2 **Conceptos Plásticos.**

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Figure 37. A school constructed using recycled plastic bricks (Conceptos Plásticos, n.d.).

Bogota, the capital city of Columbia, is notorious for plastic waste where it is estimated that 650 tonnes of plastic is discarded everyday (Al Jazeera, 2017). Architect and founder of Conceptos Plasticos, Oscar Mendez, sought out to change this issue by turning plastic waste into building blocks for housing.

The plastics are heated to melting point and compressed into brick shape moulds to produce the by-product building block. Although not free, these blocks do provide a cheap housing method, complete with integrated electrical and plumbing channels.

Collection occurs with the traditional means of a recycling truck gathering waste plastic from homes but also through local recyclers. Through government support, additional recycling centres were established throughout the city of Bogota. Conceptos Plásticos (2019, para. 1) explains that "we educate and promote behaviour change in waste disposal, we involve recyclers communities in logistics and improve their income by generating value in plastics that we do not commercialize today". This project was not only to repurpose waste plastic but also one of helping those in need. These blocks go back into the community where many of the houses are constructed in Columbias slum districts.

Figure 38. Right (Top) - Corner connection (Conceptos Plasticos, 2016, June 4).
Figure 39. Right (Bottom) - Construction assembly of the recylced blocks (Conceptos Plasticos, 2016, April 1).

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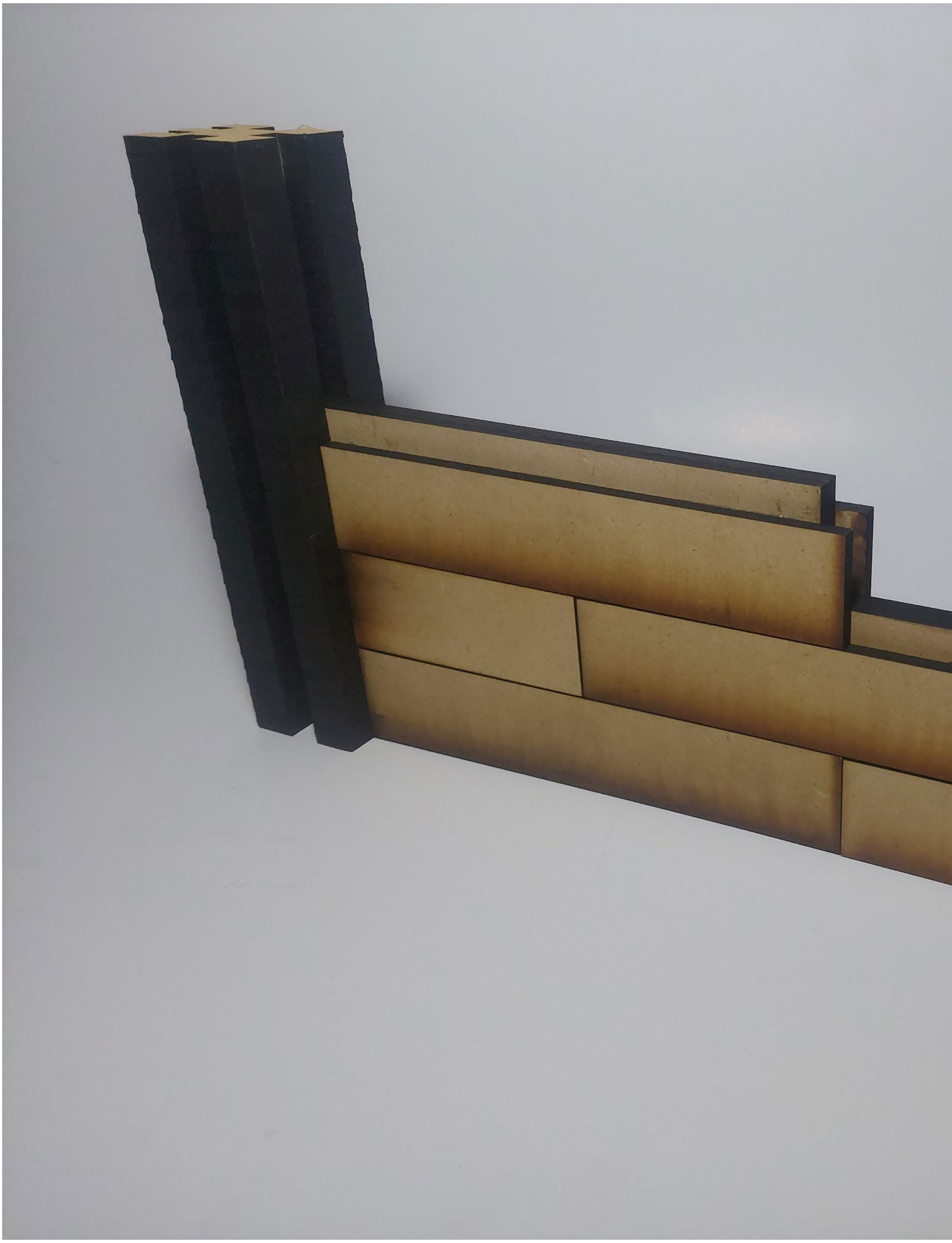
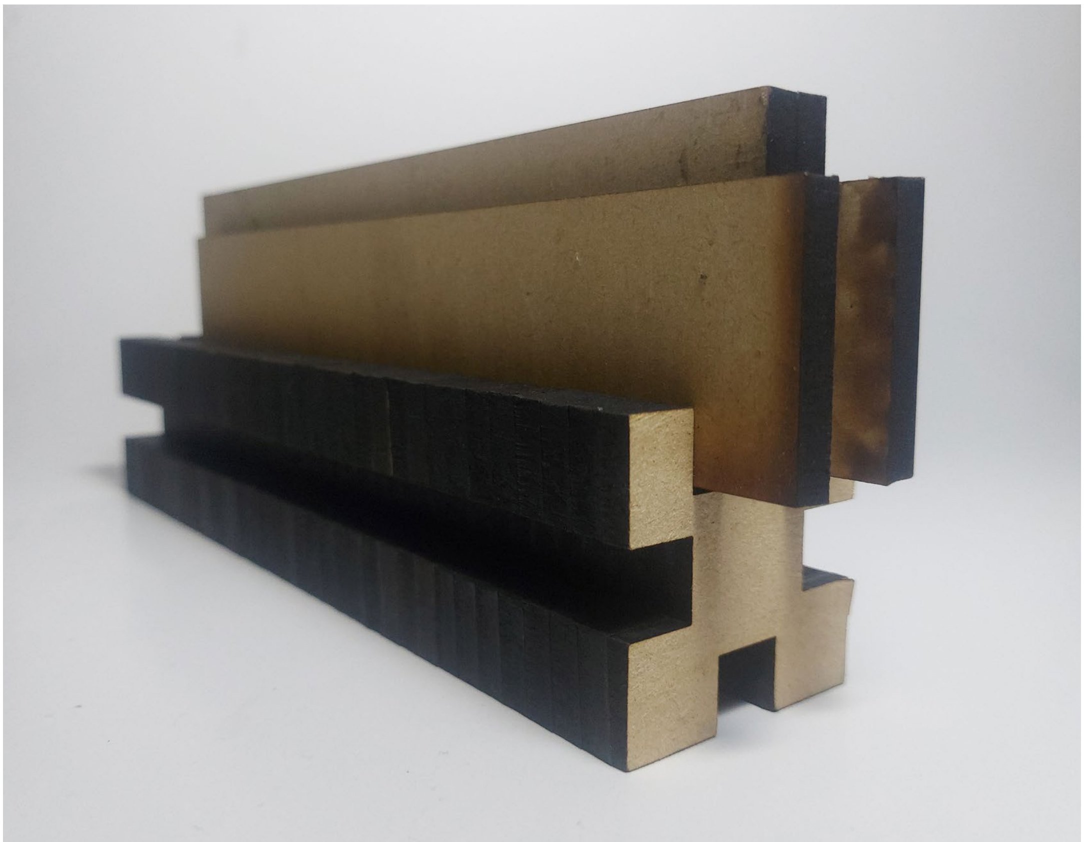
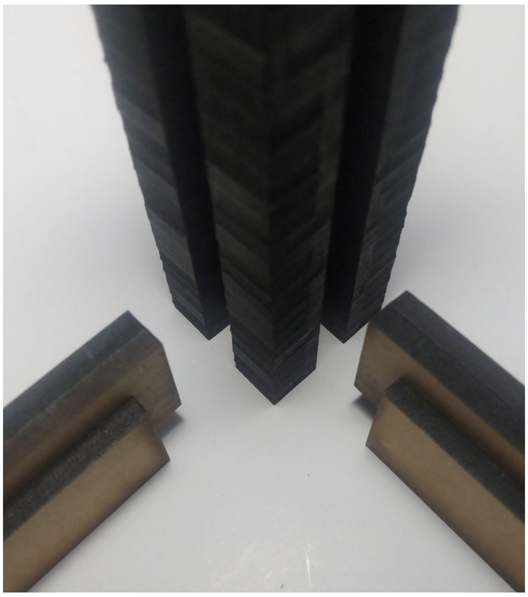
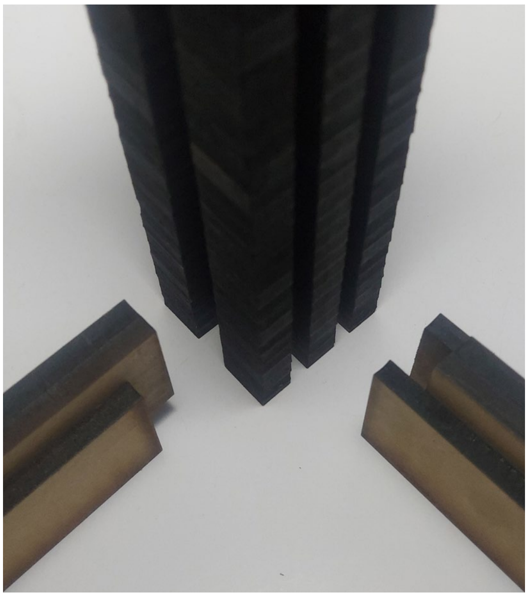


Figure 40. Physical model of Conceptos Plásticos (a).

To better understand the product by Conceptos Plásticos, a 1:3 scale model was produced to assess the constructability and usability of the connection points.

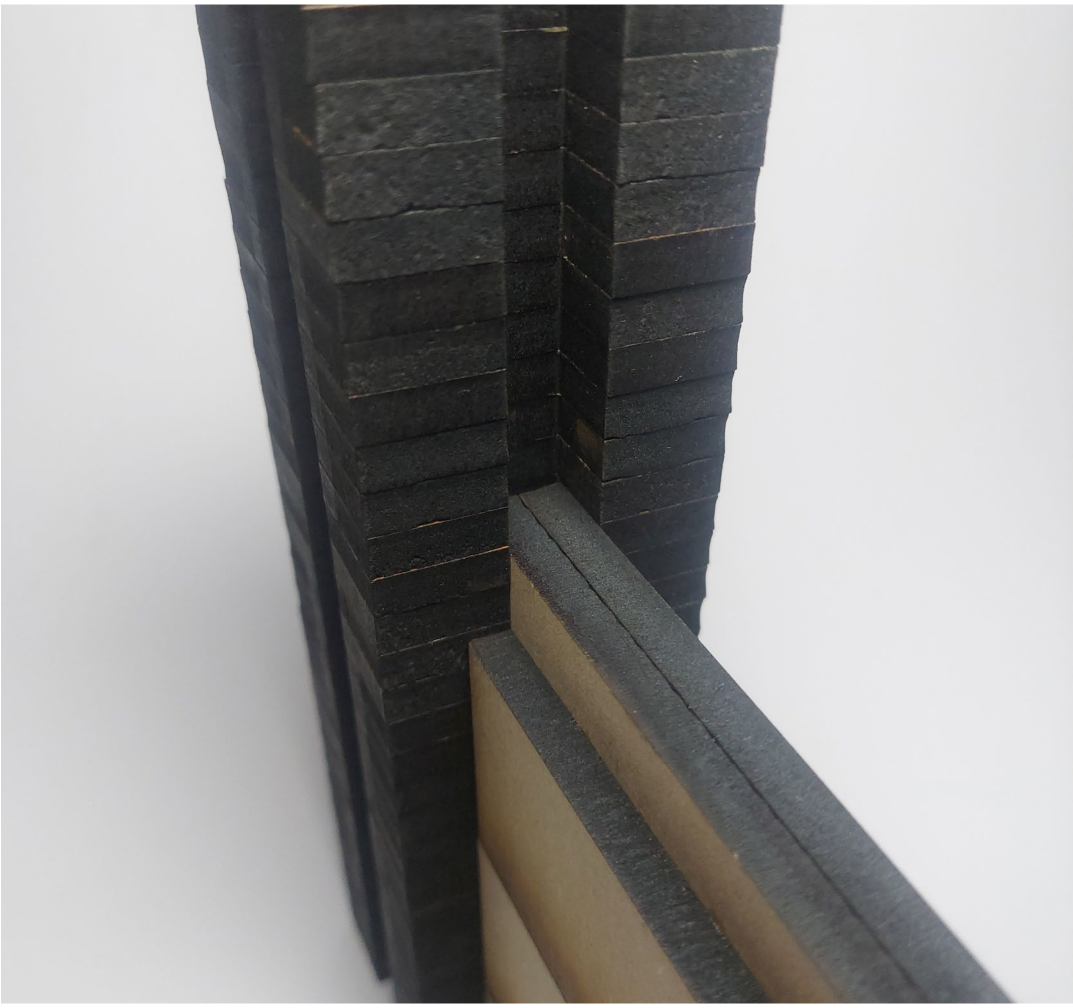






This product assembly is unique due to the multi-faced column construction. Universal in design, the column acts as three components within the build, the main vertical structure as well as the top and bottom plate. This one column interlocks a section of bricks, changeable through rotation, allowing the buildings to be built in a grid-like fashion. This four-faced design allows for maximum adaptability through one volume, ensuring simplified manufacturing processes as less fabrication of individual components is required.

Figure 41, 42, 43, & 44. Physical model of Conceptos Plásticos (a).



Pros

- 100% Recycled plastic which is melted and injected into a mould to form the shape of the blocks.
- Cheap material as it's all recycled plastic.
- Reducing plastic waste.
- Requires no glue for assembly.
- Has channels for electrical built in, similar to SIPS design.
- Strong interlocking structure.
- Easy and quick construction.
- Modular Construction
- Made for struggling families in developing countries.

Cons

- Unappealing visuals.
- Poor Insulation properties.
- Specialised roofing per building.

4.1.3 **Gablok.**

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This content is unavailable. Please consult the figure list for further details.

What looks like giant Lego blocks, Gablok utilizes a similar wedge together system relying solely on gravity, staggering, and interlocking to provide a strong structure. Each block is prefabricated, composed of oriented strand board (OSB) housing cubes of insulation within each bay, to allow for ease of construction. The cube insulation provides the interlocking strength while allowing a seamless insulation top to bottom. The building blocks have undergone rigorous testing and comply with structural, acoustic performance, and energy-efficient standards (Gablok, 2020). With the option for self-build, Gablok does allow users the option to build the outer shell themselves, accompanied by plans. However, problems surrounding the roofing arise as each roof truss system is custom built specifically for each house and installation of the truss members becomes better suited to professional installers. This reduces the amount of self-help involvement that each of the users can contribute to building the home. Further investigation of roofing typologies and connection methods could see larger engagement from the users throughout the building process.

Figure 45. (Top) - Installation of Gablok blocks (Gablok, 2019, June 13a).
Figure 46. (Bottom) - House constructed by Gablok (Gablok, 2021, June 12).

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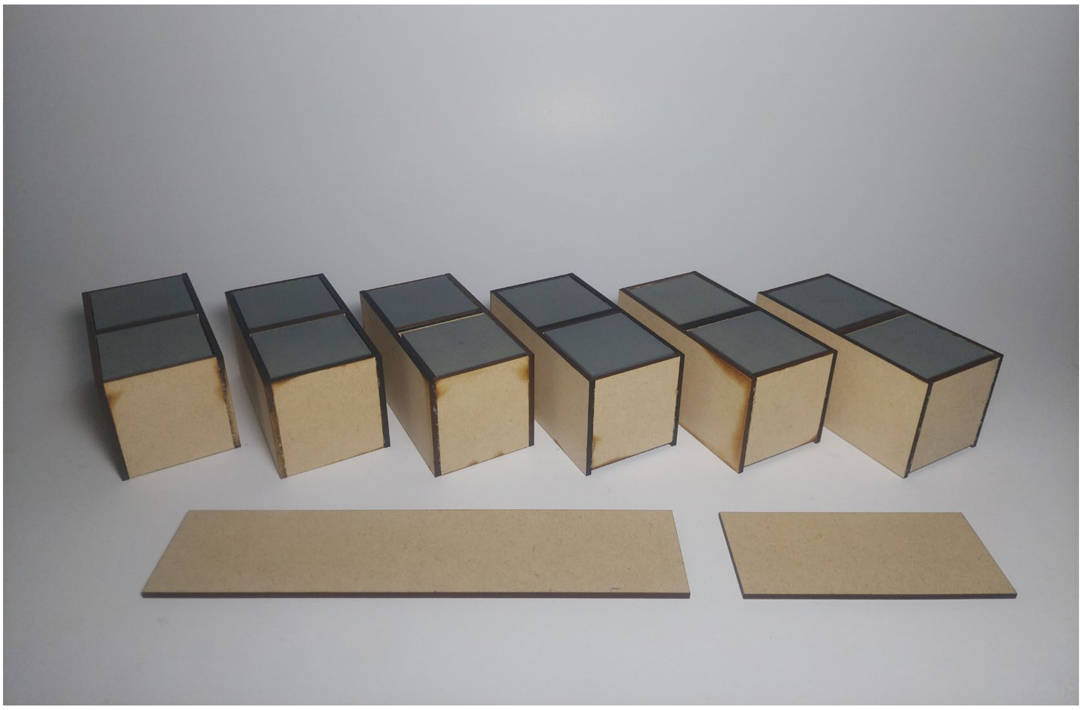
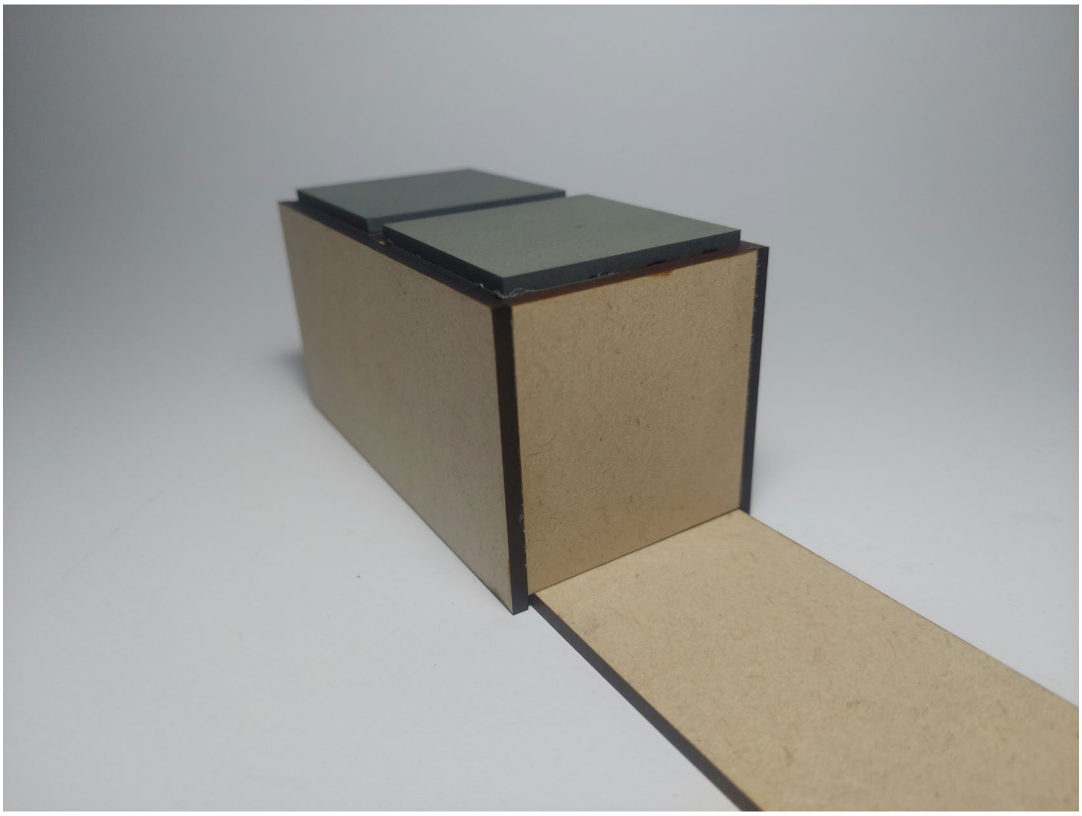
Figure 47. 8 parts and insulated blocks (Gablok, n.d.).

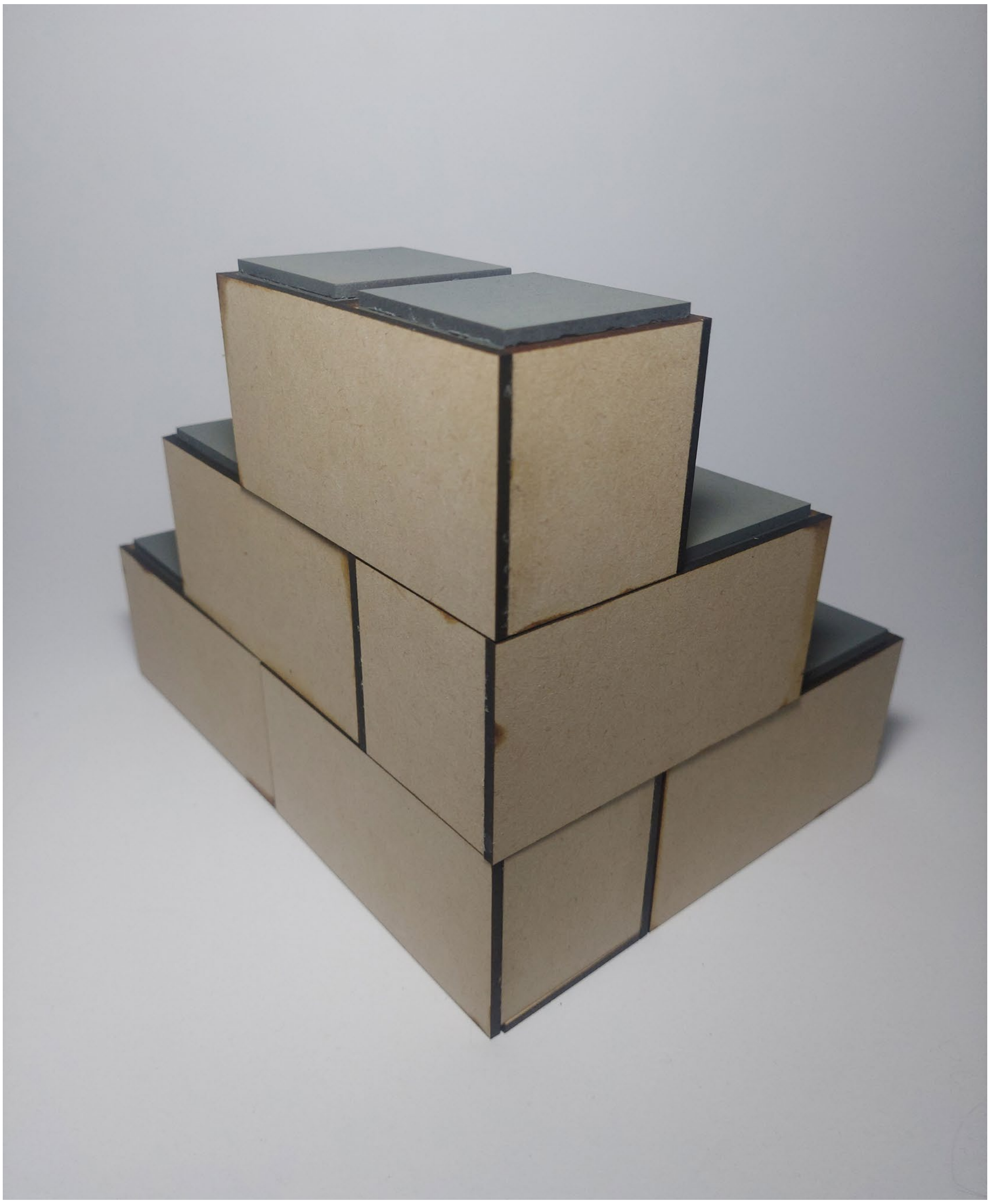
Above is a collection of the building blocks that make up the walls and flooring structures. Each block is lightweight, allowing for ease of construction for any person.





To better understand the product by Gablok, a 1:6 scale model was produced to assess the construction and deconstruction aspects.

Figure 48, 49, & 50. Laser-cut models of Goblak's block design (a).



Pros

- Strong interlocking structure.
- Easy and quick construction.
- Self-build potential.
- Appealing end result.
- Pre-insulated.
- Minimal waste.
- Requires no glue for assembly.
- Lightweight components.
- Modular construction.

Cons

- Specialised roof blocks and trusses per building.
- Excessive material.

4.1.4 **U-Build.**

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Figure 51. U-Build construction indoors (Coolthings, 2019).

U-Build is a clever do it yourself screw together system. Almost resembling flatpack furniture in construction, this structure is built entirely out of plywood, held together by screws and bolts.

U-Build, and like the aim of this research, is focussing on the willingness of individuals to employ the self-help method to reduce labour costs during construction by giving people the necessary tools to build their own homes. The underlying principle here is that if you are willing and able to assemble flatpack furniture, then you can build your own house using U-Build. This is a case of assembly rather than advanced tool skills.

Instructions to build the house are digitally sent and act in a similar way to Lego box set manuals. The simplicity of a step-by-step instruction method broadens the spectrum of users who would be willing to construct their own home as anyone with any form of flatpack furniture or Lego experience will understand the construction process.

DIY Experience with UBuild.
Two small homes were built within 7 days, showcasing the speed of construction that the U-Build boxes present. Although fast, this was with the use of professional builders. Reducing the time of construction will still vastly reduce the overall building costs, however, the aim of this research is to target the audience willing to build it themselves. A young couple within the video file were shown building their own tiny home in 3 months with no existing building knowledge (Dirksen, 2021).

- Details were not given regarding the time it took to assemble the frame, or
- How long it took before the house was waterproof, or
- If they were working on this full time.

The construction of the U-Build boxes highlights some key issues surrounding time constraints. The face of the box acts as the internal finish and structural bracing for the homes. This creates problems when battling the weather as the frame, internal linings, and insulation have to be exposed before waterproofing the building (see figure 49). For this particular couple, they had access to a large covered barn which served as their building factory. Access to such facilities is not an option for many people therefore making this method of construction more difficult for DIY enthusiasts.

Additionally, the CNC cuts required for each component create an easy to assemble box, however, this level of depth and variations produced can see the rise in expense using the CNC machine.

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Figure 52. Intergrated bookshelfs made from U-Build structure (U-Build, 2019).

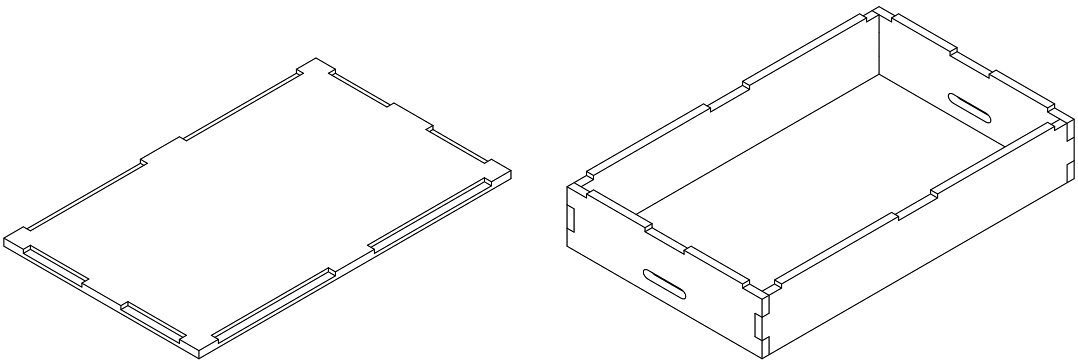

Figure 53. U-Build box components (a).

Pros

- Easy to build.
- Simple to understand.
- Wall boxes construct both the flooring and roof elements.
- Interior panels act as braced walls
- Internal walls make good use of structural elements as functional furniture.

Cons

- Waterproofing happens after internal lining and insulating.
- Complex CNC cuts with varying depths.
- Walls aren't modular as each component is custom for doors and windows.
- Not expandable.

4.1.5 **Brikawood.**

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Figure 54. Installation of Brikawood Building Blocks (The Awesomer, 2018a).

The Brikawood system is a load bearing wall with a pre-finished interior and exterior face (similar to Conceptos Plásticos). Each brick is constructed using only four wooden components, all held together through dovetail connections. Due to the nature of the dovetails, the side flanges cannot come off once constructed and laid. This eliminates the need for glue, nails, rain or vapour barriers, and any additional cladding. The internal transverse spacers are symmetrically positioned to line up with surrounding blocks to create a unison vertical structure within the walls. Because all of the dovetails are equally spaced and run the full lengths of each component, machining them does not require any technical cuts.

Insulation is done through their high-performance thermal insulation which is made from the leftover wood chips resulting from the dovetail machining (minimal wastage).

Prices start from $1668 for the 20 square meter studio kits and can range upwards of $3000NZD per square metre for the home kits (prices as of 05/10/2021). This cost includes delivery to site; however, assembly is still required. In comparison to the GJ Gardners build cost of a brand-new home on page 11, the apollo 139 equates to $2590 NZD per meter square based on the high estimate of $360,000.

Figure 55. Right (Top) - Brikawood building blocks (The Awesomer, 2018b).
Figure 56. Right (Bottom) - Brikawood dovetail joint connections (a).

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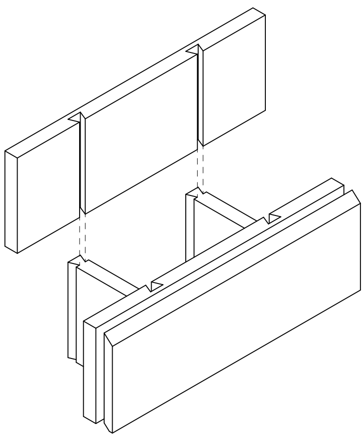

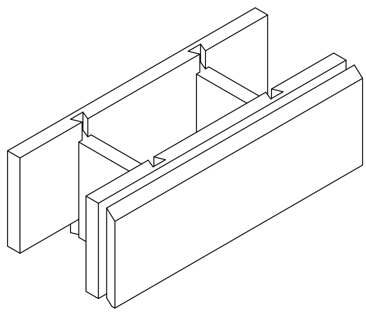

Pros

- Easy and quick construction.
- Minimal tools required.
- Requires no glue or nails for assembly.
- Finished interior and exterior faces.
- 100% renewable resources.

Cons

- Uses a large amount of timber.
- Expensive.
- Requires traditional roofing methods.
- Lack of weatherproofing
- Unappealing visuals (Subjective).

4.2 **Summary.**

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Figure 57. (Left) - Roofing installation for Conceptos Plásticos (Conceptos Plásticos, n.d.).
Figure 58. (Right) - Roofing installation for Gablok (Gablok, 2019, June 13b).

Upon further analysis of the envelopes and structures of the previous set of precedents, it was clear that the direction of research should direct towards developing an expandable frame system. As the frame envelope is the building block for the rest of the house and its various components, it is important that this portion of the design is thought through thoroughly to ensure usability for self-help construction through affordable means.

Below is a summary of the main points taken from this precedent study

Key benefits
- All had elements of prefabrication
- Modular/customisable in size
- Opportunities for self-help engagement
- Glueless
- Reusable products

Key issues
- Roofing elements
- Expansion potential
- Modulation was primarily only possible at the design stage
- Aesthetics

Moving forward, there is still opportunity for improvement through the incremental approach of building. Although some of these precedents engage with self-help techniques, there is uncertainty surrounding the implications of expansion, particularly with roofing elements.

Below is a list highlighting the key ideas for further development.

1. Roofing methods should not require specialised designs/components for each building.
2. Expansion should be possible upon multiple axes.
3. Modular and reusable components.
4. Minimal material usage.
5. Visual appealing.

Due to the question being research, it is understood that some design elements will be limited to fully cater the affordable and incremental aspect. Pointing out the issues related to these precedents is by no means diminishing their designs, but rather, highlighting the gaps that need further researching.

4.3 **Design Criteria.**

Based on the previous research and design undertaken, there was a need to create a strategy checklist for future designs. The following is a design criteria which has been broken down into three categories, design, construction, and expansion. Each of the 14 criteria are issues or necessities required to help guide future designs in order to test viability, practicality, and all-around plausibility of the design in question.

Design	Construction	Expansion
Affordable	Minimal tools	Expandable at any time
Fast Construction	No specialist components	Modular components
Simple Design	Glueless	Extendable roof
Lightweight	Dry/Watertight/Insulated	Expansion would not require the building to be open
Self Help	Minimal Waste	

5 Design Phase 2.

Developed design considerations.

5.1 **Development Direction.**

The objective of design phase two is to create an expandable system based on the principles set out in the design criteria. With the likes of the do-it-yourself attitude (big kids Lego) of XFrame, Conceptos Plasticos, Gablok, U-Build, and Brikawood, the primary focus will be on self-help installation requiring simplicity in the design.

To achieve this simplistic approach for self-help construction, the following will be considered:

- A repetitive building technique will be employed which will enable users to build duplicate structural components with limited change in assembly.
- CNC techniques from XFrame and U-Build will prove valuable due to the flatpack design allowing users to assemble on site, reducing factory assembly time and shipping costs through compact loading.
- Generate modular components that are thoughtfully designed for incremental extensions which are easily accessible at any given time.

5.2 Initial Iterations.

5.2.1 Clip Together Block.

A collection of initial designs showing the iterative process.

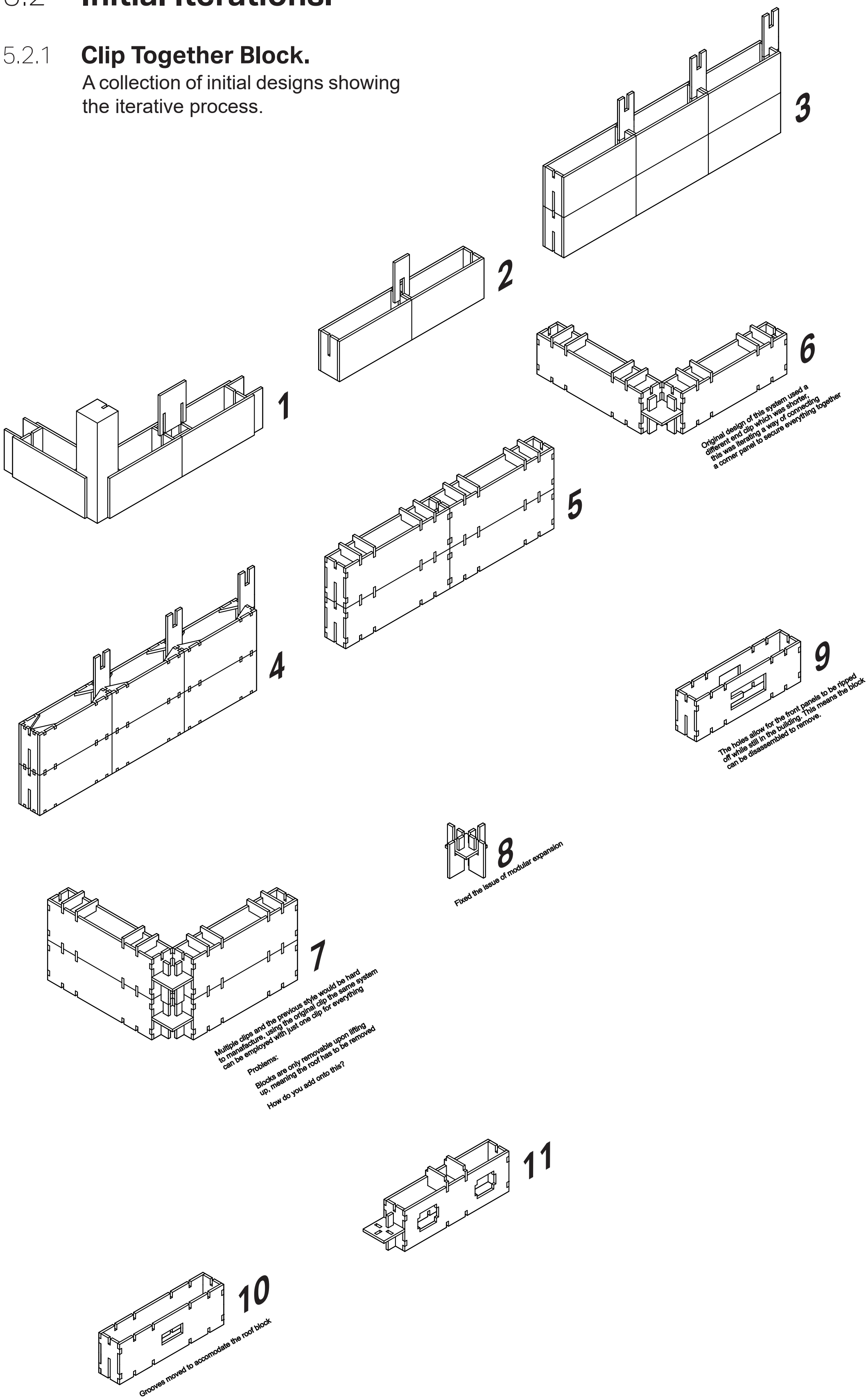
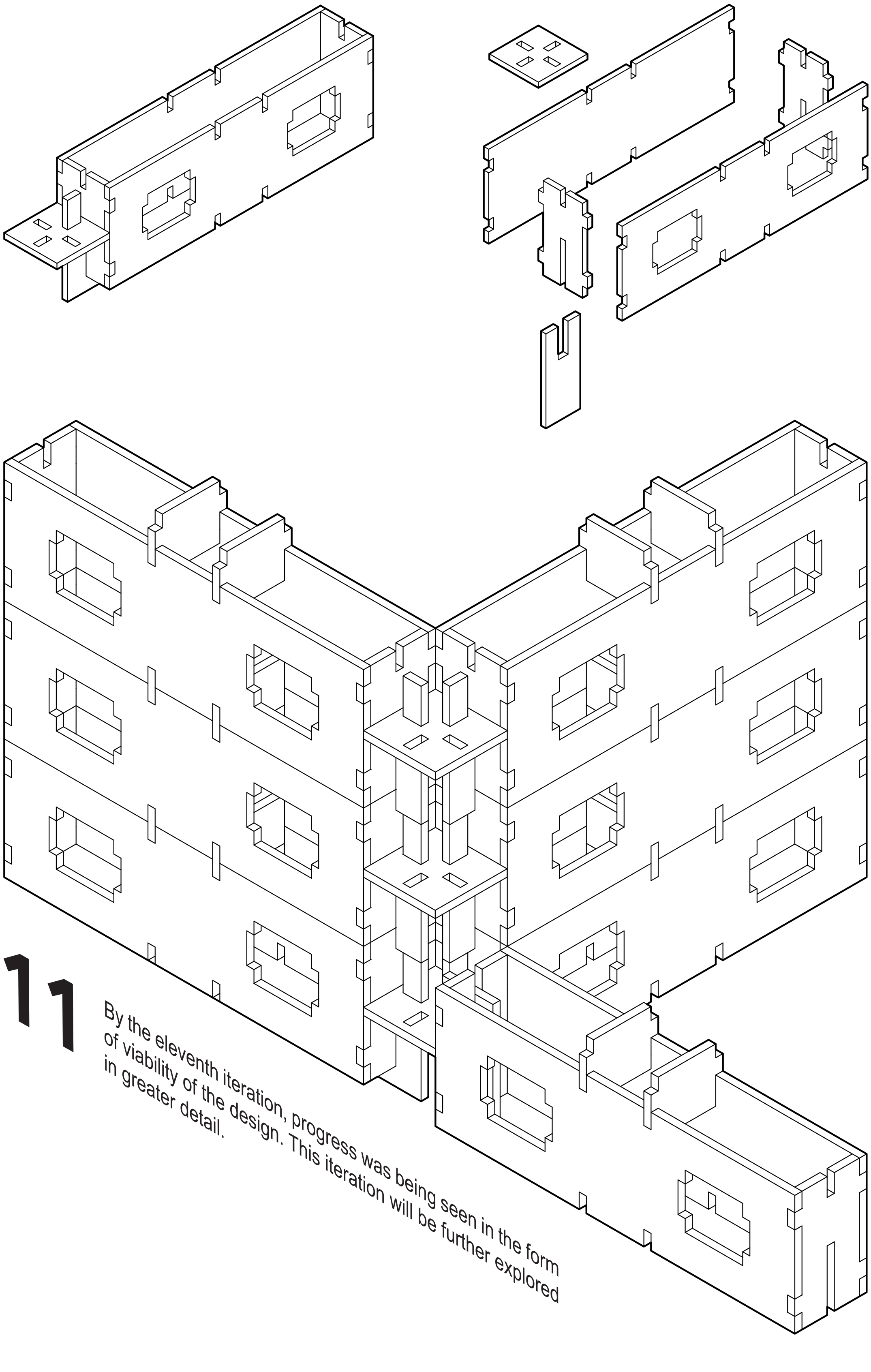


Figure 59. Initial concepts for a clip together block (a).



11

By the eleventh iteration, progress was being seen in the form of viability of the design. This iteration will be further explored in greater detail.

Figure 60. 11th iterative process in the initial testing phase (a).

5.2.2 **Expansion.**

Expansion is currently not possible through the current pin and locking mechanisms. The pin is unable to be inserted into the locking mechanism even when it is at its greatest height, shown by figure 59. A 1:1 scale model of the corner was created to test different pin shapes as to what can be installed into a pre-existing wall. The model shows the corner piece in its utmost position allowing for the maximum amount of space to install a pin as demonstrated by the diagrams below.

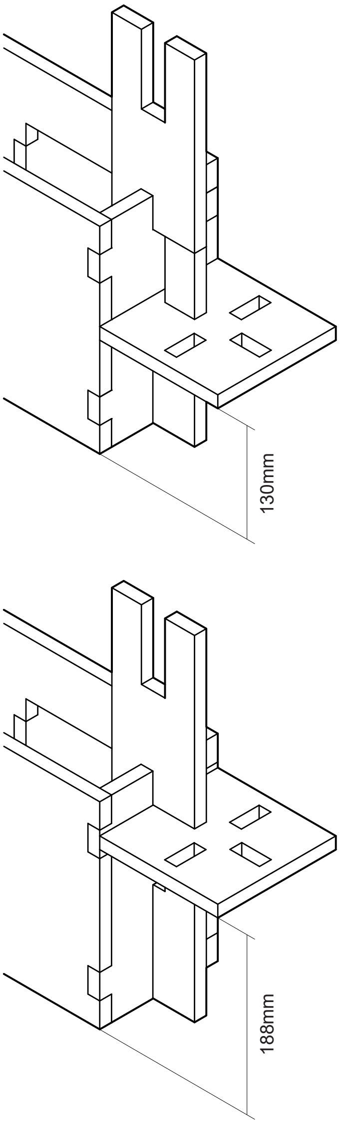
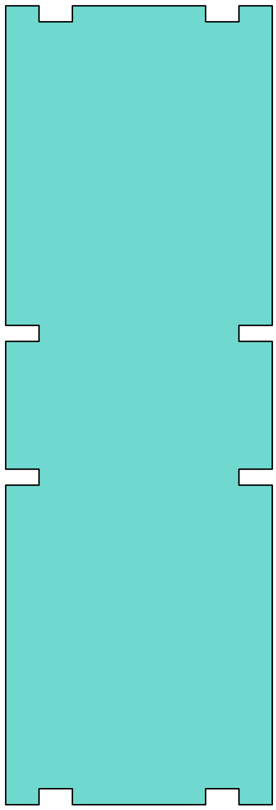


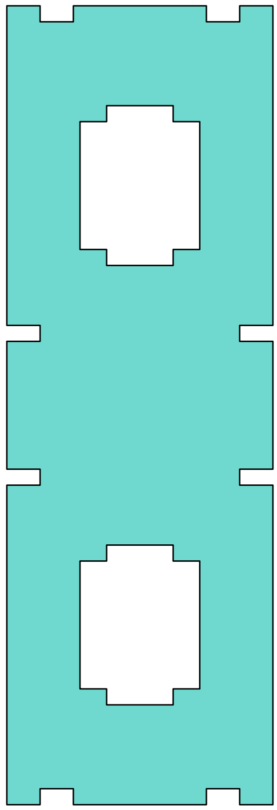
Figure 61. (Left) - Corner component height movement (a).
Figure 62. (Right) - Variations of locking pins (a).

5.2.3 **Pieces.**

Similar to U-Build, the aim was to achieve a finished interior face included in the construction of the block. This helps reduce costs as additional linings such as gypsum plasterboard does not need plastering which is a difficult and a technical task not suited for amateurs. This meant designing the construction of the block to suit a smooth finish interior face. The result consisted of disruptions from components three and six, although aligned with the interior faces, would produce distinct patterns within the wall.



Component 1.



Component 2.

Component 1.
The interior panel, designed as a complete solution that does not require any additional lining.

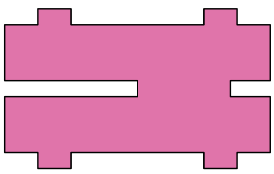
Component 2.
The outward facing panel which still requires exterior cladding for waterproofing.

Component 3.
The end panel which locks components 1 and 2 together.

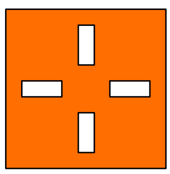
Component 4.
The corner component which acts as a hub for a total of 4 walls to splice off at 90-degree increments. Great for adding internal walls into exterior walls.

Component 5.
The locking pin which fixes the full block to the corner (component 4).

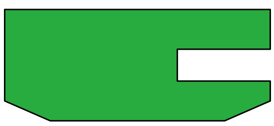
Component 6.
Cut from component 2, this is designed to prevent lateral movement while also acting as a guide when stacking vertically.



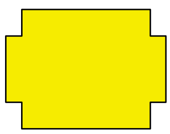
Component 3.



Component 4.



Component 5.



Component 6.

Figure 63. Various components (a).

5.2.4 **Roof.**

Considerations for the roof have been made in conjunction with the design of the block. Throughout the iterative process, different roof ideas have been tested alongside the wall. Ensuring the roof is susceptible to self-help and incremental construction, similar techniques to XFrame have been used as a starting point. As this is a preliminary design of the roof, issues have already been found. These consist of the following:

- Expanding in multiple directions.
- Removing walls without removing the roof.
- Creating a pitch that is able to be joined upon extension in different horizontal axes.
- Vertical building.

Many of these issues would be easier to solve if the building were to only extend upon one axis, however, due to the previous research stating that land size and value is an issue, justifying this approach would not be ethical. This entails that at least one horizontal and the y axis need to be considered for roof expansion.

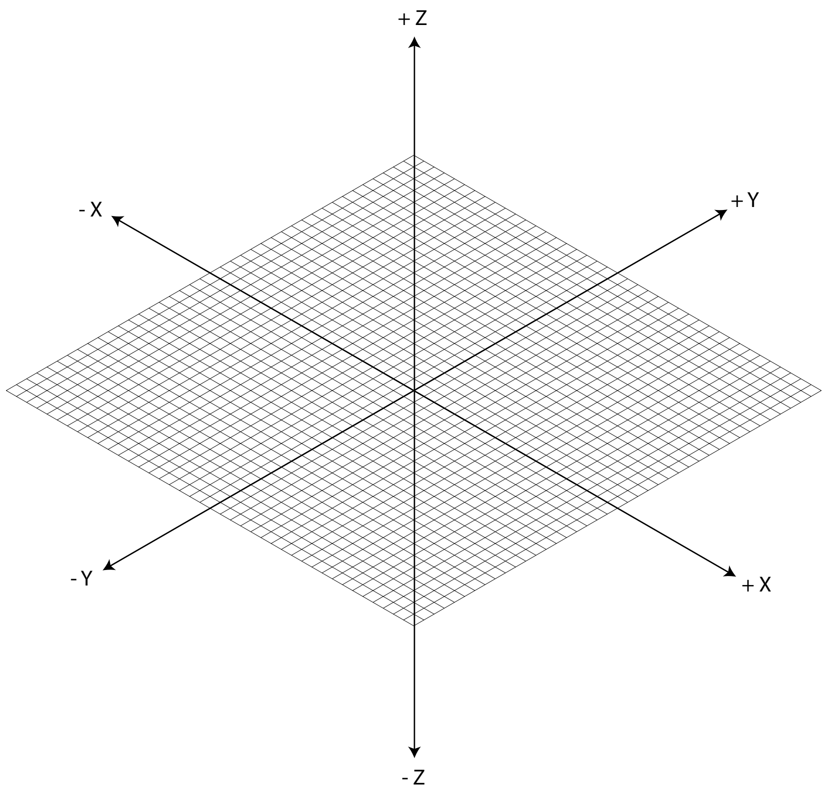


Figure 64. 3D axis (a).

Vertical expansion once a roof is already in place proves challenging as a second floor is now required. Incorporating a roofing structure that can accommodate a change in the y axis will require some form of removability to ensure reusability of the roof and its components for cost saving effects. This also needs to be a fast procedure and preferably achievable by the clients themselves for further cost savings.

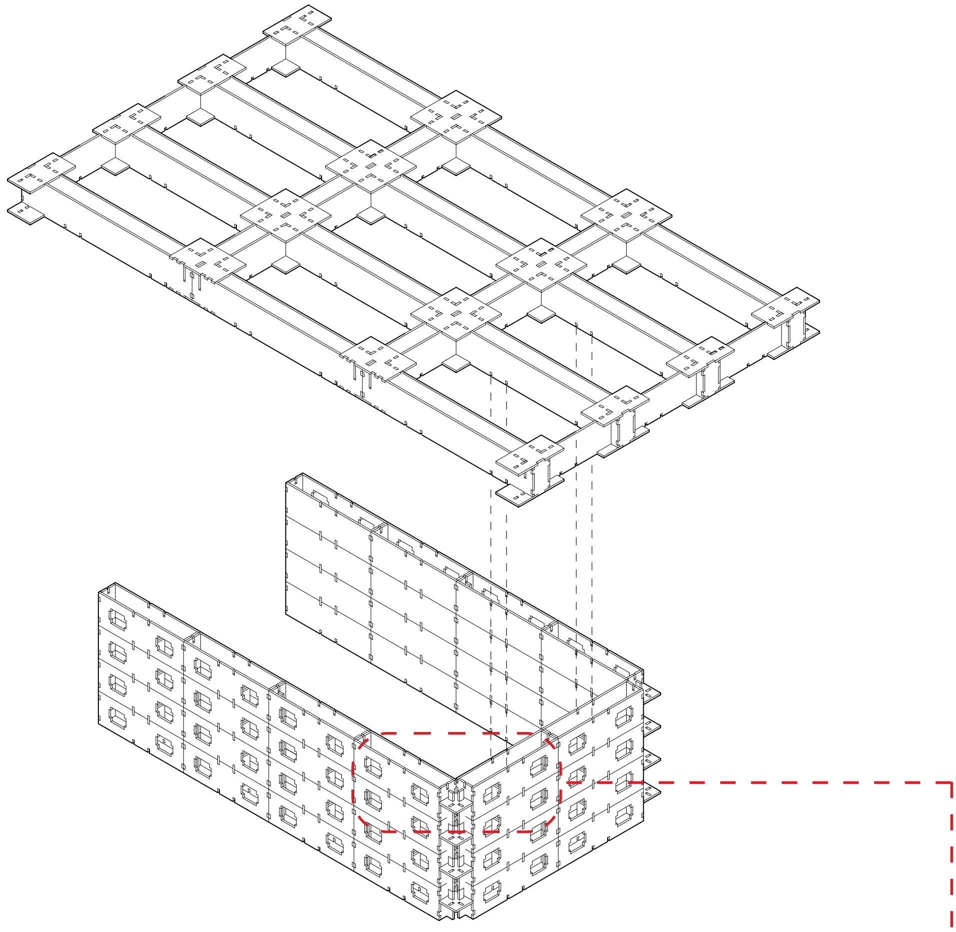


Figure 65. Wall and roof connections (a).

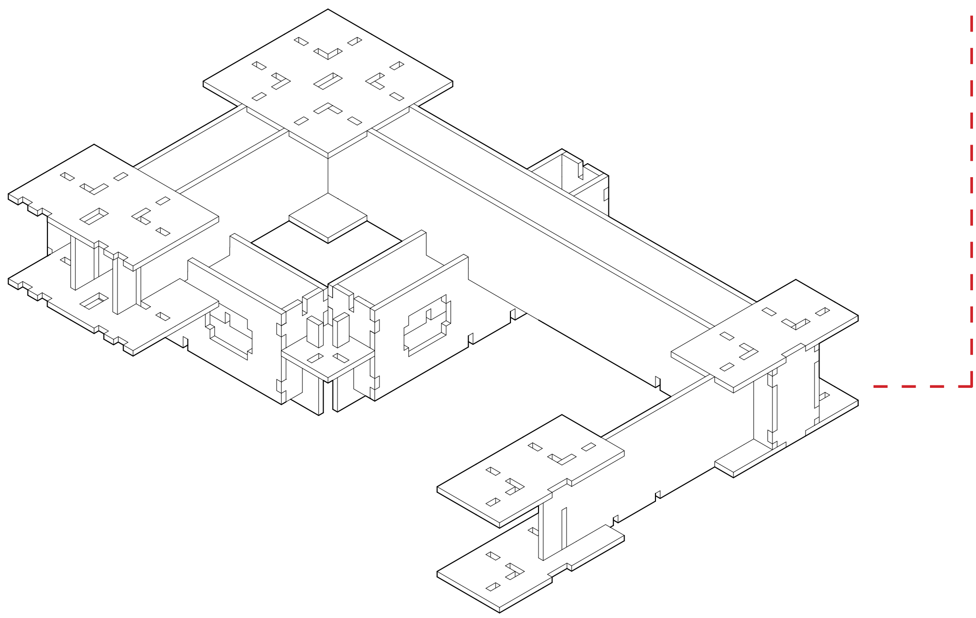


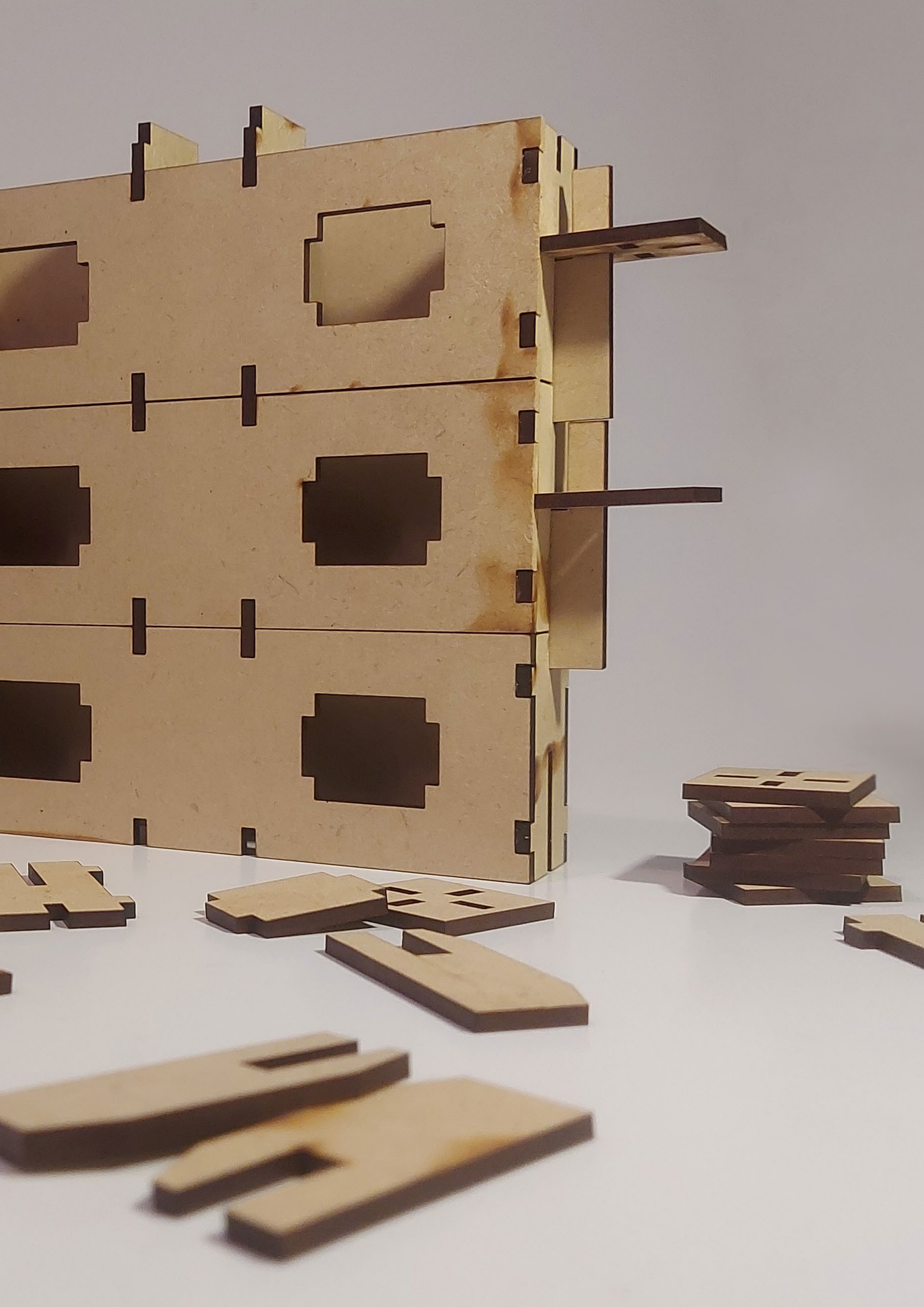
Figure 66. Close up connection point between wall and roof (a).

5.2.5 **Physical Model.** Scale 1:4

ClickBlock.

Designed as a do it yourself (DIY) building block, this concept is derived from flatpack furniture through CNC manufacturing. The construction makeup of plywood allows for CNC precision to cut the six individual components that only require a rubber mallet for assembly. Due to the limited components and the repetitive nature of construction, the block is ideal for the DIY enthusiasts.

Figure 67. ClickBlock laser-cut model (a).



5.2.6 **Strength Test.**

Horizontal y-axis.

Figure 68 & 69. Testing various weights on a scale model of ClickBlock (a).

Although the design is in early stages of prototyping, a rough demonstration occured where weights of increasing values were placed on top of the blocks to test for horizontal and vertical weak points. After the initial y-axis test took 17kg with ease, the author (weighing 72kg) used their full body weight to test the blocks' full limit with the expectation of breakage. As shown by figure 67, the blocks handled the weight with only minor deflection and no breakages.

Scaled at 1:4, these blocks are constructed using 3mm medium-density fibreboard (MDF). Of the six ClickBlocks used in this demonstration, the total weight of the components came to 257 grams meaning that the structure could withstand 280 times its own weight.

Figure 70. Component weight (a).

Vertical z-axis.

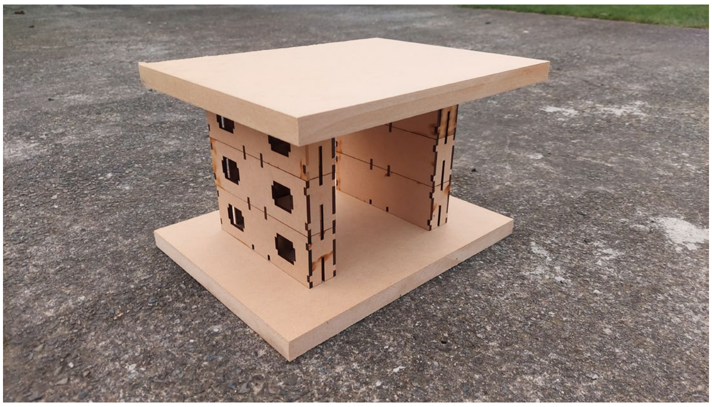


Figure 71. Vertical strength preparation (a).

Figure 72. Vertical strength test using authors weight (a).

The vertical z-axis required separation of two groups of three ClickBlocks to ensure a stable foundation for the author to stand on. The results showed similar outcomes where no breakages or deflections occurred. If the ClickBlocks were spread further apart as well as increasing the amount blocks vertically then the data would vary to what is shown. For the purposes of this experiment, it was left at a safe height for initial testing.

Note: Small amounts of glue were used in the recesses of components one and two in order to prevent component three from falling out due to slight inaccuracies while laser cutting. Although the amount of glue was miniscule, this would impact the data of the strength test.

Horizontal x-axis.

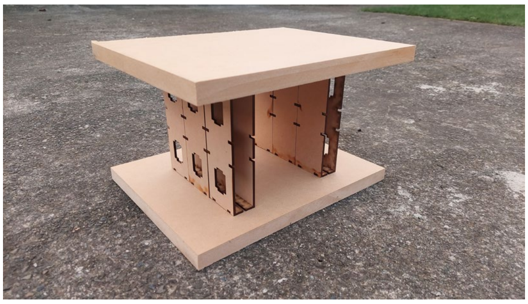


Figure 73. Horizontal test before applied load (a).

Figure 74. Horizontal test after applied load (a).

In this instance the blocks failed after 19.5kg. The nature of the structure meant that without vertical load occurring on the blocks, there was no structural rigidity holding the components together. This issue could be improved with dovetail connections between components one, two, and three but due to the CNC process this is not possible. Multiple manufacturing processes could be used to achieve a dovetail connection at the cost of production speed. This would result in additional costs that can be avoided if components one, two, and three are redesigned to better interlock under horizontal x-axis loads. Additionally, this test has discrepancies as the overall structure becomes increasingly sturdier once corners and locking pins are used. In this example, neither are used due to the size and number of models produced. Below highlights weak points where only components two, three, and six were affected but all with expected breakage points

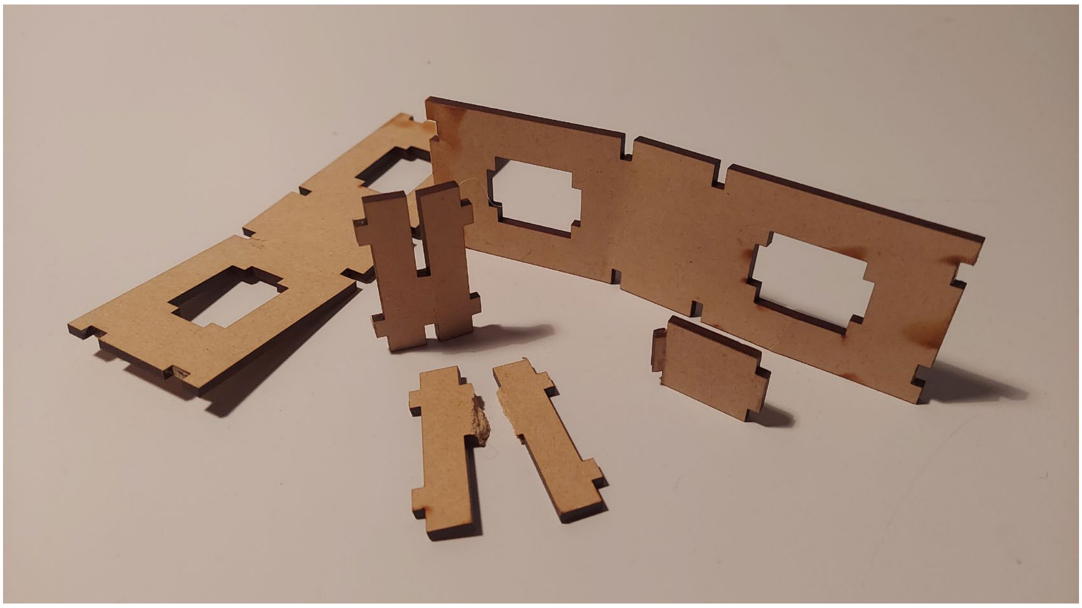
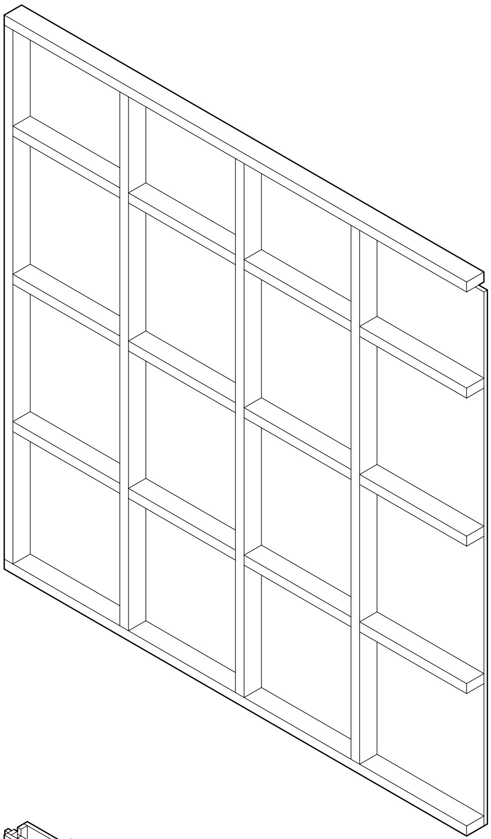


Figure 75. Broken components as a result of horizontal strength testing (a).

5.2.7 Critical reflection.

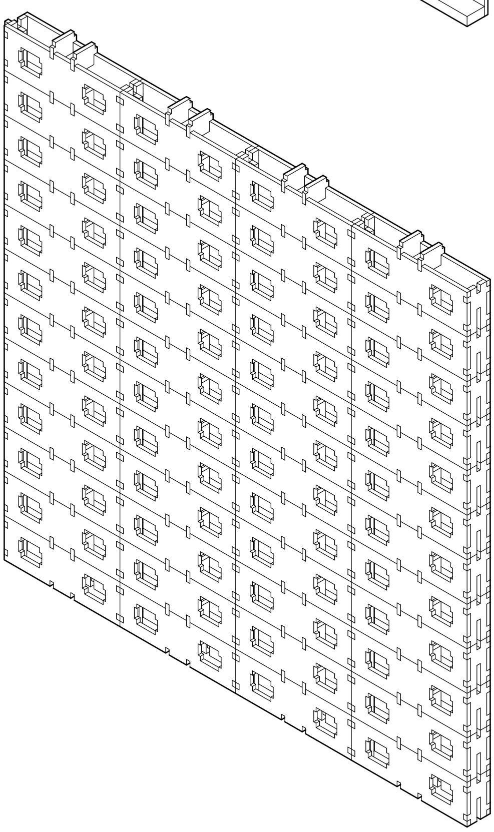
It is unclear at what weight breakages will occur on the y and z axis as adding more weight in a safe manner becomes difficult in the current set up. Future strength tests should be conducted using more but smaller scaled blocks that better represent a house structure which should require less weight for safer testing. This should also allow for better testing to occur in the x-axis as a complete system of pins and corners can be constructed. The reasoning behind the ClickBlock structure not staggering such as a traditional brick was due to the choices about modularity and removability. In order to remove blocks from the centre of the wall for a new door insert in a traditional brick layout would require much of the wall to be removed. However, information from the x-axis strength tests shows the weakness resulting from a non-interlocking structure.

5.2.8 **Material Usage.**



0.189m³

Traditional timber framing made from 90x45mm at 600 centres lined with 18mm plywood.



0.243m³

ClickBlock wall constructed using 18mm plywood.

28.5%
Increase

Although slightly higher material usage, the benefits of reusability through nailless and glueless construction outweigh the increase in material.

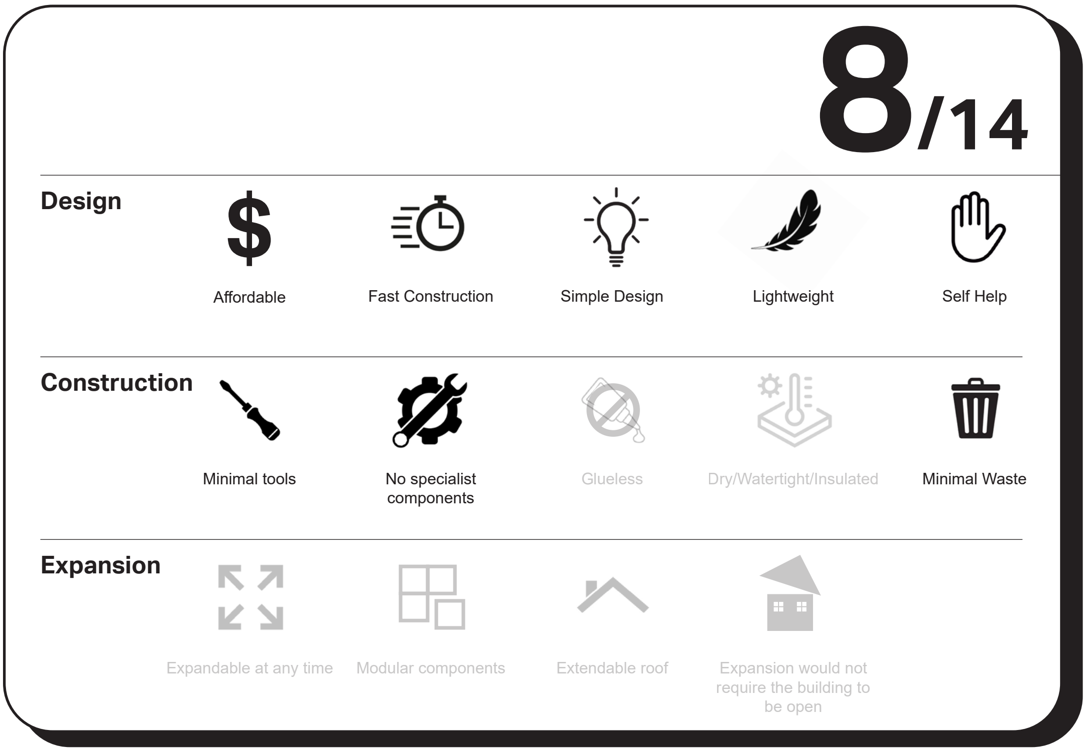
Figure 76. Material usage difference between ClickBlock and traditional framing methods (a).

5.3 **Findings.**

5.3.1 **Critical reflection.**

The design guide has been used to score the current design to show areas of strength and weakness. The subsequent score was based on the following:

- As the blocks and pins rely on gravity for securing, cut-outs for future windows and doors would result in blocks acting as lintels to fall.
- Component 6 (yellow guide) removes the ability for a block to be removed anywhere in the wall. Removing blocks require the entire wall to be disassembled.
- Exterior cladding becomes problematic when fixing to the 18mm plywood due to the limited fixing depth.
- The modulation features of ClickBlock are currently limited to the wall. Additional features such as windows, doors, roof, and flooring need development to generate a fully modular system.
- Integration of the roof shows a diverse range of potential issues.
    - The roof can be extended with relative ease along one axis, however, extending horizontally and vertically proves problematic with removal and waterproofing of roofing elements.
    - There are currently no considerations for fixing the roof in regards to uplift forces.

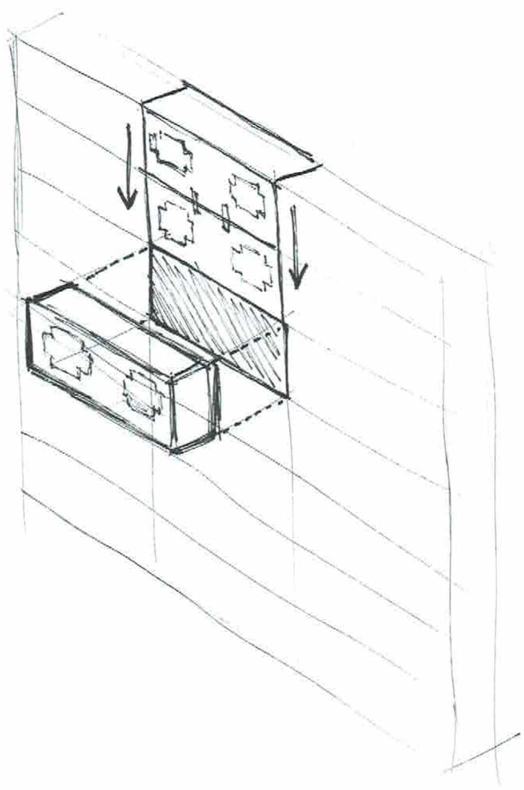


5.3.2 **Observations.**

- The glueless factor can be achieved through slight alterations when laser cutting.
- Additional observations of the internal finishing's could be problematic through unsatisfactory aesthetic visuals. Although designed with affordability at the forefront of design, the lack of uniformity from the internal lining could deter users. The goal of making a pre-lined block needs further development as to how the affected interior face is presented.
- Moving forward, a staggered formation should be explored for structural benefits to the block. This should also explore how the blocks can be added or removed from within the wall without requiring half of the wall to be disassembled.

5.4 **Developed Concept.**

Based on the previous findings from ClickBlock, there was a clear need to revise the structure to better accommodate windows and doors for flexibility in design. The key problem analysed was component 6 (yellow guide) limited the removability of a singular block within the wall. Because of this, removing a section of blocks would require the disassembly of the entire wall. Additionally, structural capabilities were noted as being poor due to the lack of overlap between the blocks. A focus for this section will be designing removable blocks situated anywhere within a wall and producing a stagger formation to better improve strength and stability.



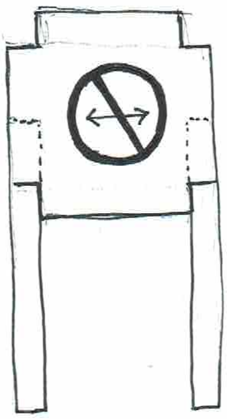


Figure 77 & 78. Sketches of the removal issues of ClickBlock (a).

5.5 Construction.

5.5.1 Locking Pins and Stagger.

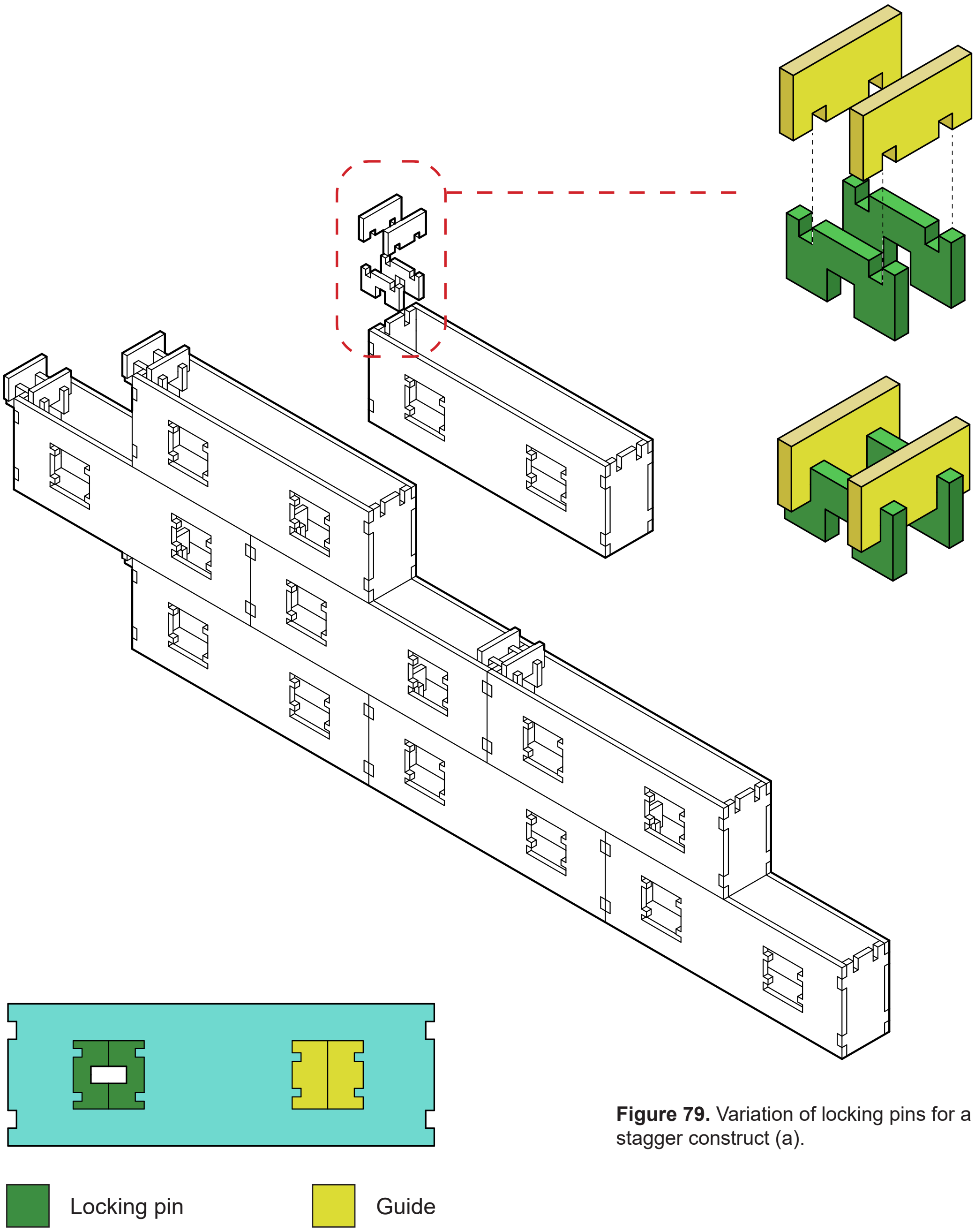


Figure 79. Variation of locking pins for a stagger construct (a).

The revision of the locking mechanisms led to the locking pins working in conjunction with the guides. Both components interlock into one another and are placed on top of the blocks. Both the guide and locking pins are removed at once, through the front face holes, when a block is to be removed. This method allowed for the blocks to have a stagger construct as each guide was centred to the block on the above row.

5.5.2 Doors and Windows.

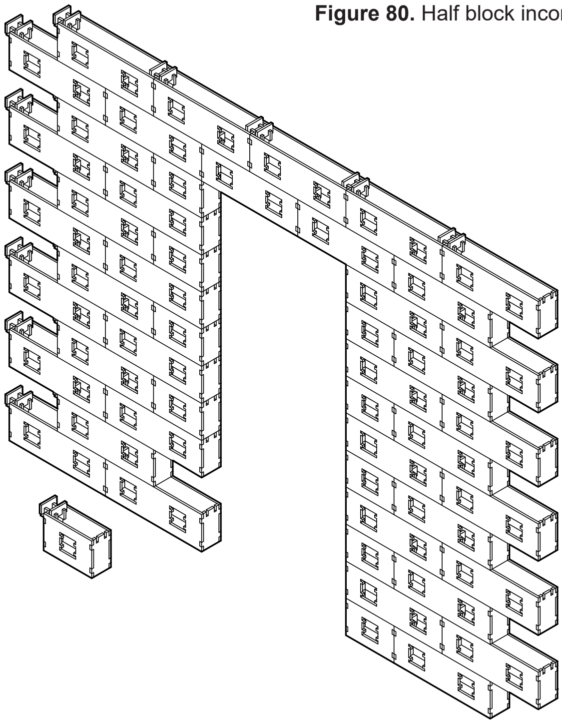


Figure 80. Half block incorporation (a).

Due to the stagger construct of ClickBlock, half blocks were necessary.

Issues observed:

- Regardless if the pin is on the top or bottom, the blocks will still fall. This will require a lintel block to be constructed to support window and door frames.
- There is no structural element to fix windows and doors to.

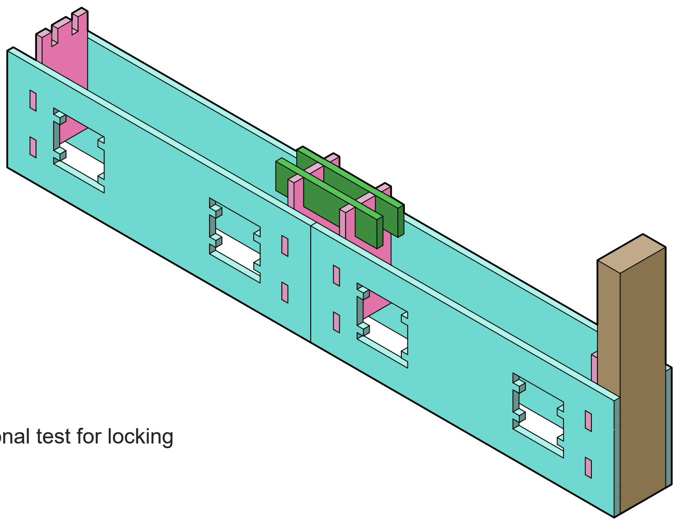


Figure 81. An additional test for locking mechanisms (a).

TTo remedy the issue of fixing for windows and doors, 4x2's are recessed into the blocks. The 4x2's are simply secured by screws via the two face plates (components 1 and 2, blue) to allow adequate fixing for windows doors. This also allows component 3 (pink) to stay locked into the face plates rather than being semi loose on the end. Now it can no longer fall off during construction of the block, something the author found to be an issue during the model constructions and strength tests.

Additionally, an attempt to use component 3 as a direct replacement for the guide (component 6, yellow). This was quickly scrapped as it resulted in similar problems to the original guide where the blocks can not be removed without dismantling the entire wall. It is compulsory for there to be two separate components to allow the blocks to be removed.

5.5.3 **Rebates.**

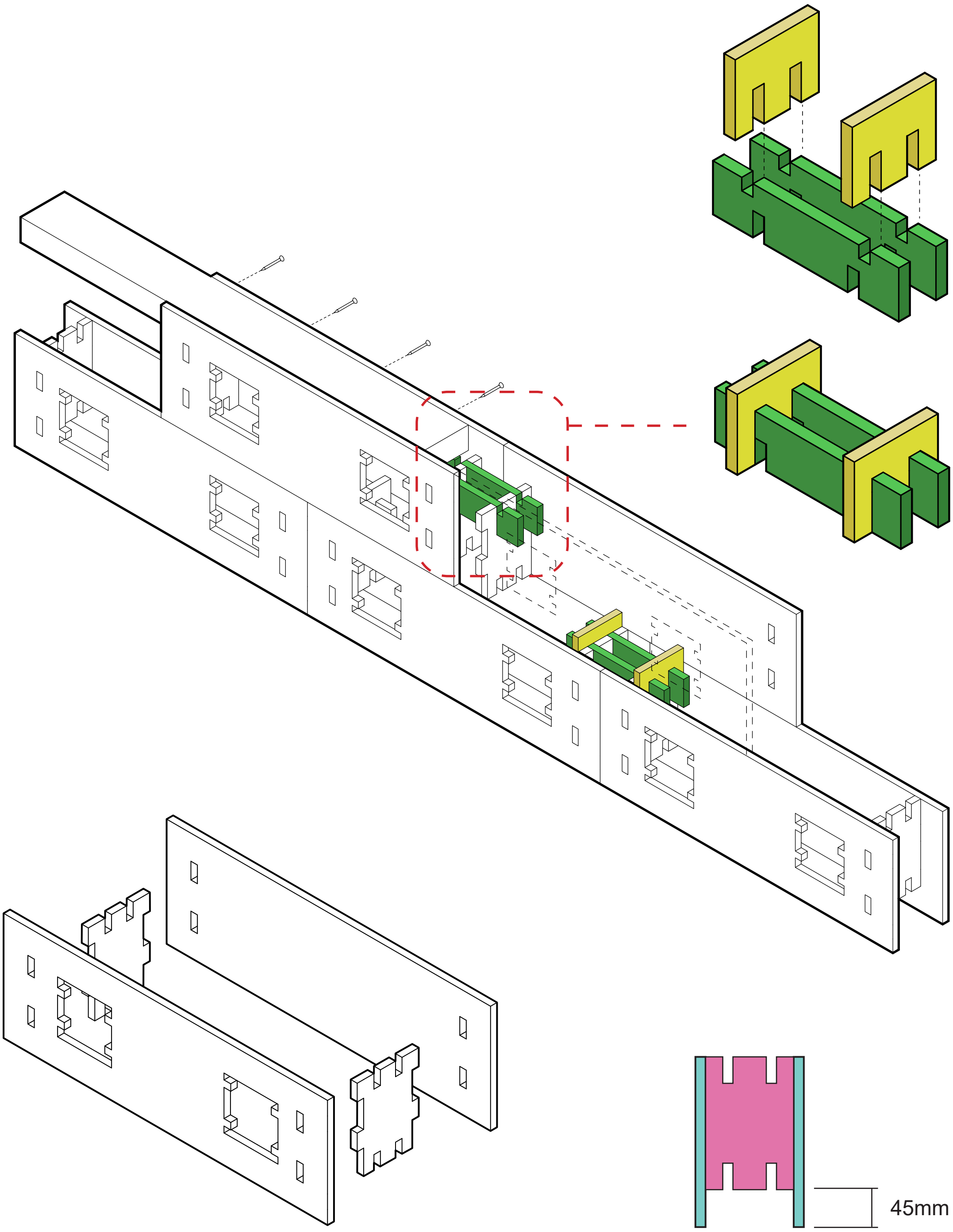


Figure 82. Block construction to allow for 45mm rebates (a).

In addition to vertical timber supports, there should also be horizontal fixing for windows and doors. The height of component 3 (pink) has been reduced to 155mm, 45mm less than the total block height. This allows a 4x2 to run horizontally for fixing windows and doors but also into top and bottom plates when the block is flipped 180 degrees. This required component 3 to have grooves in both ends to support the locking pins in any orientation.

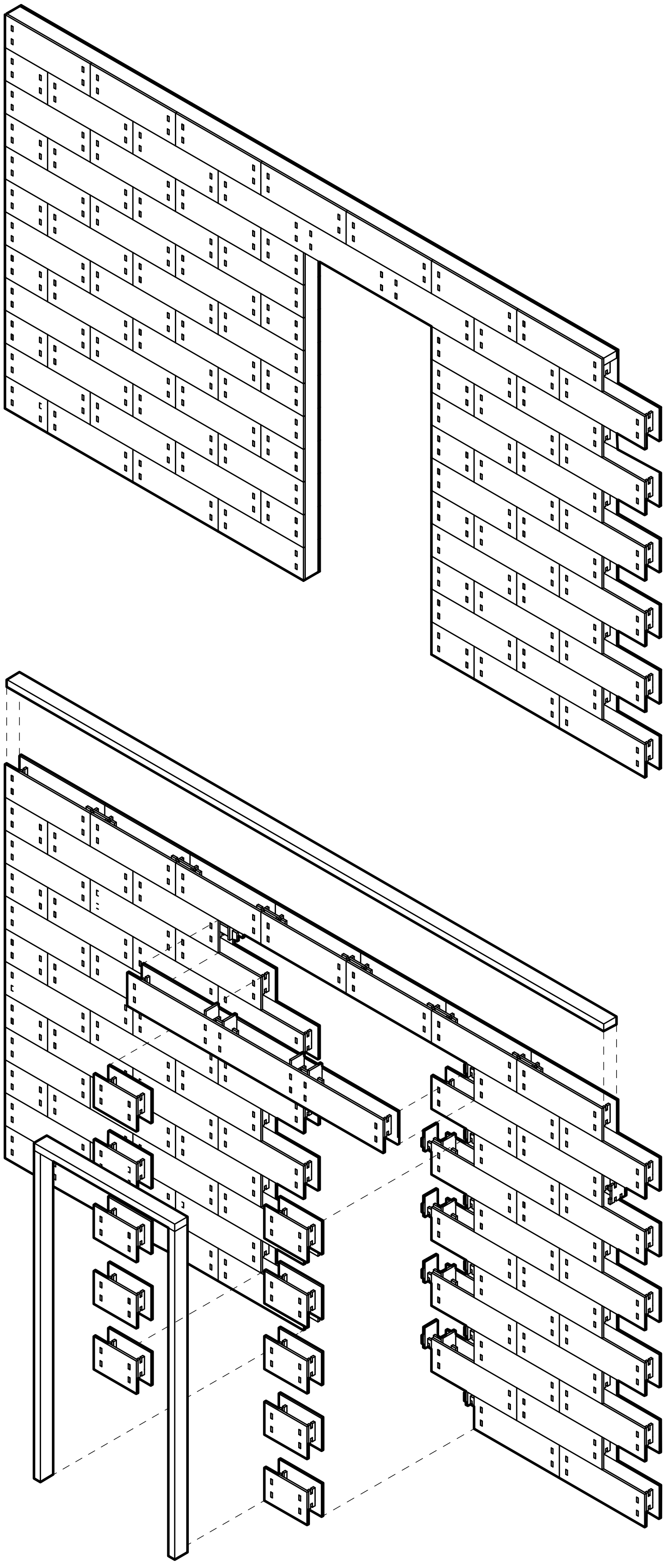
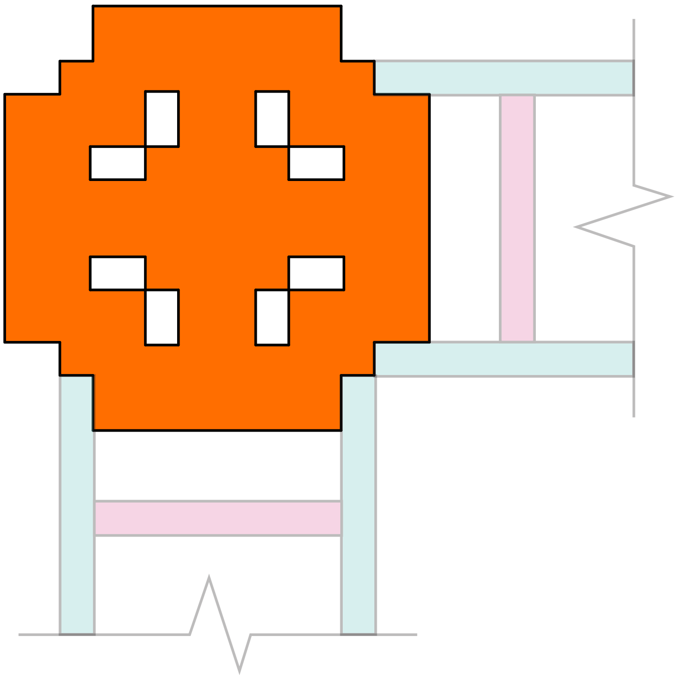


Figure 83. Exploded axonometric showing the wall components (a).

5.5.4 **Corner and Expansion.**

Currently the corner does not work in terms of addition after construction due to the change in locking mechanisms and the 45mm rebates. This means that after stage one of the incremental build is complete, adding on to it would require major deconstruction of the already constructed building.

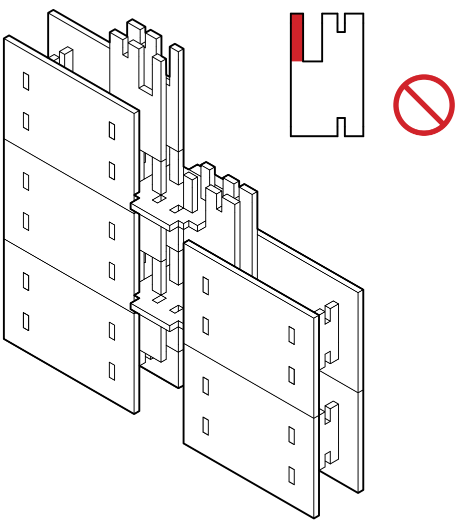
Corner Component.



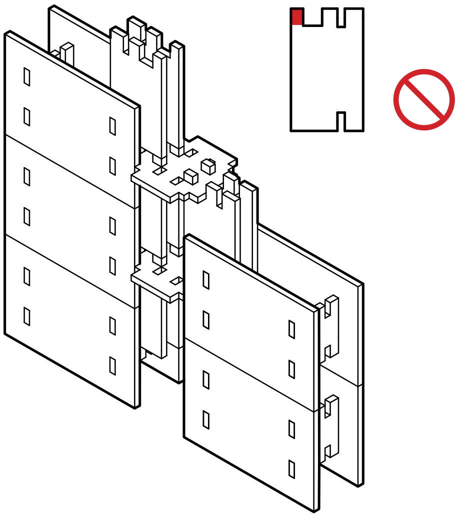
Remains similar in concept to the original corner component except this has two holes per side to allow for two locking pins. This will help to reduce any twisting between blocks. The additional extrusions on the perimeter act as guides for locking into the blocks, another form of lock to help remove any potential twisting motions from occurring. Additionally, these are extruded 20mm, the same depth as standardised cavity battens to ensure cladding is not disrupted.

Figure 84. Top view of corner component (a).

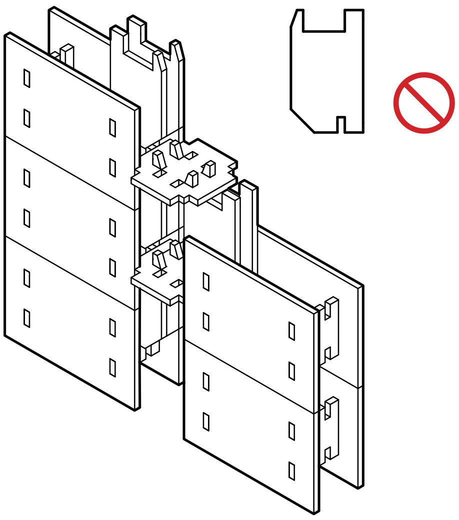
Corner Locking Pins.



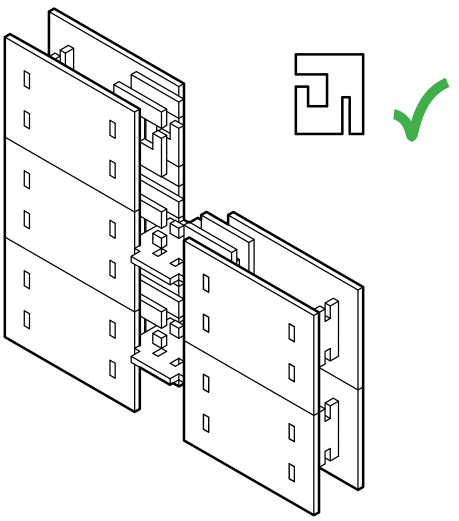
This design does not work as the pin catches on component 3, the same result seen in 5.2.2 where the locking pin catches when the gap is fully extended. Additionally, the highlighted red area on the locking pin was seen as a potential high-risk place for breakage to occur during construction and deconstruction.



This iteration limited the travel distance of the corner component to lower the height of the locking mechanism in the pin (highlighted red) to reduce the breakage potential. As the 45mm rebate sets back the locking pin, it is hard to achieve the same entrance angle of the pin seen in 5.2.2. This causes the alternate bottom and top of the corners of the locking pin to get wedged, similarly to the first pin design in 5.2.2.



Even when testing the angled cuts on the locking pins, results were the same as before. Because of the width of the pin and length it is required to travel to lock into both the corner component and block, it is not possible. In order to lock the corners in place, the pins must be secured into both the corner component and the locking pins. A completely new design has to be created to solve this issue.



These pins do not touch top to bottom like previous designs. This removes the continuous path for load bearing, reducing structural strength. In addition, the lack of vertical loading caused by the stagger construct eliminates any form of stud bracing in either the corners or the walls. A scale model will be constructed to understand the weak points shown from this iteration.

Figure 85. Left (Bottom) - Pin development 1 (a).
Figure 86. (Top) - Pin development 2 (a).
Figure 87. (Middle) - Pin development 3 (a).
Figure 88. (Bottom) - Pin development 4 (a).

5.5.5 **Physical Model.** Scale 1:4

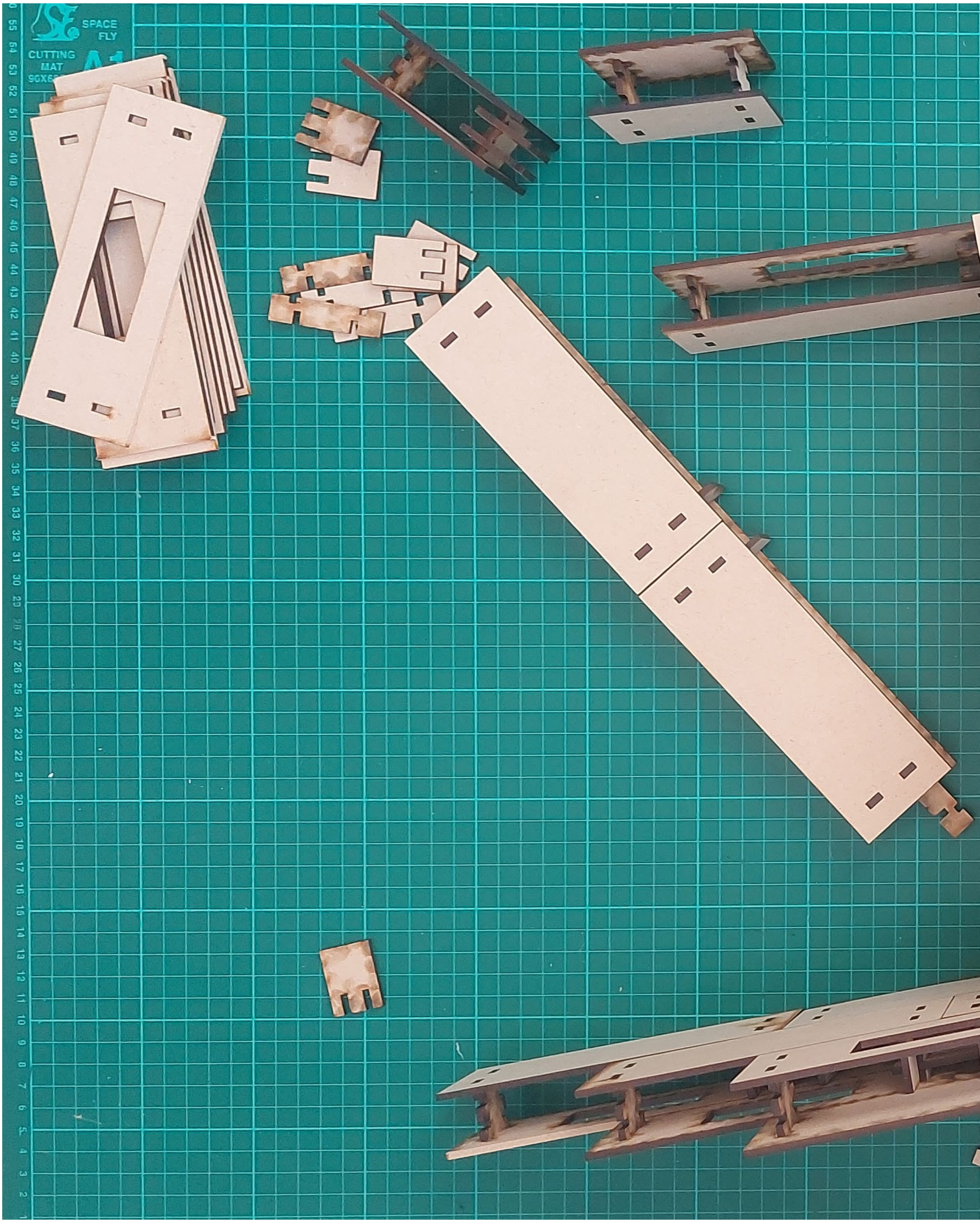
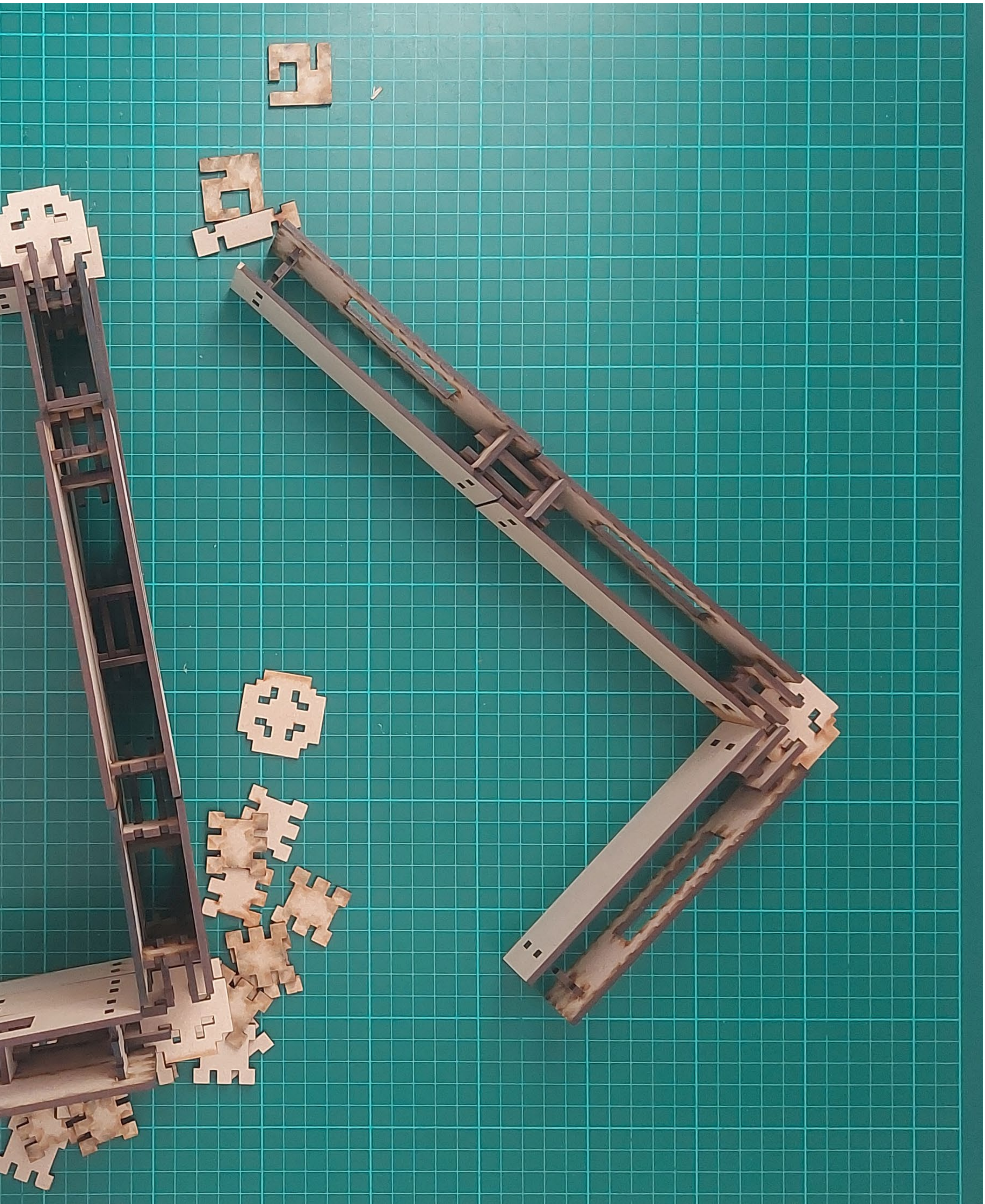


Figure 89. Laser-cut model with new variations applied (a).



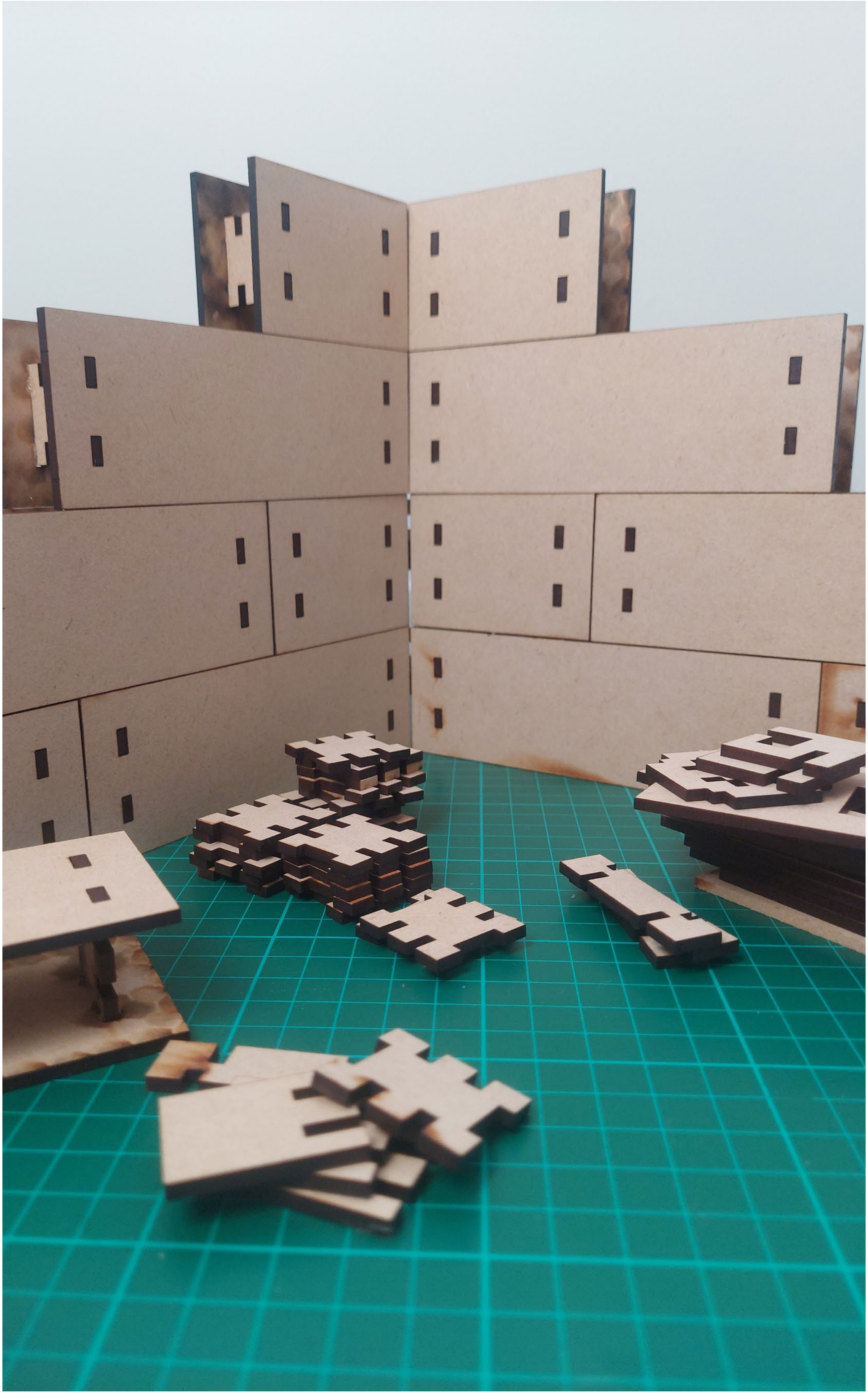
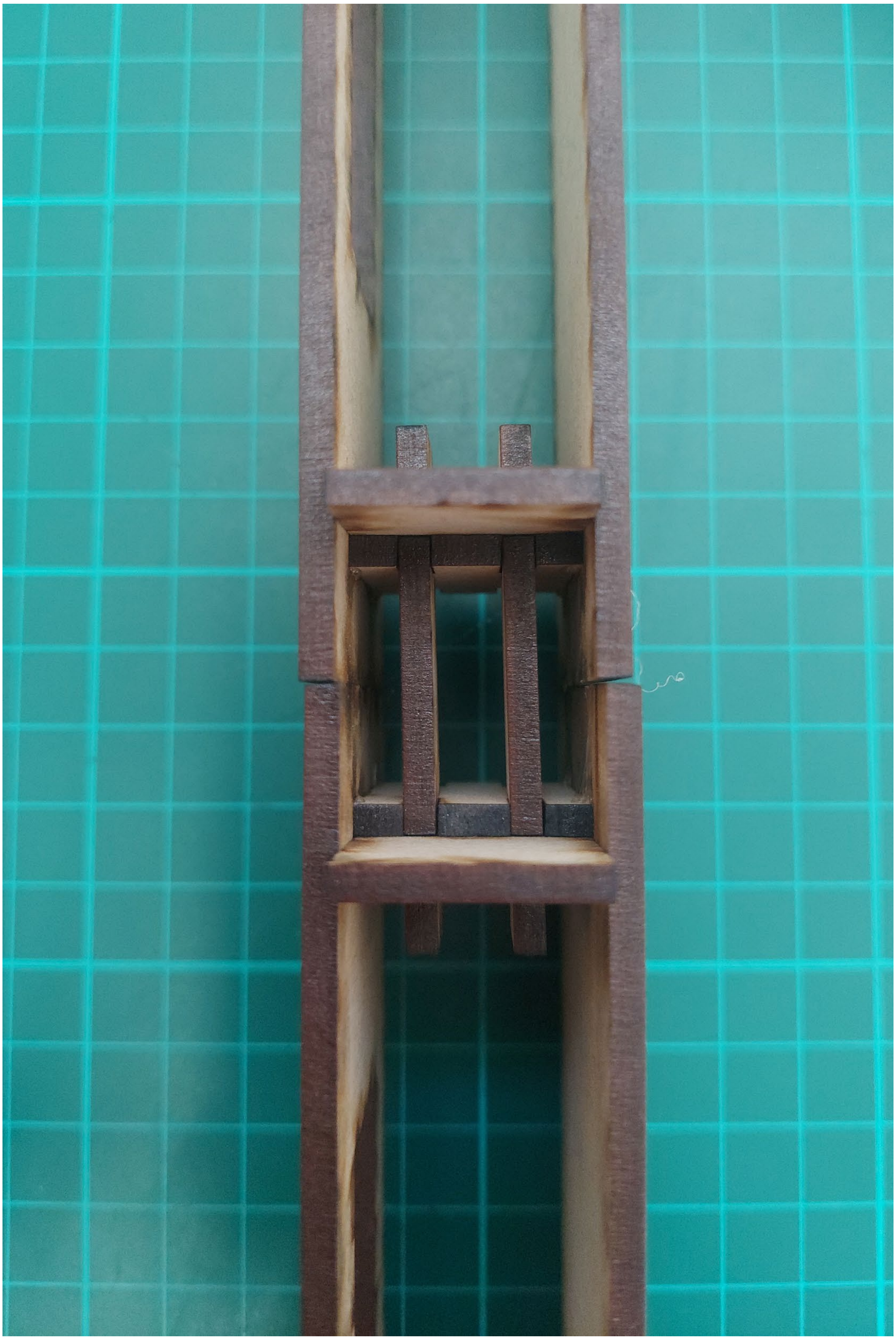
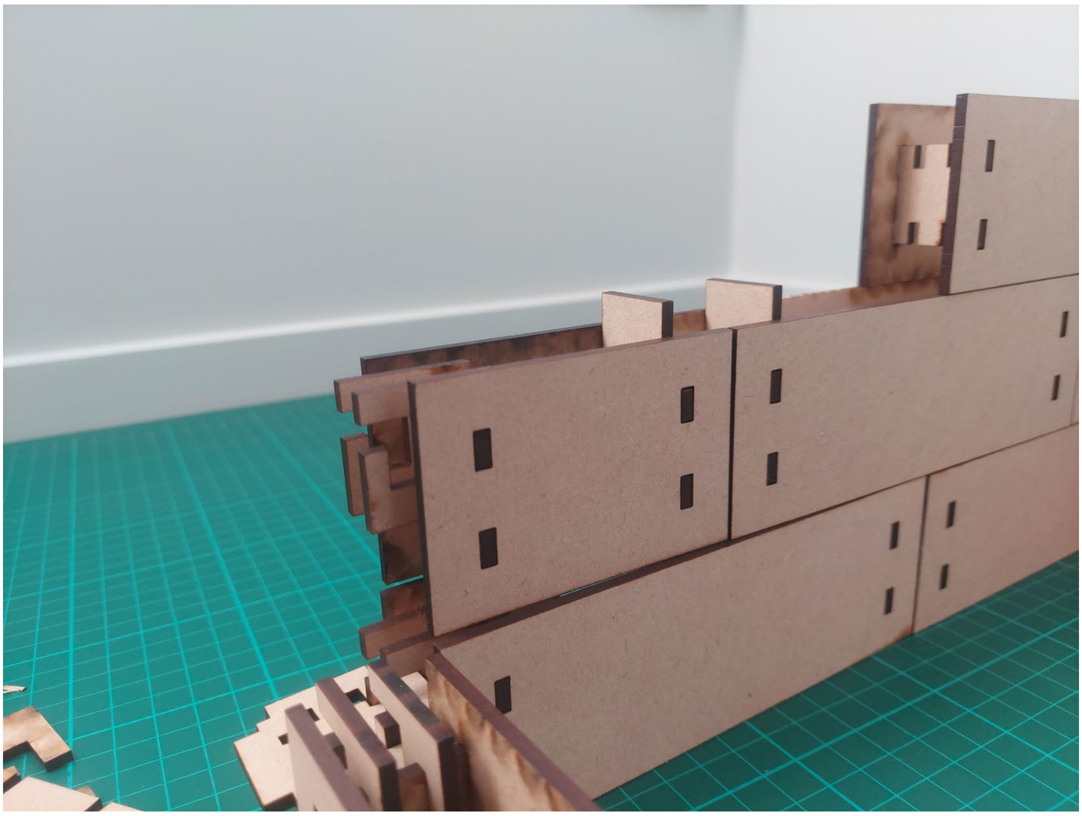


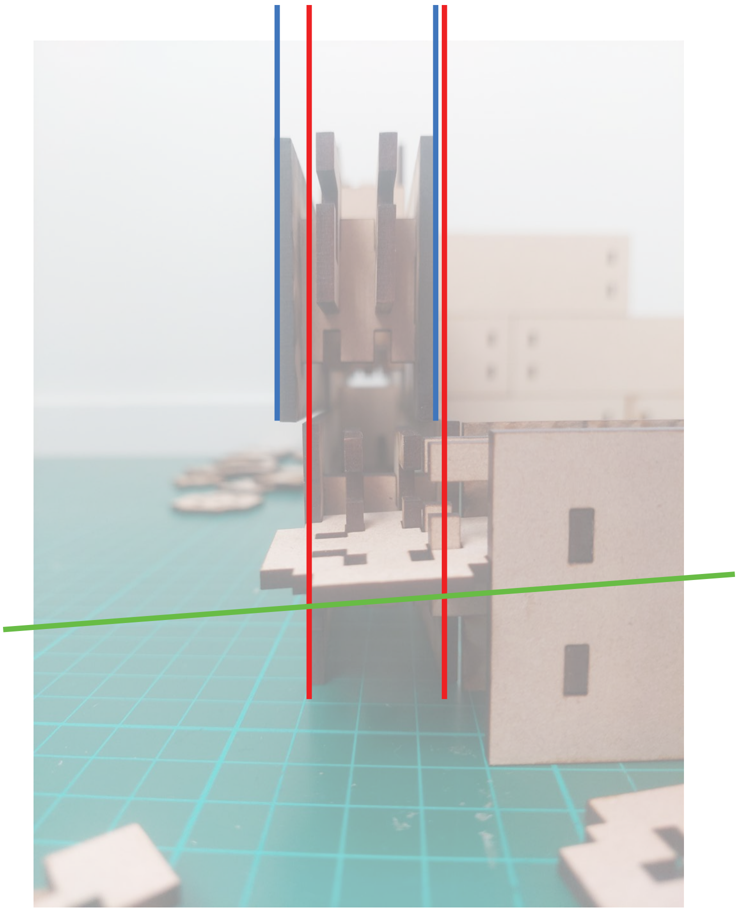
Figure 90. Laser-cut model with new variations applied (a).

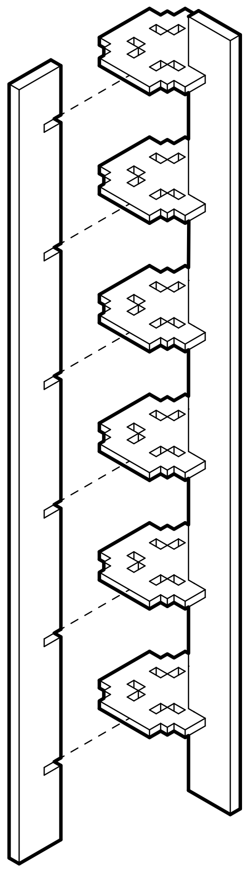


There is a significant amount of movement between these two blocks. As the guides only act as locks for the above block, there is no support between the join of these two blocks. Turning the guides 90 degrees would strengthen this joint and limit movement.

Figure 91. Connection joint showing movement (a).







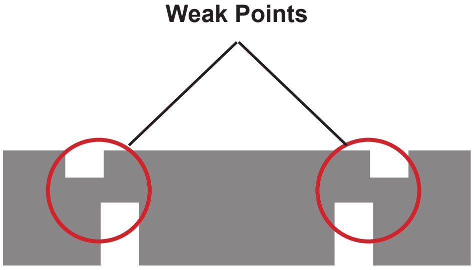
5.5.6 **Observations.**

- As the original guides prevented the blocks from moving in both the x and y axis, this was also what gave the blocks their structural stability. To remove a block anyway in the wall resulted in only locking the blocks in the x axis. The blocks now rely solely on the corner to stop them from being pulled horizontally along the wall.

- Additionally, as the half blocks do not have a guide (the locking mechanism in the big blocks), on the corners there is nothing stopping these half blocks from sliding perpendicular to the wall as shown by figure 90.

- To easily install and adjust the corner component for future extensions, the slots for the locking pins cannot be extremely tight. This would create difficulties in moving the corner component up and down to add/subtract from. Because of the semi loose connection, the corner piece slants 20 degrees. This is fixed when there are a minimum of three walls connected, ensuring equal balance on the corner component. Where only two walls meet, a devised component shown in figure 92 will support the additional two sides. As the blocks rely on the corner to prevent their horizontal movement, this concept starts to lose any structural strength it may have previously had.

- In general, all of the blocks have some degree of horizontal slippage which could be resolved through a more robust locking pin and guides.

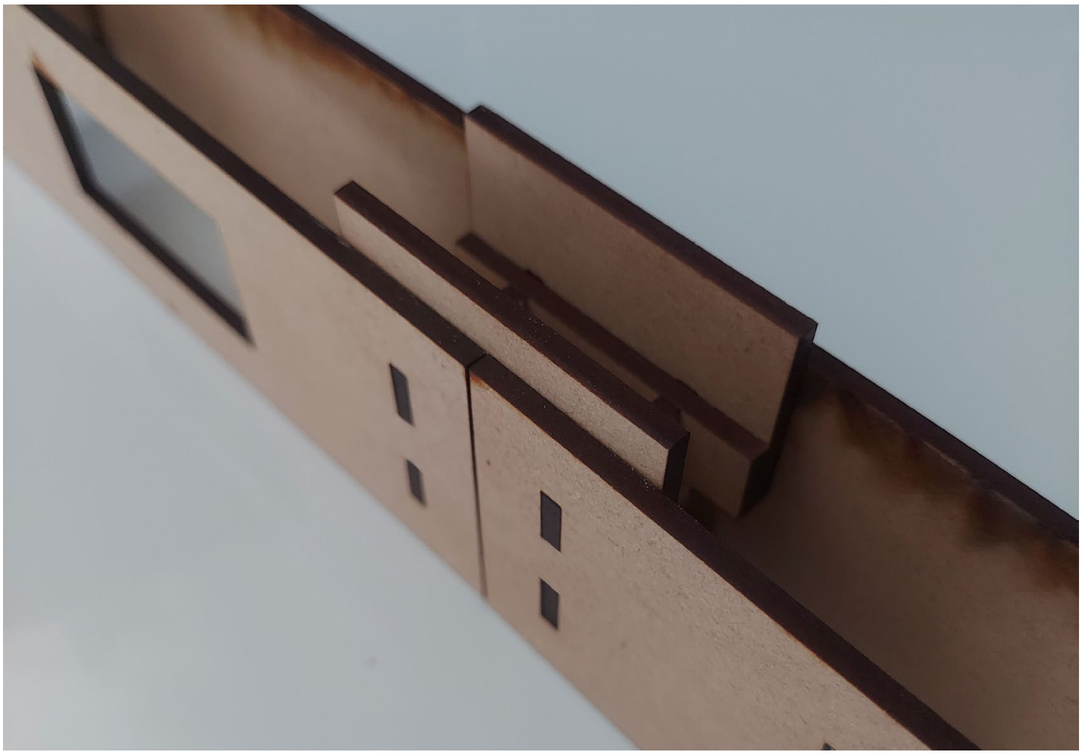


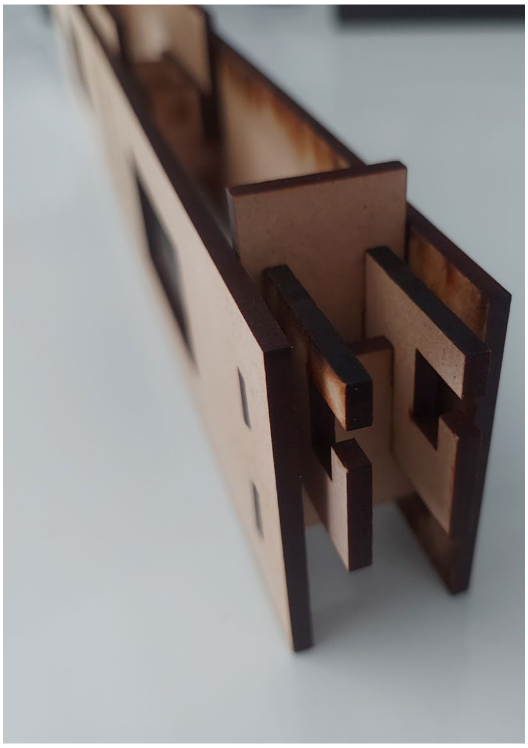
Also noted from this model experiment, upon moderate force of removal, some locking pins failed at the denoted weak points depicted in the above diagram. As the guides will be rotated 90 degrees to strengthen the join of two horizontal adjacent blocks, the additional top slot in the locking pin can be removed (revised locking pin).

Figure 92. Left (Top) - Half Blocks not locked in place (a).
Figure 93. Left (Left) - Half blocks and corner component inconsistencies (a).
Figure 94. Left (Right) - Additional support for corner components (a

5.5.7 **Redevelopment.**

To achieve less movement between the two joining blocks, the guide needs to run parallel to the wall. Below shows a model constructed using this idea where the concept was a success. The two blocks had no movement occurring at this point. Modifications have also been made to the corner locking pin to allow an additional guide to lock the half blocks in place.





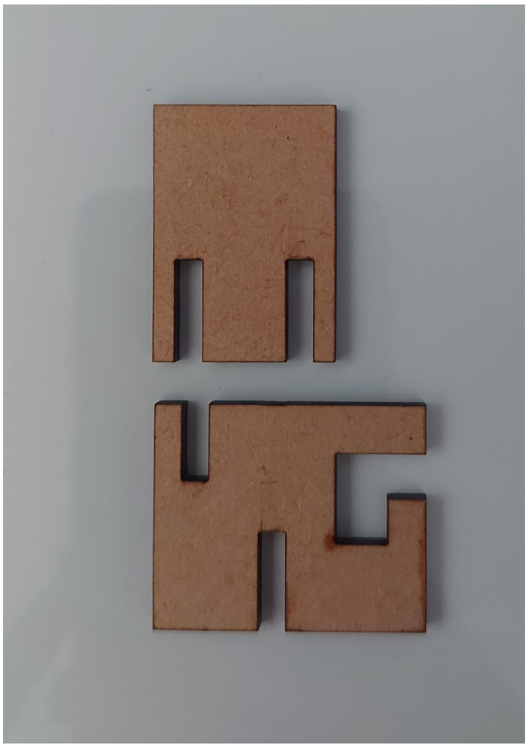


Figure 95, 96, & 97. Redeveloped guide system and additional half-block support (a).

5.6 Findings.

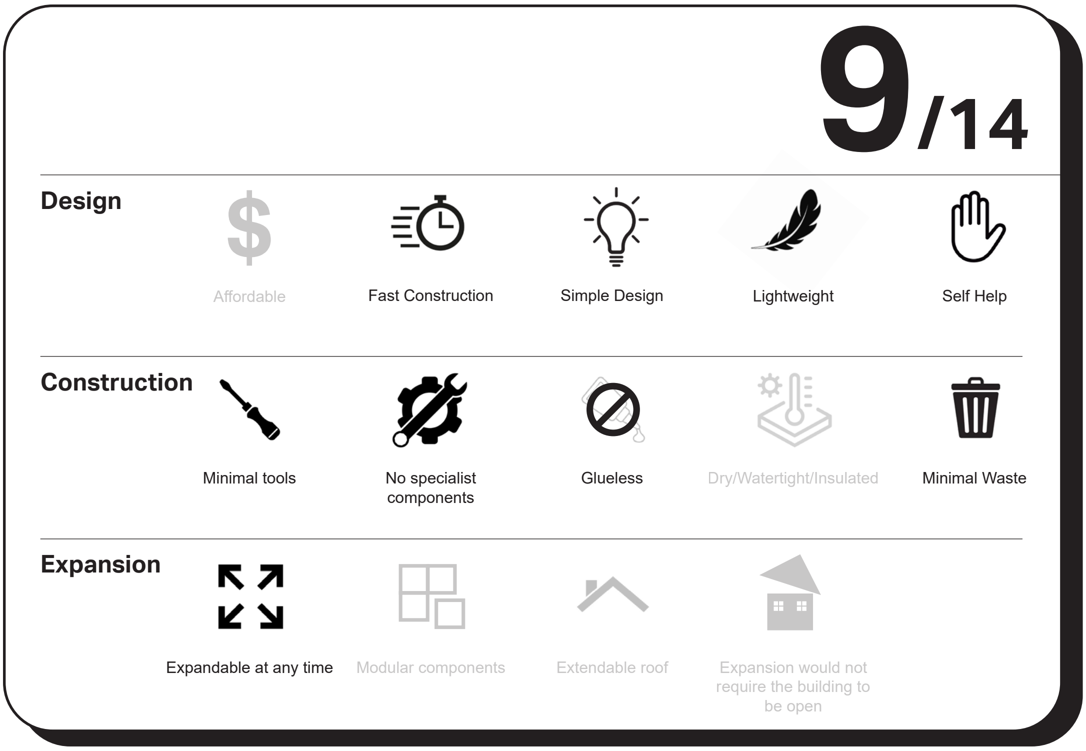
Critical reflection

Lack of Vertical Loading
- There is no continuous stud within the walls. To make the blocks removable in this fashion does not work as any form of overlapping or staggering component makes removal require an entire wall to be taken down. Vertical elements would have to be integrated within each block to correctly line up with below and above blocks. This would eliminate the 45mm rebate designed for window and door fixings.

Poor Structural Rigidity
- The model showed poor structural rigidity during its construction with no loads acting upon it. The test showed installing components to be fine, however, removal was significantly more difficult. The corners also suffered from loose connections even with the modified guides and locks.

Horizontal Slippage
- Preventing the blocks from sliding along the wall relies solely on the corners and cavity battens to lock them in place.

Bad Design
- Even though it scores a 9/14 on the design guide, this concept would never work. The structural rigidity of the blocks and corner joints would not be sufficient to support roofing elements. Although shown by the stress test to support high gravity loads, lateral loads caused by earthquakes have a high chance of unsettling the building due to the lack of continuous vertical structure.
- Installing a vertical structure within the blocks is a possibility, however, this increases material usage. Although it may be a simple product to install for DIY enthusiasts, the combination of the CNC process and additional timber would see the prices increase significantly. Therefore, the continuation of this concept will be stopped.



5.7 **Evaluation.**

Although ClickBlock was unsuccessful, understanding its strengths and weaknesses is an important step when moving forward. This will help build a starting point on where to focus in the design phase three.

- The idea of allowing each block to be removable anywhere in the wall is not a necessity. Greater thought during the planning stage would eliminate the need for this to occur.
- Making each block bigger.
  - Benefits of this include: faster to manufacture, less CNC cutting, faster build time per sqm, less labour on site and in factory. All of this would result in cost savings.
- Utilize screws for fixings to eliminate technical CNC cut joints. As this is designed as affordable homes, the use of screws is simpler and more cost effective over screwless CNC pin locks. As screws only require a drill to use, this makes them perfect for the DIY enthusiasts.

6 Design Phase 3.

Developed design considerations.

6.1 BuildaBlock Concepts.

BuildaBlock is the new working title for the next series of iterative design moving forward. This is a direct continuation from ClickBlock.

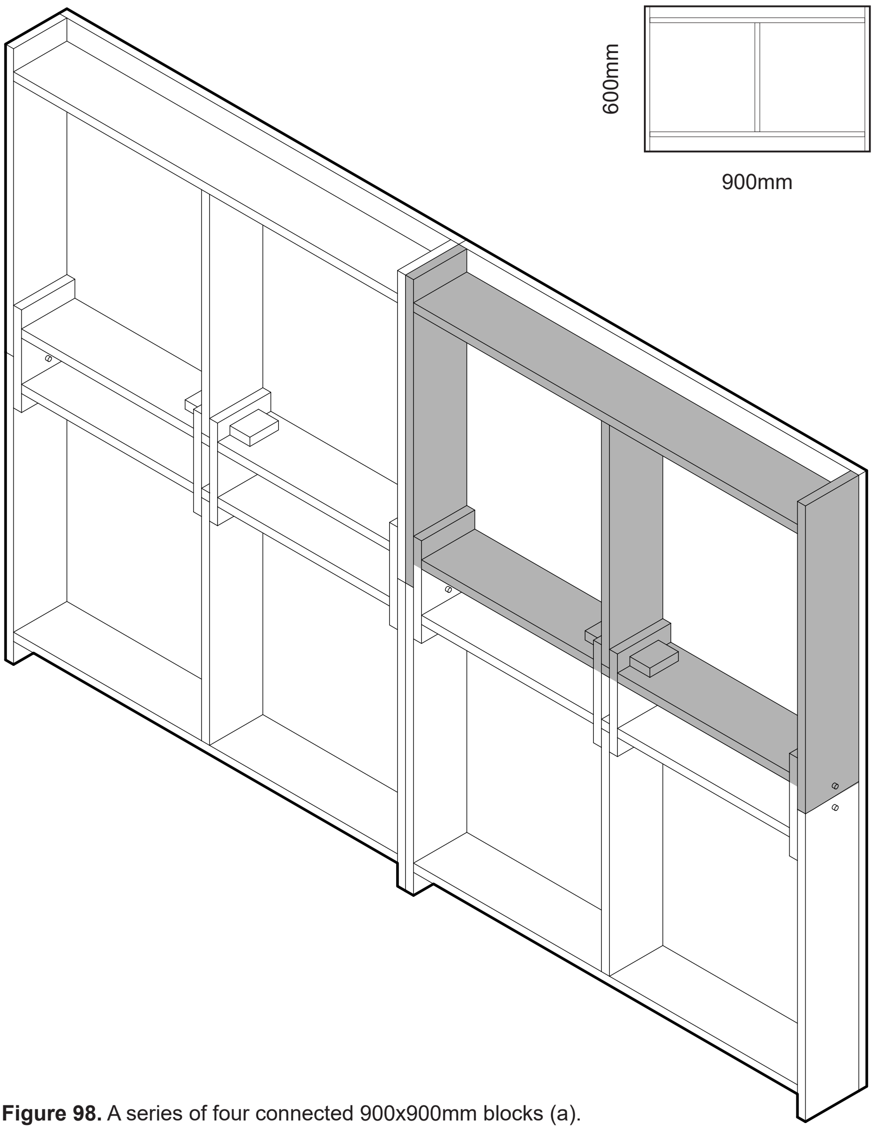
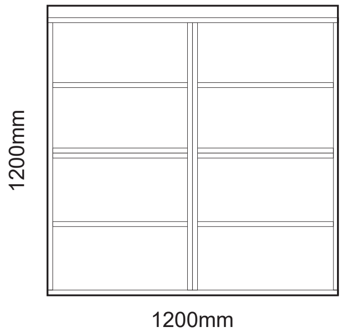


Figure 98. A series of four connected 900x900mm blocks (a).

6.1.1 Working Concepts.

Initial tests resulted in the experiment of a 900x600mm grid block with interlocking plywood connections. Additionally, the experiment introduced the inclusion of a 45mm rebate for a standard 4x2 timber to be fitted for a top or bottom plate and also window cut-outs.

Although this concept delivers better vertical loading over previous concepts and a faster construction time through larger blocks, it could benefit from simplification of connections points and arrangement of components for easier instalment of insulation.



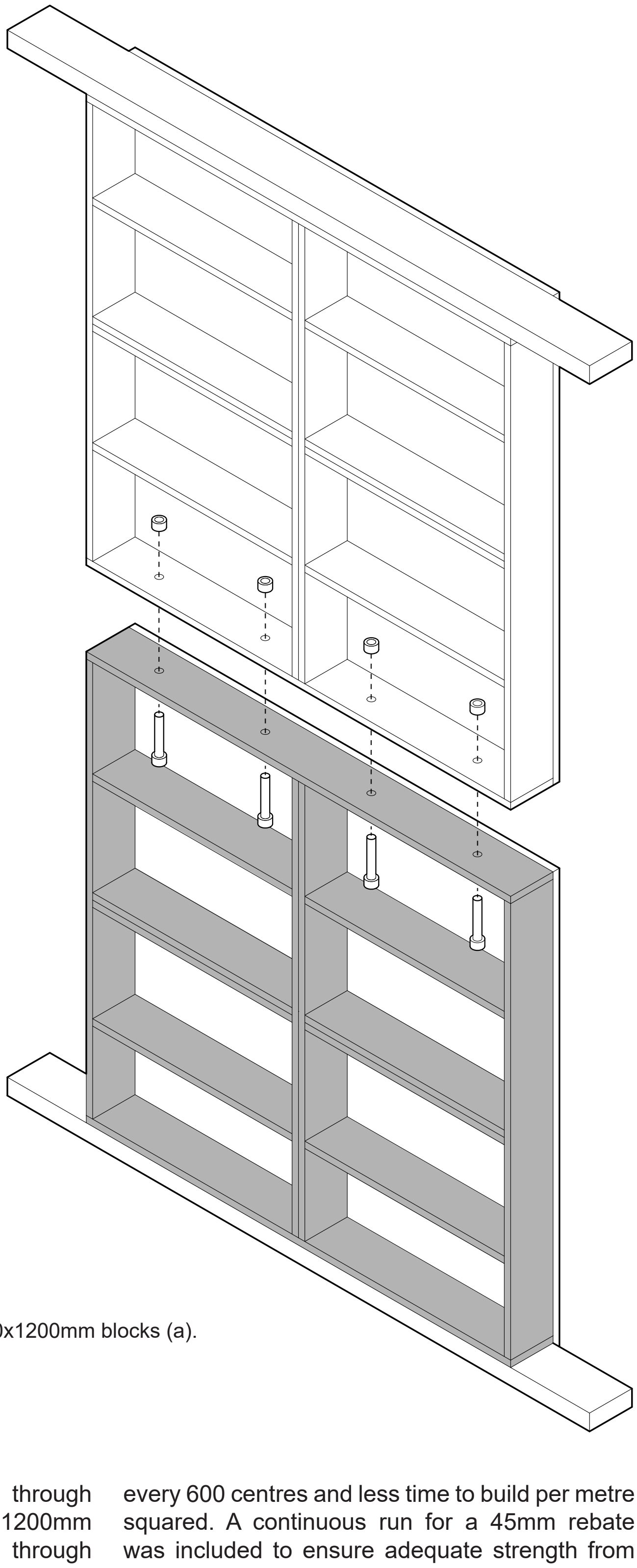


Figure 99. Connection of two 1200x1200mm blocks (a).

6.1.2 **Grid Analysis.**

This example worked on simplification through a more standardised grid formation of 1200mm for faster build time and less wastage through standard internal and external lining applications. This allowed for symmetry with the vertical and horizontal loading components which delivers continuous lines for load dissipation. Additional benefits include for cavity battens to be fixed at every 600 centres and less time to build per metre squared. A continuous run for a 45mm rebate was included to ensure adequate strength from the top and bottom plates. Fixing between blocks has been simplified by using a similar method as U-Build, with nuts and bolts, allowing for quick installation and removal for additions in windows and doors in future expansions.

6.1.3 **Windows and door cut-outs.**

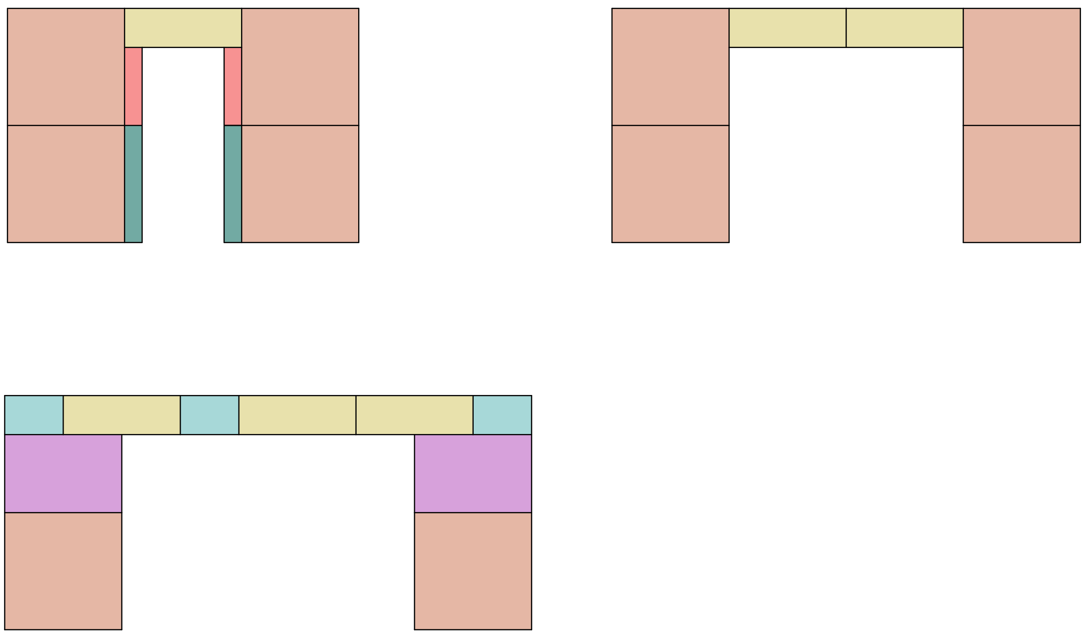
To ensure the buildings are unique and customisable for any user, there has to be some degree of custom window and door sizes available. In order to achieve unison between multiple variations and layouts, the following block additions were created to generate a range of different window and door sizes. Each new block type works in ratios of 1200 to ensure symmetry while reducing the total number of differing blocks to achieve the level of customisation for each user. The 45mm rebate was removed to achieve a higher level of flexibility within the wall construction. This removes any issues with height differentiations within window and door cut-outs. The following diagram below shows that with seven total wall block types, there are three standard doorways and eight basic window configurations. This enables each client a variety of configurations for customization to suit their specific needs.

Block type sizes.

Width x Height

1200 x 1200mm	1200 x 400mm	180 x 1200mm
1200 x 800mm	600 x 400mm	
600 x 1200mm	180 x 800mm	

Doors.



Windows.

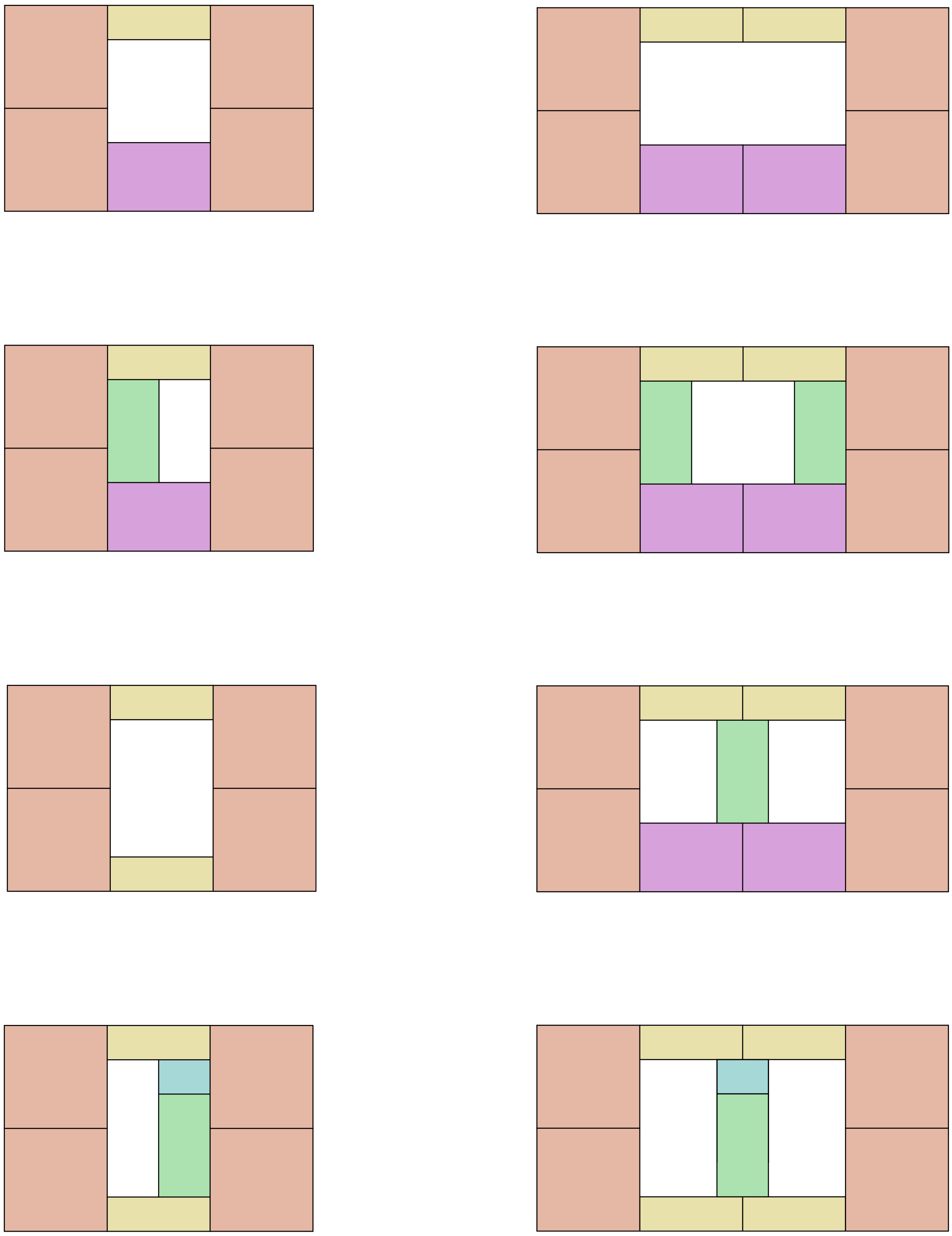
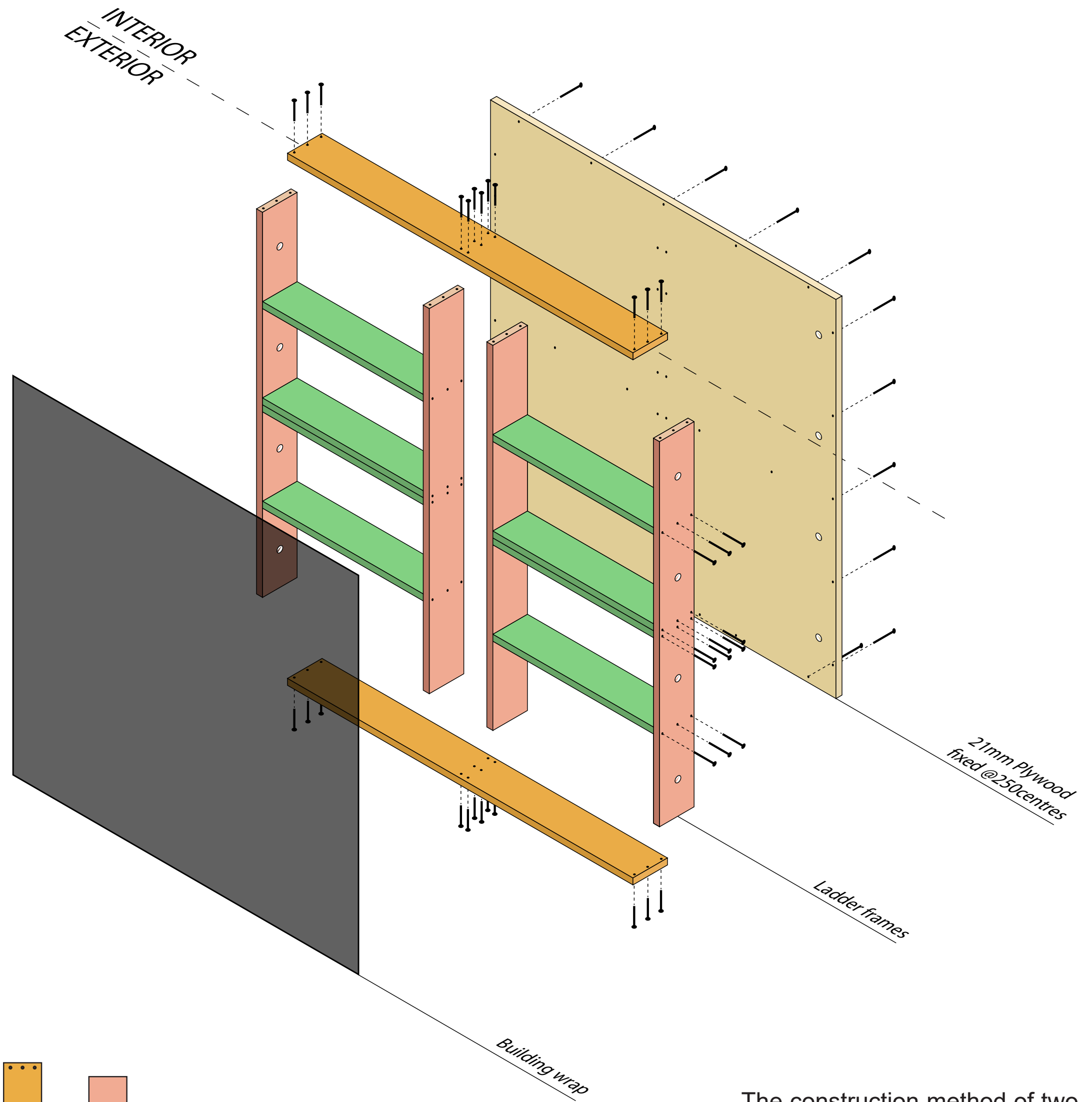
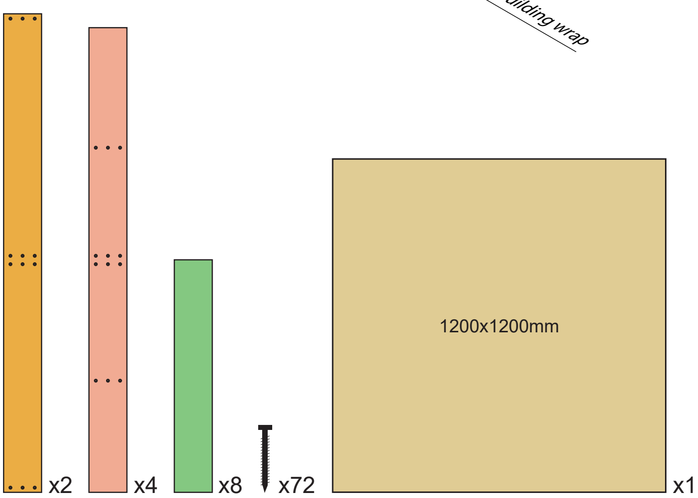


Figure 100. Grid analysis for windows and doors (a).

6.2 Block Construction.

6.2.1 Exploded 1200x1200 buildaBlock.





The construction method of two individual ladder frames allows for a double plywood stud in the centre of each block. This also allows for each horizontal member (dwang) to be screwed in securely and easily. Once multiple blocks are connected together, double studs of 42mm thick will measure every 600 centres allowing adequate fixing for cavity battens. This method allows for variants of 600 widths with the addition of only one new component, creating a greater level of customisation.

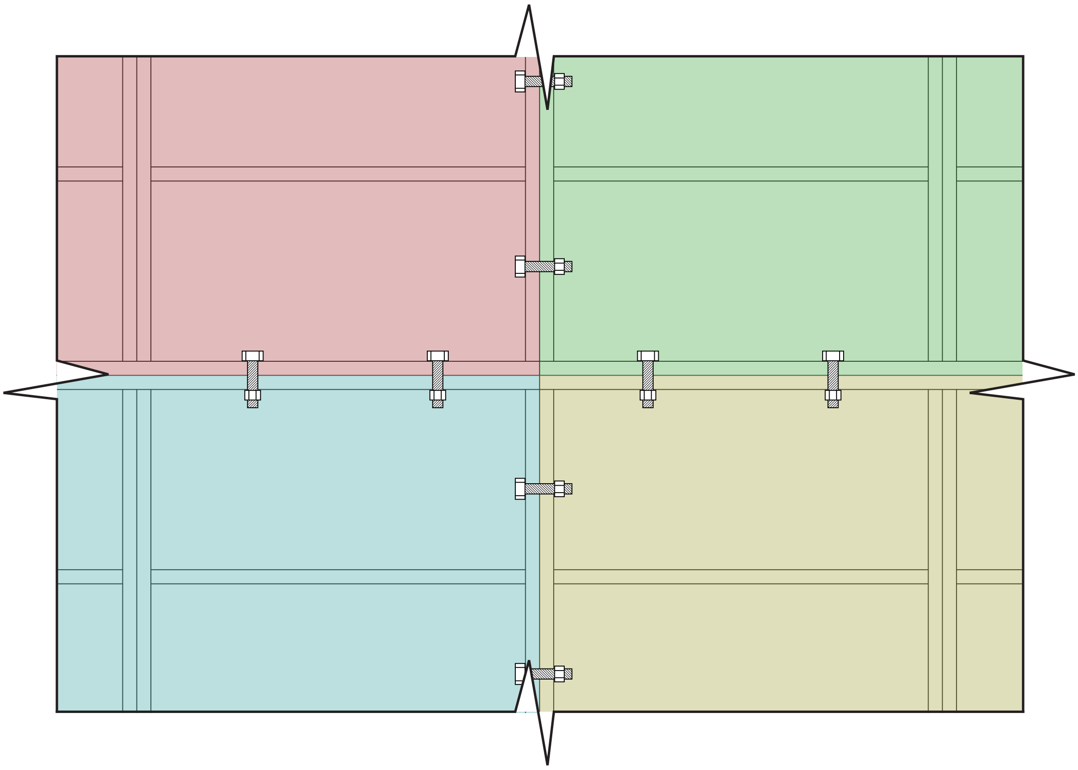
Figure 101. 1200 block construction and components (a).

6.2.2 Block Connections.

As shown by the exploded isometric diagram of the block's construction, each component is simply screwed together. This follows in a similar direction as flatpack furniture where pilot holes will be pre-drilled into the individual components ensuring ease of assembly for the “average” DIY enthusiast. This limits the construction of the individual blocks to a single drill, ensuring safety and simplicity for novice users.

Connecting multiple blocks together is simply done through using nuts and bolts. This allows the blocks to be removable and reusable for future extensions and modifications throughout the house's life cycle.

Note: Colours are purely for a visual indication to differentiate the edges between FOUR blocks.



Connections occurring at a 90-degree angle use the same set of nuts and bolts, fixed through the internal sheet of plywood. The internal sheet is designed to provide additional strength to each block while providing perpendicular connections for external or internal walls.

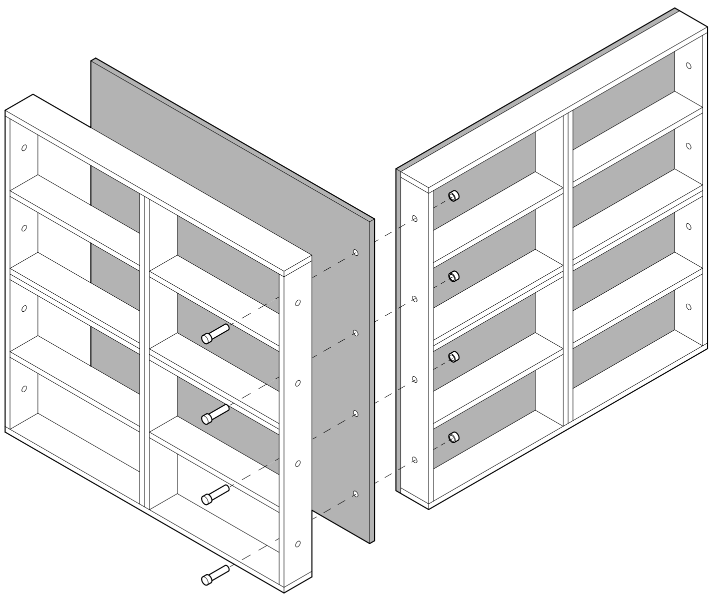
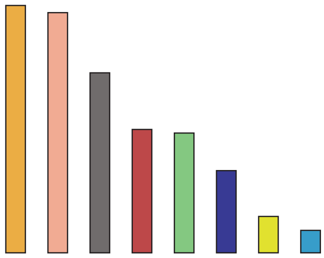


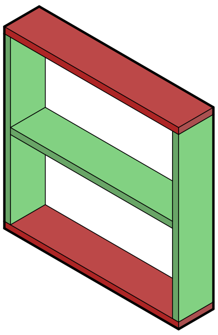
Figure 102. (Top) - Adjacent connections between 1200 blocks (a).
Figure 103. (Bottom) - Corner connections between 1200 blocks (a).

6.2.3 **Shared Components.**

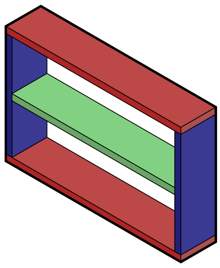
To achieve affordability, there was a need to derive multi-use components which would lower machine times for individual block types but also create a simpler construction for users. The following showcases 10 wall block variants constructed using the same 8 components.

These have been designed to follow the 1200 grid format in order to achieve a modular system. The principle of this design is that there are no complex cuts required, meaning that all cuts can be achieved by a CNC machine.

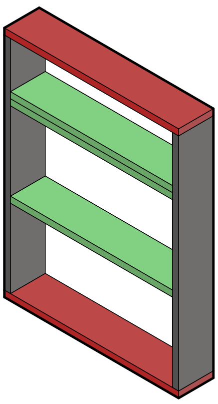




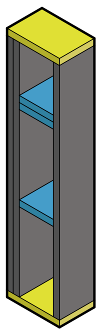
600x600mm
Typical use -Wall panel or window infill for desired size.
Weight: 4kg



600x400mm
Typical use - Doorway and window lintel.
Weight: 3.5kg

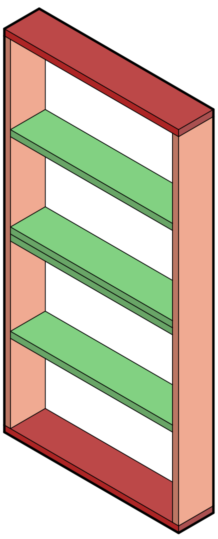


600x800mm
Typical use -Wall panel or window infill for desired size.
Weight: 6.2kg

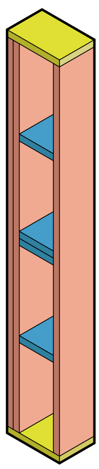


180x800mm
Used in conjunction with 180x1200mm to accommodate a standard 840mm door into the 1200 grid.
Weight: 4.2kg

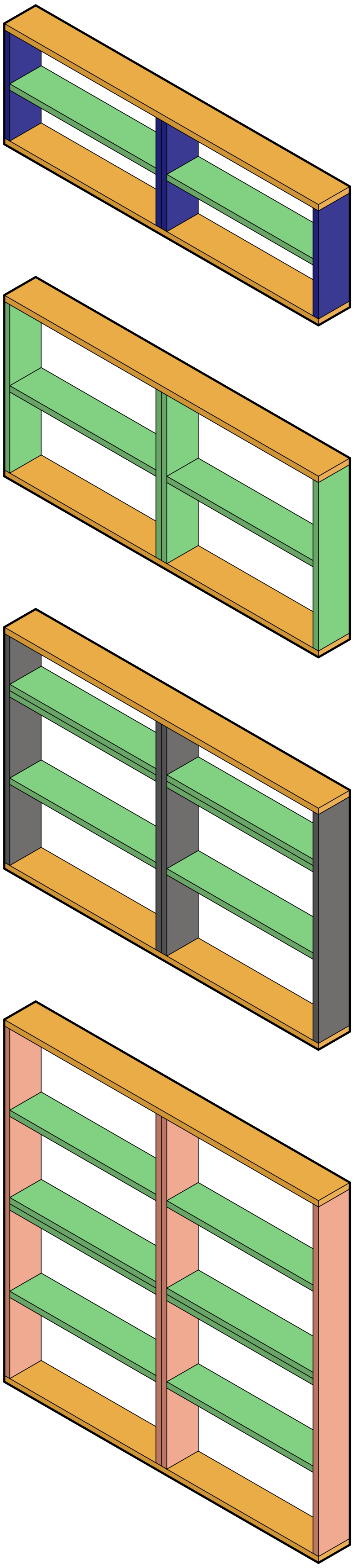
Double vertical component on one side for additional vertical loading and greater fixing depth for the door jam.



600x1200mm
Typical use -Wall panel or window infill for desired size.
Weight: 8.1kg



180x1200mm
Used in conjunction with 180x800mm to accommodate a standard 840mm door into the 1200 grid.
Weight: 6kg



1200x400mm
Typical use - Doorway and window lintel.
Weight: 7kg

1200x600mm
Used in conjunction with a 1200x800 and 1200x1200 to achieve vertical overlap for stronger connections.
Weight: 8.1kg

1200x800mm
Used in conjunction with a 1200x600 and 1200x1200 to achieve vertical overlap for stronger connections.
Weight: 12.4kg

1200x12000mm
The largest block for longer spans of walls.
Weight: 16.25kg

Note: All components constructed from 21mm structural plywood with weight being calculated by volume based on a total sheet weight of 33.88kg (Bunnings, 2021c).

Figure 104. Block variations and their shared components (a).

6.2.4 **Wall Configuration.**

As the idea is to expand the building overtime, it is difficult to have a brick like stagger to support and increase the strength between the joins of the blocks. This would result in similar issues to Conceptos Plasticos and Gablok where half of the wall would need removing in order to expand or add in additional windows. Taking the vertical staggered approach from U-Build and applying it to this design works perfectly with the expansion properties of the wall. This ensures there are not four different block corners meeting in one location. It allows for each horizontal join between two blocks to be supported by a full-length vertical block to ensure adequate lateral strength. As shown by figure 103.

The bolt hole locations have been designed to work alongside every block, regardless of window or door blocks, to ensure each overlap is supported and tied into the adjacent full block. Below is a diagram showing the positioning of the bolt holes in relation to the different block types.

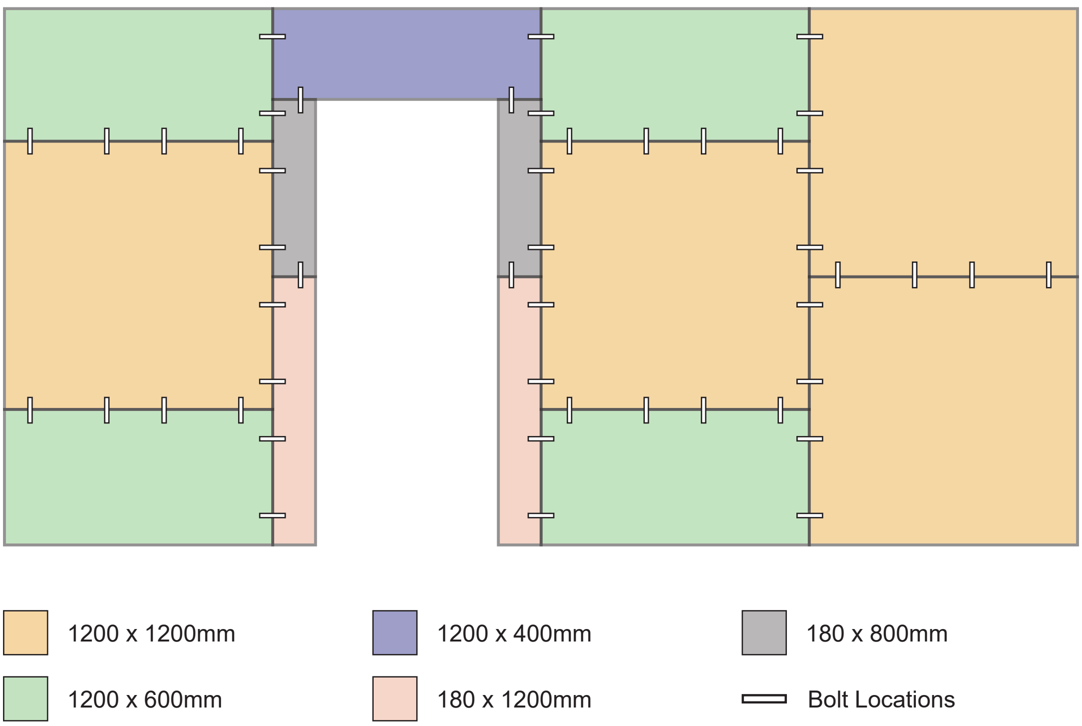
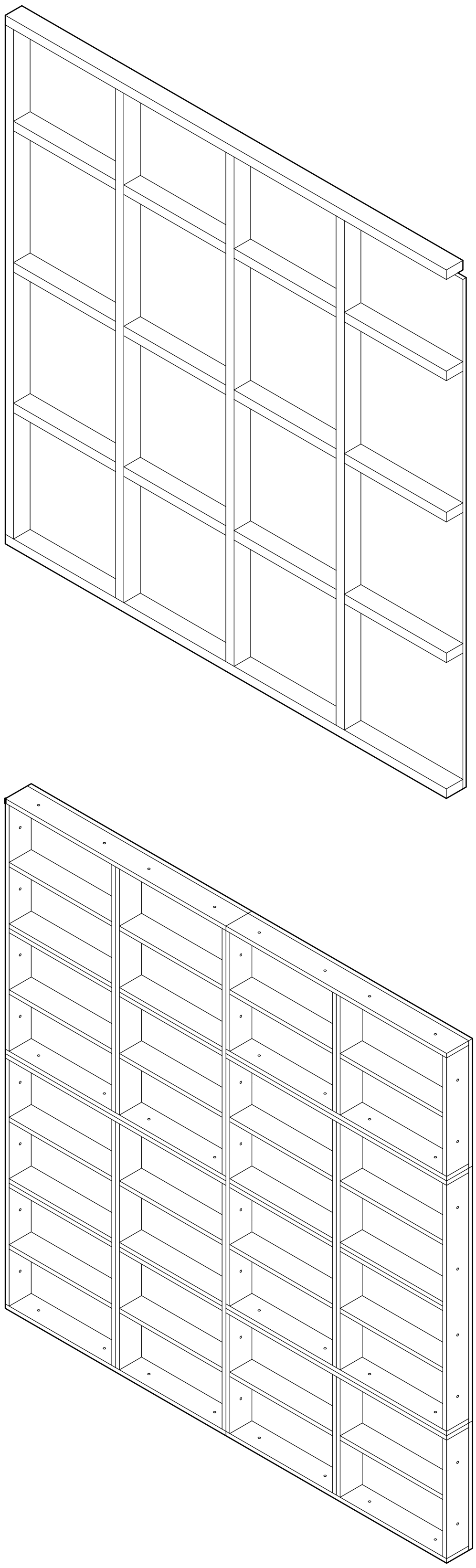


Figure 105. Wall configuration and bolt locations (a).

6.2.5 **Material Usage.**



0.189m³

Traditional timber framing made from 4x2 at 600 centres lined with 18mm plywood.

Critical Reflection:
This system does not benefit from lower usage of materials but instead the unskilled labour from both, making the pieces in the CNC factory and the on-site installation of the blocks. A further review will be undertaken to determine its viability and future direction based on the design criteria where analysing and redefining the scope of the project may be required.

0.237m³

buildaBlock wall constructed using 21mm plywood.

25.4%
Increase

Note: All volume calculations are based on a 2400 x 2400-millimetre wall. Excludes door and window framing.

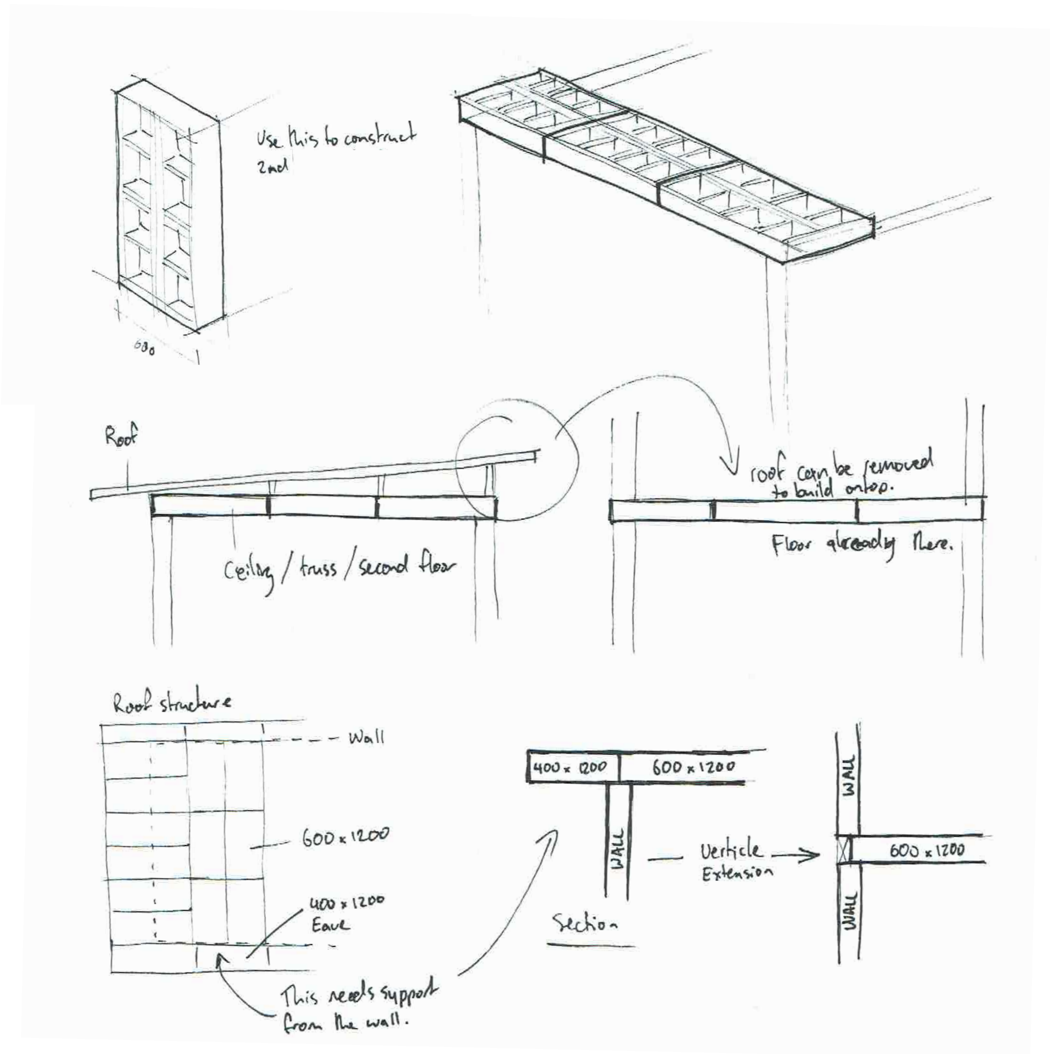
Figure 106. Material usage difference between buildaBlock and traditional framing methods (a).

6.3 **Roof Construction.**

The roof construction is the most challenging aspect for incremental expansion. All of the previous precedent studies show the roof as being a fixed object with no intention of being specifically designed for future extension. Villa Verde is an exception where although the roof is fixed, it has been designed to cater for expansion. The main issue surrounding this method is the roof must be fully completed to the desired final outcome of the house, meaning that the occupant has no option for increasing or decreasing the footprint of the house after the roof construction is complete. Additionally, the format of Villa Verde does not lend itself to customisation which could be seen as unappealing to the masses.

The solution to the roof is generating a system that works in cohesion with the walls through its construction and expansion properties. This will require standardised lightweight components, such as the walls, allowing for ease of construction and removal of each roofing element upon extension. An important aspect to consider when designing the roof is to ensure it does not follow the precedents with their unique solutions for each individual build. This will affect the budget and build time as additional time fabricating one off pieces for each individual build will be required. This could also see the potential outcome of a more complex build construction, too great for a D.I.Y. enthusiast. Ensuring the user is able to construct the roof without the need for specialist tools or equipment is vital to this research as it will compromise the self-help approach designed to save on labour costs.

6.3.1 **Concept Sketches.**



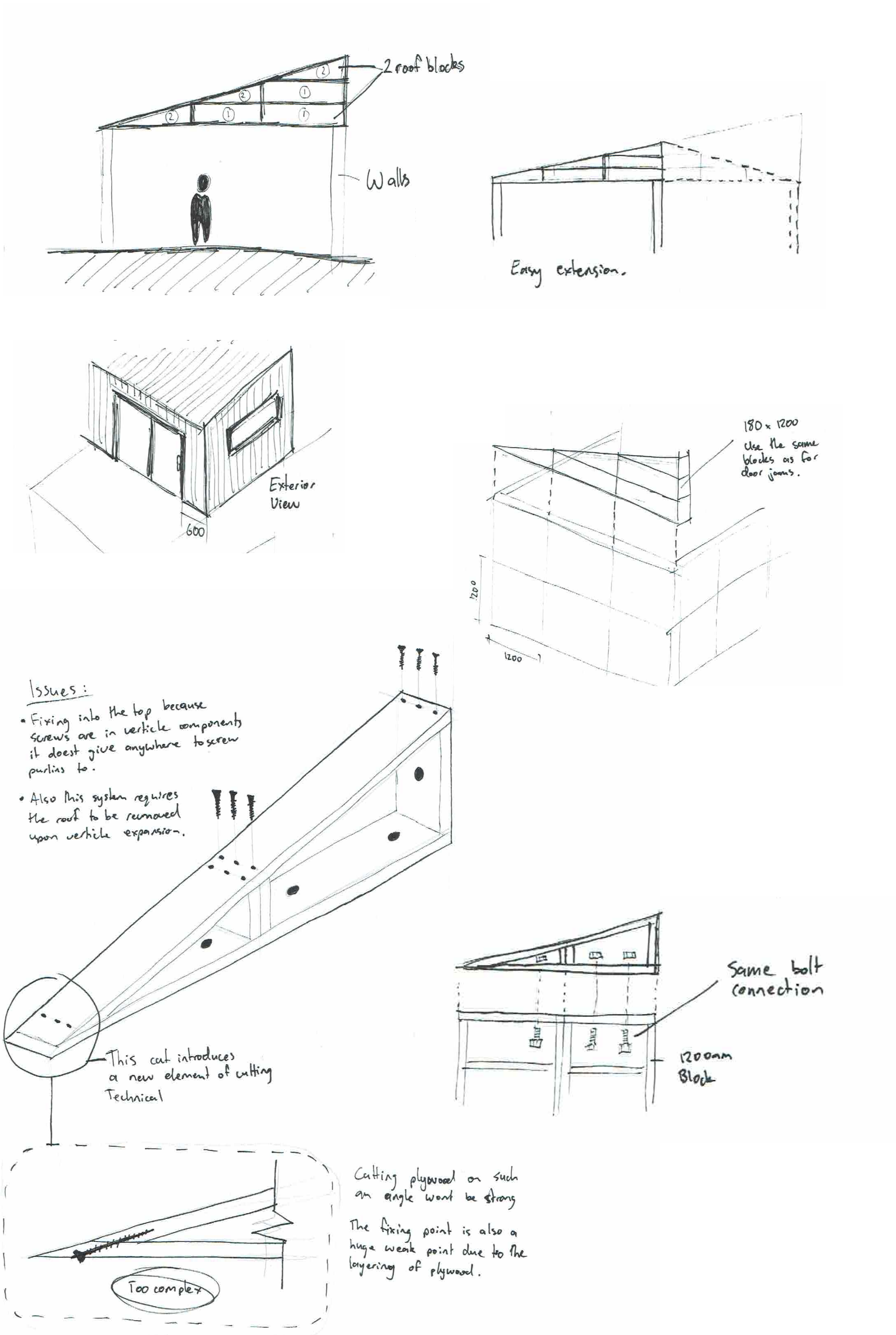


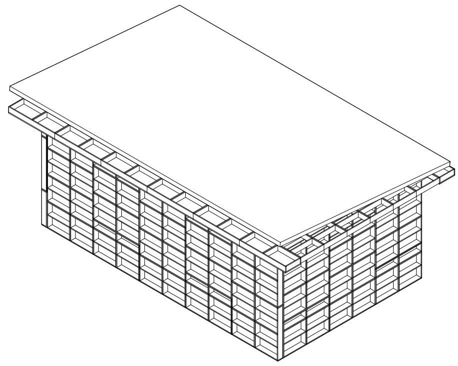
Figure 107. Concept sketches for roofing designs (a).

6.3.2 **Vertical Expansion.**

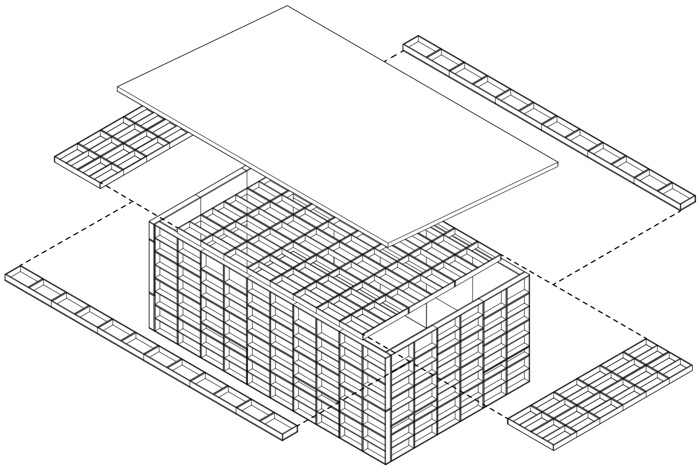
Building from the concept drawings, these diagrams explain how the roof could be impacted through the various stages of incremental construction. This working concept was drawing on the principles that the roof could be paired with a flooring system. This implies that upon vertical expansion, a second floor is already in place meaning the occupied space below does not have to be opened to the elements during construction. This encourages faster construction of the second storey through proper foundations being laid in the previous stage of construction.

The roof pitch will be obtained through a simple method of applying furring strips, ensuring minimal new components and weight are added to the roofing elements. This method can be seen with U-Build where furring strips are screwed into the ceiling assembly after being covered in a waterproof membrane (Dirksen, 2021).

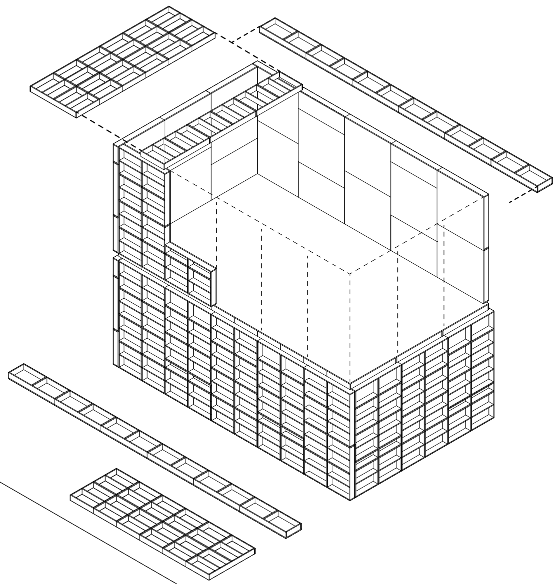
Critical Reflection:
Removal of the roof during the vertical expansion phase could show signs of problems. The time in which the second storey floor is exposed to the elements is determined by how long it takes the occupants to build and secure the second floor. This method could see the flooring exposed for lengthy periods of time, jeopardising the watertightness, leading to potential water damage within the structure.

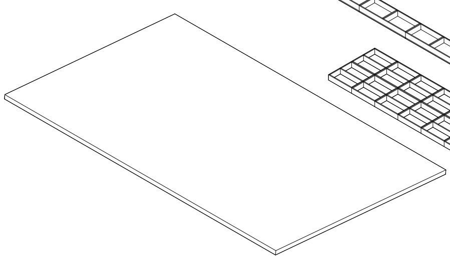


STAGE 1.



STAGE 2.

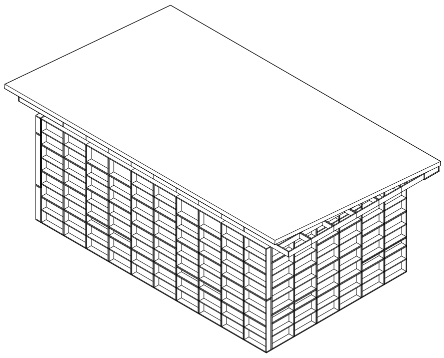




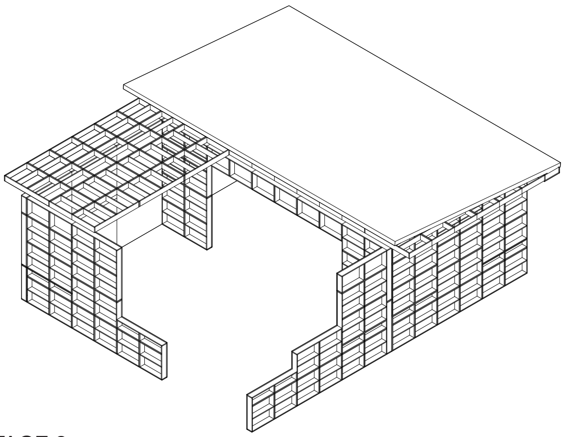
STAGE 3.

Figure 108. Vertical expansion with buildaBlock (a).

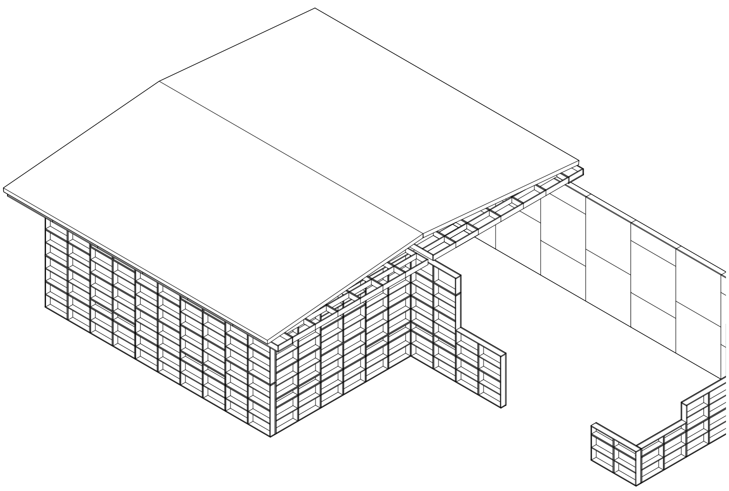
6.3.3 **Horizontal Expansion.**



STAGE 1.



STAGE 2.



STAGE 3.

Figure 109. Horizontal expansion with buildaBlock (a).

Additional problems appear when expansion occurs horizontally through potential high risk leak areas through roofing joins. As this work was designed to be undertaken by the occupants through self-help means, if not enough care is taken to correctly secure and join existing roofing to the new construction, foreseen water damage is inevitable. Ensuring correct methods of waterproofing and flashing fixings are used is essential for any expansion to occur.

In order for expansion to occur, some wall blocks in the expansion direction are needed to support the roofing structure. The roofing system is not strong enough to span large distances without support from underneath, hence the need for some walls to remain. There is the potential for this to be remedied through new interior walls from the additions of extra bedrooms to act as the new supports for the roof, however, this solely relies on a correct and strict internal layout which could compromise the customisation and flexibility of the floorplan.

Critical Reflection:
Because each flooring block only runs 1200mm, the structural support and strength between each block and bolt would not support a large span for open spaces. It could be argued that limited sized spaces are acceptable for a budget home, however, this can lead to poorly designed layouts which will create terrible homes for living. The objective of this research is to find an affordable solution that does not punish people with poor design. Cheap does not mean bad, it means careful and considerate design choices.

6.3.4 **Limitations of 3 Axes Expansion.**

Shown by the previous concept of a three axes expansion, multiple problems are encountered which limit the feasibility of this approach. The overall layout design becomes very disorganised, primarily along the horizontal axes, making for poor design and living spaces. This created the effect of multiple singular additions which gives the building a low-cost kitset appearance. Although the project is to create a budget kitset building, better considerations need to be made to ensure the end product is of high quality so there is demand for the final product.

It could also prove difficult for waterproofing roof extensions where there is a change in the roof hip angle. As this is intended to be built by a non-professional, with incorrect installation, problems with water leaks and damage are a potential high risk. Additionally, furring strips would be required. These will have to be constructed out of a non-plywood material and in greater lengths than the standard 1200 that is standardised for this design.

As previously stated in section 5.2.4, generating a roofing system which is expandable in all 3 axes is extremely complex and highly unlikely given the time frame and budget set out for this specific project. This is not to say it is not possible, but it should be noted that understanding the limitations and time will compromise the level of detail able to be explored in this research.

Based on previous literature and findings surrounding costs, land value, and land size, this research will focus on incremental expansion in two axes, vertical (y) and ONE horizontal (x OR z) to ensure a developed design can be produced within the timeframe of the working thesis.

6.3.5 **Gable Roof.**

Overview
Now the roof is limited to a two axis expansion, design work can begin on the process for how the roof and wall extension can be constructed simultaneously. To remove the need for unique roof trusses that many of the precedent studies showed, taking a gabled roof approach can utilise a similar block type as the walls to support the roof while using the same connections and components. Additionally, a gabled roof exaggerates the height of the building creating the illusion of a larger space within confined areas. This space also has the potential to be used as a loft for additional bedrooms even in a single storey dwelling, perfect for smaller builds such as a tiny home.

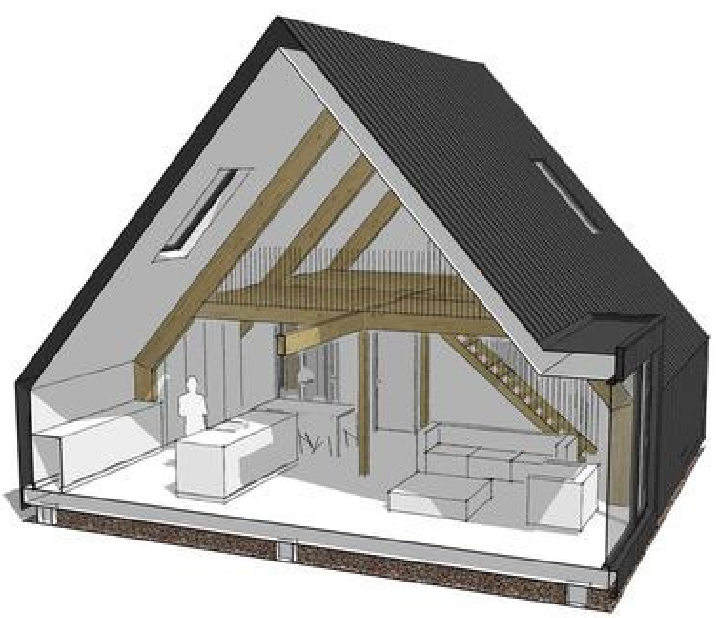


Figure 110. Barn house (Bouwboek, n.d.).

Expansion
To achieve simultaneous expansion amongst wall and roof blocks, a series of limiting factors defined by safe building practices and structural limitations need to be addressed as these will affect the final design outcome.

1. The building will be limited to a width 6 meters for the following reasons:
    - The roof is self-supporting (i.e., no trusses) which means the span cannot be too large.
    - It also has to be man-handled into place and can't be of a dangerous height. A width of six meters already puts the highest point at 5400mm.
    - Too high and a crane would be required. This is an option as the roof could be built in sections on the ground and then craned into place for faster construction.

2. The difficulties of vertical expansion is the removal of the roofing elements. If the house is two storeys to begin with, then the later expansions only have to occur upon the horizontal axis. This will not only cut costs for later construction, but it will also make expansion easier, quicker, and less disruptive on the existing house as construction can be done without opening the roof or walls.
3. The gable roof must be a 45-degree pitch so new components can be correctly fitted to the 1200 grid. This ensures minimal amounts of additional components need generating to suit varying

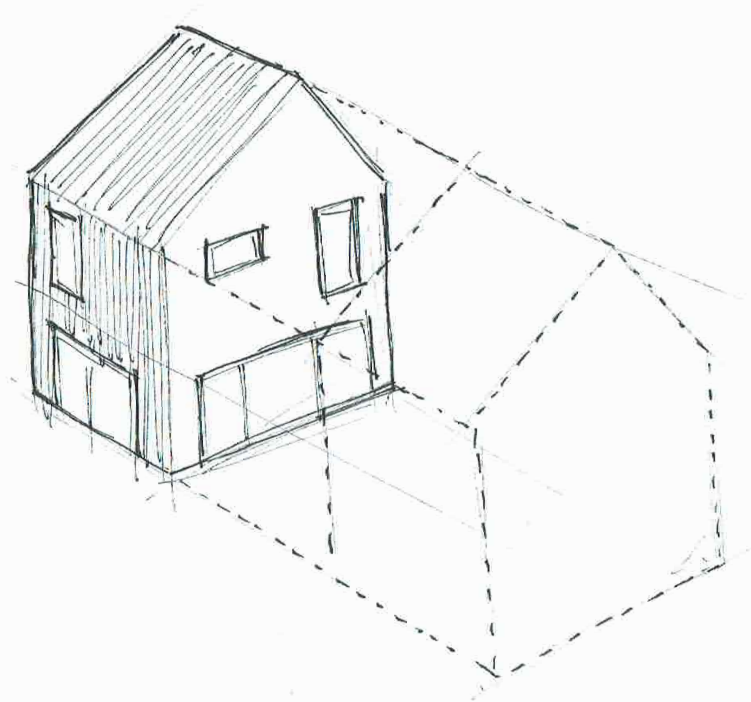


Figure 111. Incremental expansion solution for roofing elements (a).

6.3.6 **Example Situation.**

Although limiting factors have prevented certain design choices, there is still plenty of customisation for any lifestyle needs or section sizes. Below shows a hypothetical situation and the design possibilities of a two-storey dwelling.

Example.

A young couple in their early twenties are looking at getting into the housing market. Both are heavily career focused and have managed to secure a small 300sqm section in the city near their jobs. They currently have a small social life outside of work so they are not in need of a large space but have future plans to start a family within the next 10 years.

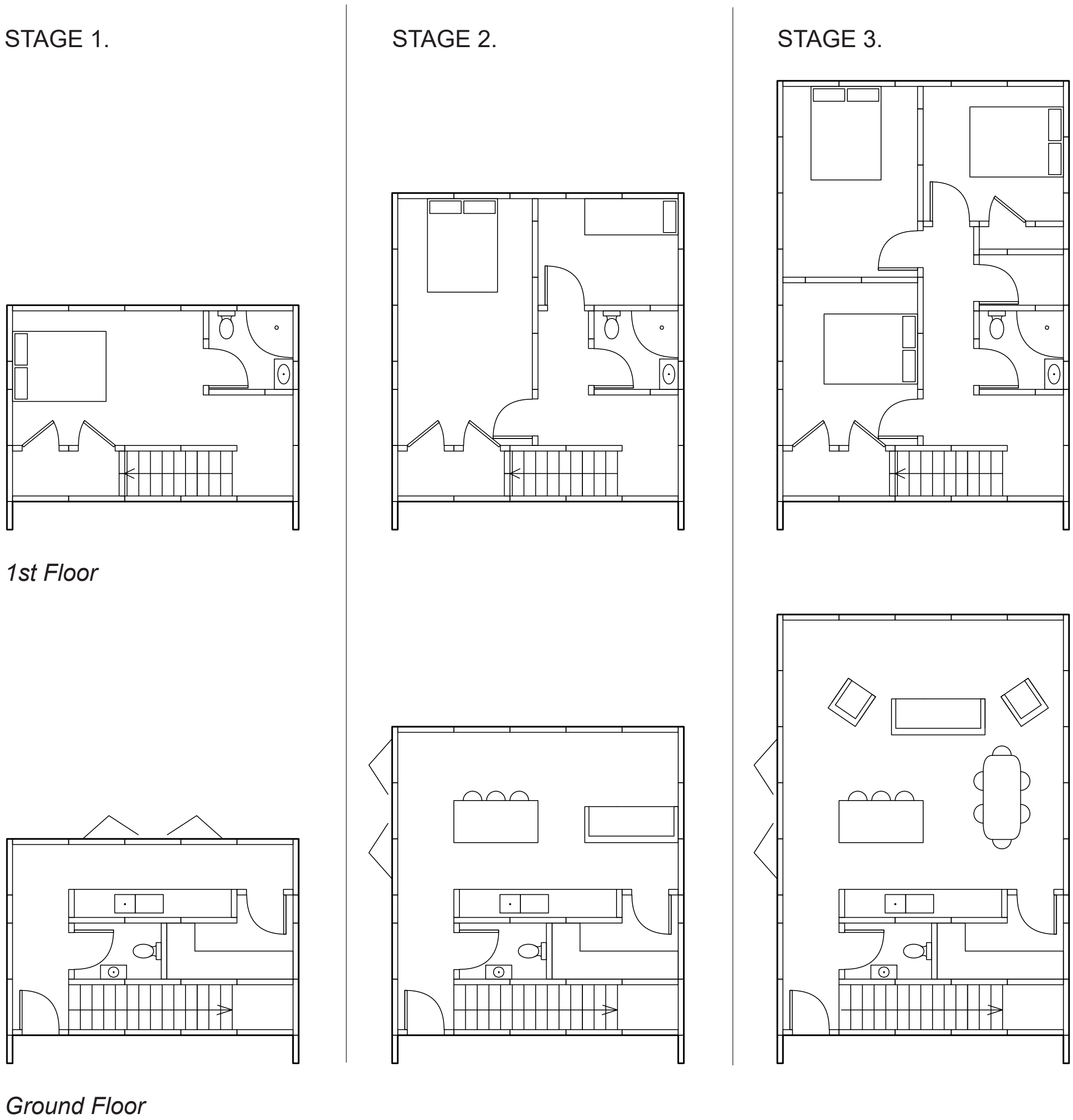


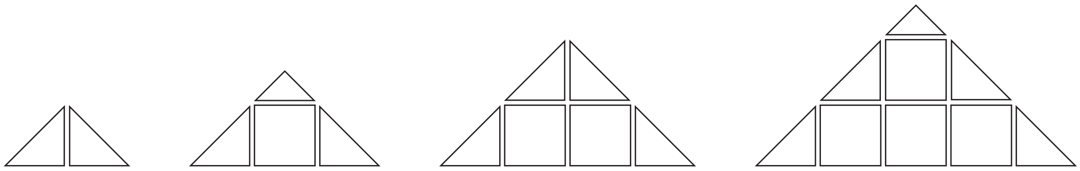
Figure 112. Example floorplan using an incremental building process (a).

In this example it was especially important that both bathrooms were correctly placed from stage one. Adding in additional bathrooms later is possible but knowing the general layout was going to be small, it makes it difficult to add additional bathrooms without interfering with new spaces. This approach saves on plumbing costs as all of the wet services are located within the same 15sqm and do not need to be touched in any other stages.

Note: While planning these floorplans, it was noted that an additional wall block of 480mm x 1200mm would be beneficial to generate cohesive floor plans.

6.3.7 **Gable End Walls.**

Now there is a distinguished layout, there needs to be blocks to fill the gaps between the walls and roof. As the gable roof allows itself to be flexible in the width of the building as demonstrated by the below diagram, the following end pieces must lock into both the walls and roof using a similar system. Adhering to the 1200 grid, we can generate the smallest "usable" width building at 2400mm using two 45 blocks. Due to the nature of the 45 angle, new components had to be created to suit the larger length of the hypotenuse. Paired with the difficulties of screwing pieces together on non-right-angled components, a total of 8 components makes up the two blocks below.



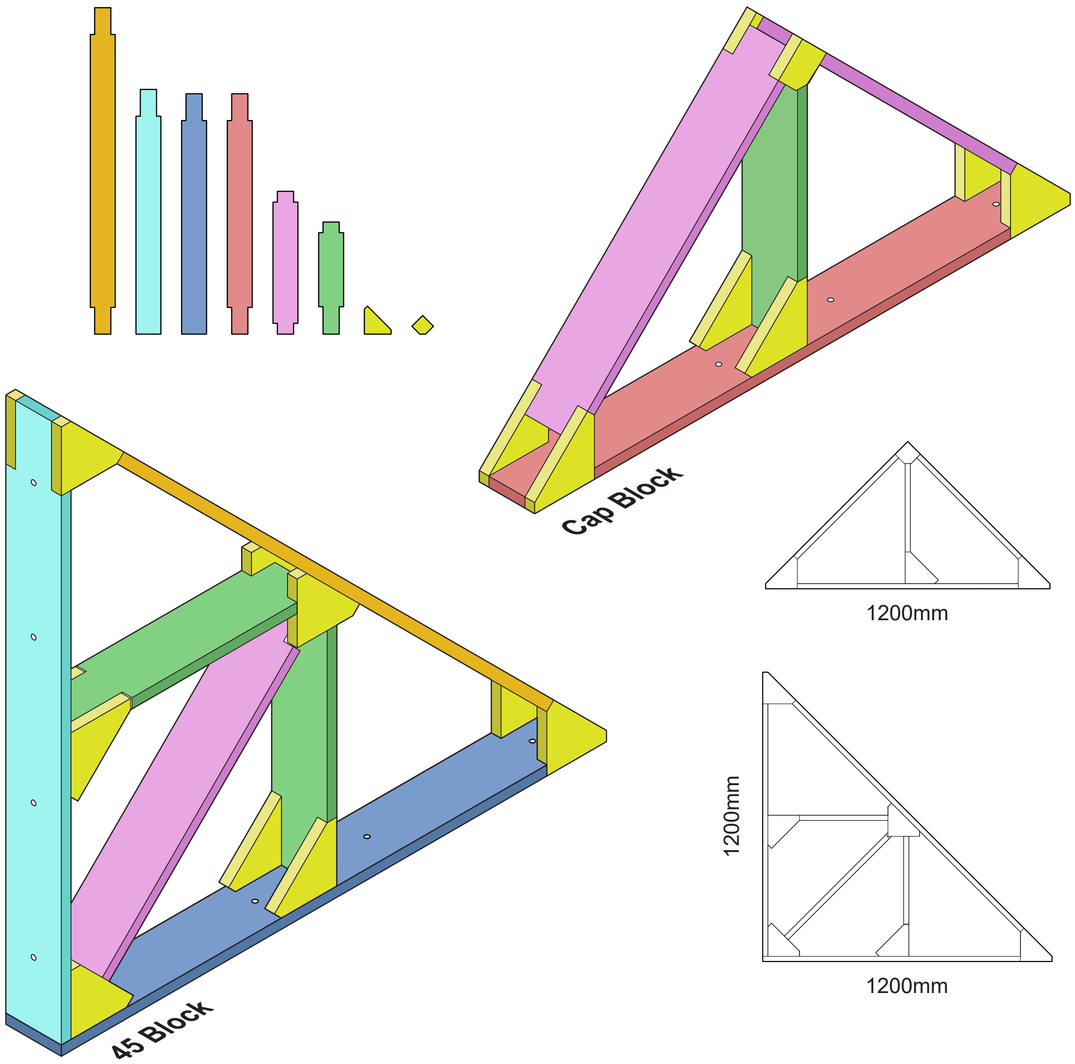
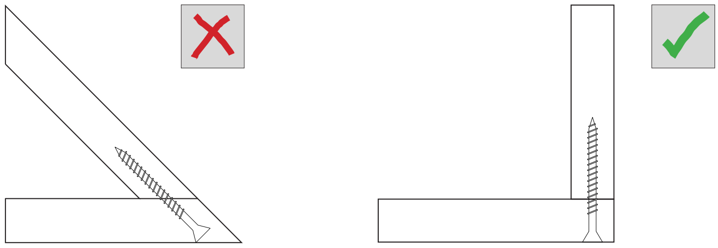


Figure 113. (Top) - Flexible width with gable roof type (a).
Figure 114. (Bottom) - Gable end blocks and their components (a).

Gable Bracket.

The largest challenge in designing the gable end blocks was how to screw them together. As most components met at a 45-degree angle, screwing them together directly would have resulted in poor strength due to the grain of the plywood. This would have also required angled cuts and pilot holes, something that would increase the difficulty of manufacturing.

The yellow bracket shown on figure 112 was developed to remove these advanced cuts to ensure each piece of plywood is fixed at 90 degrees. The bracket works in any orientation for both the 45 Block and Cap Block end gables. All of the pilot holes in the bracket correctly correspond to a pilot hole located in each component piece within the gable end blocks. None of the pilot holes overlap and all only work in their correct placement and orientation for that specific piece. This means it is impossible to incorrectly install the yellow bracket.



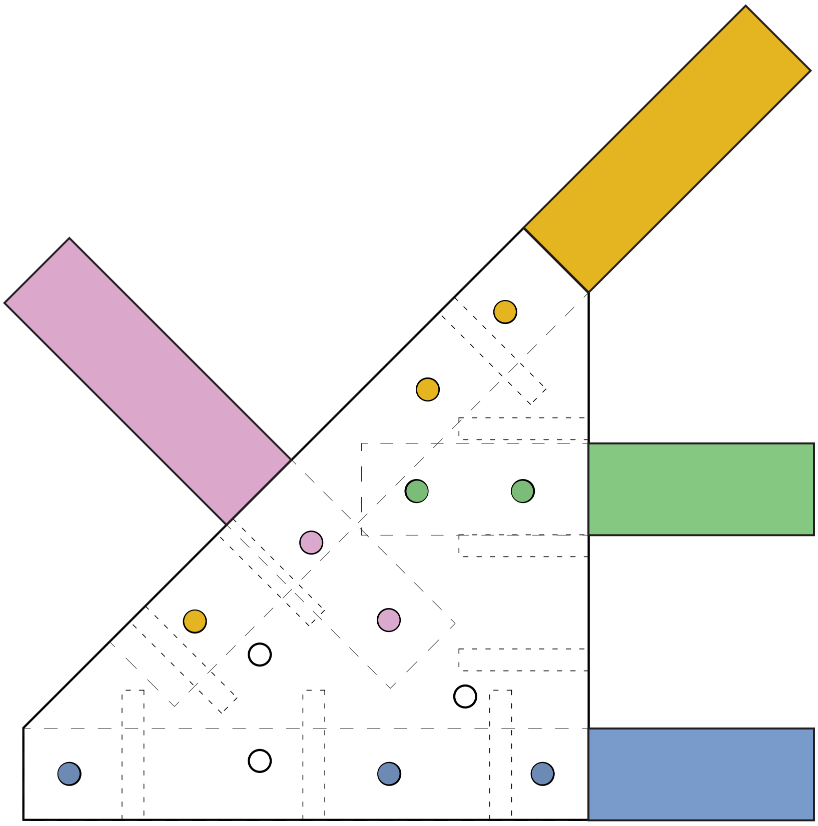


Figure 115. (Top) - The correct method for screwing into plywood (a).
Figure 116. (Bottom) - End gable block brackets (a).

6.3.8 **Load Transfer - Roof to Wall - 135 Block.**

As the main component of the roof will be constructed using a combination of 600 wide blocks, it is important that the loads are correctly transferred down into the walls. This was achieved using a new block, adding only one new component, which would eliminate the need for any form of connection at the pivot point between the roof and wall. This allows the loads to be continuously transferred without putting the load stress primarily onto the connection joint.

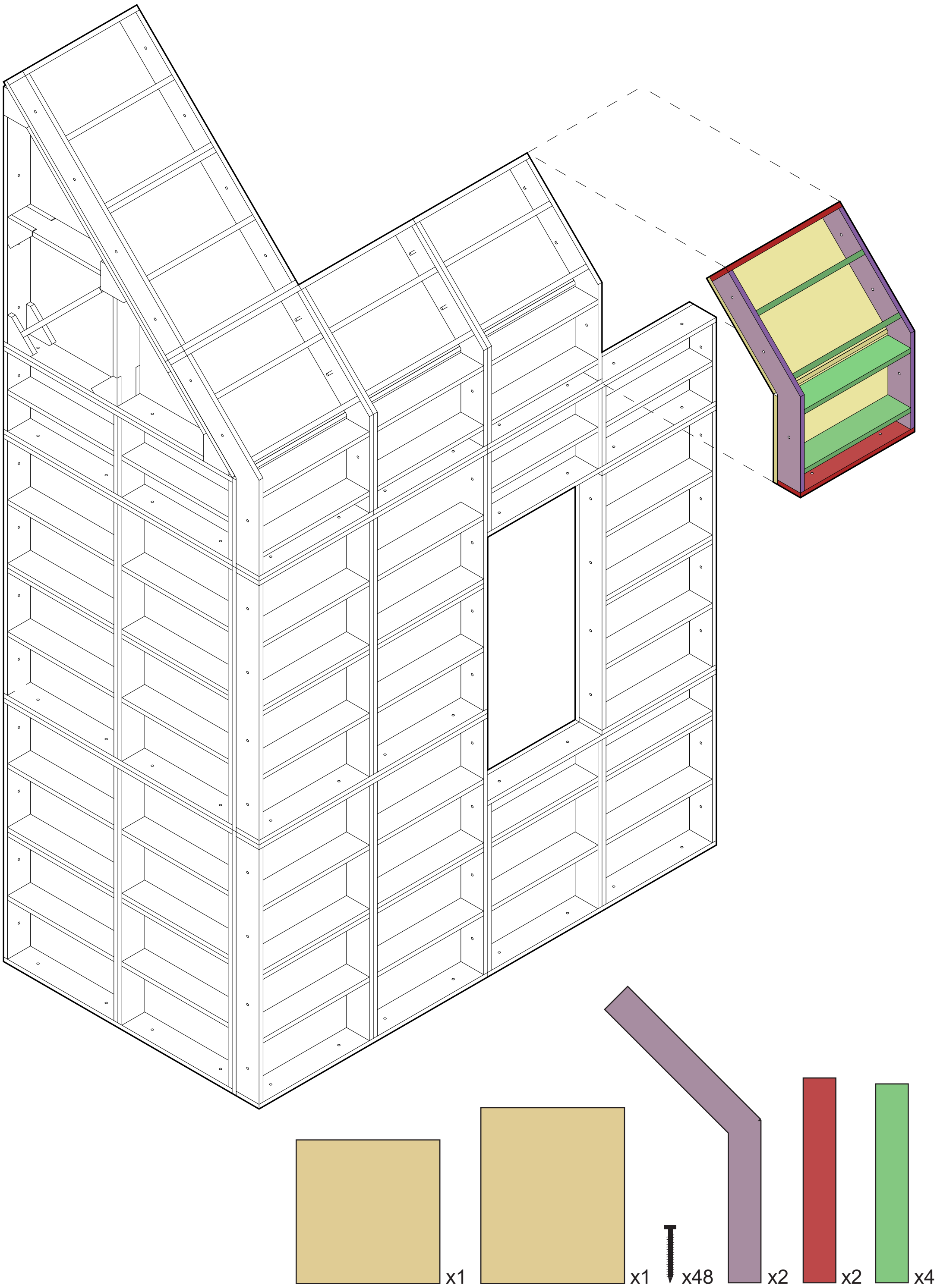


Figure 117. Roof to wall block (a).

6.4 **Wastage.**

Along with precision cutting, the other main benefit of using a CNC machine is that one machine can do all of the cutting. There is no need for swapping machines or accessories for different sheet cuts, it is a matter of programming the next sheet into the machine for cutting. For this reason, to maximise the number of components per sheet, the following layouts were derived.

Most components have been split into one component per sheet. Where multiple components share the same sheet, correct proportions have been used to ensure excess pieces do not accumulate (eg. sheet seven has the correct ratio of 4 yellow: 7 blue.). The following calculations have been based on sheet sizes of 2400x1200mm and a CNC bit of 5mm. A 10mm bit can be used where the dust waste percentage would be doubled and solid waste would be reduced by the initial dust waste.

Note: SW = Solid Waste, DW = Dust Waste.

Reducing Waste

Reducing waste further can be done by various means of recycling. This can be conducted through composting materials or more beneficial to the budget and circular economy, made into wall and ceiling insulation for the homes (Woolley, 2006). Acknowledging the potential is important, however, as this is not the main target of this research further investigation will not be conducted in this area.

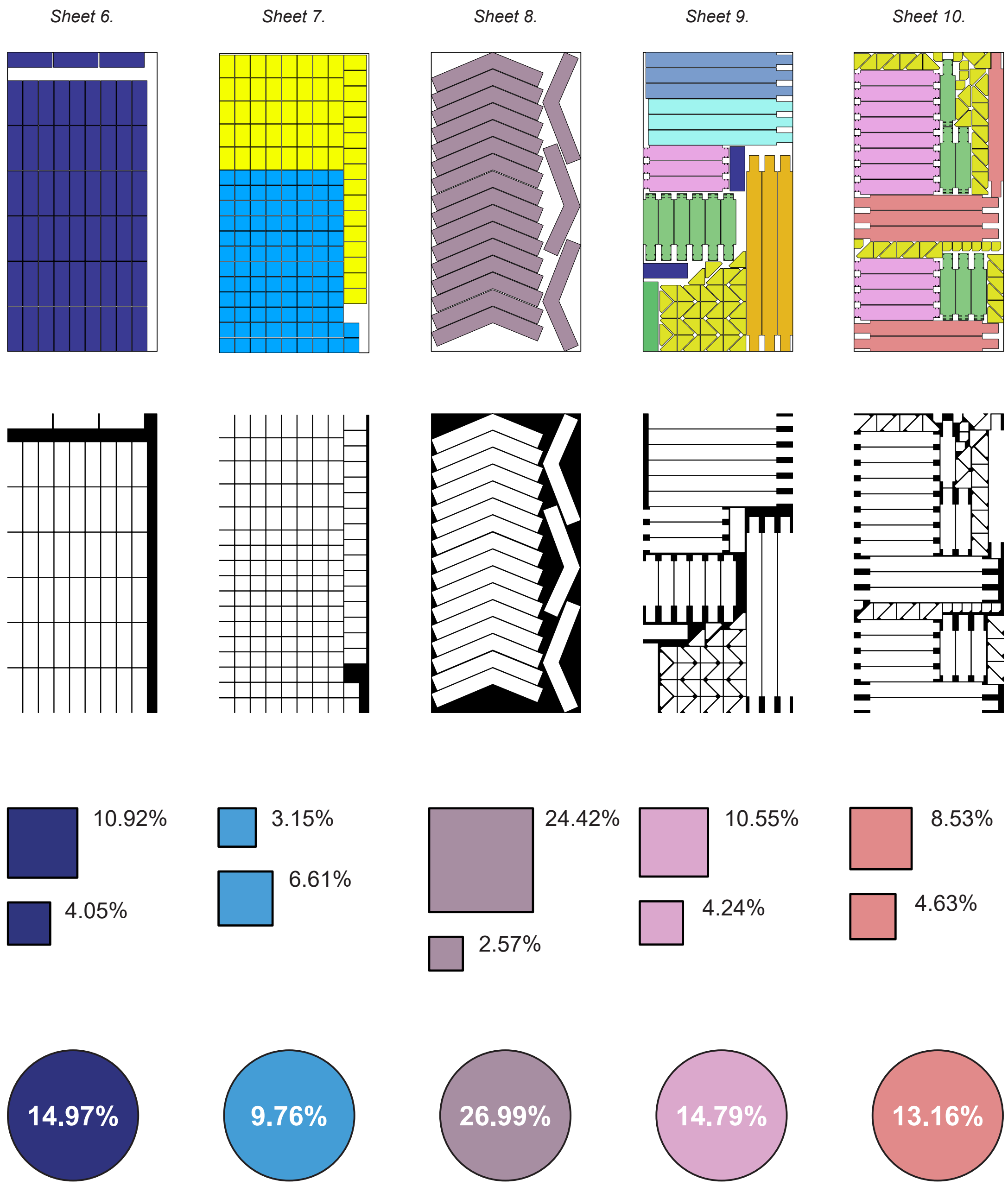


Figure 118. CNC sheet wastage (a).

6.5 Costings.

6.5.1 Components.

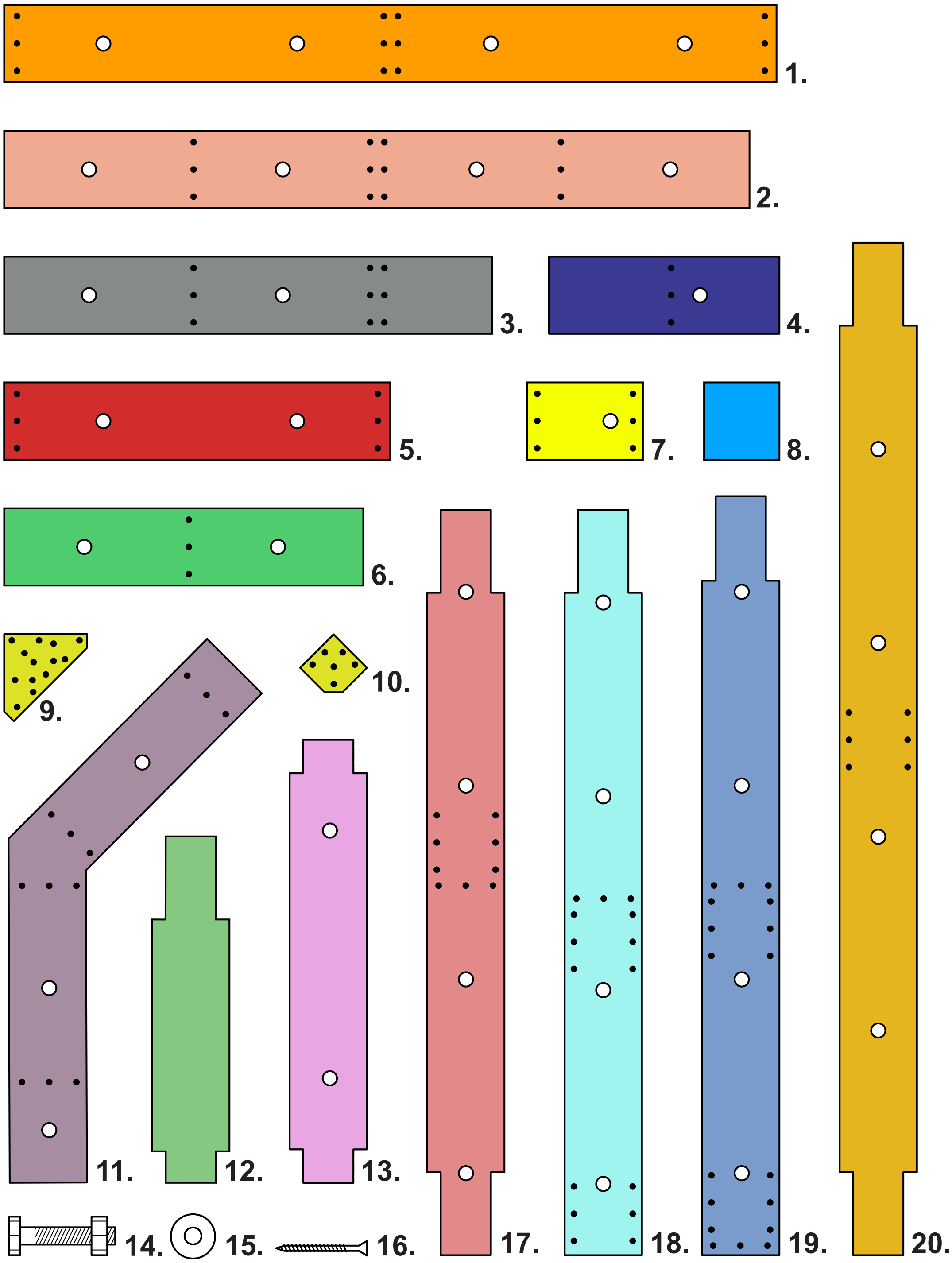


Figure 119. All components of buildaBlock (a).

6.5.2 **Price Per Component.**

Component.	Price.	Description.
1.	$14.43 ea	1200H
2.	$15.36 ea	1200V
3.	$10.30 ea	800V
4.	$5.59 ea	400V
5.	$7.77 ea	600H
6.	$7.77 ea	600H&V
7.	$4.12 ea	180H
8.	$2.40 ea	117H
9.	$4.25 ea	Bracket (Large)
10.	$1.94 ea	Bracket (Small)
11.	$15.56 ea	135^{o}
12.	$7.92 ea	Gable 1
13.	$8.99 ea	Gable 2
14.	$0.79 ea	M10 x 60mm Hex Bolt, Zinc Plated
15.	$0.09 ea	M10 x 21mm Zinc Plated Round Flat Washer.
16.	$0.11 ea	10 c 75mm Screws
17.	$15.82 ea	Cap Bottom
18.	$16.63 ea	45-1
19.	$17.22 ea	45-2
20.	$20.40 ea	45-Long

*All pricing is from various NZ retailers as of Sep 2021. Prices do not include shipping or bulk purchases**

Calculations supporting these numerical results can be found in the appendix referenced 9.1 & 9.2.

6.5.3 **Price Per Block.**

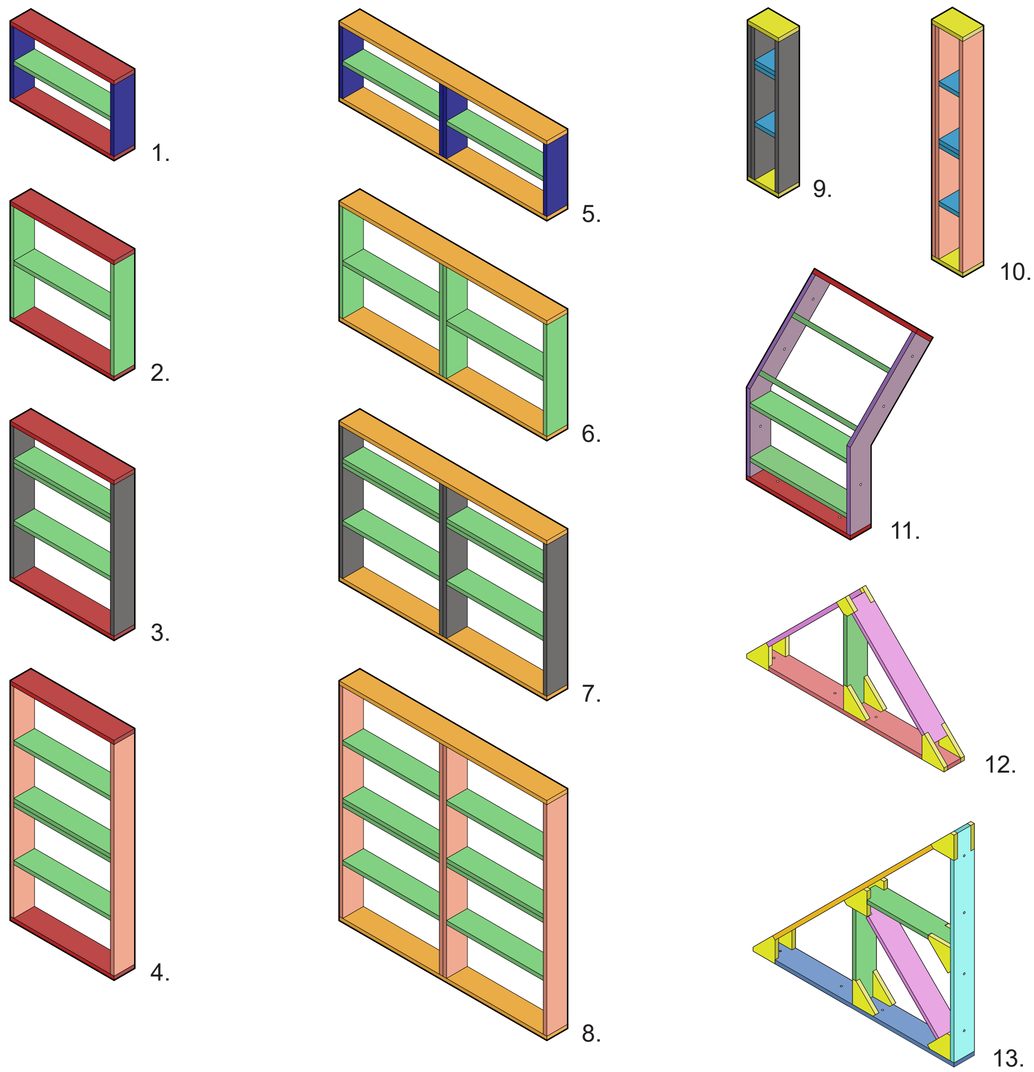


Figure 120. Blocks and their respective prices (a).

1. 600x400 = **$39.11**	6. 1200x600 = **$86.48**	11. 135 Block = **$86.10**
2. 600x600 = **$44.35**	7. 1200x800 = **$130.32**	12. Cap Block = **$82.97**
3. 600x800 = **$66.27**	8. 1200x1200 = **$170.94**	13. 45 Block = **$146.14**
4. 600x1200 = **$86.58**	9. 180x800 = **$53.16**	
5. 1200x400 = **$76.00**	10. 180x1200 = **$74.92**	

*Prices include costs of screws and bolts. They do not include costs of internal lining options**

Calculations supporting these numerical results can be found in the appendix referenced 9.3.

6.5.4 **Cost Per Square Metre.**

The key undertaking behind budget builds is supplying an affordable housing solution for first home buyers. To ensure buildaBlock meets the affordable criteria, calculations of cost per square meter by GFA (gross floor area) were undertaken. Below shows three examples of costings. Traditional and buildaBlock methods were calculated based on Rawlinsons 2012 with the inclusion of inflation. GJ Gardners was added as a control variable to show the potential inaccuracies of the costing system of Rawlinsons with the sudden cost changes and impacts to the housing sector within the last 9 years. Although the findings may indicate buildaBlock as being the cheapest outcome of cost per square meter, a note to consider is that this price does not account for labour as it is a self-build project.

Note: When comparing costs to buildaBlock, traditional will be used as the comparable alternative. As calculations were both made using Rawlinsons 2012, the pricings should be of equal value.

$2590

GJ Gardner
Calculated from base price of $360,000 divided by 139 square meter (Apollo 139).

$2032

Traditional
Calculated from Rawlinsons 2012.

$1955

buildaBlock
Calculated from Rawlinsons 2012.

Calculations supporting these numerical results can be found in the appendix referenced 9.4 & 9.5.

6.6 **Scale Model.**

Note: As this is a scale model, screws had to be mimicked with the use of glue.

Figure 121 & 122. 1:4 scale model of buildaBlock (a).

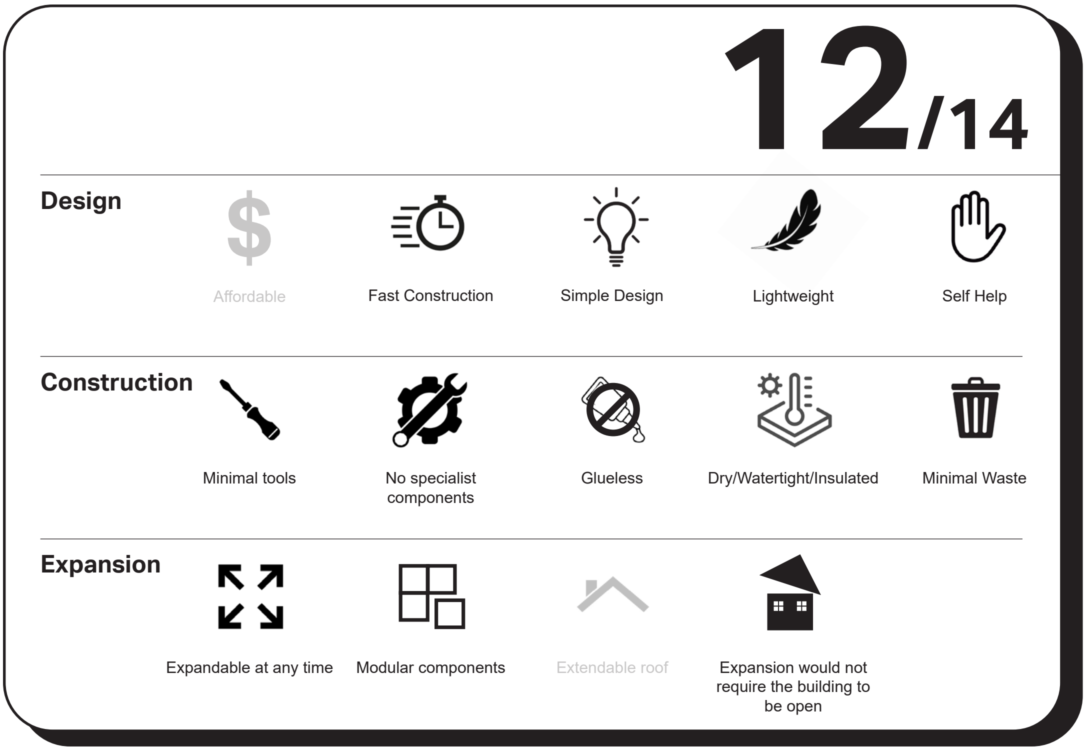
6.7 Findings.

Critical reflection

The following is a simple pros and cons list surrounding the benefits and drawbacks of buildaBlock based on the design criteria.

Pros
- The gable roof and the block types allow for the gain in loft space. This means a single storey dwelling has the option for additional occupiable space in the otherwise unused roof cavity.

Cons
- The roof is only expandable on one axis. Due to the roof types and DIY aspect of buildaBlock, creating an expandable roof in multiple directions proved challenging within the given time frame of this research.
- BuildaBlock is expensive in contrast to a traditional build as assembly is still required. The prices of buildaBlock do not factor in the client's time value for the construction period, therefore, the affordable aspect was not achieved for standard house construction.



Observations

- BuildaBlock may cost the same as a traditional build but the user still has to put in the time to build the house, therefore not meeting the affordable criteria.
- Although expensive given the construction is not included, this product is still beneficial in the sense that you can start small and slowly add to it. Including the ideas of incremental construction, the possibilities of smaller living and expansion could see potential cost savings given the clients are willing to build themselves.

6.8 **Design Scope.**

The initial idea surrounding budget builds was to create a new solution for budget friendly houses. This was aimed at first home buyers to reduce the costs of housing by creating a system that employed incremental and self-help construction methods. Successes following buildaBlock have been made in the form of incremental expansion and self-building techniques through prefabricated means of CNC cutting.

Although designed for DIY enthusiasts, foreseen problems include costs and construction times. Although similar pricing to traditional building methods, buildaBlock still requires assembly. This concept may be a deterrent for inexperienced users as constructing a 50 square meter home could take considerable time. Pair this with working full time, weekends may be the only available time to work on constructing the house, potentially extending the building process to multiple years.

Between the similar cost price and assembly of the house, buildaBlock may be seen as a bad investment compared to traditional builds based on cost per square meter. However, a traditional house requires full upfront costs without the option of future proofing the home through incremental expansion. The incremental expansion component gives flexibility by future proofing the home compared to a traditional build being difficult to expand later. The key benefit of buildaBlock is that homes can be built in stages, reducing the initial costs of construction as you pay for the rooms you are using as you go. This means you are not limited to building a three-bedroom home when only one bedroom is needed at that current time.

The option of using professional installers is another possibility. Due to the ease of buildability, professional carpenters would be able to construct a buildaBlock house in a relatively short period of time compared to traditional methods. However, using this method would come as an additional expense to the clients. This may be worth the additional cost as upfront savings of smaller initial builds would prove beneficial over traditional methods.

Scope Direction

If this is to be successful for DIY enthusiasts, the speed of construction has to be the main focus otherwise the effort and cost associated with buildaBlock will be unsuccessful. This slightly shifts the direction of the type of buildings being constructed out of buildaBlocks to small sleepouts, flats, and tiny homes. Larger homes are still a possibility, however, as many New Zealanders work full time jobs to support families and other expenses, the likelihood of them being able to build a full-scale house themselves is unlikely. Therefore, buildaBlock will be limited to a maximum initial build size of 50sqm unless constructed by professionals. This will ensure the size limitations allow inexperienced users enough time to construct these buildings outside of work hours. Additionally, further extensions constructed by non-professionals should not exceed the size of 50sqm at any given stage of construction. This will require careful and smart planning to ensure all amenities are thoughtfully designed into each build and stage to create a cohesive design suitable for each user.

Moving Forward

Due to the limited timeframe given with this research, showing the most useful information is essential. The aim moving forward is to show what will benefit the current research the most through narrowing the research into one of the possible design directions listed below.

- Construction
- Details
- Connections
- Loads
- Cladding
- Geometry
- Architectural planning

As majority of the work completed surrounding buildaBlock and various other concepts lend towards the construction and usability of the designs, moving forward, it would be important to demonstrate the possibilities architecturally that this has to offer through generating usable and functional buildings. From this standpoint, architectural planning will benefit the current research as no information is currently shown surrounding the design or how the blocks are used to create and expand spaces. Although there is much work to be completed within all other categories listed, what is now needed is to show how this product will interact with its environment and clients by showcasing its ability to be flexible and expandable.

Because of the larger cost per square meter of buildaBlock and the ever-increasing price of land, it is vital to maximise every space within the building to reduce the overall footprint. This will mean utilizing much of the loft spaces as bedrooms in single-storey dwellings.

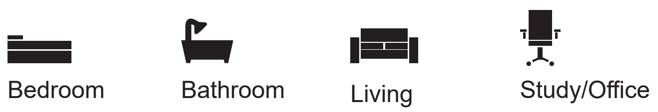
7 Examples & Renders.

Variations of homes created with buildaBlock.

7.1 Overview.

BuildaBlock was designed to be flexible, so the clients had the ability to design and build their own layouts based on their current and future needs. The following are examples of designs created by the author to showcase the ability of compact and expandable living produced from using the buildaBlock system. Due to the large customisation of buildaBlock, the three examples shown are just a few potential layouts and material combinations possible with buildaBlock. Each provides usable and/or future proof homes for growing families of various sizes, small, medium, and large. All examples focus on compact living to maximise the dollar per square metre. Each stage has been carefully designed so that the layout works cohesively as a home throughout all stages. This means that no space is disconnected if the user wishes to stop construction at any stage.

Key:



Note:
All costs are rough estimates based on the GFA of each build. Refer to section 6.5.4 for more details.

7.2 Student Sleepout.

14 sqm

$27,370 inc GST

1 (bed) 0 (bath) 0 (sofa) 2 (chair)

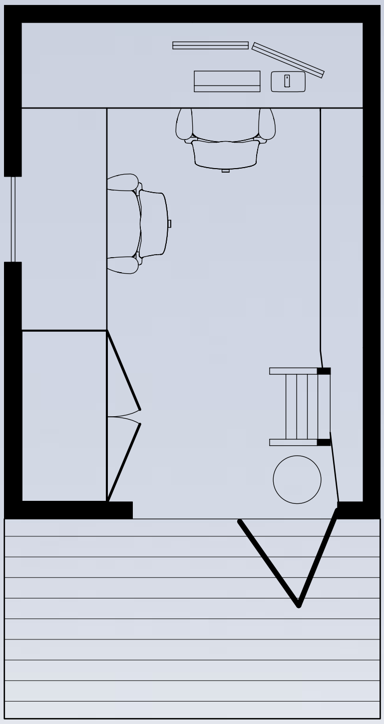
The student sleepout is designed as an addition to any family home. Designed as a self-build, backyard kit, this layout caters towards young adults seeking private space while living with their parents. This allows for independence through personal space for them and their partners to move in while saving for a house.

This concept was not designed with expansion in mind due to the 10 square metre detached dwelling rules here in New Zealand (Building Performance, 2021) This was purely to showcase the small-scale backyard builds possible with buildaBlock.

Figure 123. Exterior digital render (a).
Figure 124. Right - Student sleepout floor plans (a).

Floor Plan.

Ground Floor



Loft

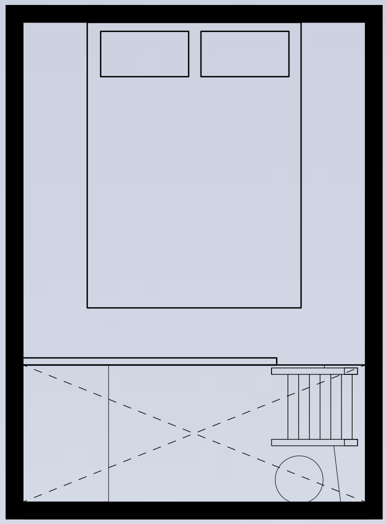


Figure 125. Interior digital render of the workspace (a).

Figure 126. Interior digital render of the sleeping area (a).

7.3 **Family Home 1** / Stage 1.

50 sqm

$97,750 inc GST

2 1 0 0

Family home 1 benefits from compact living which stays within the maximum of 50sqm expansion per stage. To maximise the available space, this iteration opted for the use of sliding ladders to access the loft spaces. This ensures easy access without compromising space on bulky stairs. Stage one opts for the inclusion of two bedrooms over a living space to maximise the number of occupants living in stage one. If a living room is preferred, the downstairs bedroom can be created into the living room until completion of stage two, or, family home 1 can be left at stage one as a one-bedroom dwelling with all essential utilities. The kitchen facility has been designed to cater throughout all stages, requiring no additional modifications. This iteration may not suit some families with younger children. See family home 2 for stair incorporations.

Figure 127. Exterior digital render (a).
Figure 128. Right - Family home 1 / stage 1 floor plans (a).

Floor Plan / Stage 1.

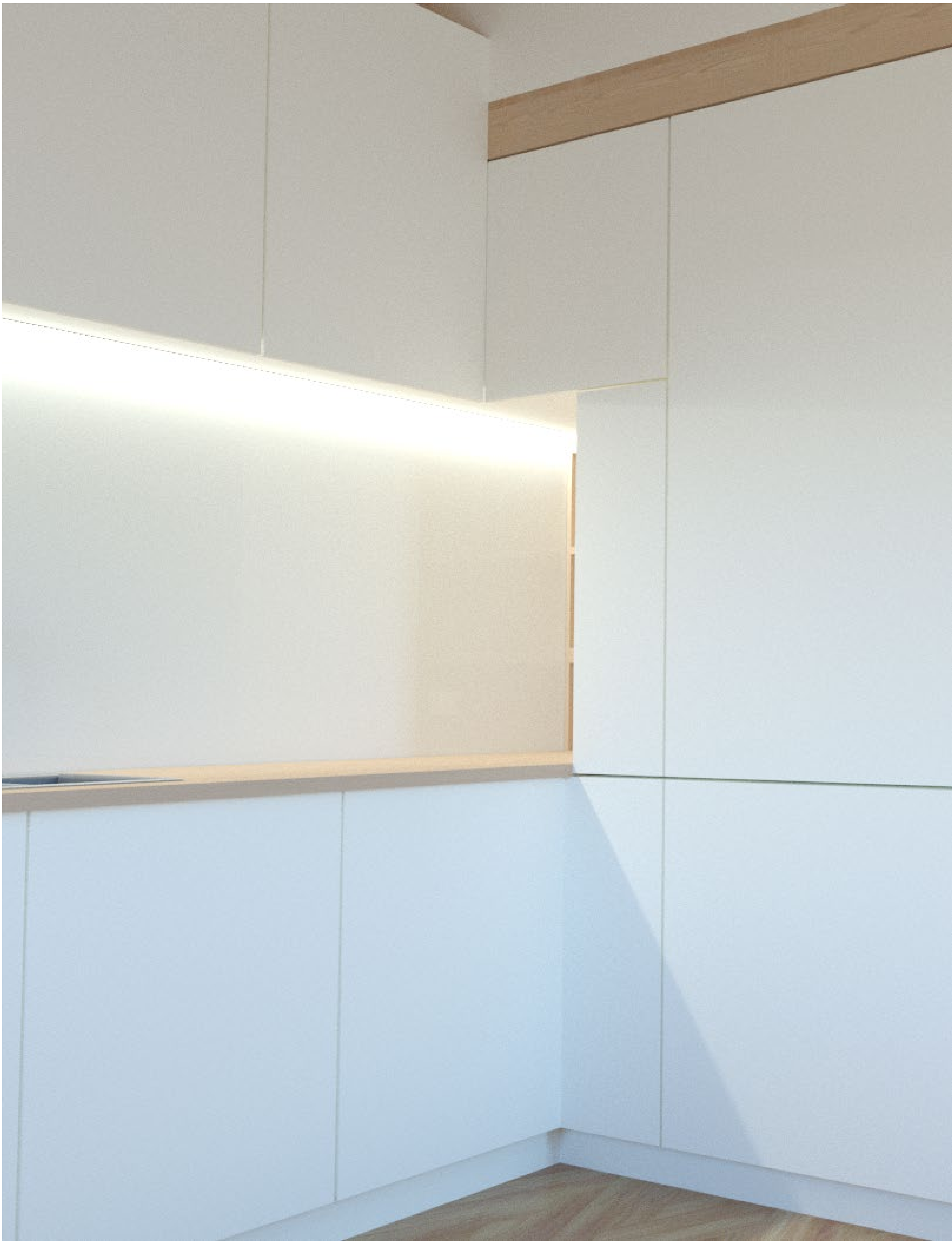


Figure 129. Interior digital render of the kitchen (a).

Figure 130. Interior digital render of upstairs bedroom (a).

To maximise the available space, ladders were used instead of stairs. Due to limited space surrounding doors and entrances, the ladders were put on a rail system allowing them to be relocated where conflicts occurred.

This was extremely useful in the living space of stage 2 where limitations of the loft height required the ladder to be positioned central of the building. The rail allows the ladder to be stored on the edge of the building when not in use.

Figure 131. Interior digital render of upstairs bedroom (a).

7.4 **Family Home 1** / Stage 2.

85 sqm

$68,425 inc GST

Total Cost
$166,175

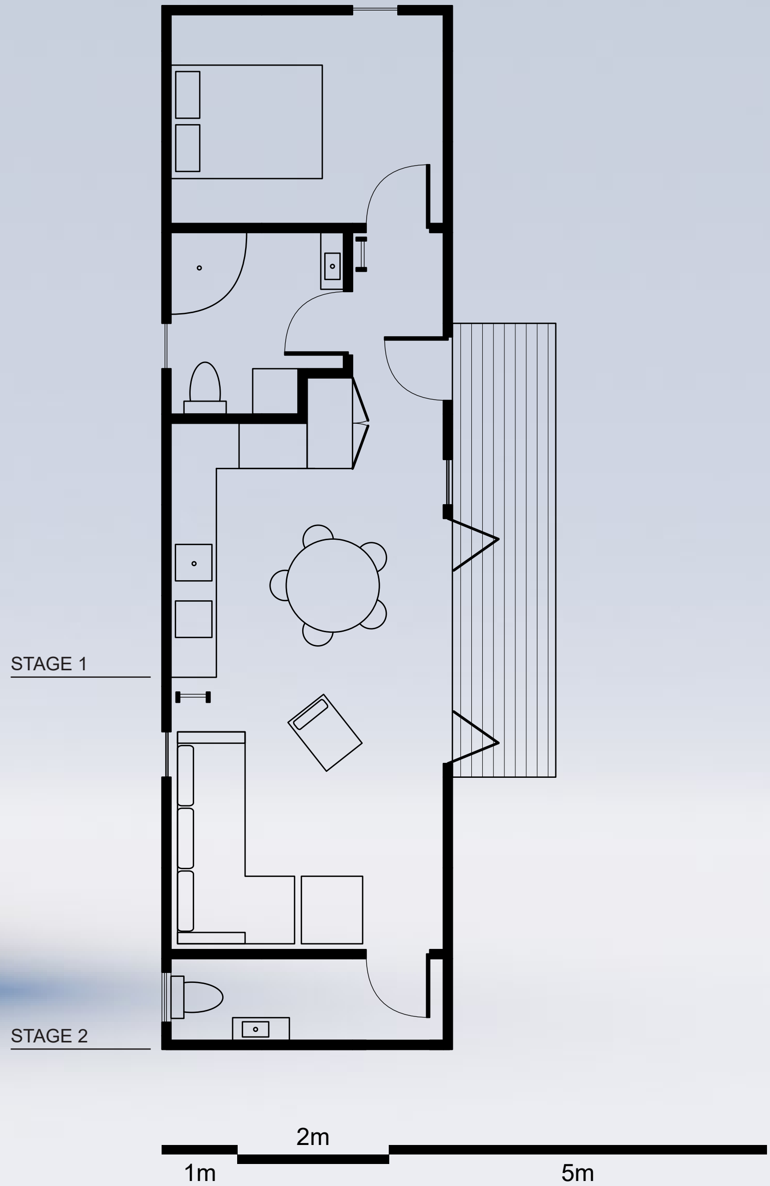
3 (bedrooms) 2 (bathrooms) 1 (living) 0 (office)

Stage 2 includes the addition of a living space, additional toilet, and a second loft bedroom. Slight variations to stage 2 can be made to suit individual clients and their current and future needs. If a fourth bedroom is required in stage 2, adding an extra 1200mm block in length could see the living space turned into the fourth bedroom. Upon stage 3, this can then be converted back to a living space if desired.

Figure 132. Exterior digital render (a).
Figure 133. Right - Family home 1 / stage 2 floor plans (a).

Floor Plan / Stage 2.

Ground Floor



Loft

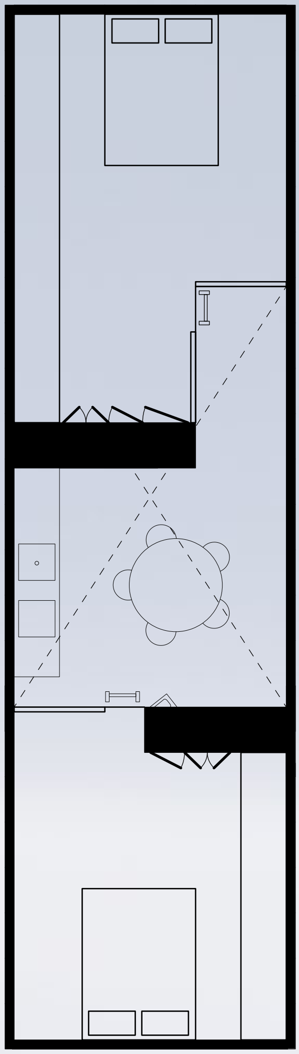


Figure 134. Interior digital render of expansion joint from stage 1 -2 (a).

Figure 135. Interior digital render of the living room (a).

7.5 **Family Home 1** / Stage 3.

98 sqm

$25,415 inc GST

Total Cost
$191,590

4 2 1 0

Stage 3 consists of the addition of one extra bedroom. Although possible to keep adding on, the length of the building would start to exceed the length of many sites. Additionally, the size of the lounge and kitchen inhibits the number of bedrooms possible with this layout before occupants exceed facility size and quantities.

Figure 136. Exterior digital render (a).
Figure 137. Right - Family home 1 / stage 3 floor plans (a).

Floor Plan / Stage 3.

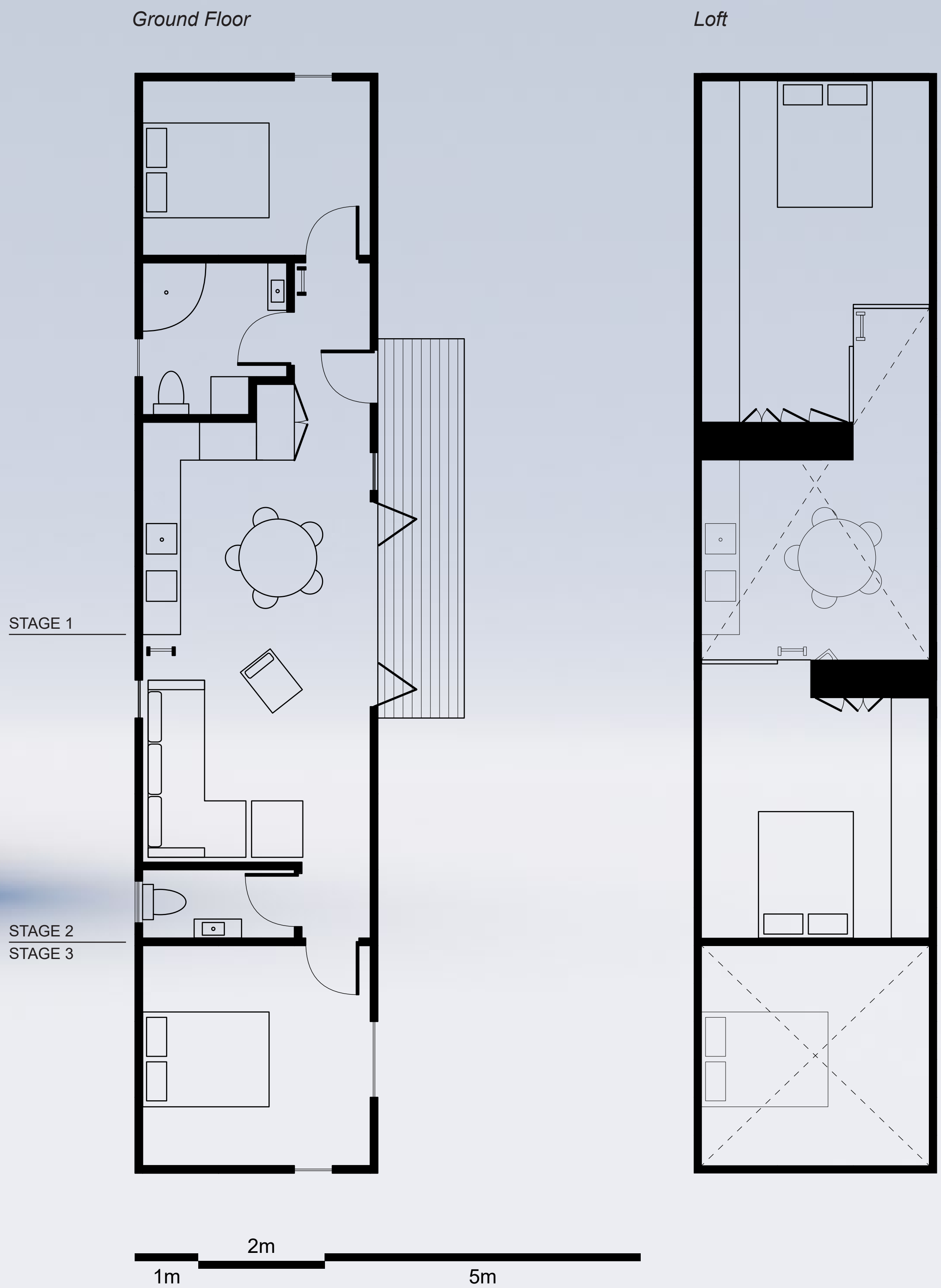


Figure 138. Interior digital render of the dining and living room (a).

7.6 **Family Home 2** / Stage 1.

72 sqm

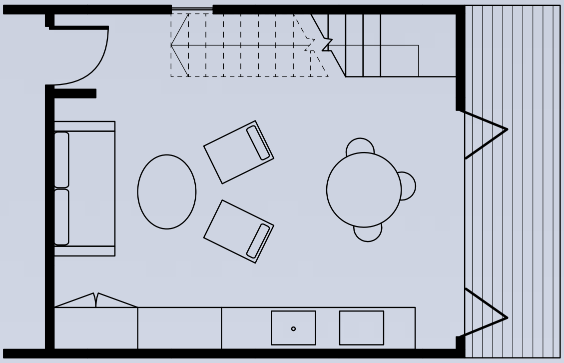
$140,760 inc GST

1 1 1 1

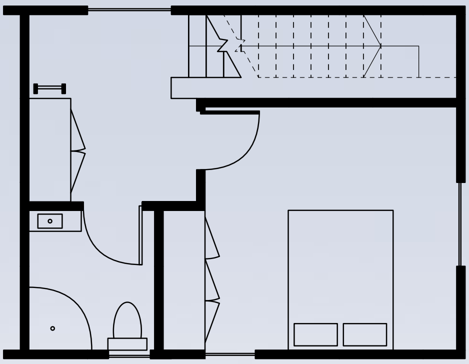
As budget builds were set out to be affordable first homes, this would include many young families. For this reason, family home 2 incorporates the use of stairs as a family friendly design for younger children. The layout of stage one was important to ensure functionality carried across the future stages. Positioning of the kitchen, stairs, and bathroom needed to be in fixed positions where a functional layout is achieved throughout each various stage. To ensure this worked correctly, the first stage does exceed the 50sqm rule for DIY enthusiasts, requiring the expertise of professionals to construct stage one.

Figure 139. Exterior digital render (a).
Figure 140. Right - Family home 2 / stage 1 floor plans (a).

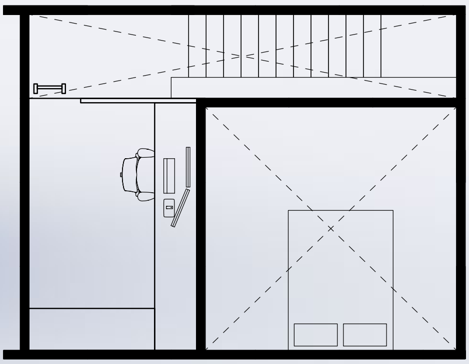
Floor Plan / Stage 1.



Ground Floor



Second Floor



Loft

Figure 141. Interior digital render of the dining and living room (a).

Figure 142. Interior digital render of the upstairs landing (a).

Figure 143. Interior digital render of the upstairs loft office (a).

7.7 **Family Home 2** / Stage 2.

122 sqm

$97,750 inc GST

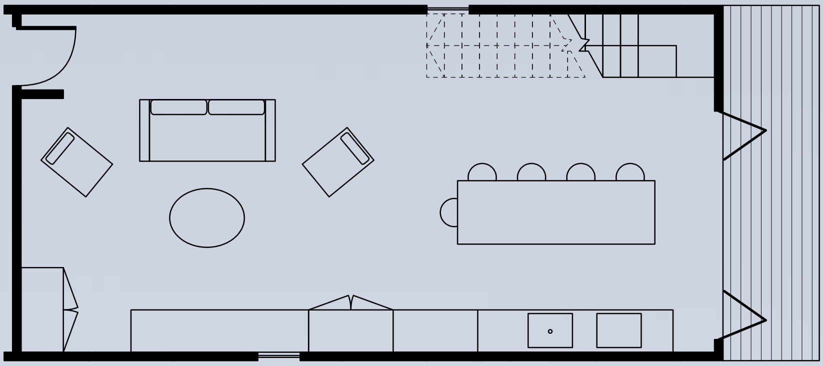
Total Cost
$238,510

4 1 1 1

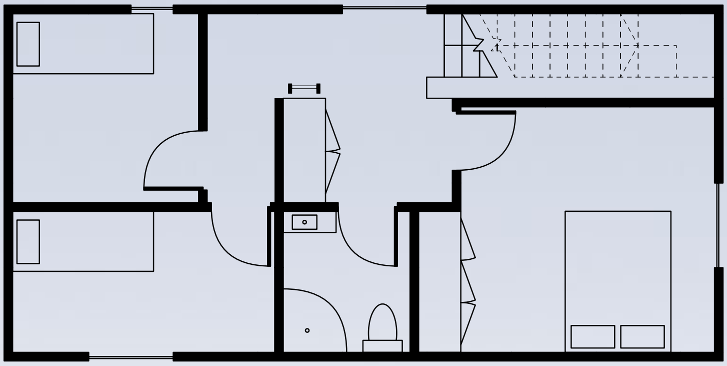
Due to larger size and expenses included in stage one, stage two focused on maximising and expanding the potential space for a family with minimal size increase. To achieve this, an additional two single bedrooms were included as well as a study and double bedroom in the loft. Various layout changes could be made to suit a variety of situations. This could include changing the study for an additional bedroom, increasing the home to five bedrooms.

Figure 144. Exterior digital render (a).
Figure 145. Right - Family home 2 / stage 2 floor plans (a).

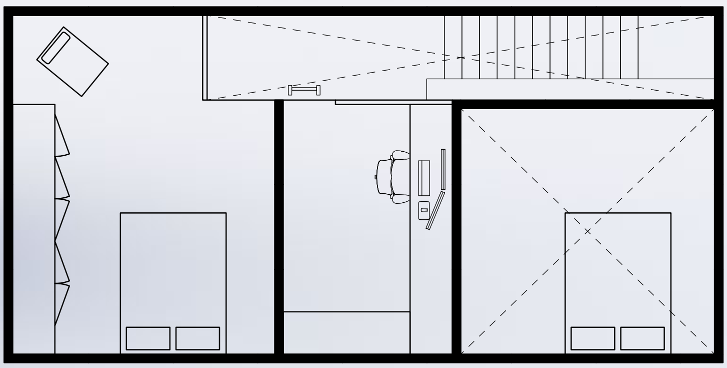
Floor Plan / Stage 2.



Ground Floor



Second Floor



Loft

Figure 146. Interior digital render of the kitchen (a).

7.8 **Family Home 2** / Stage 3.

156 sqm

$66,470 inc GST

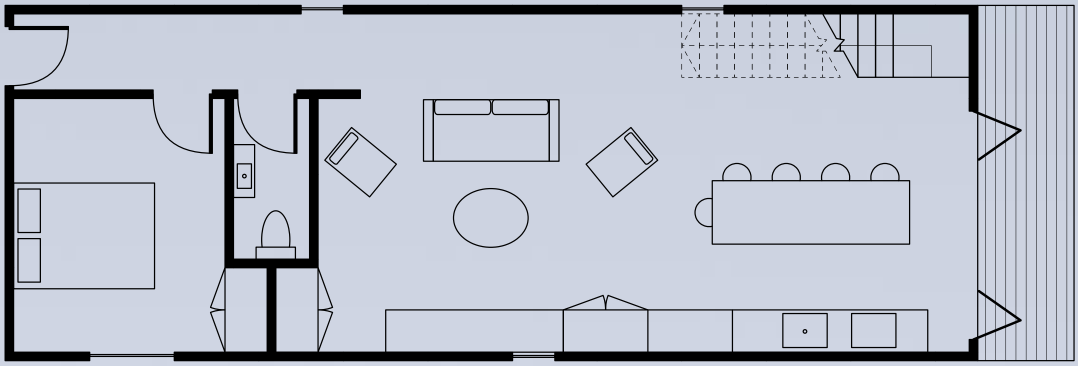
Total Cost
$304,980

5 2 1 1

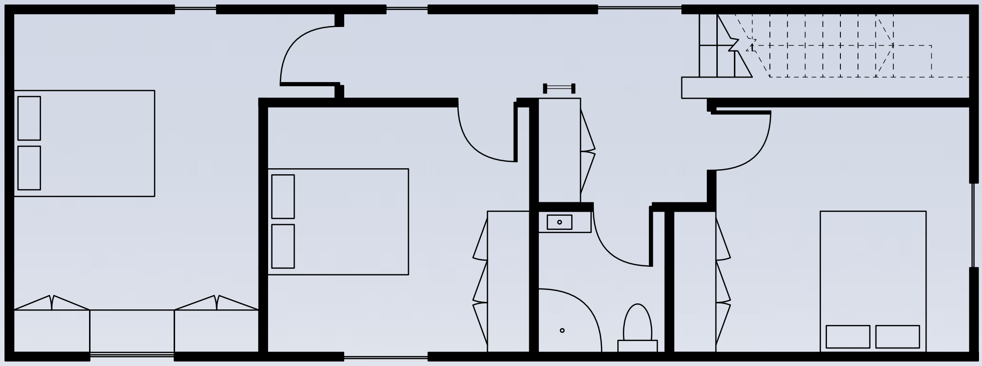
Stage three targets comfortable living through generating larger bedrooms. Although the addition was an increase of 44 square metres, only one additional bedroom, half bathroom, and storage were included. The two single rooms have been changed into one double bedroom, creating a five double bedroom house.

Figure 147. Exterior digital render (a).
Figure 148. Right - Family home 2 / stage 3 floor plans (a).

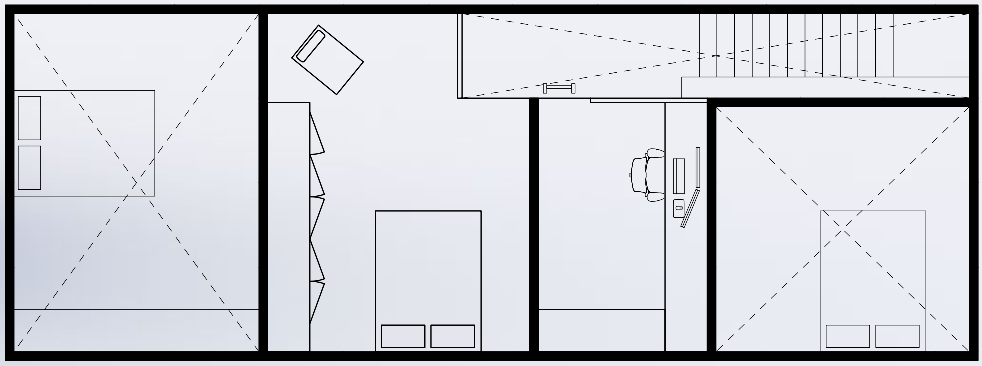
Floor Plan / Stage 3.



Ground Floor



Second Floor



Loft

Figure 149. Interior digital render of the dining and living room (a).

7.9 Cost Comparisons.

	Family home 1 (Stage 1).	**Apollo 139.**
		This content is unavailable. Please consult the figure list for further details.
Size (m^2)	50	139
Bedrooms	2	3
Bathrooms	1	2
Car Parking	0	1
Costs (exc land)	$97,750	$340,000
Costs (inc land)	$427,750	$670,000

Total Savings.

The following is the total savings when using buildaBlock:

House (exc land) = 71%
House (inc land) = 36%

7.10 Critical Reflections.

7.10.1 Project Scope.

Much of the work undertaken in this research was trial and error. Although the initial concepts help to show the working process of the final outcome, they have little relevance to the question in research. This is because the scopes range was too broad which did not allow for a well resolved product. There are aspects missing or needing completion which resulted in a semi complete product which ultimately did not achieve the affordable. The end solution successfully implemented strategies of incremental and self-help methods through prefabricated construction. The project successfully aimed at its target audience of DIY enthusiasts throughout each stage of design but was limited by the manufacturing and material choice of construction. Benefits would have been seen if early research was conducted to determine multiple material options for the construction of the building blocks. This may have yielded a greater success towards budget friendly housing that was not examined in this dissertation.

7.10.2 System Issues.

Costs.
Initial savings from buildaBlock was meant to be significantly cheaper than traditional builds. As discussed earlier, material choice and manufacturing caused an increase in price resulting in similar costs per square meter to traditional methods. Comparing the costs of the apollo 139 from GJ Gardners and family home 1 stage 1 shows that there is only a 36 percent savings in costs, provided the houses are built on the same land ($670,000: $427,750 respectively). Although family home 1 is three times cheaper, when factoring in the cost of land the price drop is not significant enough to entice people to build their own home. On top of that, apollo 139 is almost three times the size with an additional bedroom and bathroom being built by a professional carpenter.

Time to Build.
The time required to build the house becomes problematic for the target audience. As this aims primarily towards first home buyers, the principle is both people are working full time as a means to generate income. This limits construction to weekends, ultimately increasing the time of construction. This meant generating smaller floor plans to create faster build times, however, the incremental aspect became difficult to minimise movement paths such as hallways. The current sized floor plans may still be too large for a DIY enthusiast to complete. Further time spent on generating example constructs using buildaBlock would have been beneficial.

No tests or estimates were conducted as to how long it would take to construct a full house. This was due to covid restrictions and time constraints limiting the authors ability to create a full-sized model for determining the build time of a singular block. If the system takes significant time to build, then buildaBlock will not succeed. Given that for the same cost per square metre a house will be built for you, buildaBlock is at a significant disadvantage.

Size.
Although initially designed as a system to fit in the boot of a car, the interior panels being 1200x1200 diminish this objective. However, the quantity of materials required to build any form of building or extension would require multiple boot loads thereby making a truck the preferred method for delivery.

7.10.3 Further Investigation.

Reducing costs through material choice.
The downfall of the project was the cost of fabrication on the CNC machine as well as the raw cost of materials (primarily plywood). At this current stage in time, creating fully customisable flatpack kits are limited by the available materials and production line methods to create suitable products. This project would have seen greater success if the raw material cost was lower, potentially utilizing repurposed materials such as recycled plastics. The ultimate goal of buildaBlock would be to utilize recycled plastics such as Conceptos Plasticos as a greener way of building by reducing plastic waste and helping clean the planet. At this stage, plastic recycling for building blocks is limited and would not adhere to building codes. Once better methods of recycling plastics become available, this area should be investigated.

Cladding.

As shown in the render's, corrugated iron was the choice of cladding because of its simple install, cost, and glueless factor. This allowed it to be an easily removable cladding requiring only a drill for removal, perfect for DIY enthusiasts. Further research should be conducted on cladding to determine the best option for this particular field. The author understands that alternative cladding methods exist, such as the Circle House in Denmark where they use upcycled plastic shingles (GNX, 2018).

Foundations.

To allow for the constant change in expansion and decrease, ground screws were considered as a suitable foundation due to their flexibility by allowing additions to existing foundations, services, and their minimal environmental impacts on removal. It is understood that there are limitations surrounding weight capacity with ground screws. This could prove problematic where two storey buildings are constructed. The author understands that this may not be the correct solution for larger scaled buildings such as family home 2. Future evidence and research are needed to determine if ground screws are a suitable option for budget builds.

Additional Investigation Required:

- Does it meet New Zealand building code requirements?
- Details - Cladding, foundations, roofing, skylights, screw spacings
- Loads - How much can the blocks support. What are their capabilities in terms of lateral and gravity loads. Are they able to support a second storey?
- Geometry- More block types.

This content is unavailable. Please consult the figure list for further details.

Figure 150. Upcycled shingle facade (GNX, 2018, p.16).

7.11 **Final Remarks.**

This research is addressing the question - How can we implement strategies of incremental housing and prefabrication within a first world context to produce affordable homes?

As house prices continued to rise throughout the undertaking of this research, it is evident that the issue of affordable housing needs to be addressed. As it is impossible to change the cost of existing homes, the project was limited towards building new homes. Unfortunately, with the current land shortage, increasing costs further, severely impacts the course of this project aiming towards budget friendly construction. Incorporation of third world building techniques helped towards bridging the gap between high land values and lower house prices through the experimentation of incremental construction and self-help methods. The key focus being on deriving simple and effective building methods accessible to a wide range of inexperienced users through prefabricated methods. Although the project focussed on budget, this did not sacrifice on the quality of living generated through the designs. The effective result of buildaBlock is a system that is highly customisable to suit any client's needs, present or future, using careful design planning and considerations.

Unfortunately, the end result did not make enough impact in budget reductions due to the high costs of the chosen building materials and manufacturing process aimed at fast and simple construction. Although the cost comparisons showed a 71 percent savings in the building alone, based on the square metre costs, a professional could build a house of similar size for the equivalent costs. Additionally, there is only so much that can be achieved due to the land values being high as they equate to half of the build cost. This led to the final build prices shown in cost comparisons to reduce by 36 percent (see 7.9). This reduction is not great enough for the difference in the end results of the two properties shown when factoring size, bedrooms/bathrooms, and self-built circumstances. These factors alone make buildaBlock an ineffective solution. In order for budget builds to be successful, further research and development needs to be made in material choice, manufacturing processes, land analysis, and council regulations to have a greater impact on reducing house prices for New Zealand.

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8.2 **Figures.**

Note: Authors own image is represented by (a).

Figure 1. buildaBlock concept dwelling (a).
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Figure 4. Affordable house price (a)
Figure 5. House sizes by year (a).
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Figure 21. Lockwood. (2018). *The Lockwood building system* [Image]. Retrieved from https://lockwood.co.nz/wp-content/uploads/2018/07/Building-System-Overview.pdf
Figure 22. Sketches for potential concept ideas (a).
Figure 23. Removable SIPS panel (a).
Figure 24. Removable SIPS panel junctions (a).
Figure 25. Removable SIPS panel with substructure (a).
Figure 26. Incremental construction of the post and beam structure (a).
Figure 27. SIPS panel to substructure connection (a).

9 Appendix.

Supporting material.

9.1 **Total Component Cost Breakdown.** *(for sheets 1-8)*

Constants.

Sheet price	$188.00
Sheet area	2,880,000mm^2
CNC feed speed	35mm/sec
Cut cost	$0.04/sec
2 passes required	Double cut cost
Pilot holes	0.006hr ea
Unskilled labour	$20.86

Notes:

- *Sheet price as of September 2021 from Bunnings.*
- *Pilot hole times are based on an average of 22 seconds per hole drilled.*
- *Unskilled labour costs are based on hourly-paid wage rates for a labourer from Rawlinsons 2012. Inflation has been included*.*
- *Sheet 7 - Calculations for components 7 and 8 were done separately on the basis of a half-sized sheet. This does not affect overall prices as there are correct ratios of these two components and are both sold in the same bundle.*

Raw Material Cost Per Component

$$\frac{\$188.00}{\text{Component Quantity}}$$

Notes:

Component waste is included in each pieces costing

+

Total Cut Cost Formula Per Component.

$$\frac{(\$0.04 \times 2)\left(\frac{(\text{Component Quantity} \times \text{Length})}{35\text{mm/sec}}\right)}{\text{Component Quantity}}$$

As the length of cuts from sheets 1-8 share cut lines with adjacent components, the cut length is halved. Additionally, the full total length of bolt hole cuts is included.

+

Pilot Hole Cost Formula

$20.86 x 0.006hr x Pilot Hole Quantity.

= Total Cost Per Component

9.2 **Total Component Cost Breakdown.** *(for sheets 9 & 10)*

Notes:

- *Sheet price as of September 2021 from Bunnings.*
- *Pilot hole times are based on an average of 22 seconds per hole drilled.*
- *Unskilled labour costs are based on hourly-paid wage rates for a labourer from Rawlinsons 2012. Inflation has been included*.*
- *Each component will be calculated separately based on its percentage of used material from one sheet. This will change the sheet price in the calculations to the used percentage of materials being used by the component in the calculation for the new cost. This allows for accurate length and time calculations in regards to shape, pilot holes, and bolt holes for individual components.*

Component Percentage Per Sheet

$$\left(\frac{2,880,000 - (2,880,000 - (\text{Component Area x Quantity}))}{2,880,000}\right) \times 100 + 2.4\%$$

Notes:

As sheets 9 and 10 have a total solid wastage of 19% and 8 new components for calculations, an additional 2.4% is added to each component group to ensure wastage is included in the final costings.

New Sheet Price - *Based on Components Percentage*

Component Percentage x $188.00

The final percentage from above is then multiplied by the sheet cost.

Raw Material Cost Per Component

$$\frac{(\$)\ \text{New Sheet Price}}{\text{Component Quantity}}$$

Component waste is included in each pieces costing

+

Total Cut Cost Formula Per Component.

$$\frac{(\$0.04 \times 2)\left(\frac{\text{Component Quantity x Length}}{35\text{mm/sec}}\right)}{\text{Component Quantity}}$$

Length cuts on sheets 9 & 10 cannot be halved like the previous 8 sheets. The lengths are calculated based on the perimeter length of each component minus the touching portions to adjacent components.

+

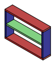
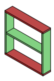
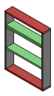
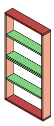
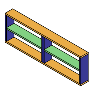
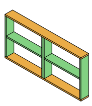
Pilot Hole Cost Formula

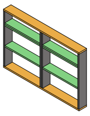
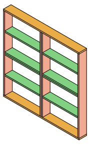
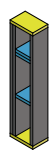
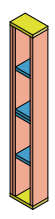
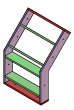
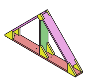
$20.86 x 0.006hr x Pilot Hole Quantity.

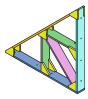
= Total Cost Per Component

9.3 **Total Block Cost Breakdown.**

*Quantities of bolts and washers have been halved per block**

Name.		Components	Quantity	Price
1.	600x400	400V	2	$11.18
		600H	2	$15.54
		600H&V	1	$7.77
		M10 x 60mm Bolt	3	$2.37
		M10 x 21mm Washer.	3	$0.27
		10 c 75mm Screws	18	$1.98
			Total	$39.11
2.	600x600	600H	2	$15.54
		600H&V	3	$23.31
		M10 x 60mm Bolt	4	$3.16
		M10 x 21mm Washer.	4	$0.36
		10 c 75mm Screws	18	$1.98
			Total	$44.35
3.	600x800	800V	2	$20.60
		600H	2	$15.54
		600H&V	3	$23.31
		M10 x 60mm Bolt	4	$3.16
		M10 x 21mm Washer.	4	$0.36
		10 c 75mm Screws	30	$3.30
			Total	$66.27
4.	600x1200	1200V	2	$30.72
		600H	2	$15.54
		600H&V	4	$31.08
		M10 x 60mm Bolt	6	$4.74
		M10 x 21mm Washer.	6	$0.54
		10 c 75mm Screws	36	$3.96
			Total	$86.58
5.	1200x400	400V	4	$22.36
		1200H	2	$28.86
		600H&V	2	$15.54
		M10 x 60mm Bolt	6	$4.74
		M10 x 21mm Washer.	6	$0.54
		10 c 75mm Screws	36	$3.96
			Total	$76.00
6.	1200x600	1200H	2	$28.86
		600H&V	6	$46.62
		M10 x 60mm Bolt	8	$6.32
		M10 x 21mm Washer.	8	$0.72
		10 c 75mm Screws	36	$3.96
			Total	$86.48

Name.		Components	Quantity	Price
7.	1200x800	800V	4	$41.20
		1200H	2	$28.86
		600H&V	6	$46.62
		M10 x 60mm Bolt	8	$6.32
		M10 x 21mm Washer.	8	$0.72
		10 c 75mm Screws	60	$6.60
			Total	$130.32
8.	1200x1200	1200V	4	$61.44
		1200H	2	$28.86
		600H&V	8	$62.16
		M10 x 60mm Bolt	12	$9.48
		M10 x 21mm Washer.	12	$1.08
		10 c 75mm Screws	72	$7.92
			Total	$170.94
9.	180x800	800V	3	$30.90
		180H	2	$8.24
		117H	3	$7.20
		M10 x 60mm Bolt	4	$3.16
		M10 x 21mm Washer.	4	$0.36
		10 c 75mm Screws	30	$3.30
			Total	$53.16
10.	180x1200	1200V	3	$46.08
		180H	2	$8.24
		117H	4	$9.60
		M10 x 60mm Bolt	8	$6.32
		M10 x 21mm Washer.	8	$0.72
		10 c 75mm Screws	36	$3.96
			Total	$74.92
11.	135 Block	135°	2	$31.12
		600H	2	$15.54
		600H&V	4	$31.08
		M10 x 60mm Bolt	5	$3.95
		M10 x 21mm Washer.	5	$0.45
		10 c 75mm Screws	36	$3.96
			Total	$86.10
12.	Cap Block	Cap Bottom	1	$15.82
		Gable 1	1	$7.91
		Gable 2	2	$17.98
		Bracket (Large)	6	$25.50
		Bracket (Small)	2	$3.88
		M10 x 60mm Bolt	8	$6.32
		M10 x 21mm Washer.	8	$0.72
		10 c 75mm Screws	44	$4.84
		Total		$82.97

Name.		Components	Quantity	Price
13.	45 Block 	45-Long	1	$20.40
		45-1	1	$16.63
		45-2	1	$17.22
		Gable 1	2	$15.84
		Gable 2	1	$8.99
		Bracket (Large)	12	$51.00
		M10 x 60mm Bolt	8	$6.32
		M10 x 21mm Washer.	8	$0.72
		10 c 75mm Screws	82	$9.02
		Total		$146.14

9.4 Cost Per Square Meter Breakdown.

Note: As Rawlinsons accounts for labour costs, the buildaBLOCK design will differ in some areas. Areas including substructure, electrical, and plumbing will remain the same due to professional installation required. Many of the flatpack costings are based on raw materials with the inclusion of adhesive and fixing accounted for. Variations to Rawlinsons costings have been made where more accurate sourcing has been used. All costs are from Rawlinsons 2012 unless otherwise stated.

Inflation of 14% has been accounted for all Rawlinsons costings. All rates include GST of 15%. All figures are from Rawlinsons 2012 unless otherwise stated.

House, single storey. Moderate Quality

Task.	$/m2	Source
Site Preparation	23.33	
Substructure	222.18	
Frame	113.08	
Structure	**358.59**	
Roof	156.73	
Exterior Walls	234.35	
Windows & Doors	179.48	
Exterior Fabric	**570.56**	
Interior Walls, Partitions	45.94	
Interior Doors	99.75	
Floor Finishes	60.28	
Wall Finishes	220.40	
Ceiling Finishes	143.87	
Fittings & Fixtures	156.68	
Interior Finishing	**726.92**	
Sanitary Plumbing	106.58	
Electrical Services	60.49	
Drainage	45.38	
Services	**212.45**	
Preliminaries	74.75	
Margins	58.33	
Contingency	30.04	
Prelims, Contingency	**163.12**	
Total	**2031.64 inc GST**	

9.5 buildaBlock, single storey with loft.

Calculations based on a 90sqm house.

Task.	$/m2	Source
Site Preparation	23.33	
Substructure	222.18	
Frame	302.65	Calculated based on figures in section 9.3.
Structure	**548.16**	
Roof	156.73	
Exterior Walls		
Corrugated steel 0.55 mm, PVF2 precoated	122.34	(Page, 2015)
Build Wrap	8.93	(Bunnings, 2021d)
Cavity Battens	12.46	(Bunnings, 2021f)
Fixing Supplies	8.53	(Bunnings, 2021g)
Insulation	22.25	(Bunnings, 2021a), (Bunnings, 2015b)
Windows & Doors	179.48	
Exterior Fabric	**510.72**	
Interior Walls, Partitions, & Loft Flooring	134.85	
Interior Doors	99.75	
Floor Finishes	60.28	
Wall & Ceiling Finishes		
Plywood 21mm	65.27	(Bunnings, 2021c)
Polyurethane	3.29	(Bunnings, 2021e)
Fittings & Fixtures	156.68	
Interior Finishing	**520.12**	
Sanitary Plumbing	106.58	
Electrical Services	60.49	
Drainage	45.38	
Services	**212.45**	
Preliminaries	74.75	
Margins	58.33	
Contingency	30.04	
Prelims, Contingency	**163.12**	
Total	**1954.57 inc GST**	

Notes:

- Frame costings based on an 90sqm house design using buildaBlocks. Cost was determined based on total cost for all blocks divided by 90. Roof blocks and insulation are also included in this figure.
- Insulation calculations based on R3.6 ceiling and R3.2 wall values. Calculations included the total amount of each product for the 90sqm house divided by 90 to give the $/m2 cost.
- Polyurethane cost has allowed for two coats per meter square.
- Corrugated steel cladding has included an inflation of 11%.

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