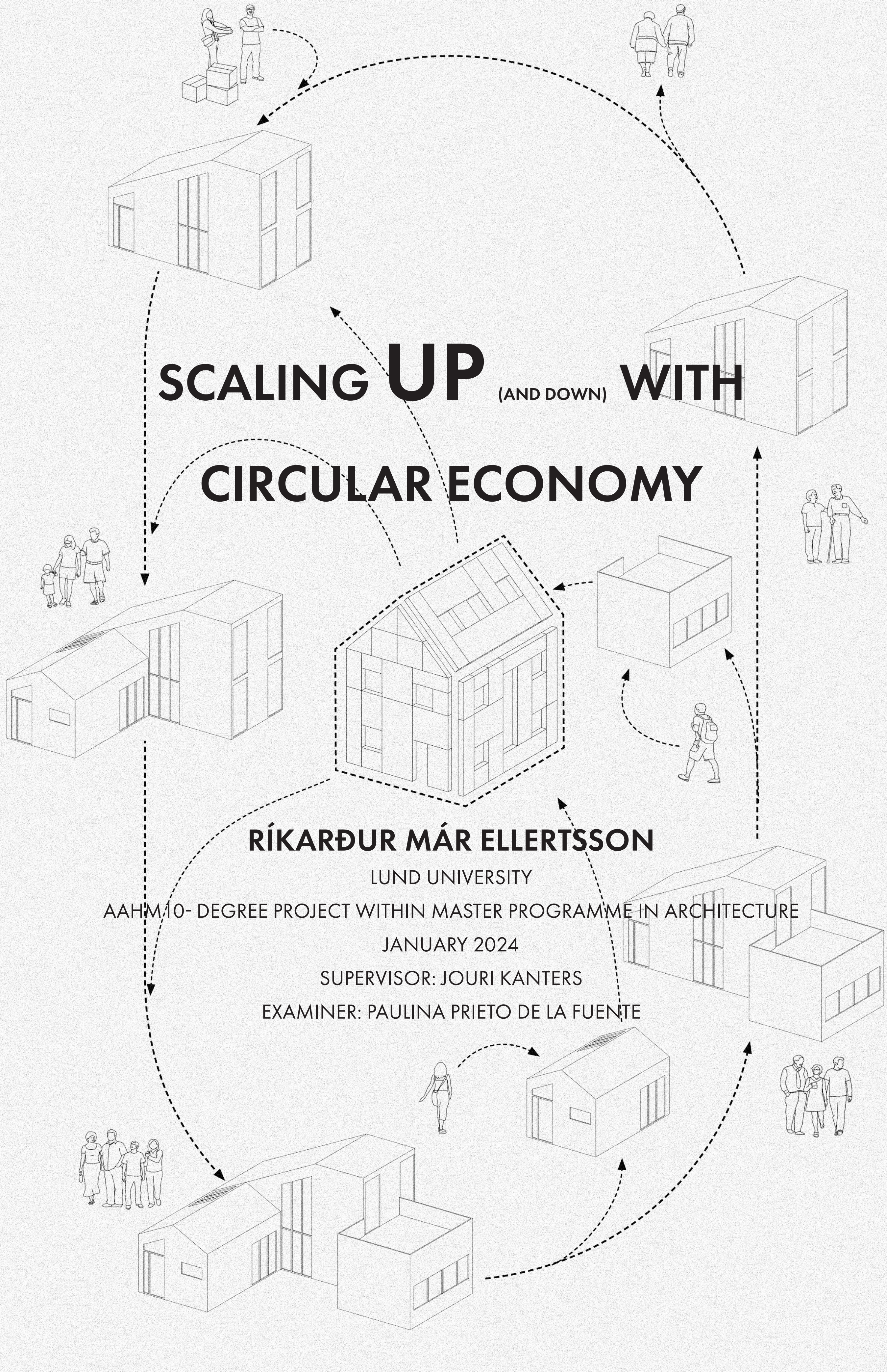

SCALING UP (AND DOWN) WITH CIRCULAR ECONOMY

RÍKARÐUR MÁR ELLERTSSON

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SUPERVISOR: JOURI KANTERS

EXAMINER: PAULINA PRIETO DE LA FUENTE

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Abstract

This project commences with a personal reflection. I, the author, find myself on the verge of completing my academic journey and embarking on the pursuit of an independent life. This involves securing employment and establishing a place to call home, with the ultimate goal of starting a family. However, upon exploring housing options in my home country, Iceland, it has become evident that this endeavour is fraught with challenges. The real estate and rental markets in Iceland are currently experiencing unprecedented highs, and obtaining bank loans for housing has become increasingly more difficult.

Faced with the seemingly prohibitive costs of both renting and buying, the prospect of building a home from scratch emerged as a viable alternative. This aligns with a personal aspiration of mine to construct my own dwelling, affording me control over my living space and the opportunity to imbue it with a unique personality. However, delving into the traditional methods of home construction, I soon realised that this avenue can be just as expensive, potentially even more so than purchasing an existing property.

Confronted with this reality, the notion of building on a smaller scale and gradually expanding the structure over time, in alignment with financial and spatial considerations, took shape. It was during this exploration that I stumbled upon the concept of the circular economy, which resonated with my vision of sustainable and economically prudent home construction.

This realization led to a pivotal question:

Can the principles of the circular economy pave a path towards more accessible home acquisition, and if so, how could that process look like?

This thesis embarks on a comprehensive journey, initially addressing the housing challenges prevalent in Iceland. Subsequent chapters delve into the theoretical underpinnings and strategic frameworks of the circular economy within the construction industry. Next, three case studies, spotlighting applications of circular economy principles will be discussed. Once sufficient knowledge has been acquired on the subject, a rudimentary circular economy building system is developed. The culmination of this endeavour manifests in a practical application—a four-step house design. This design intricately aligns with the evolving spatial needs of its occupants at different moments in time, embodying the essence of a circular economy approach to home construction.

THEORY

HOUSING MARKET IN ICELAND

How does the Icelandic housing market look for young buyers? This question is best answered through a mathematical example.

Jón is a young adult who wants to start his independent life by supporting himself and living on his own terms.

Jón gets a job that earns him a disposable income of 3.090 EUR/month*.

Jón is lucky and manages to rent a 60 sqm apartment in the most affordable neighborhood of the greater capital area of Iceland costing him 1.200 EUR / month*. Additionally, his monthly expenses are estimated to be 1.460 EUR*.

That leaves Jón with savings of 430 EUR that he diligently puts aside in order to buy his own property.

The cheapest average apartment prices in the greater capital area of Iceland are in a neighborhood called Bakkahverfi. They are roughly 3960 EUR/sqm*. Accordingly, a 70 sqm apartment should then cost around 275.000 EUR.

Jón has no way of gathering all that money with his monthly savings so he must take a loan from the bank.

There are two main factors that determine how big of a bank loan a person can afford. First off, in order to be eligible for a "first time home buyers"- bank loan from Icelandic banks, a person must be able to pay 15% of the property's value. In Jón's scenario, it would take him 7 years and 6 months to save up for that amount. Secondly, the ratio between wages and monthly loan payments must not exceed 40% and the person must undergo a payment capacity check.

It is possible to calculate Jón's payment capacity on Arion Bank webpage. It estimates that Jón has a payment capacity of roughly 1240-1310 EUR*.

Jón can only afford to get a mixed loan of 25% non-indexed and 75% inflation-indexed. This loan borrows Jón ca. 234.000 EUR over a period of 40 years*.

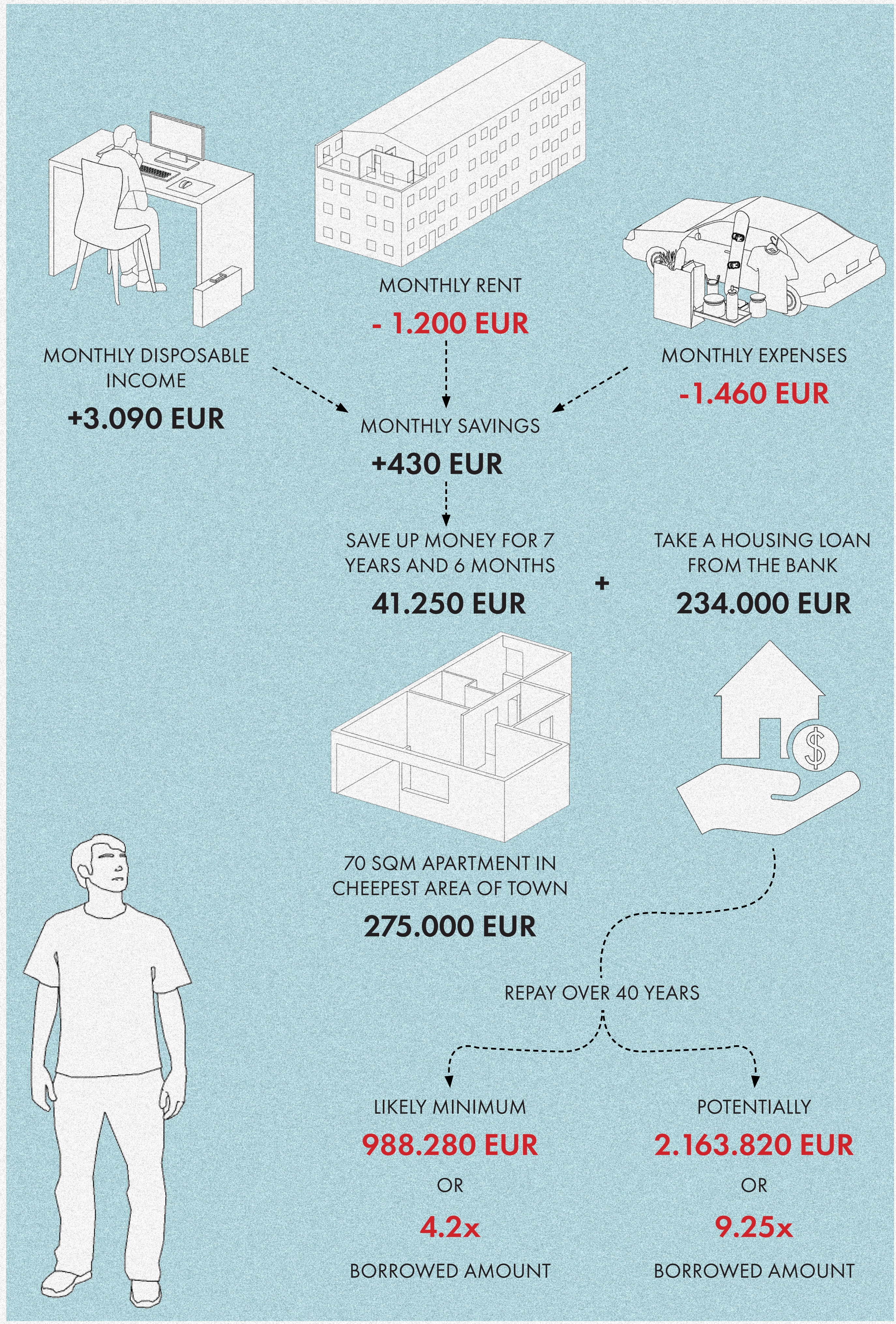
If average inflation over the next 40 years stays the same as the average of the previous 10 years, 3.8%, Jón can expect to pay the bank back 988.280 EUR or 4.2 times the loan amount. However, if inflation over the next 40 years rises to e.g. 7.6%, the the average of the last 12 months (in August 2023) the total amount paid is estimated to be 2.163.820 EUR or ca. 9.25 times the loan amount*.

The main problem with these loans is that they are very volatile and unpredictable since monthly repayments can fluctuate with inflation. This, in turn, influences the renting conditions directly as new apartments that are bought with these loans are rented out at higher and higher prices to cover the cost of the loan. In fact, the rent situation in Iceland is so bad that 88% of renters do not wish to be renting (Grettisson).

Finally, if a person would want to buy a piece of land (in the outskirts of the greater capital area of Iceland) and build their own 1 story timber home it would cost them ca. 4.140 EUR/sqm*.

This is a big part of why another housing option type is needed in Iceland. One where there is not the same need for such large sums of loans. This is where the concept of CIRCULAR ECONOMY could step in.

*Calculations and their sources for this page are referenced the appendix at the end of the document.


MONTHLY DISPOSABLE INCOME
+3.090 EUR
MONTHLY RENT
- 1.200 EUR
MONTHLY EXPENSES
-1.460 EUR
MONTHLY SAVINGS
+430 EUR
SAVE UP MONEY FOR 7 YEARS AND 6 MONTHS
41.250 EUR
+
TAKE A HOUSING LOAN FROM THE BANK
234.000 EUR
70 SQM APARTMENT IN CHEEPEST AREA OF TOWN
275.000 EUR
REPAY OVER 40 YEARS
LIKELY MINIMUM
988.280 EUR
OR
4.2x
BORROWED AMOUNT
POTENTIALLY
2.163.820 EUR
OR
9.25x
BORROWED AMOUNT

CIRCULAR ECONOMY

While the term **circular economy** has been discussed since the 1970s it is only recently that it has attracted an increased attention from governments, major global companies and the public[Wautelet, 1]. The Ellen MacArthur Foundation (EMF) is a prominent force in implementing and advocating for the concept of circular economy and they describe the concept of circular economy as:

"a systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It is based on three principles driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature"
(The Circular Economy Glossary)

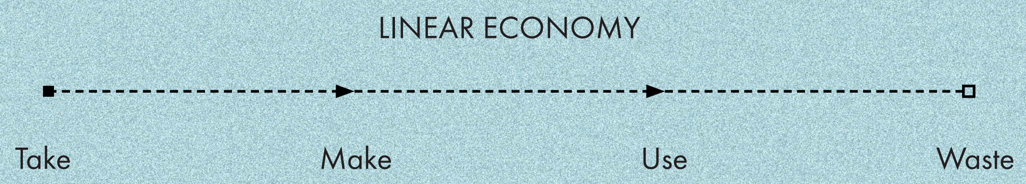
In other words, it challenges the linear manufacturing model that has persisted since the industrial revolution. The current one-way model of production and consumption is built on products that are manufactured from finite resources extracted out of the earth, sold, used, and then incinerated or discarded as waste with little to no possibility of being used again. This so called "take-make-waste" way of thinking and manufacturing has persisted mainly because it is the foundation and breadwinner of almost all major industries.

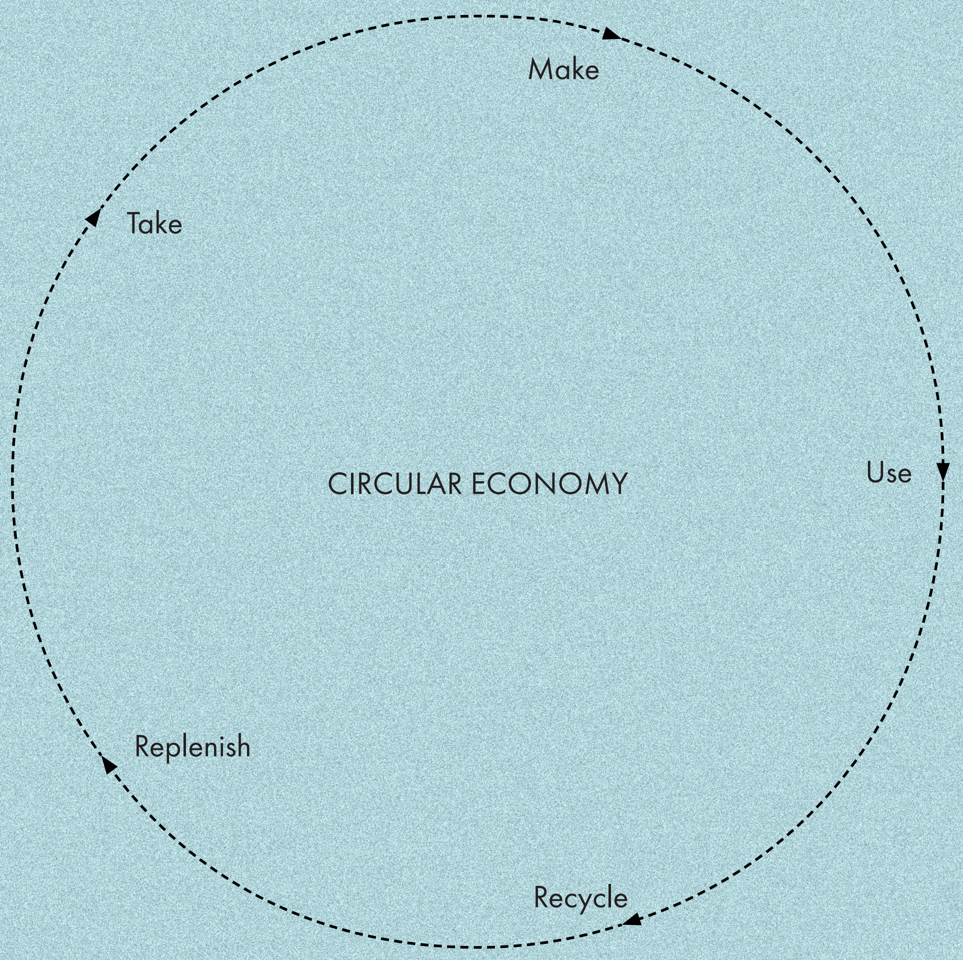
Architect William McDonough and chemist Michael Braungart criticizies the current linear economy in their book, Cradle to cradle by saying:

"... in the race for economic progress, social activity, ecological impact, cultural activity and long-term effects can be overlooked." and yet "... while the economic payoff immediately rises, the overall quality of every aspect of this system is actually in decline."
(McDonough and Braungart, p37, p35)

Buildings in a linear system are built from finite "virgin" resources that retain the energy used in mining, refining, and producing them. Additional effort, expense and time goes into designing and building the structure. The building is then put into use and is used for as long as it functions and is needed. In the system we live in now the building will ultimately be demolished, which takes additional effort and expense. Once that happens all the material and the embedded energy behind them goes to waste. Tons of potential nutrients for the building industry alone are wasted each year and new raw material must continually be extracted. The cost of extraction is then constantly added to each new product and material. This model is extremely wasteful, unsustainable and polluting.

It is vital that this model is challenged since experts estimate that on a global scale, 60% of the buildings that will exist in the year 2050 are yet to be built [Cities in the circular economy, 10]. That number becomes less surprising as the global population is predicted to reach 9.7 billion in 2050 [Population]. This can only mean that humanity will need more resources as they become scarcer and as they do, they will be increasingly costly. Furthermore, an enormous proportion of all the materials ever extracted in human history are located in today's built environment [Sabchez and Haas, 999]. This might suggest that buildings will become a major temporary material stock to supply future demands.





LINEAR VS CIRCULAR ECONOMY

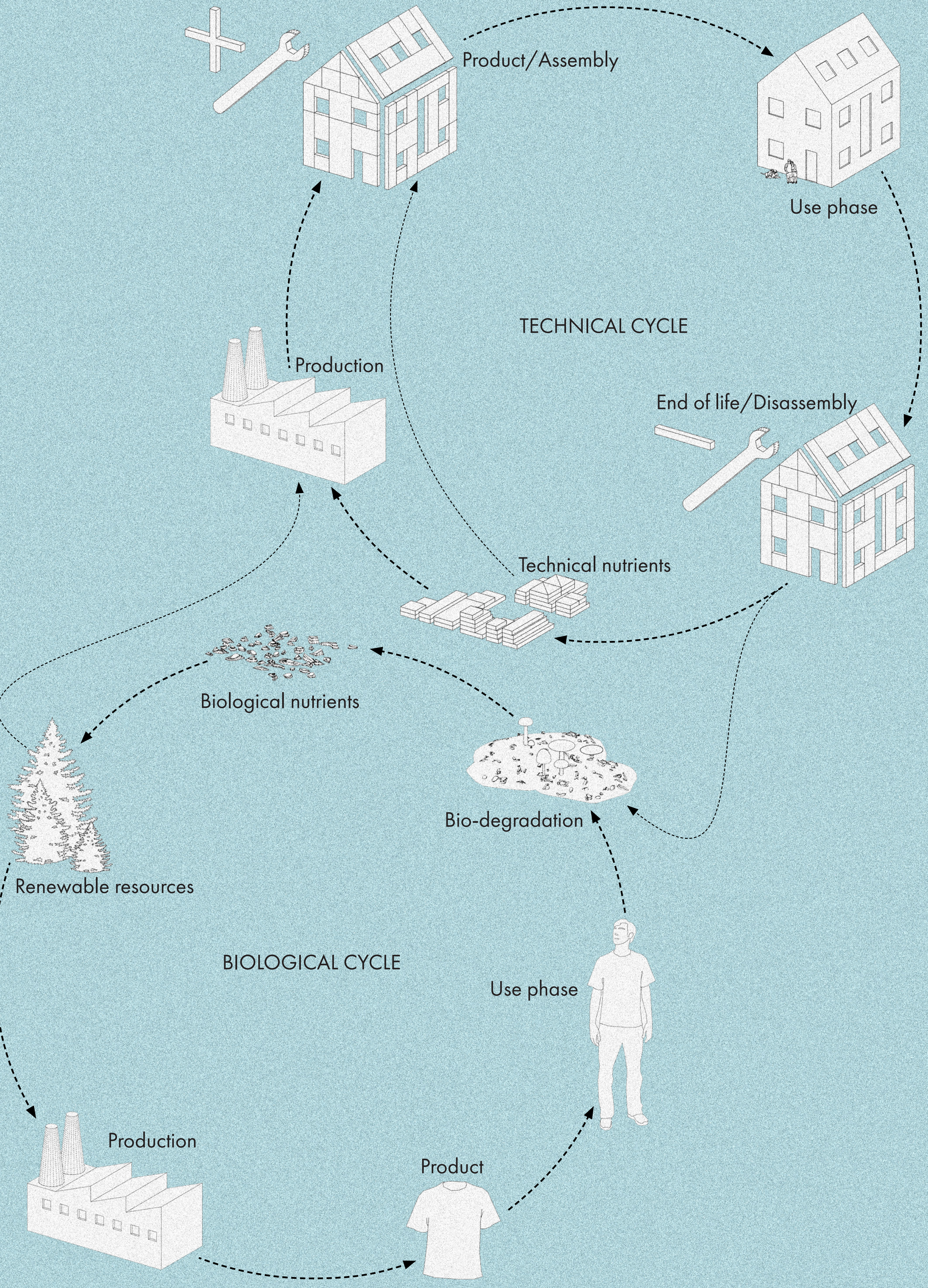
If CE is to be implemented it needs to prove its economic potential. That is exactly what the Ellen MacArthur Foundation is working to achieve. In a publication released in 2020 they claim that:

"The circular economy presents a multi-trillion-dollar economic opportunity" (Financing the circular economy, 12)

They further state that if Europe were to adopt CE principles in mobility, the built environment, and food industries, it could offer an annua benefit of 1.8 trillion euros by 2030 (Financing the circular economy, 22). In another publication EMF speaks of the "circular city". A circular city is enabled by an urban system that is regenerative, accessible and abundant by design. The built environment should be designed in a **modular** and **flexible** manner, minimizing virgin material use and relying on efficient construction techniques. The circular city will be optimally utilized thanks to shared, flexible and modular office spaces and housing. Additionally, this report argues that a CE development path could increase the disposable income of an average European household by 3000 euros or 11% higher than the current developmental path by the year 2030 (Cities in the circular economy, 9). It is clear that the circular economy is not only about reusing volume, but also retaining value. By building with components and materials that fit into the concept of CE, the building becomes a much greater investment. At the end of its life, it can be disassembled and the same parts used elsewhere or sold, instead of becoming waste.

The concept of CE has been deeply connected to eco-sustainability and emerged largely in effort to decrease the considerable environmental impact emanating from our society. The principles of CE have the potential to address many of today's complex challenges, including the loss of biodiversity, climate change, finite resource depletion, water stress, population growth, conflict over energy and resources, geopolitical tension and economic failure (Moreno et al., 2). In the light of that, it should easily have the potential to benefit everyday people and their housing needs. This project will propose how that could look like.

Finally, in the book *"Cradle to Cradle"* authors William McDonough and Michael Braungart speak of the concept of CE as the next industrial revolution, that is founded on nature's effective design principles, on human creativity and prosperity and on respect, fair play and good will. The book recognizes that nature operates according to a system that consists of nutrients and metabolisms in which there is no such thing as waste. It goes on to identify two kinds of material nutrients; biological nutrients and technical nutrients. The idea of a circular economy is to return these nutrients back into the system. The authors declare that with the right design, all the products and materials manufactured by industry will safely feed these two metabolisms, providing nourishment for something new. As the main focus of this project is not eco-sustainability a greater importance is placed on technical nutrients. Technical nutrients are materials or products that stay in closed-loop technical cycles, in which they continually circulate as valuable nutrients for industry (McDonough and Braungart, 103-115).



SIMPLIFIED CIRCULAR ECONOMY CYCLES

HOW COULD IT LOOK LIKE?

The whole concept boils down to: People buying/building/owning a home that they can afford at the time of buying and gradually increasing and decreasing the size of their home as their financial and spatial situation calls for.

POSSIBLE SCENARIO

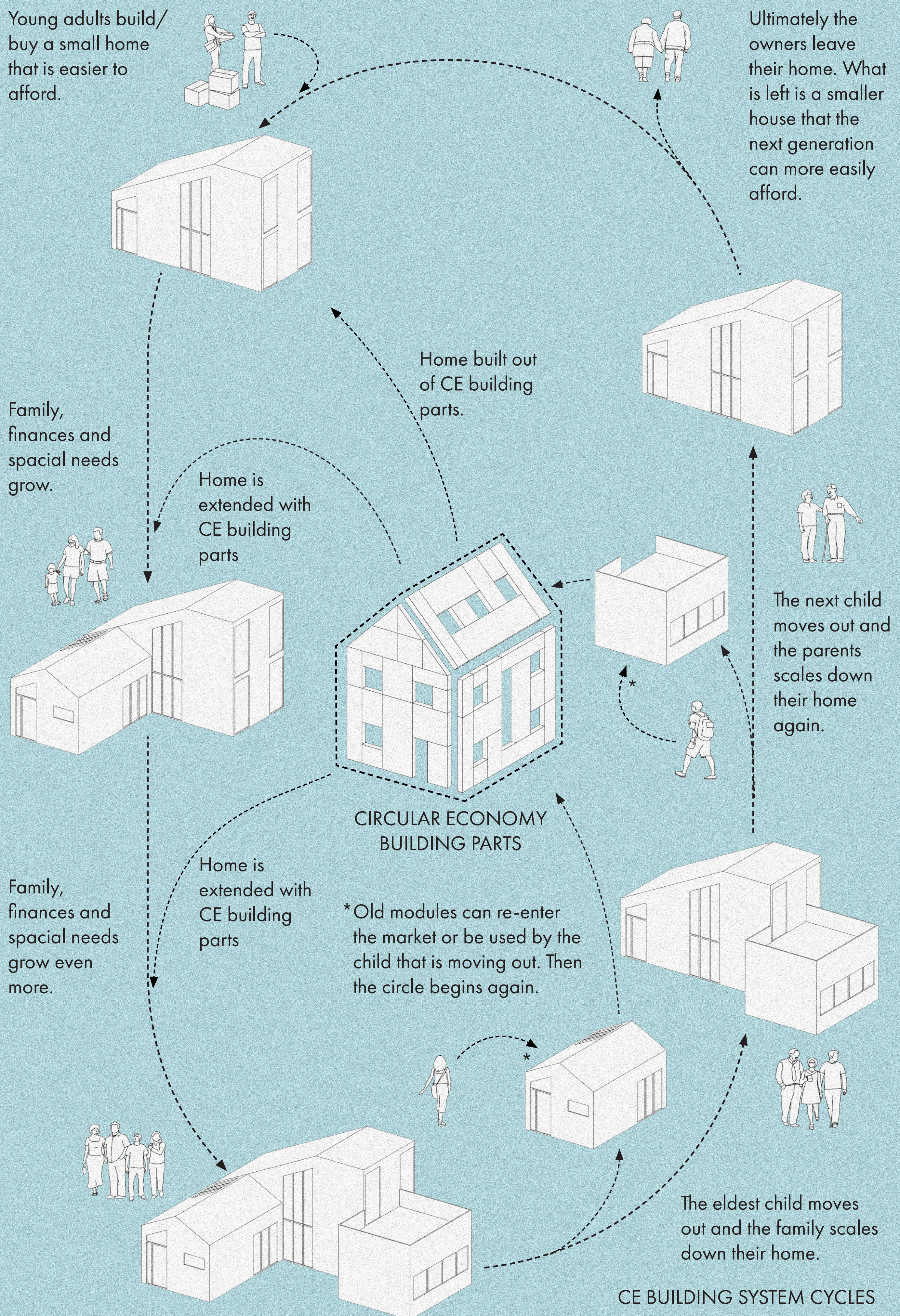
Young adults, buy/build a small house that they can afford made from a circular economy building system. The house could be built out of older building parts that have re-entered the market or be built out of new building parts that will re-enter the market at a later date. This means that these building parts retain their value.

As their family and financial situation grows, they can easily expand their home using the same building system. This can be done again and again until a desired outcome is reached.

When the homeowners start to age, their children are reaching a stage where they might want to start their own homes. Now the homeowners can scale down their property according to their needs. That means less space to take care off and pay property taxes on. The same part that got removed could be used to help their children to start their own home and start the cycle over. It could also re-enter the general market.

Ultimately, the house changes hands and gets new owners. If the previous owners stayed in the house till old age and scaled it down according to their needs, the house would enter the market as a smaller living space that the current young generation could more easily afford to acquire.

Now the cycle can start over again.



Young adults build/ buy a small home that is easier to afford.
Ultimately the owners leave their home. What is left is a smaller house that the next generation can more easily afford.
Home built out of CE building parts.
Family, finances and spacial needs grow.
Home is extended with CE building parts
The next child moves out and the parents scales down their home again.
*
CIRCULAR ECONOMY BUILDING PARTS
Family, finances and spacial needs grow even more.
Home is extended with CE building parts
*Old modules can re-enter the market or be used by the child that is moving out. Then the circle begins again.
*
The eldest child moves out and the family scales down their home.
CE BUILDING SYSTEM CYCLES

CASE STUDIES

CASE STUDY 1: CIRCLE HOUSE

The Circle House project is a social housing project constructed according to the principles of CE. The project's main focus and objective is that 90% of its materials can be reused without any loss of value.

The project involves more than 30 enterprises from the Danish construction sector across the value chain. However, its main partners are:
Client: Lejerbo
Architecture firms: Vandkunsten, Lendager Arkitekter, 3XN and GXN
Building contractor: MT Højgaard
Engineering firm: Kingo Orbicon
Demolition firm: Kingo Karlsen
Additional participants: Danish Building Research Institute (SBi), The Danish Association for Responsible Construction and the City of Aarhus.

The project consists of 60 social housing units in the Lisbjerg Bakke district in Aarhus, Denmark. The building typologies are a mix of 2- and 3-story terraced houses and 5-story tower blocks consisting of:

5 single-room units of 30-35m2
5 two-room units of 70m2
10 four-room units of 110m2
40 three-room units of 90m2

The Circle House projects aim is to showcase how circular economy is realized in architecture at the time of construction and act as a catalogue of available circular solutions for the building industry.

"Circle House will be a crucial proof of concept that circularity in architecture is achievable today" (Partners Circle House, 12).

By taking on this project the partners wish to learn what the transition to circularity will require from the regulatory frameworks and how the construction sector's business model will have to be adjusted. The aims of the project also include sharing the knowledge generated by the project with the building industry and policy makers in order to take a crucial step towards a circular economy within the building sector in Denmark.

"the Circle House project is not presenting ready-made solutions; we are offering suggestions with the hope of bringing Denmark a few steps closer to a circular economy"
(Partners Circle House, 42)

Finally, the project aims to demonstrate that a Circle House unit will offer more flexibility in use and future possibilities than typical housing projects.

To achieve these goals the project relies on 15 underlying principles that act as guidelines and strategies for implementing reuse and circularity into the built industry. These principles fall evenly within three main categories, Design for disassembly, Material ID, and Circular economy.

Image 1: Visualisation of Circle House by RUM

CIRCLE HOUSE 15 UNDERLYING PRINCIPLES

DESIGN FOR DISASSEMBLY

Materials
Select materials with properties that ensure their recyclability.

Service
The building must be designed with a focus on its entire life span.

Standards
Design a simple building that fits into a larger and coherent system.

Connections
Design reversible connections that can be disassembled and reused several times.

Disassembly
A schedule for the disassembly is essential as well as a schedule for the assembly.

MATERIAL ID

Documentation
To secure the quality and value of the materials and resources.

Identification
Physical identification of the single element is important to gather the right information.

Maintenance
To secure the value of the material, correct maintenance is essential.

Safety
Maintenance of safety procedures throughout the entire lifespan of the building.

Transition
Gather the necessary information of how the different materials should be handled through transitions.

CIRCULAR ECONOMY

New business models
To complete the circle of circular economy new business models must be developed.

Incentive
All parties in the supply chain must have a positive financial return.

New models
Instead of creating new products, business models must be based on offering customer service instead.

Partnership
Partnerships and cooperation agreements are necessary as no one can operate a circular economy alone.

Circulation
The value of the products in the biological and technical circuits must be maintained as long as possible.

STRUTURAL SYSTEM

The project was originally scheduled to be finished in 2020 but has been pushed back to 2023. Although the building is not completed yet, a 1:1 mockup and exhibition space has been constructed where all the building's layers, materials and products are exposed, displayed and described.

For a sustainable building, some might find it surprising that the main strucural elements of the Circular House are concrete components. However, it underlines the fact that circular economy can be achieved with conventional building materials, by making them reusable and thus preserving their value and decreasing the overall energy put into creating the materials. The concrete components are connected via mechanical joints made mainly from steel. This choice was based on already existing solutions from the Circle House Partners: Precast concrete elements from Spæncom, mechanical joints from Peikko and the connections are cast with lime mortar from Kalk.

A total of six different precast concrete structures are used for the main structure of one unit. Multiple units can then be fixed together creating a variety of layouts. However, the structure's main customizability comes from its finishing materials. Its floor, ceiling, wall covering and facade materials can be all kinds since careful consideration is put on how they are mounted on the building. That means each unit can take on different forms and be highly personalized for each individual occupant.

The grid that the structural system follows is a multiplication of 1200mm. The reasons for this are not stated but it is likely that it is due to industry standards for building products such as plywood boards, insulation panels, window sizes etc.

Image 2: Circle House 2nd story of tower block (emphasis on 1200mm grid)

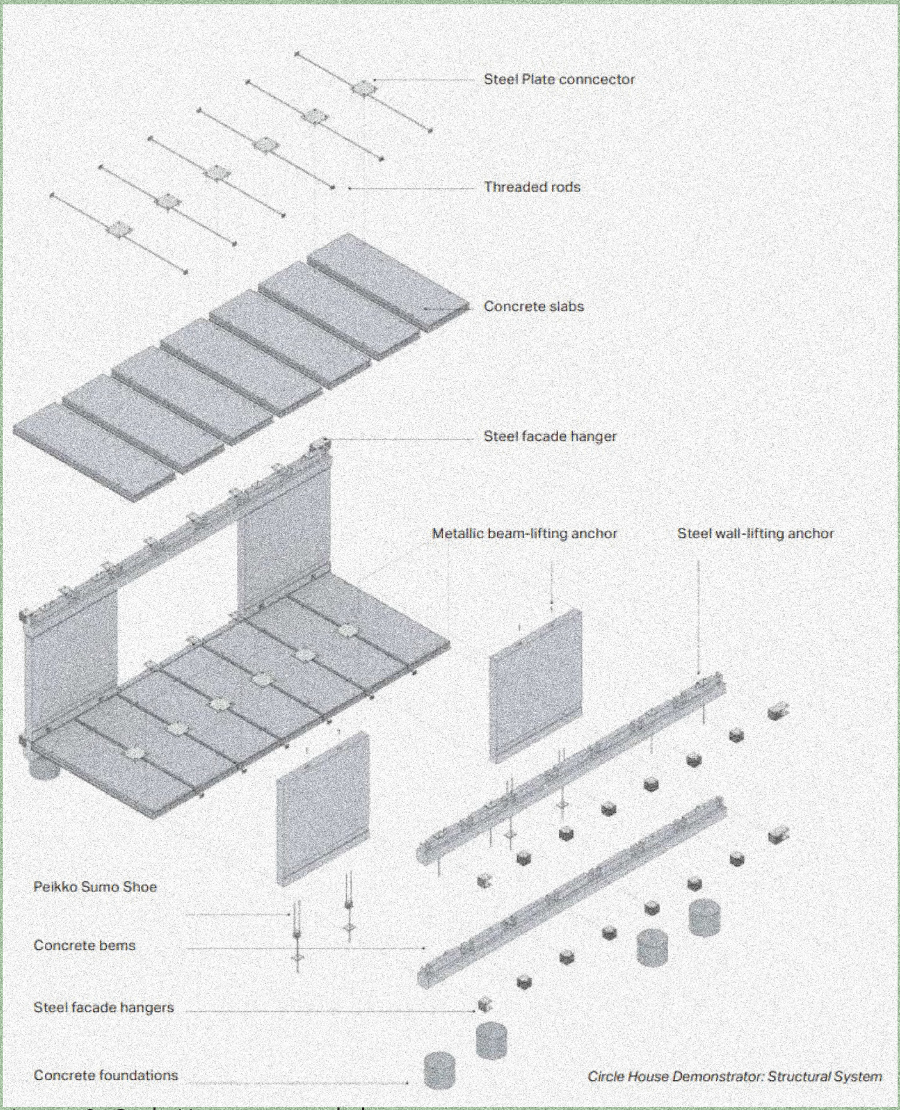


Image 3: Circle House structural elements

Image 4: Circle House assembled units

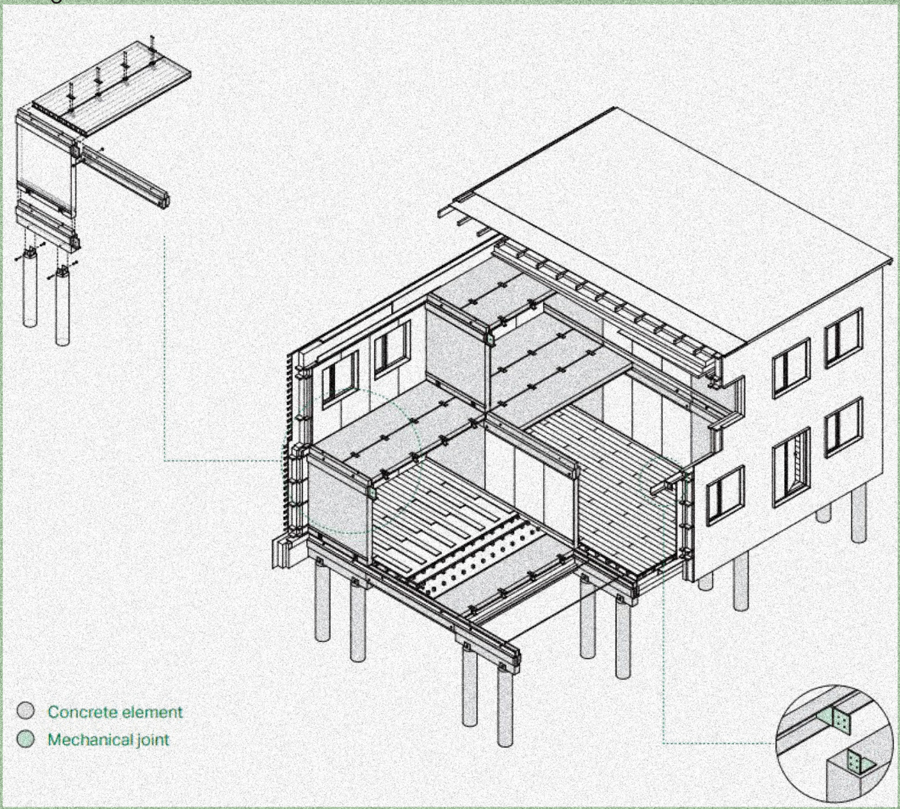


Image 5: Acoustic wall panels with smart mounting system

Image 6: Click-in-place flooring system

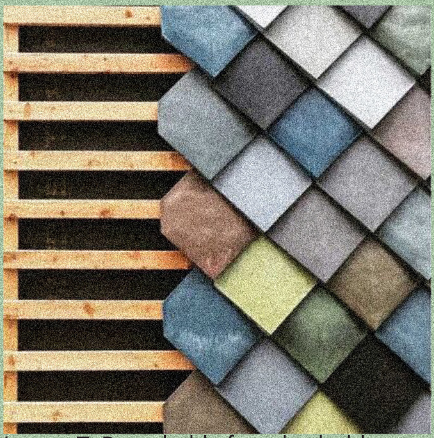


Image 7: Detachable facade cladding mounted on larch wood grid

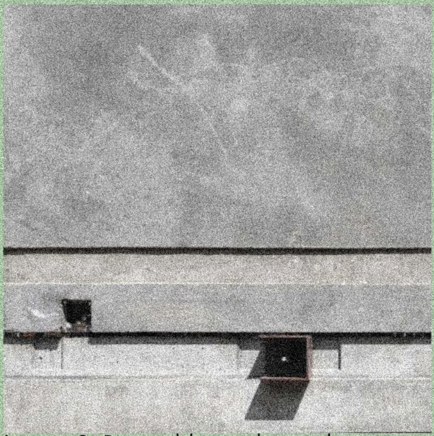


Image 8: Reversible mechanical joints between concrete elements

HOW DO THE OCCUPANTS AND OWNERS OF THE CIRCLE HOUSE BENEFIT FROM THIS TYPE OF CONSTRUCTION?

The main benefit for occupants of the Circle House is that the flexibility of each unit is designed to allow for easily adjustable layout variations. The inhabitants of the apartments can change the layout of bedrooms and living rooms to suit their current and future needs. They can change from a large living room to either two small bedrooms or one large bedroom. The interior walls are non-structural and can be fairly easily moved.

The owners of the Circle House project benefit in various ways. The prefabrication of the building's components means they are cheaper to manufacture compared to on-site construction. In the 1:1 mock-up build it only took the construction crew an hour to finish assembling the concrete pieces of one unit. This ease of assembly means that less time and money is spent on building the project.

Additionally, the housing association retains all the physical value of the parts of the building that can be disassembled and reused. This means that the initial costs a much greater investment. The housing association is saving costs and these same saving should be transferred to the occupants. Furthermore, the housing association will have the option to change the mixture of units. They can opt to have fewer but larger apartments or more smaller apartments if future demand shifts.

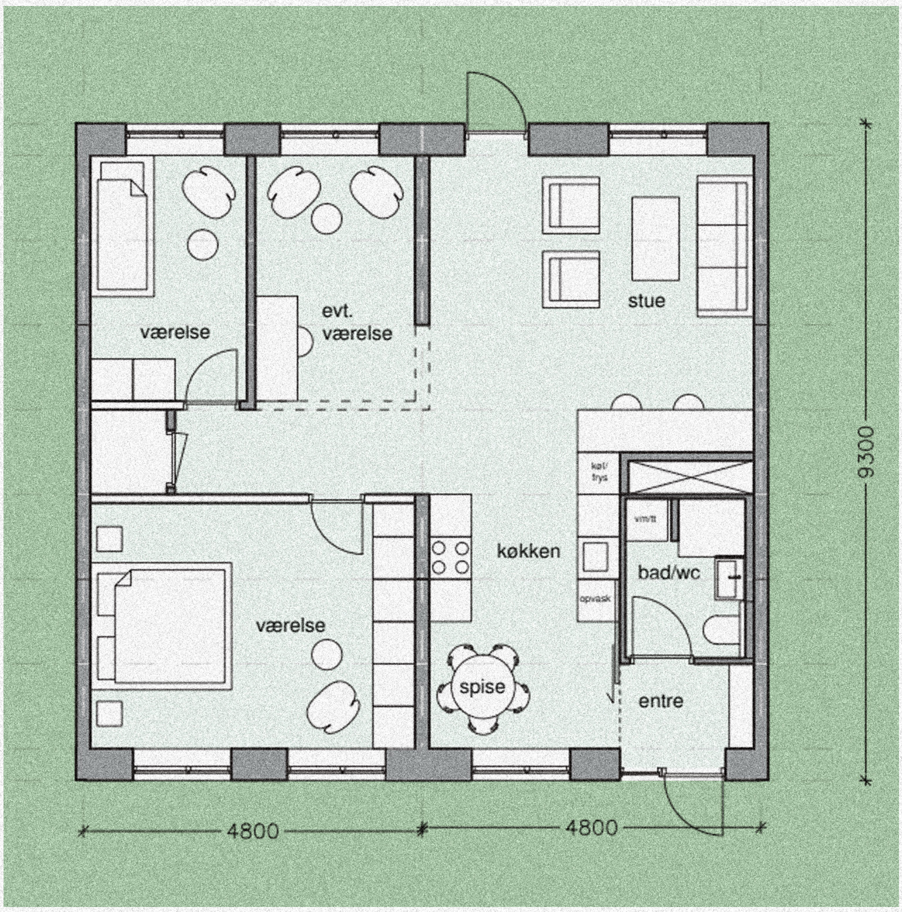


Image 9: An example of how a 90 m2 unit can be altered

AESTHETICS

Aesthetically, circular buildings have an opportunity to incorporate visible connections as decorative features as well as facilitate easier disassembly. The structure, connections and installations could be on display as integral, aesthetic features of the architecture. The Circle House does not embrace this aspect of the design to the fullest and chooses to hide many of its connectors. However, its insides clearly express its modularity.

Image 10: Circle House mock-up exterior

Image 11: Circle House mock-up interior

CIRCLE HOUSE'S SECOND LIFE CYCLE

Once the Circle House had been designed so that 90% of its materials could be reused, the partners of the project wanted to know what the future of those materials might look like. In order to do so students at CINARK (Centre for Industrialized Architecture at the Royal Danish Academy of Fine Arts, School of Architecture) were asked to come up with different future scenarios for the Circle House and it's components as academic projects.

The project for the students was twofold: Firstly, use the Circle House construction system and its associated components in a different context, and secondly, elaborate on the system by extending the construction system with further components.

These scenarios demonstrate how a Circular building system can live extra lives without having to do the exact same thing. It also shows how additional elements can be designed and fitted into the system at a later date, enabling it to be reused in various ways.

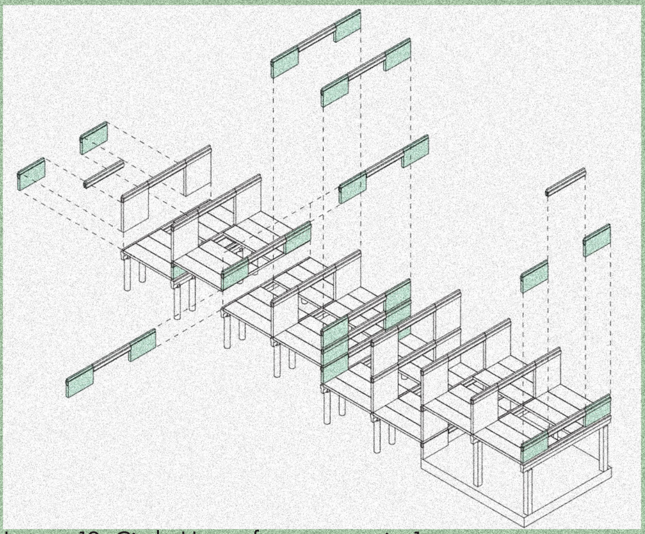


Image 12: Circle House future scenario 1

Scenario 1:
What if the Circle house was to accommodate landscape topography?

The addition of a half-wall element enables the construction system to work in an inclined location. Additionally, the incorporation of the half-wall offers varying ceiling heights.
It is perhaps obvious that the more components the system has the more flexible it becomes.

Scenario 2:
What if Circle House could be used as building blocks for a new single-family home?

When changing the building's typology for this scenario some of the building system components were displaced and rotated. New connections needed to be formed but spatial versatility increased. Additional addons such as a conservatory and a patio were envisioned to further test the flexibility of the system with new parts.

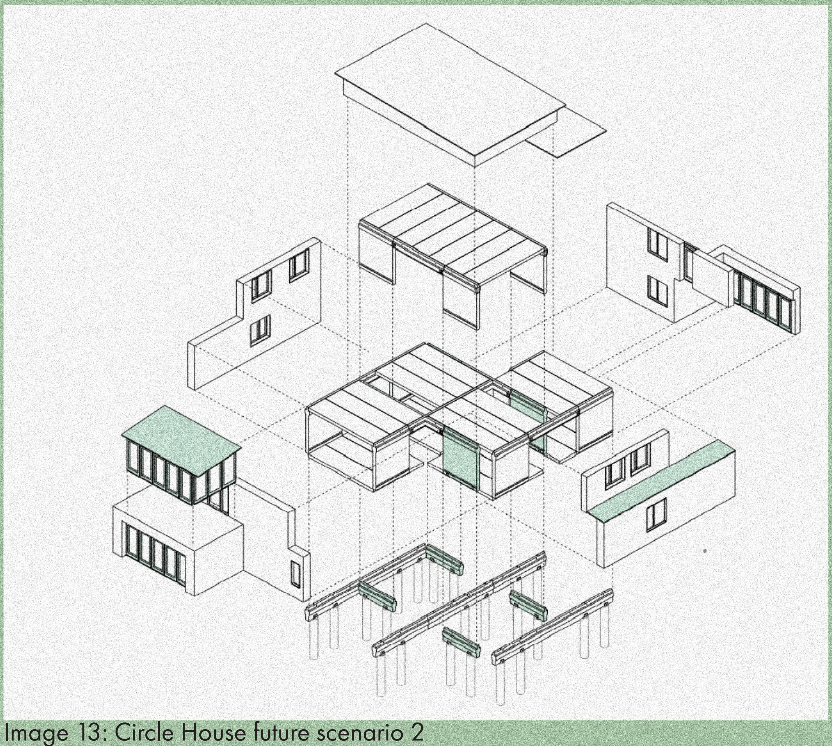


Image 13: Circle House future scenario 2

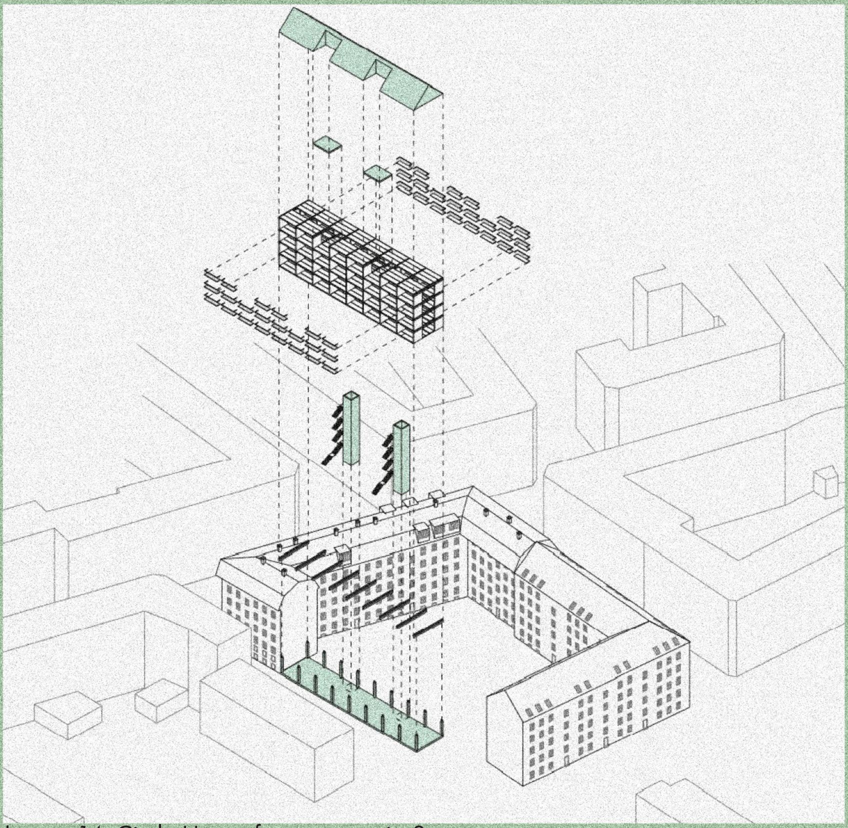


Image 14: Circle House future scenario 3

Scenario 3:
What if Circle House was to be built in an urban setting?

The system now needed to have an elevated ground floor to accommodate commercial spaces or a car park.

The construction system was given a new columnar element and longer ceiling beams.
They do not elaborate on the additional roof structure which is a shame because that is one of the trickier elements to design for disassembly.

The first two scenarios demonstrate how elements can be designed later down the line to fit the system enabling it to be reused in various ways.

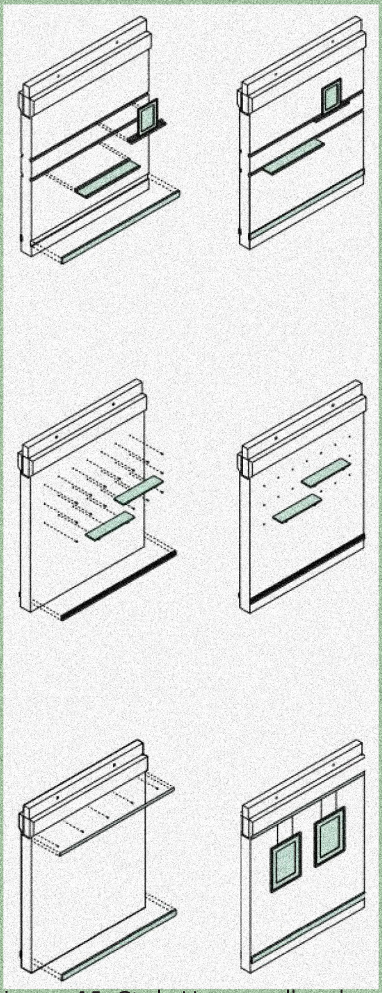


Image 15: Circle House wall study

Extra:
What if you could use your wall without drilling holes?

Altering the concrete partitioning wall to a wall that can be personalized without the use of screws and nails. This allows for even more flexibility of the unit and increases its aesthetic value.

(All information regarding the Circle House was found in their book by the same name.)

CASE STUDY 2 : ADD-A-ROOM

ADD-A-ROOM CONCEPT

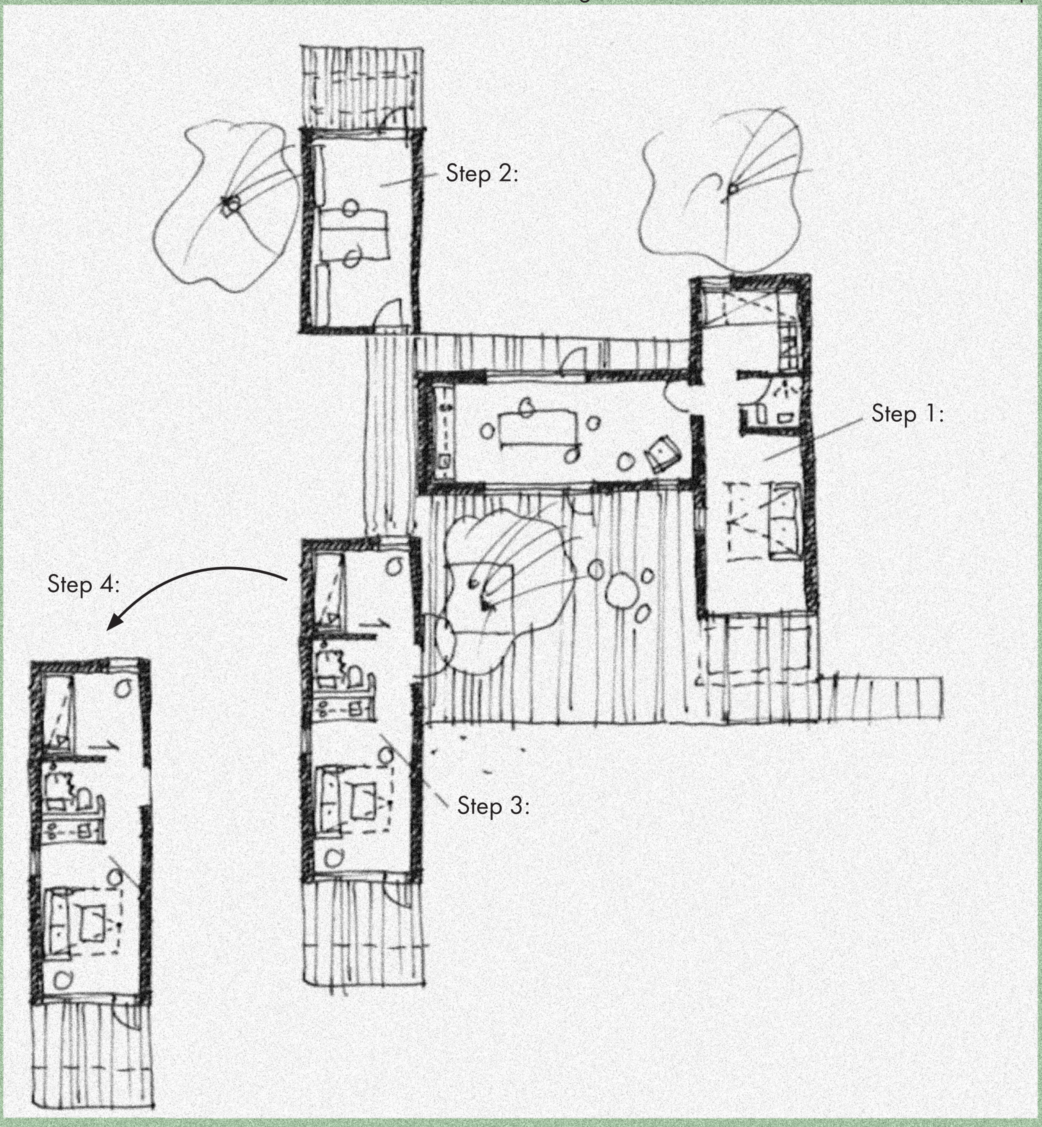
Add-a-Room is a Danish company that has designed various turn-key house modules that embody the principles of circular economy. The concept behind Add-a-Room was conceived by the Danish architect Lars Frank Nielsen and was created with the purpose of building small modular and flexible housing units of high quality from sustainable materials that incorporates the whole lifecycle of the building. A key part of the concept for this design is to strive for a more circular view of living, where only today's need of living space is consumed. The modular system achieves this by providing the opportunities to move, expand or reduce your housing in the event of life changes.

"Move today's consumption of extra living space for a future increase in family size to the future and only when it is needed" (Add-a-ROOM)

With that being said, the modules are designed with future generations in mind, assuring that the house can be handed over to the next generation 50 years later in the same high standard as when it was built.
With this concept an individual or a couple can start out with a small footprint home that suits their current needs. This home can then be expanded as the family grows by adding modules to the home. Just as importantly the home can be scaled down by removing modules. For example, when the day comes for the kids to move out, they can take a module with them. The module could also be moved to a summer house or sold. The elderly owners are then left with a smaller living space to take care of and peace of mind, being able to help their offsprings to start their own lives and homes. That also means once the house inevitably goes back on the market it is again more affordable due to the decrease in size. And the circle begins again.

Image 16: Add-a-Room sketch

Image 17: Add-a-Room circular module concept



Step 1:
A couple/individual buys a conjunction of 25m2 and 20m2 ONE+ modules equipped with a bathroom, kitchen, living room, a larger bedroom and an extra room.
This situation can support a household of two parents and a small child.

Step 2:
Some years later they can expand with a 15m2 ONE+ module for extra room/s for when the child becomes a teenager.

Step 3:
Once the first child reaches young adulthood they can add yet another module with a small bathroom and a kitchenette.

Step 4:
When one of the children is ready to move out, they have the potential to take one module with them to start their own home.

THE MODULES

Add-a-Room offers 5 different sized wooden frame modules: 10, 15, 20, 25 and 30 m2. Each module is designed to be big enough to be used on its own as a mini house. Alternatively, the modules can be connected horizontally together to form bigger living space. Additionally, the modules can be connected by an outdoor unit. The modules can also be attached to other buildings as extensions.

The modules are fully prefabricated under factory conditions. This ensures that the quality of the modules is always guaranteed, and it ensures that no moisture is retained in the house during the construction process. The modules vary in length, but their height and width are always the same. The heights are kept the same to make it easier to fit individual modules together and the external width is kept at 3 meters so they can be safely and legally transported from factory to site. The modules are also built with hooks in the roof to be more easily moved and reused.

To further facilitate the ease of installation and removal the modules are placed on screw pile foundations. This foundation method is considered very friendly to local environments as the screw piles can be easily removed without any damage to the site. Additionally this method can save up to 90% of CO_2 emissions compared to traditional concrete foundations.

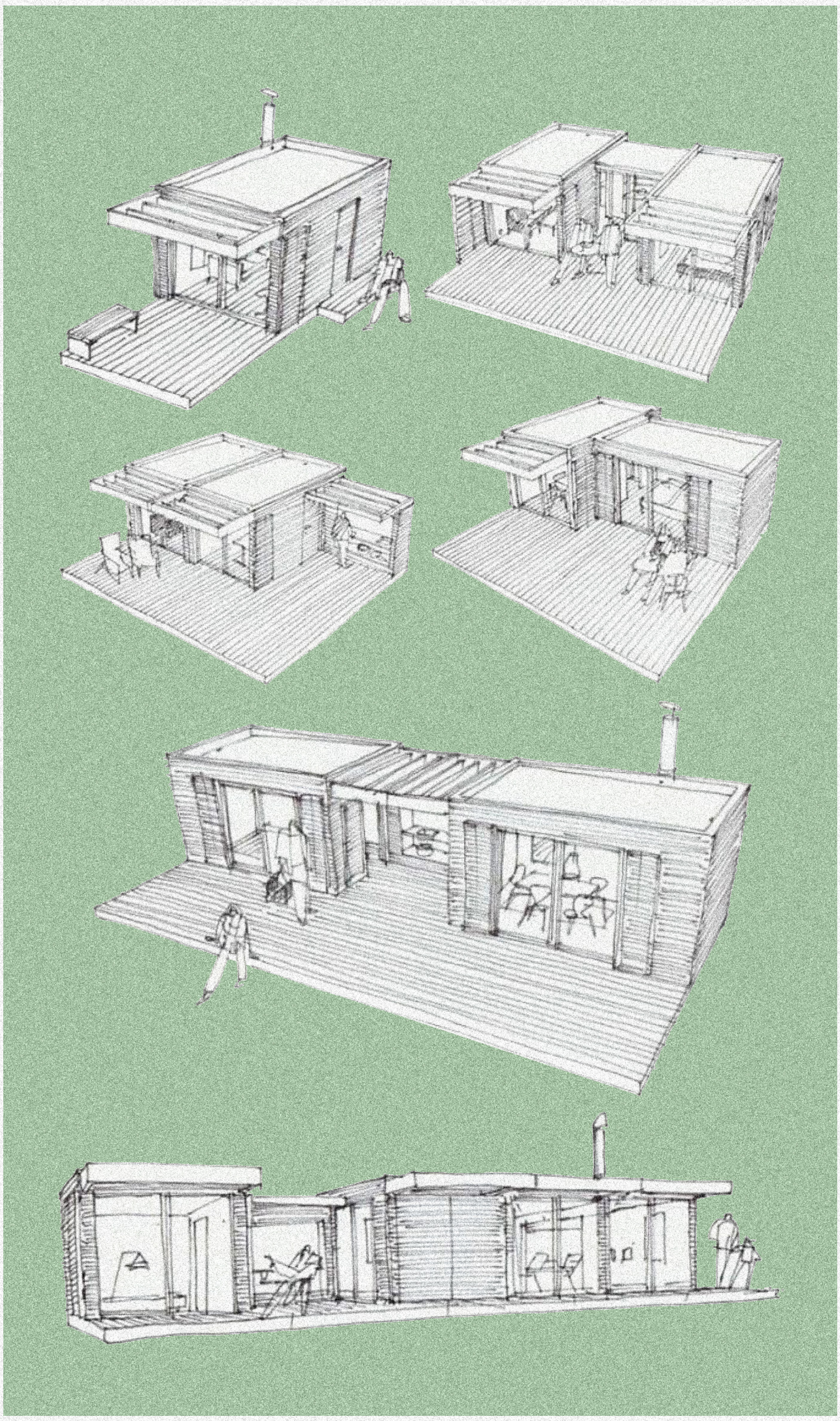
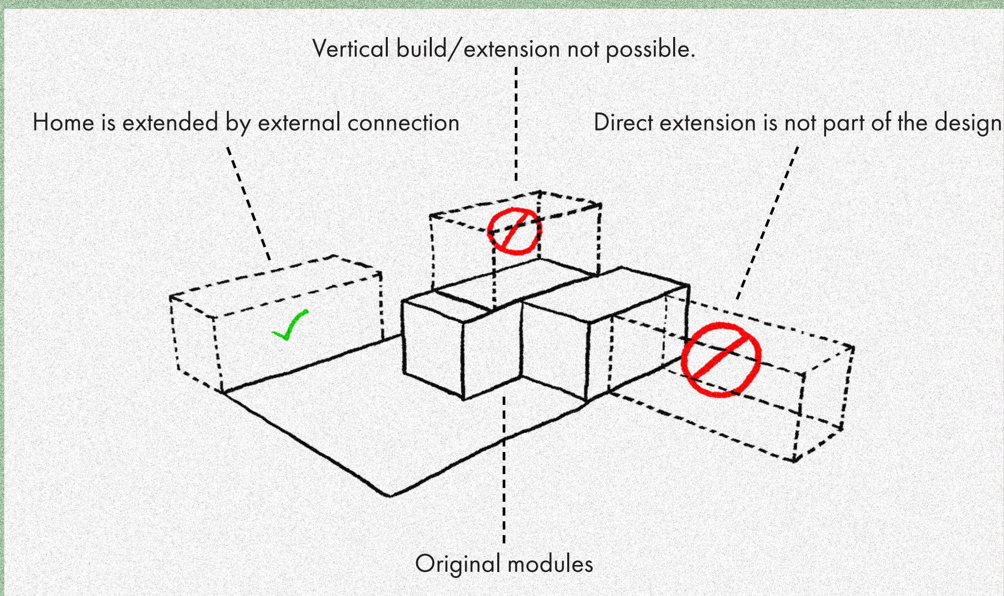


Image 18: Add-a-Room module configurations

(All information regarding add-a-ROOM was found on their official website.)

MAIN LIMITATIONS:

The modules are not designed to be added directly to the already existing building system, rather they are designed to be external add-ons connected to the original structure with a patio or something similar. It is technically possible to add a module directly to the existing structure, but that would be done in the conventional way of extending a house, that is, a part of a wall of the existing structure would have to be torn down in order to connect the next module. The walls are not specially designed to be taken apart and reused. Additionally, spatial configuration is limited to horizontal (not possible to extend in the vertical direction) connections of predetermined modular spaces. Finally, it takes more effort to personalize the modules compared to the Circle House system (case study 1).



MAIN LIMITATIONS

CASE STUDY 3 : XFRAME

XFrame is a lightweight modular wall framing system developed by Ged Finch. His vision is to proliferate circular economy based building technologies into the mainstream construction market in hopes of reducing building industry waste and facilitate end-of-life recovery and reuse. The XFrame system offers the ability to be easily disassembled and reassembled. That in turn makes the system easily recycled, updated, reconfigured, moved and on-sold. This system is just one step towards a building industry where all its products and parts will have direct reuse potential.

"Together, we believe that we can build out an entirely different way of doing business in the building sector" (XFramE)

Structurally XFrame offers two types of walls that both follow the same core XFrame logic of a scalable, self-braced, adaptable and reversible built infrastructure. One is non-loadbearing partition walls and the other load-bearing walls that can be used to construct residential structures up to two stories high. It seems that the company is mainly focusing on the non-loadbearing system at the moment.

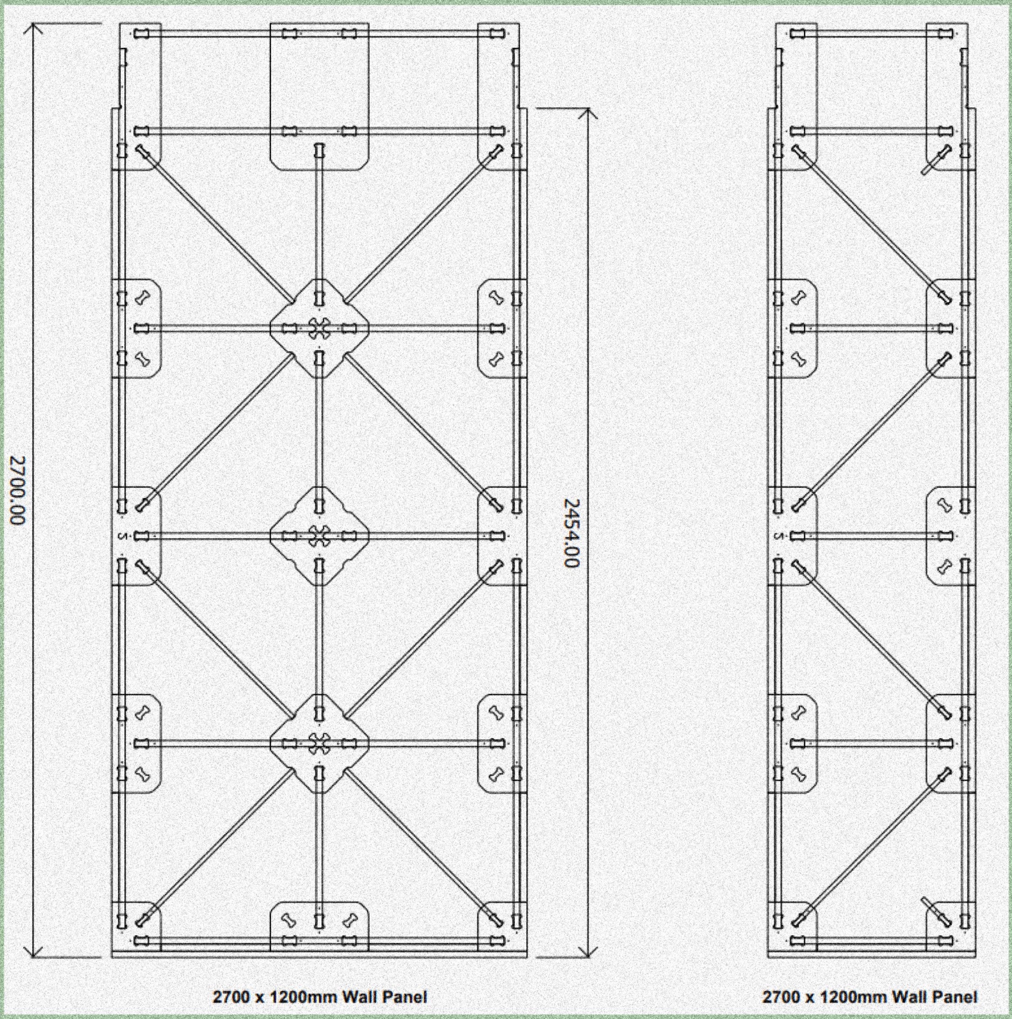
XFrame components are manufactured from sustainably sourced engineered plywood that is precisely milled by a computer controlled milling machine. The components have an interlocking pattern that allows them to fit together without the need for nails, screws or adhesives. The pieces are aligned in a Diagonal grid and interlock to form a steady brace. The precise bracing of the interlocking plywood parts is essential to keep the wall always square and true to its form which helps to make it reusable.

Currently XFrame is working to establish itself as a platform technology and want to see existing manufactures and material suppliers produce XFrame compatible lining, insulation, weather barrier and cladding solutions.

(All information regarding XFrame was found ion their official website.)

Image 19: XFrame structure

Image 20: XFrame interlocking pattern



CIRCULAR DESIGN STRATEGIES

In the paper "Building design and construction strategies for a circular economy" published in 2022, authors Eberhardt, Birkved and Birgisdóttir conducted a study through a systematic literature review to provide an overview of the state-of-the-art design and construction strategies being applied in relation to the concept of CE within the building industry. The study identifes16 overarching design and construction strategies.

The most common relations made between strategies and building typologies were for residential houses meaning that most of these strategies can be applied simultaneously on smaller residential scale buildings. However, some are better suited for larger projects and do not necessarily apply for this project (Eberhardt et al., 98-100).

Design and construction strategy	Description in literature
Assembly/disassembly	Is used to design the building, components or materials to be easily assembled/disassembled to enable e.g., direct reuse or recycling, ease of maintenance/operation and ease of adaptability/flexibility. A precondition is reversible connections.
Material selection/substitution	Choosing materials that are e.g., local, renewable, natural/eco/bio, high quality, durable, easy assembly/disassembly, reusable and recyclable, C2C certified, pure, maintenance free, retain or increase their value, match the performance lifespan, non-toxic/hazardous etc.
Adaptability/Flexibility	Design to be able to e.g., adapt to available materials, accommodate changes in future use/function requiring modifications/remodeling/expansion, secure easy and low-cost operation maintenance, prolong the lifespan of the building, components or materials, reuse and recycle, enable/enhance design for disassembly etc.
Modularity	Is used to e.g., allow for easier building/component adaptability/flexibility (upgrade, demounting/disassembly, replacement, reconfiguration, reuse and recycling), build cheaper standard buildings and lean production.
Prefabrication	Is used to ensure e.g., reclamation, reusability and recyclability, construction time optimization, enhanced assembly and disassembly, enhanced adaptability, avoidance of off-cut materials etc. e.g., wooden components such as glue-laminated timber.

Design and construction strategy	Description in literature
Secondary materials	Integrating materials that are recycled to slow and close resource loops. E.g., recycled insulation materials, textiles, cellular glass, plywood etc.
Durability	Designing or using high quality durable long performance lifespan components and materials that are easy to maintain and upgrade and can handle several service lives.
Standardisation	Is used to e.g., maximize recovery of materials at end-of-life, ensure reuse and recycling options, limit the number of different components used, avoid material off-cuts, prolong product lifespan etc.
Component and material optimisation	Reducing the number of materials used as well as the number of different types of components and materials used. E.g., reducing the use of concrete and reducing excavation by choosing a shallow raft foundation.
Reusing existing building/ components/materials	Is used to directly reuse existing buildings, components or materials for new construction projects. E.g., reusing existing buildings on thiadifluor boards, cement tiles, rubble, steel beams etc.
Optimised shapes/dimensions	Design precise material measurements specification to: suit appropriate means of handling components and materials, enhance/enable future adaptability/flexibility e.g., avoid over ordering and onsite material cut-offs. E.g. by simplifying the building form, using lightweight structures or reducing the customers' spatial needs by optimizing floor areas.
Accessibility	Used to provide good access to connections between components to enhance design for assembly/disassembly, to ease maintenance, maximize recovery of materials at end-of-life. E.g., accessible service gaps for easy service and maintenance by demountable and reconfigurable inside finish and façade systems.
Layer independence	Is used to make building components and materials independent from each other's lifespan for easier operation and maintenance, material recovery, separation and adaptability/ flexibility. E.g., by making the long-lasting building elements flexible so that short-lasting elements can be easily changed.
Material storage	Is used to design buildings as material deposits to avoid degradation of material quality over time by temporarily storing the materials in the building and minimizing in-between stockholding that may damage materials by using principles such as just-in-time delivery of the materials to subsequent building projects.
Short use	The building is only designed for its specific use and performance span. Material and product choices are adjusted accordingly. The building is then disassembled without waste.
Symbiosis/sharing	Is used to utilize residual resource outputs from one building as feedstock for another, often in relation to industrial parks e.g., sharing/outsourcing surplus water, waste and energy.

CIRCULAR ECONOMY TIMBER BUILDING SYSTEM

BUILDING SYSTEM

TYPICAL TIMBER STUD CONSTRUCTION TO A CIRCULAR ECONOMY BUILDING SYSTEM?

Typical timber stud construction could hold the key to a small-scale Circular Economy construction system. Some of its beneficial properties include that its' main structural parts are lightweight and joined together with screws and other fasteners that could potentially be replaced by reversible ones. Additionally, timber can be obtained from sustainable sources and requires much less energy to produce and refine compared to steel and concrete. Finally, building parts and even whole buildings are already being prefabricated off site with this system as is shown in the "Add-a-Room" concept. However, this building system does not embody Circular Economy principles as is and needs to be enhanced to do so.

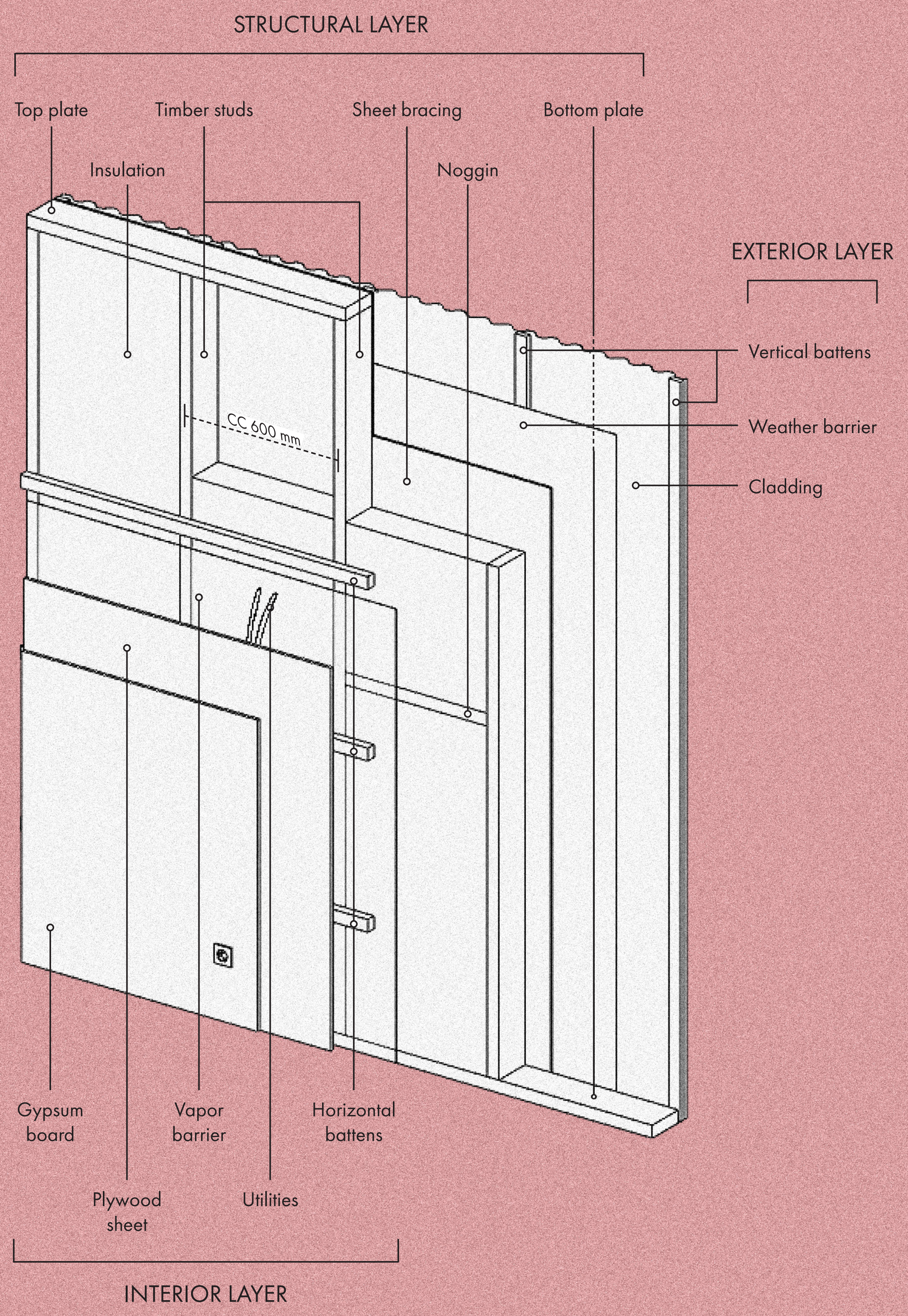
One of the main challenges of creating a building system that adheres to the principles of Circular Economy is to retain all the comforts and qualities that typical/conventional building systems provide. That is why it is important to look at how a typical timber house is built in cold climates such as in Iceland. It will suffice to examine how a typical timber stud wall is structured as roofs and floors follow much of the same logic. Typical Icelandic timber stud walls can be divided into 3 main layers: Structural layer, exterior layer and interior layer.

- Structural layer:
The structural layer holds the building upright (and usually contains thermal insulation). 145/195/220x45mm timber studs are placed every 600mm (CC) between a bottom and a top plate. Noggins are placed between studs to strengthen the structure and thermal stone-wool insulation is placed inside the gaps. The stud framework is braced on the exterior side with semi weatherproof 12-22mm thick plywood sheets.

- Exterior layer:
The exterior layer provides aesthetics and protects the building from the elements. The plywood sheet is covered with a thin weather resistant barrier. Next there are vertical battens to allow air to flow between the weather barrier and the outermost cladding. The cladding is attached to the battens and is the final protection against the element and one of the main exterior aesthetical elements.

- Interior layer:
The interior layer adds fire resistance, enhances aesthetics, conceals utilities and protects the structural layer (and insulation) from water damage. After insulation has been placed in between studs a moisture barrier is stabled in place and covers the whole wall. Next, horizontal battens are attached to the studs at equal intervals. The battens act as connectors for the final interior finish which usually consists of plywood sheets and gypsum boards. The battens also create a service gap for utilities.

All these parts are fixed together by various methods: adhesives, staples, nails, screws, etc. So, when it comes to changing anything about the structure it must be taken apart by force. It is impossible to remove most of these elements and keep them whole to be reused. It is therefore safe to hypothesis that circular economy buildings could consist of multiple parts, such as wall, roof and floor segments that are joined with reversible connections. That would make the structures more susceptible to change, repairs, disassembly and reassembly


STRUCTURAL LAYER
Top plate
Timber studs
Sheet bracing
Bottom plate
Insulation
Noggin
EXTERIOR LAYER
Vertical battens
Weather barrier
Cladding
CC 600 mm
Gypsum board
Vapor barrier
Horizontal battens
Plywood sheet
Utilities
INTERIOR LAYER

DEVELOPEMENT

By implementing the strategies listed in table x and using knowledge gathered from the case studies, an idea for a rudimentary CE timber building system gradually developed.

- LAYER INDEPENDENCE
- MODULARITY

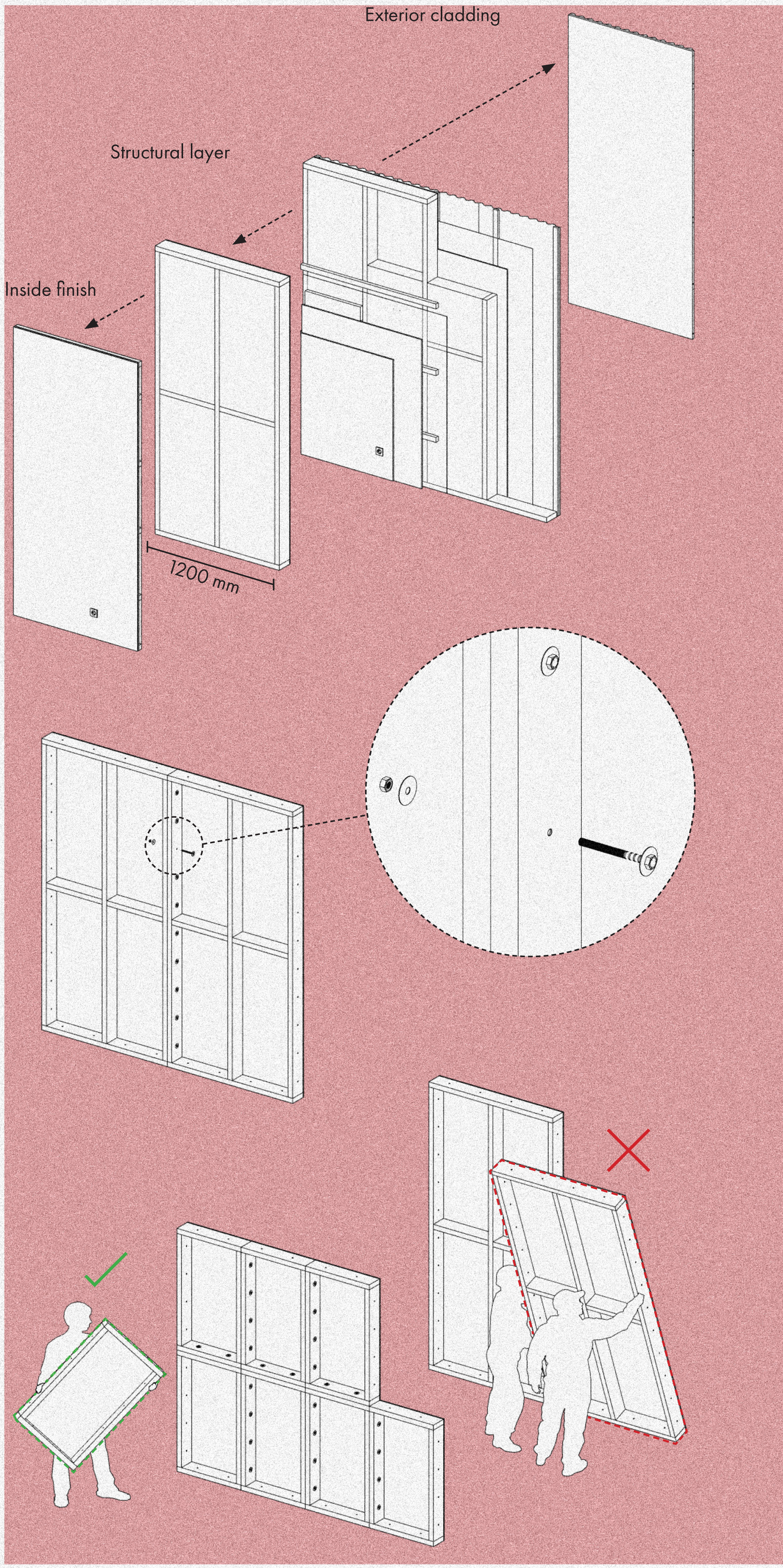
It started by examining a typical timber stud wall, its individual layers, what they do and how they connect. As "layer independence" and "modularity" is one of the key strategies for CE it makes sense to isolate the structural layer of the wall (the vertical and horizontal timber studs braced by a standard 1200 mm wide timber board).

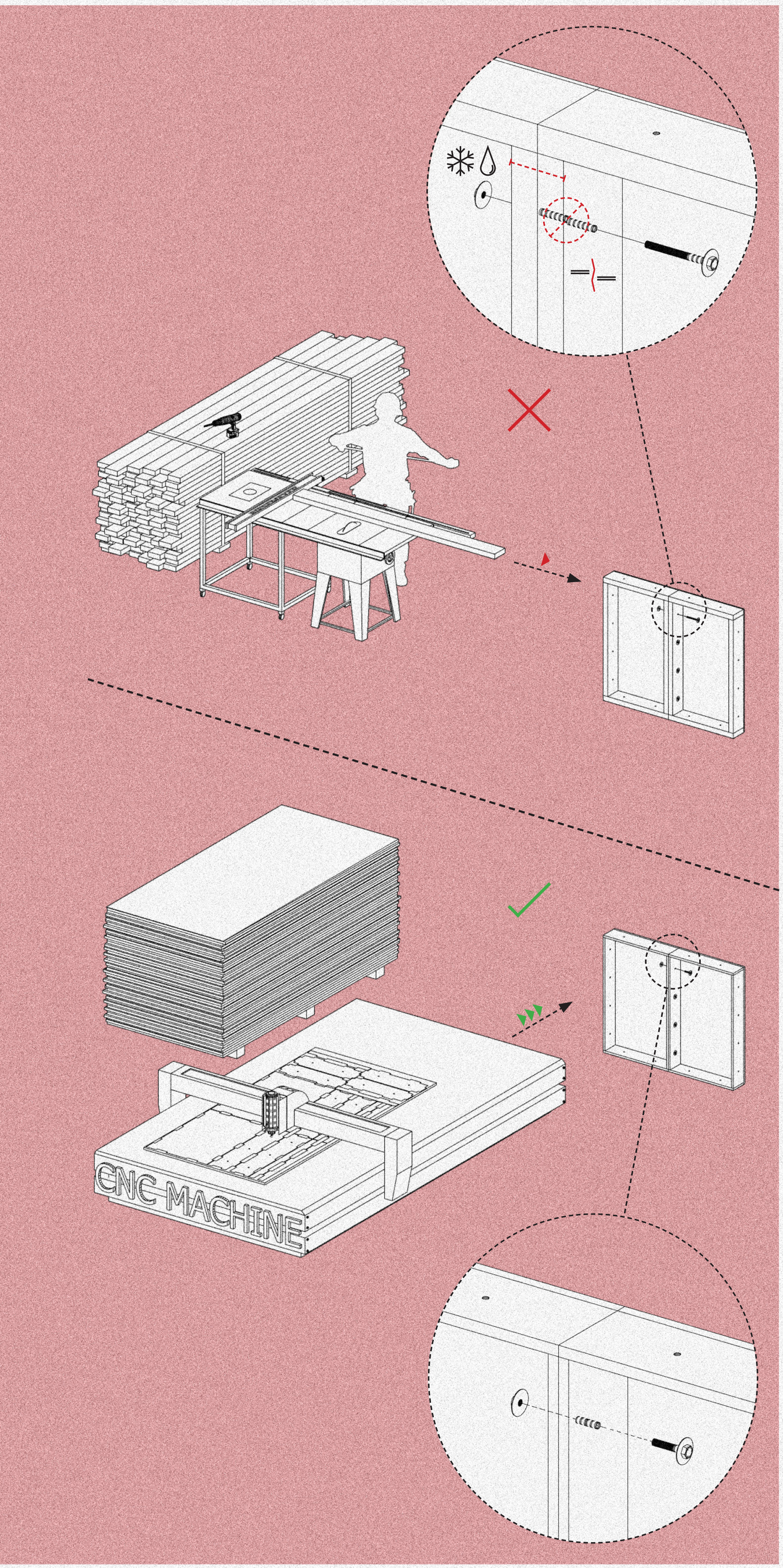
- ASSEMBLY/DISASSEMBLY

Using this module in a CE building system means that it has to be able to "assemble and disassemble" from other parts of the system without damaging either part. Bolts and nuts are the most obvious and simple method to achieve this as they fall under reversible connections.

- MODULARITY
- ADAPTABILITY/FLEXIBILITY
- ASSEMBLY/DISASSEMBLY

To further elaborate on the modular aspect of the system it can be better to have smaller and lighter modules rather than larger. This allows for easier assembly/disassembly and greater adaptability/flexibility of the system.





- PREFABRICATION
- STANDARDISATION
- COMPONENT AND MATERIAL OPTIMISATION

Substituting typical construction timber and conventional building techniques with engineered timber boards and a CNC (Computerized Numerical Control) machine yields a number of benefits.

Firstly, it facilitates a much easier and more precise prefabrication of the modules. Digitally precise prefabrication ensures that each piece will fit with the next one precisely while optimizing construction time by eliminating errors.

Secondly, it increases component and material optimization by reducing the number of materials needed for the module as the sides and the back brace could be made from the same timber boards.

Finally, it also ensures reusability as the modules become standardized sizes.
In addition to these benefits this could help reduce the price of material and work as this process can be done anywhere in the world before being shipped to its destination.

Additionally, by using thinner pieces of timber boards (plywood), the intersections of each unit is less likely to act as a thermal bridge.

FINALIZING THE BASIC MODULE

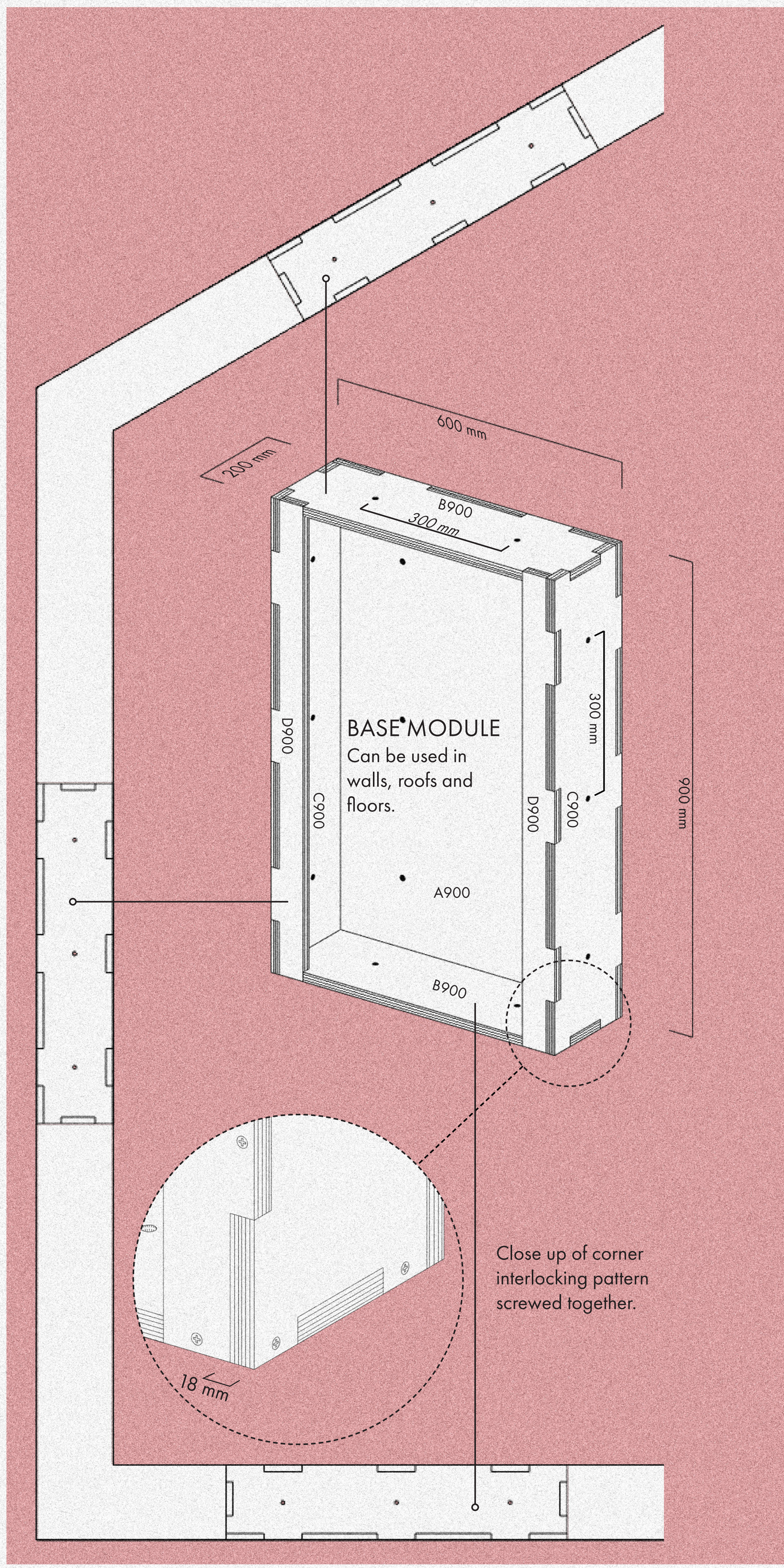
Since the modules are supposed to adhere to ideas of CE the sizes should be in simple ratios of each other and fit into a grid that is also convenient for other common structural elements such as windows and doors.

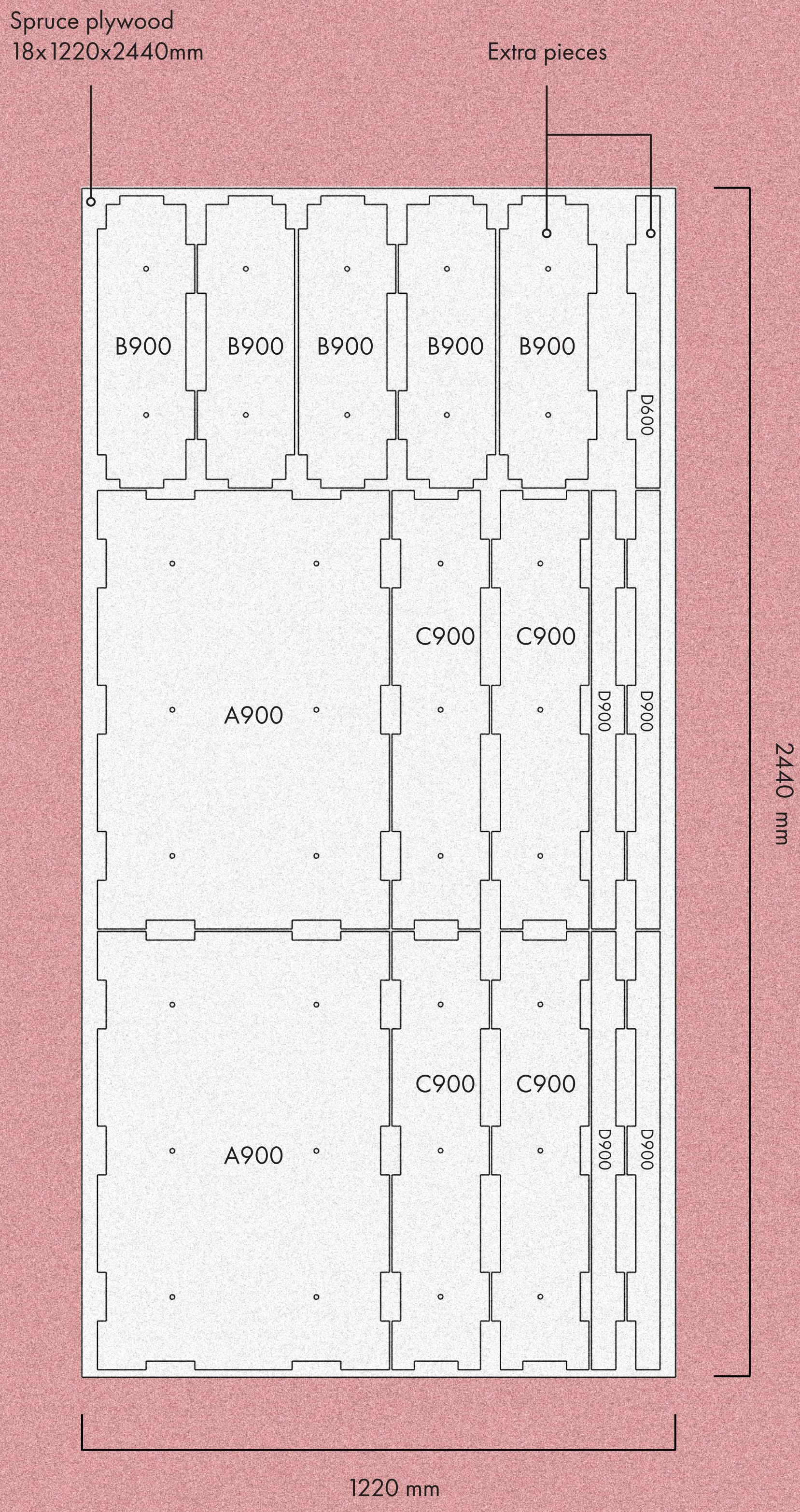
WIDTH:
The first instinctive exterior dimension for the module's width is 600 mm since typical timber stud walls are commonly studded with a 600 mm CC (center of stud to center of next stud). This frame width also allows for typical insulation sizes such as that of stone-wool insulation to fit neatly inside each module.

HEIGHT/LENGTH:
A height/length of 900 mm fits well with the width of 600 mm. With these sizes it is easy to place holes for bolts 300 mm apart (CC) and leave 150 mm from the edge of the module so that the module next to it aligns its holes with the same 300 mm in between.

DEPTH:
A depth of 200 mm will fit a roof/floor sized insulation inside of it. This thickness enables the module to be used in the walls, roofs and floors. a 200 mm thickness is also in a comfortable ratio of 1/3 of the 600 mm width.

MATERIAL THICKNESS:
The thickness of the material used needs to be strong enough to have load-bearing properties and its butt-ends need to be stable enough to handle a screw. After researching different types of timber sheets, the best material to use seems to be18 mm spruce plywood.





CNC MILLING AND INTERLOCKING PATTERNS

Just as in Ged Finch's XFrame solution, every panel of the module has an interlocking pattern that is designed to keep each module as uniform and steady as possible. This interlocking pattern takes aim of the materials thickness and simple uniform lengths. Additionally, these sizes and patterns fit neatly within a typical spruce plywood board available in Iceland (1220x2440mm).
The image on the left shows how two modules plus two additional pieces could fit on such a board if the CNC machine would be using a drill with a 5 mm diameter.

This pattern works for the sake of this project, however, there is a good possibility that a better configuration can be achieved to further reduce residual waste. The configuration on the left uses 76.72 % of the material.

MODULE PARTS AND NAMING SYSTEM

For the sake of this project each unique piece of the module follows a simple naming system of alphabetical letters followed by the height of the module. If the module has extra features, it will be marked with an additional alphabetical letter:
A = Outward facing panel
B = End (bottom/Top) panel
C = Side panels
D = Inward facing panels

The inward facing panel (D) has two functions. One is to further strengthen the box shape of the module and the other is to allow for easier installment of the inside finishing layer.

MULTIPLE SIZES

The base module has been established. Now it is possible to extend the system by introducing additional modules that work on the same principles as the base module.

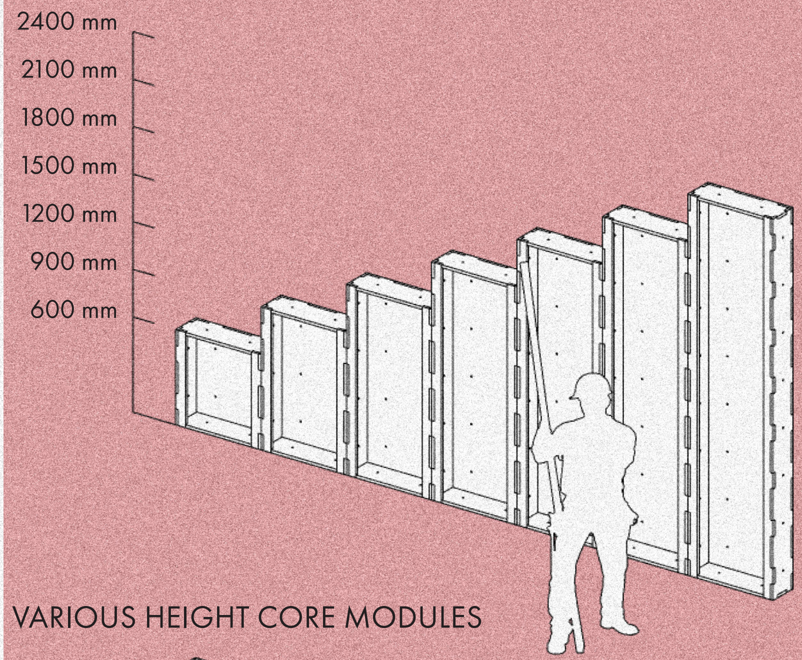
Creating more modules in various heights helps to reduce labour of assembling/disassembling each module and its connections to the next one. Additionally, it reduces the materials needed to create larger spaces as well as strengthening the structure. As long as the modules retain the same properties in regard to circular economy principles, the largest piece should be used whenever possible.

CORE MODULES

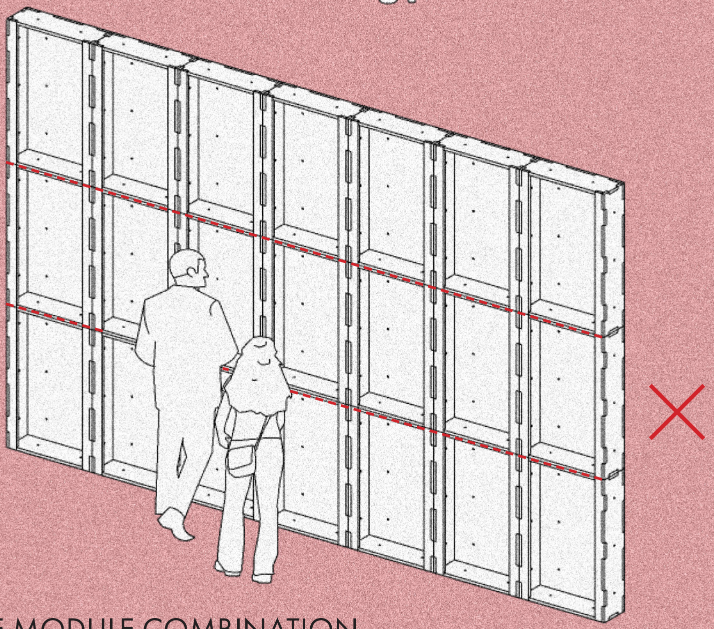
This is how one base module became seven variably tall core modules. The modules increase in height by 300 mm, starting at 600 mm and finally ending in 2400 mm high. The increase of 300 mm enables the same hole placement and interlock pattern to be repeated throughout the system.

INTERLOCKING MODULES

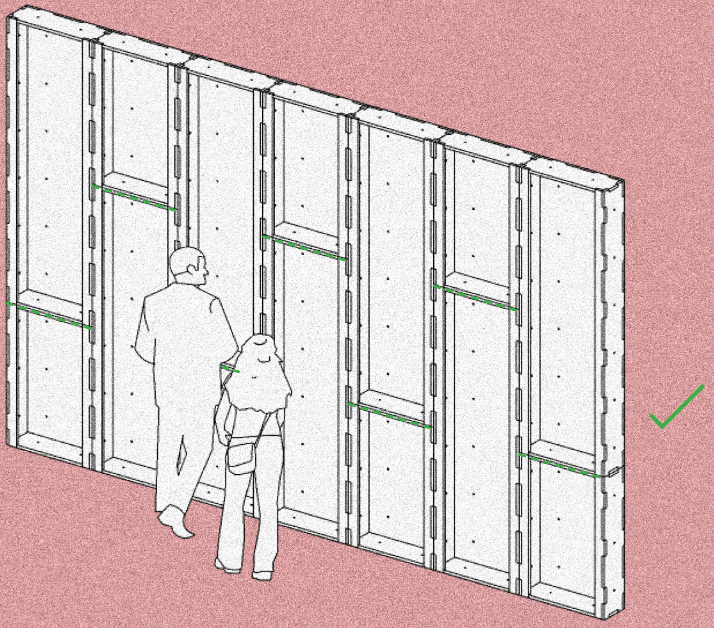
At this moment it became obvious that when placing modules to form a floor, a wall or a roof, the whole structure is much stronger if the modules form an interlocking pattern between themselves.



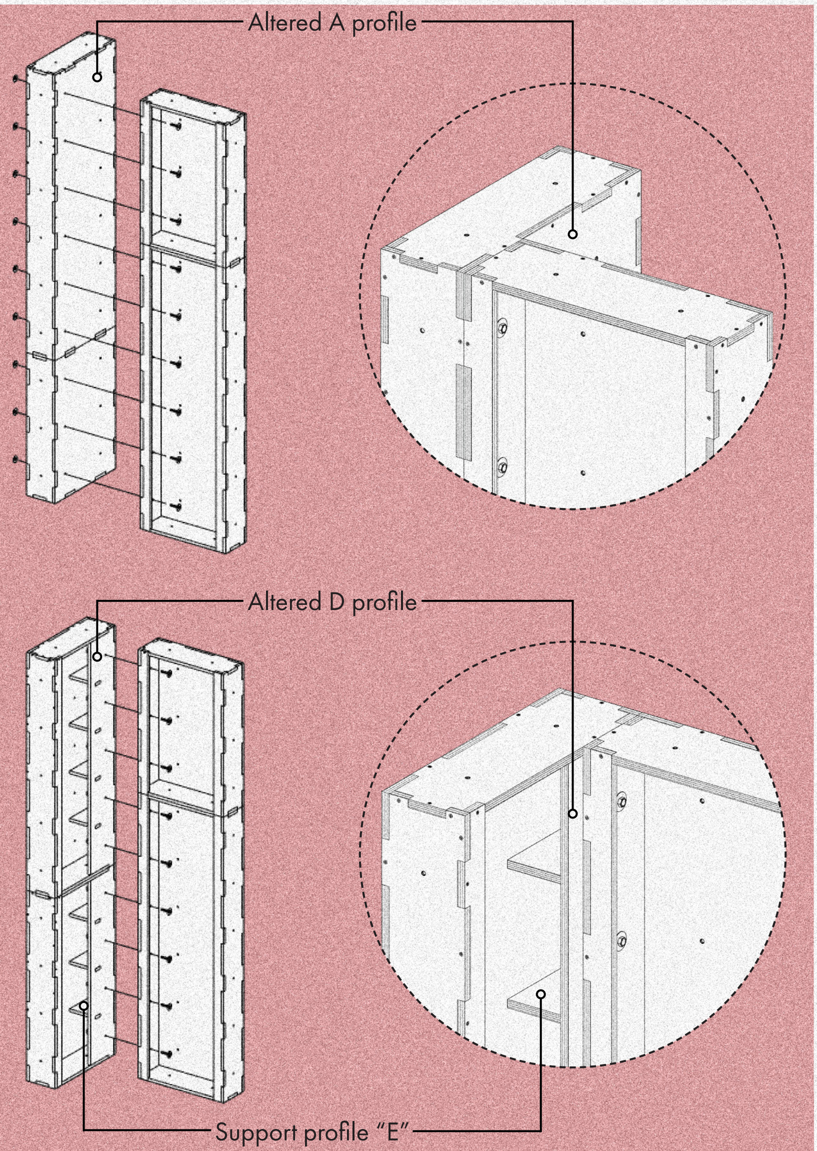
VARIOUS HEIGHT CORE MODULES



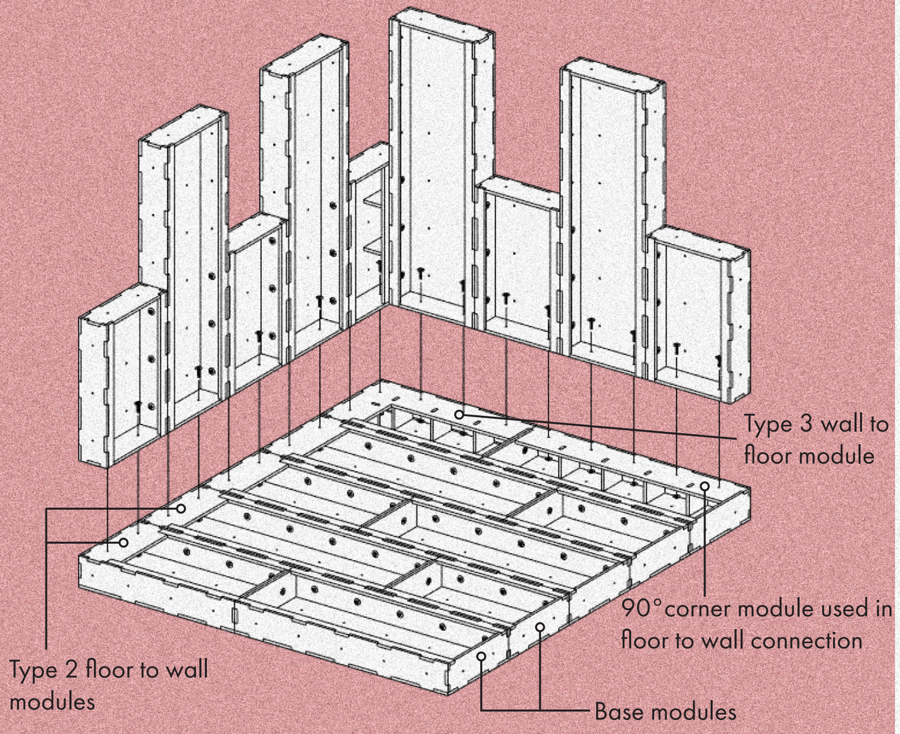
LESS STABLE MODULE COMBINATION



MORE STABLE MODULE COMBINATION



CONNECTION AROUND CORNERS



CONNECTION BETWEEN FLOOR AND WALL MODULES

CORNER CONNECTIONS

To allow the modules to connect around and form corners special corner pieces must be included.

RIGHT ANGLE CORNER MODULES

Two different modules are needed to be able to make a 90° corner and a 270° corner.

- The 270° corner modules are only slightly different from the core modules. As is shown in the picture to the left the A profile of the modules are perforated differently to line up with the holes on the C profiles. The modules can then be bolted together much in the same way as the core modules.
- The 90° corner module differs slightly more from the core module. Here one of the D profiles is larger and perforated in the same manner as the C profile. The connecting D profile has additional support behind it, cut from the same material. Finally, both the A and C profiles have notches in them so the extra support profiles (E) can be securely placed and fastened.

WALL TO FLOOR CONNECTION

Floor to wall modules need three different iterations from the core modules.

- The first type is the same module used in the 90° corner (see image to the left).
- The second type is a core module with an extra 200 mm to its length to support the wall on top of it. The holes on the extra 200 mm are placed to fit the bottom part of the wall modules.
-The third type is the module under a wall corner. It is a mix of the two mentioned above (see image to the left). - Admittedly, greater care should be put into making these connections more stable.

WALL TO ROOF CONNECTIONS

Finally, the walls have to be able to connect to the roof. When the system is put to the test several options become apparent for this type of connection.

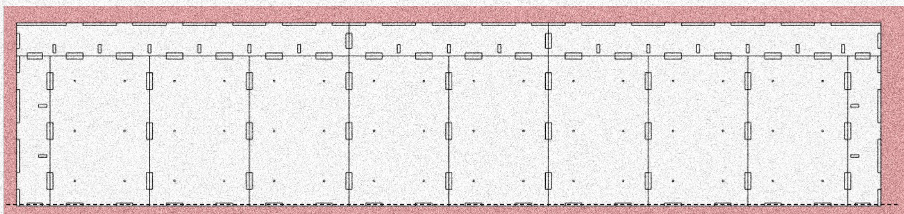
WALL TO "FLAT ROOF"
The same modules used in the "Wall to floor" connection can be used to create a flat roof. Flat roofs can be problematic as they have the risk of retaining water and snow. If a flat roof were to be used it would have to have an additional structure on top of it with an incline.

INCLINED ROOFS

Icelandic building regulations states that the minimum roof incline should be 14° for the least durable weather proofing materials. By following that number any roofing material can be used. In this building system three different inclines make the most sense: 14°, 26.6° and 45°. The degrees of the incline are derived from the sizes of the previously described module-system. This is best explained in the illustration to the right.

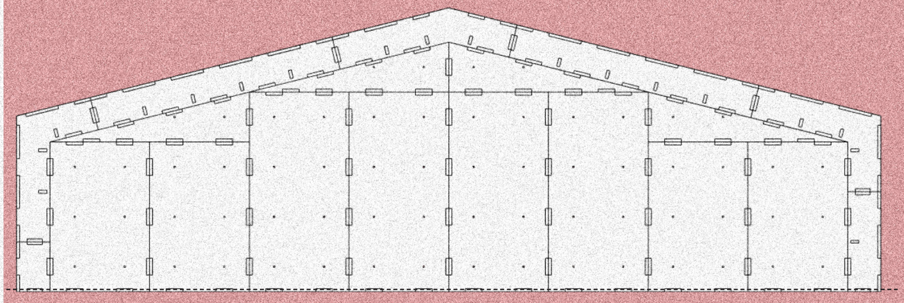
INCLINED ROOF MODULES

Each different incline variation will need to have 3 special modules, (see image on next page).
- A bent wall to roof module with one arm 300 mm long and the other 600 mm long.
- A triangular module that fits on top of a core module and underneath the inline of the roof.
- A bent top module to connect the two sides of the roof.



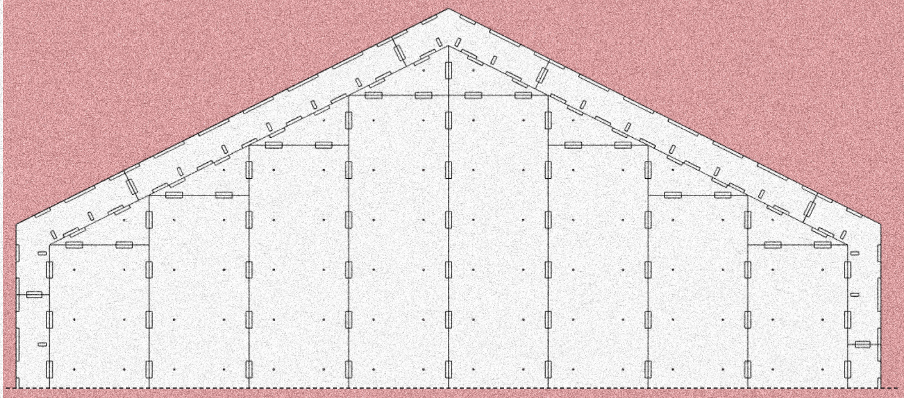
0°

Flat roofs can use the same modules as floors to connect to a wall.



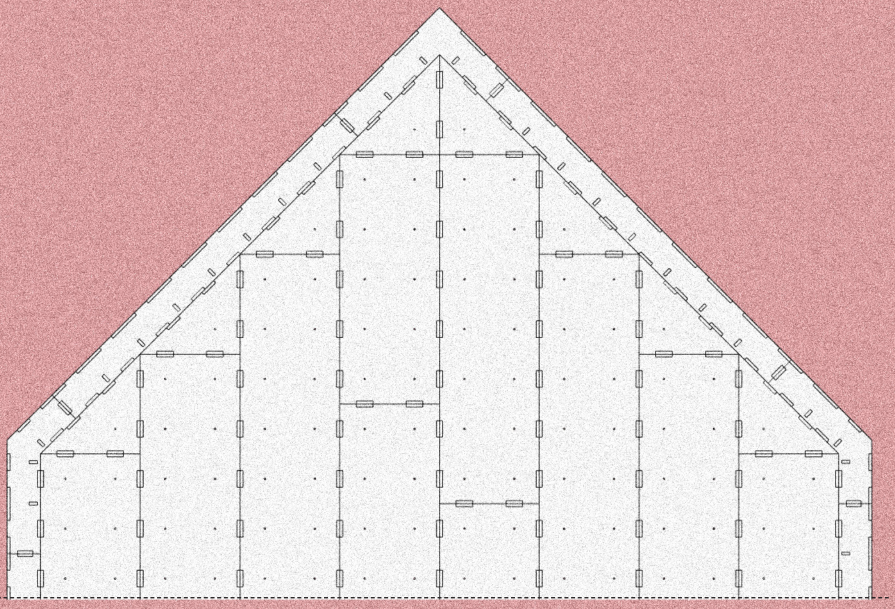
14°

14° inclined roofs are derived from a steady increase in height of 300 mm every two modules.



26.6°

26.6° inclined roofs are derived from a steady increase in height of 300 mm from one module to the next.



45°

45° inclined roofs are derived from a steady increase of 600 mm from one module to the next.

BENT MODULE (26.6°)

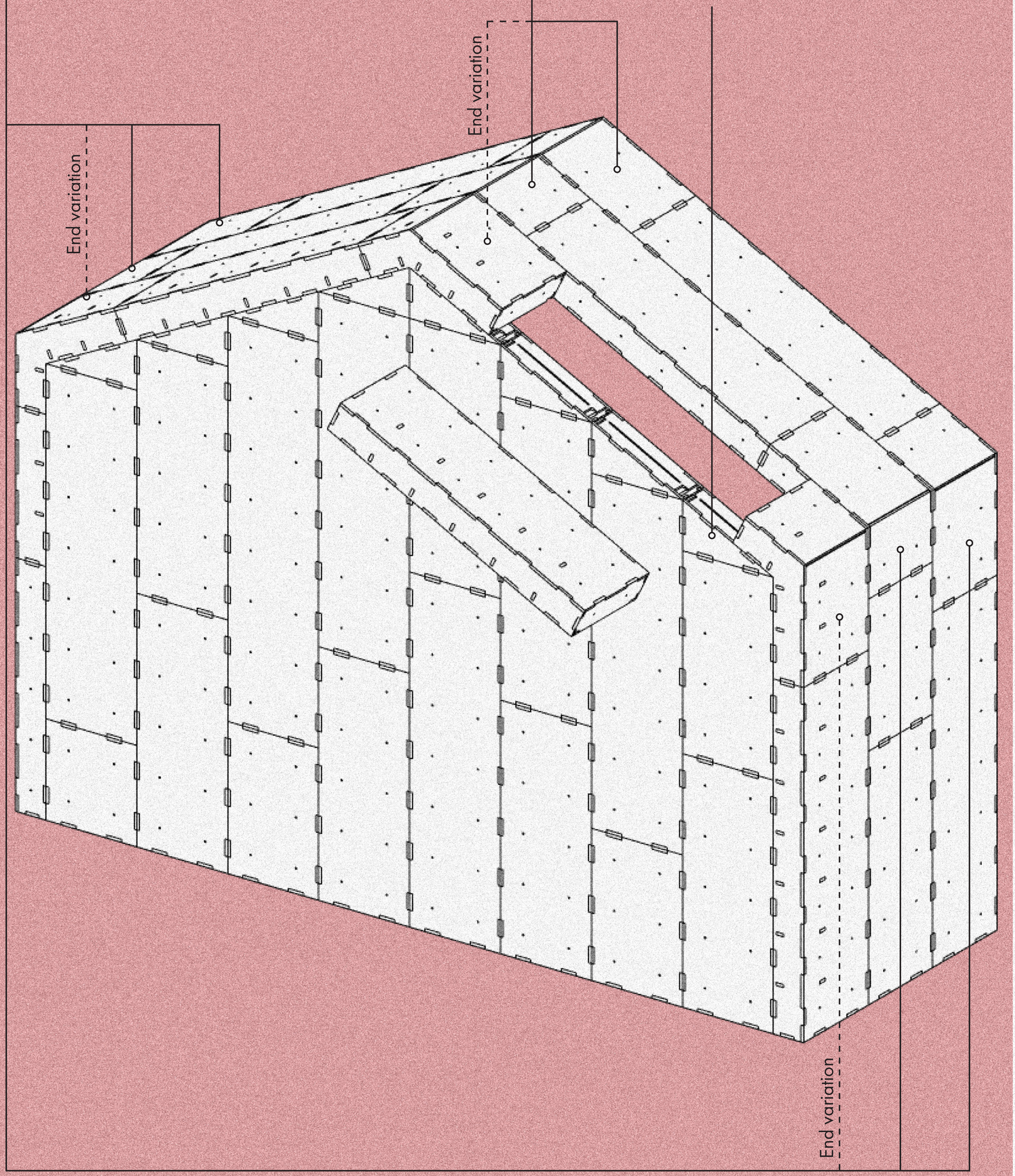
Connects walls to roofs. One arm is 300 mm long and the other is 600 mm long. Modules arranged so that they interlock with both roof and wall.

TOP MODULE (126.9°)

This module is a bit special as its' arms need to have different lengths depending on how big the roof is.

TRIANGULAR MODULE (26.6°)

This module needs to have an elongated slit on its longest side instead of holes in order to accommodate the different positions of connecting holes on the modules that lie on top of them.



ROOF VARIATIONS AND CONNECTIONS

DOORS AND WINDOWS

The structural system can be arranged in a way to leave gaps for doors and windows. The gap sizes follow the same multiplication of 300 mm as the modules do.

Doors and windows come in a variety of sizes, depending on the manufacturer. For example, a comfortable door should exceed 850 mm in width and 2200 mm in height. That means the gap left for a door should be 1200 mm wide and 2400 mm tall. If a door and a doorframe do not fill out the entire gap, the leftover space is then filled in with custom parts. The same goes for the windows.

Doors and windows manufacturers commonly offer custom sized products for individual projects.

BUILDING SYSTEM'S FLEXIBILITY/ADAPTABILITY

The building systems' modules can be arranged in countless different ways. However, they do have their limits. They can e.g., only create 90° corners (apart from the roof), fit rectangular windows and doors and fit into a 600x600 mm grid. However, this "shortcoming" can be easily amended by introducing custom modules that still fit into the core system. The custom modules would be produced separately on demand with the same CNC production method as the core modules.

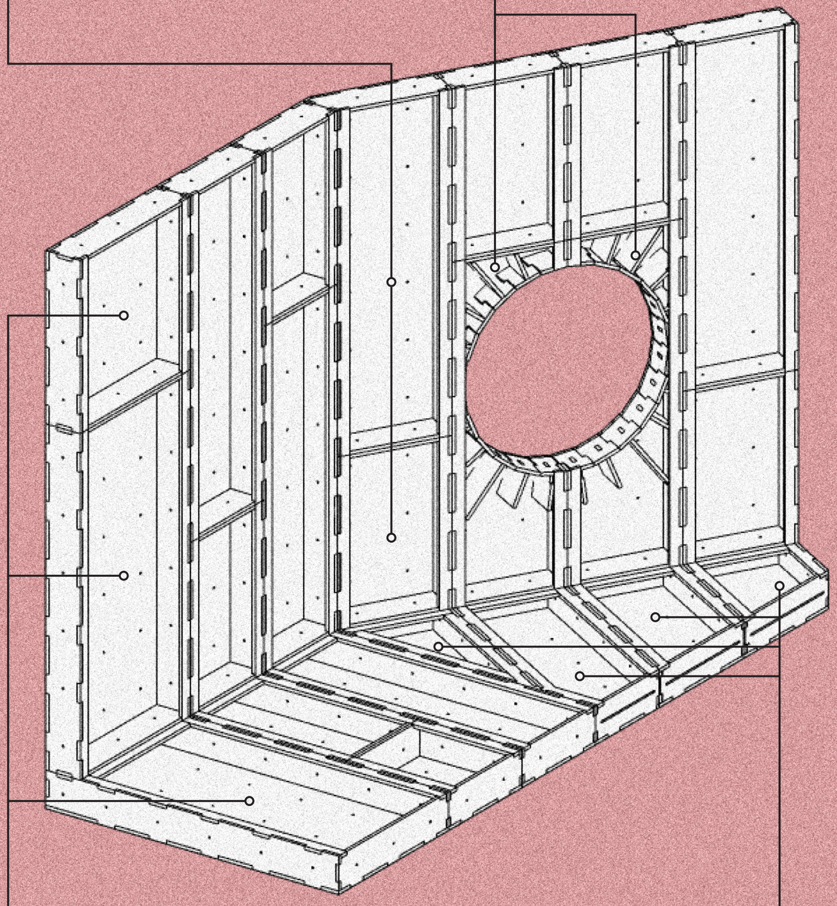
DOOR AND WINDOW FITTING

CUSTOM ANGLE WALL MODULES

Bends in a 30° corner.

CUSTOM WALL MODULES

Facilitate a circular window.

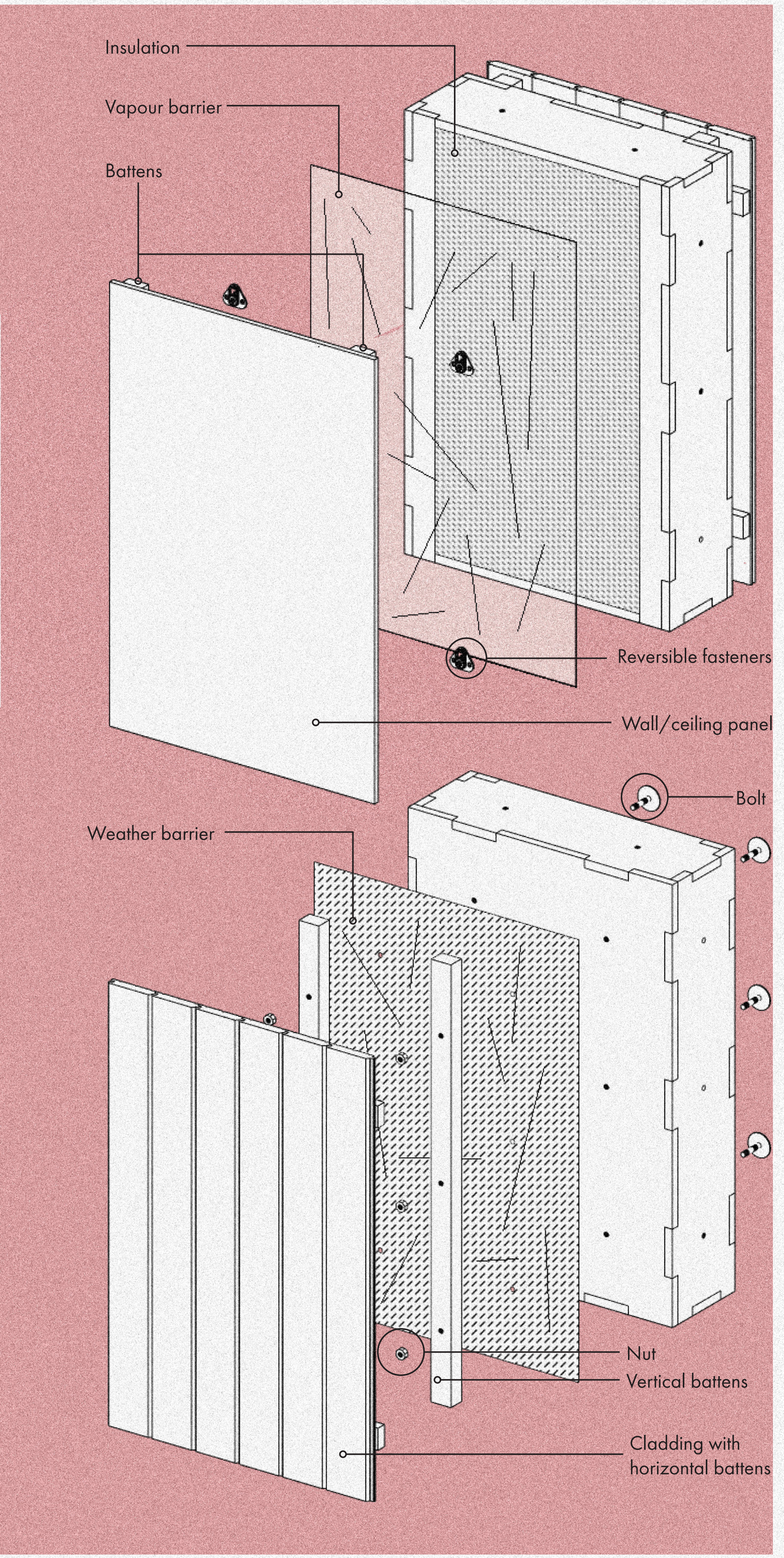


CUSTOM WIDTH MODULES

Custom wide modules to allow for more specific spaces.

CUSTOM FLOOR MODULES

Facilitate a 30° corner wall.



INTERIOR FINISH

Once the shell of the building has been completed 200 mm thick roofing insulation can be placed inside the modules. This type of insulation typically comes in the width of 560 mm which fits nicely into the gap of 564 mm between the two C-profiles. Next, a water vapour barrier is stabled on top. Now, any utilities such as water or electricity is fitted in place and the first part of reversible fasteners such as "button-fix"(Button-fix type 1) are attached to the D-profile of the modules in 300 mm intervals. Finally, wall/ceiling panels are fitted with a 21x34 mm battens (larger battens are used if there is need for larger utilities, such as plumbing) and the second part of the reversible fasteners. The wall/ceiling panels can then be attached and detached from the structural layer freely.

EXTERIOR FINISH

First a weatherproof layer covers the modules and is stabled in place. Next, pointed bolts are pushed through a few of the holes on the A-panel perforating the weather barrier. Vertical battens with holes aligned to the once on the A-panel can now be thread onto the bolts and secured in place with nuts. After that any exterior cladding system can be used as long as it can be fastened to the vertical battens. A simple cladding system would be to add additional horizontal battens and finally a vertical timber cladding. Now it should be easy to disassemble and reuse both cladding and panels without damaging to either.

FOUNDATION

The foundation much match the building system in its flexibility. Helical/screw piles are an option that seams optimal for a building project that centers on circular design. GoliathTech is one manufacturer of screw piles. According to them screw piles are a better foundation option than concrete. Some of its main qualities are rapid installation, minimal impact to the landscape, no excavation needed, year-round installation, removable and reusable, low environmental footprint, suitable in all soil conditions[GoliathTech].

In this project the screw piles connect to a grid of wooden beams attached to a plywood base on top. On top of all that lies the vapour barrier. The modules connect to the plywood base through the openings on the A-panel. This way the modules can be detached later without damage to them.


20 cm
DETAIL SECTION

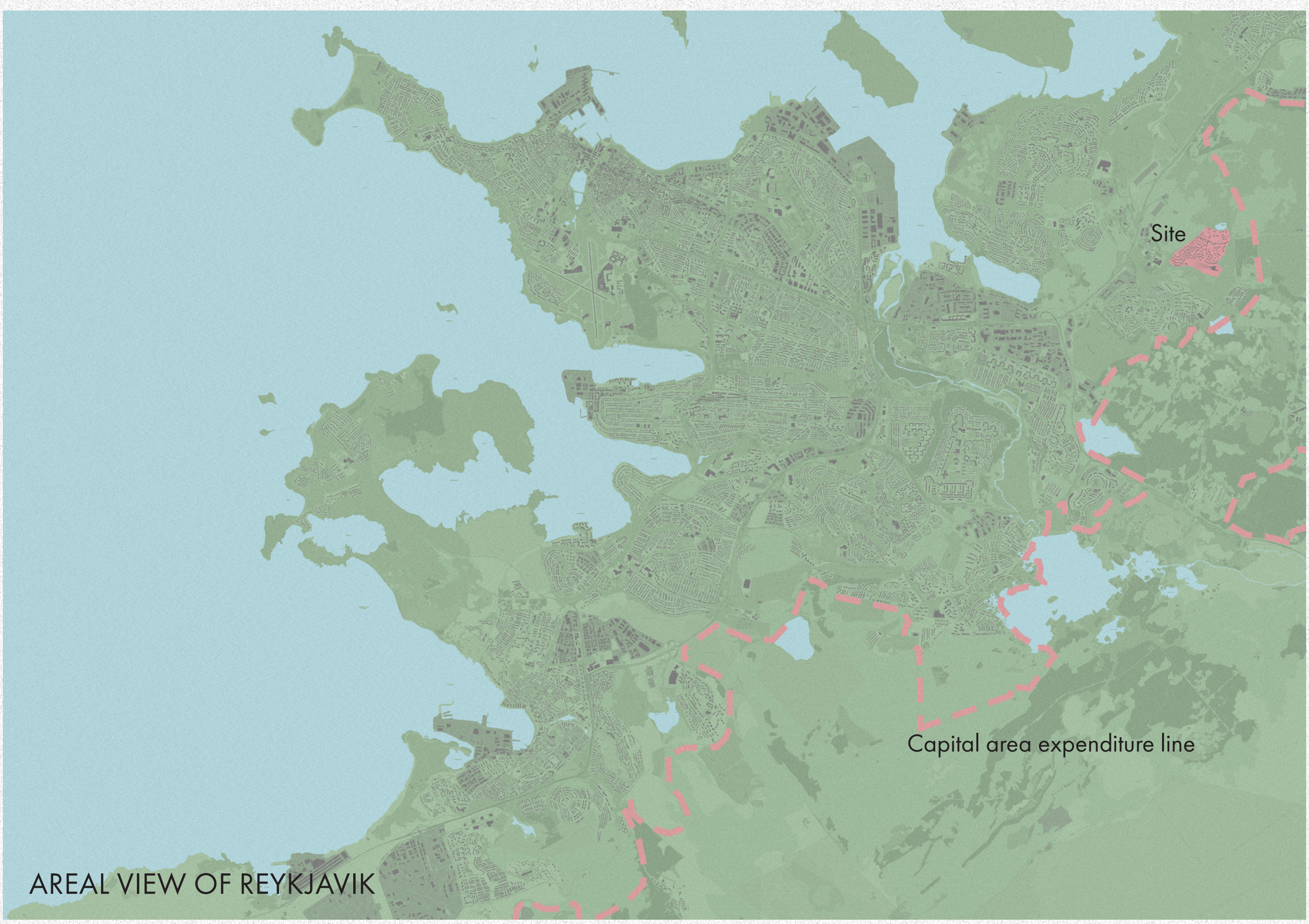
HOME DESIGN

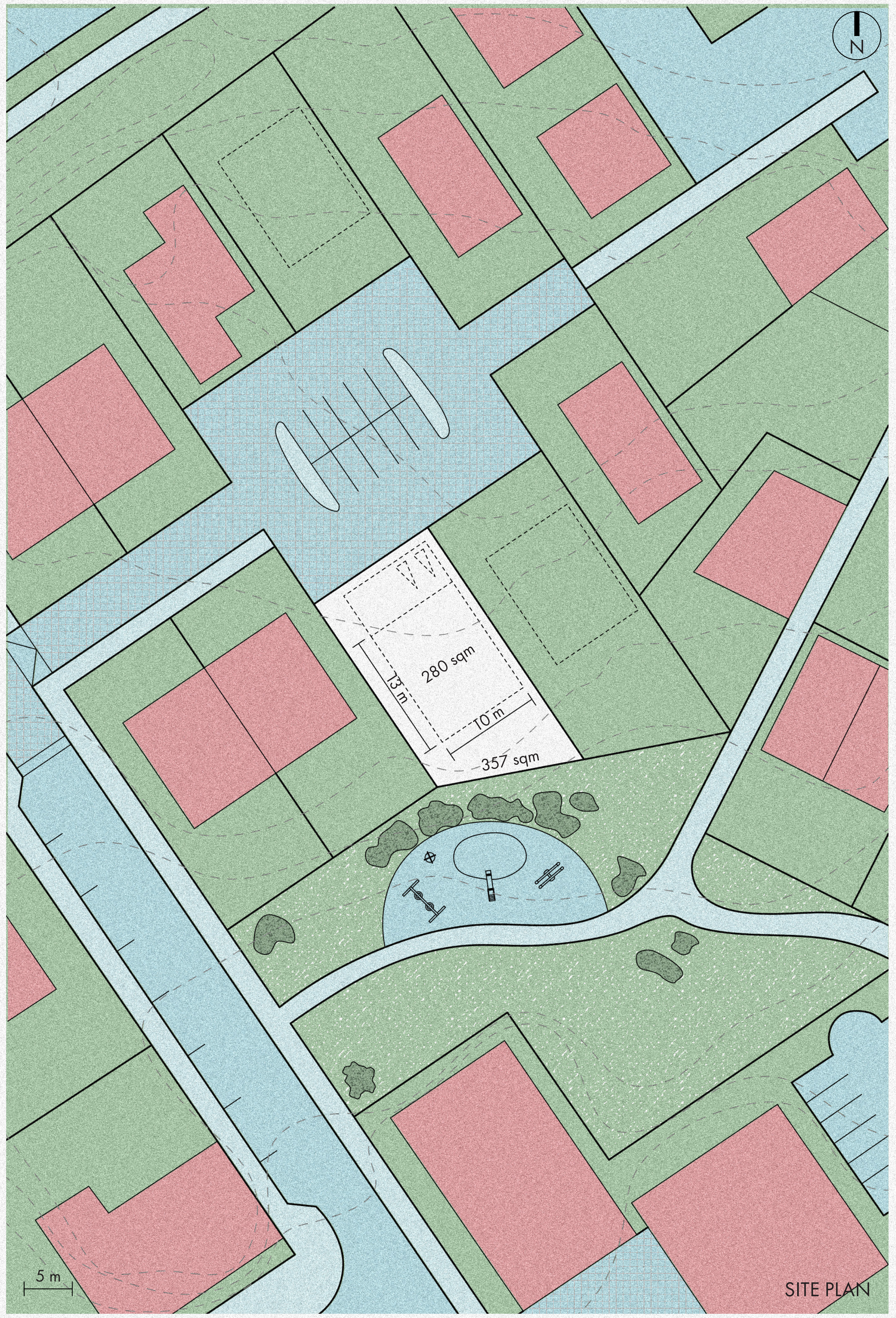
The final part of this project is to use the modular building system to design a home based on the concepts discussed in previous chapters. The design stages of the house follow the life of an individual and reflect where he is in life.

SITE

The chosen site for this project is a single-family residential plot in a neighbourhood called Úlfarsárdalur. The neighbourhood is in the suburbs of Reykjavík and is indicated on the picture below in red. The zoning plan for the neighbourhood was first signed in 2006 and its first buildings started construction in the following year. Most of the neighbourhood's plots have been/are being built on. A few remaining plots still sit empty. These plots are not for sale but have simply not been developed yet.

One of these plots is Iðunnarbrunnur 15 (white plot on the image to the right). It is among the smaller plots for a single-family home in the neighbourhood. The plot itself is 357 sqm and the plot ratio is 0.78 (because the plot can also be used for a duplex) indicating that 280 sqm building can be built on the plot. The site slopes slightly to the south/south-east. The plot is situated in a cul-de-sac and its back garden is oriented towards a public playground with favourable orientation for sunlight.



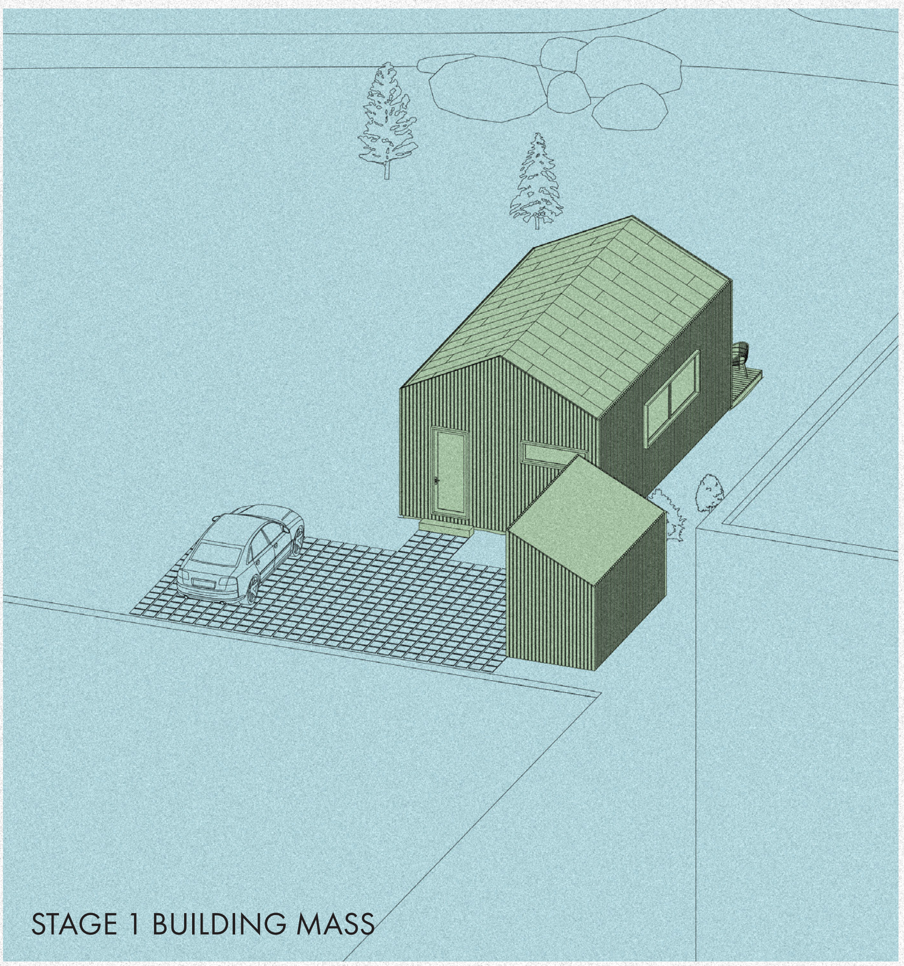

N
280 sqm
13 m
10 m
357 sqm
5 m
SITE PLAN

STAGE 1

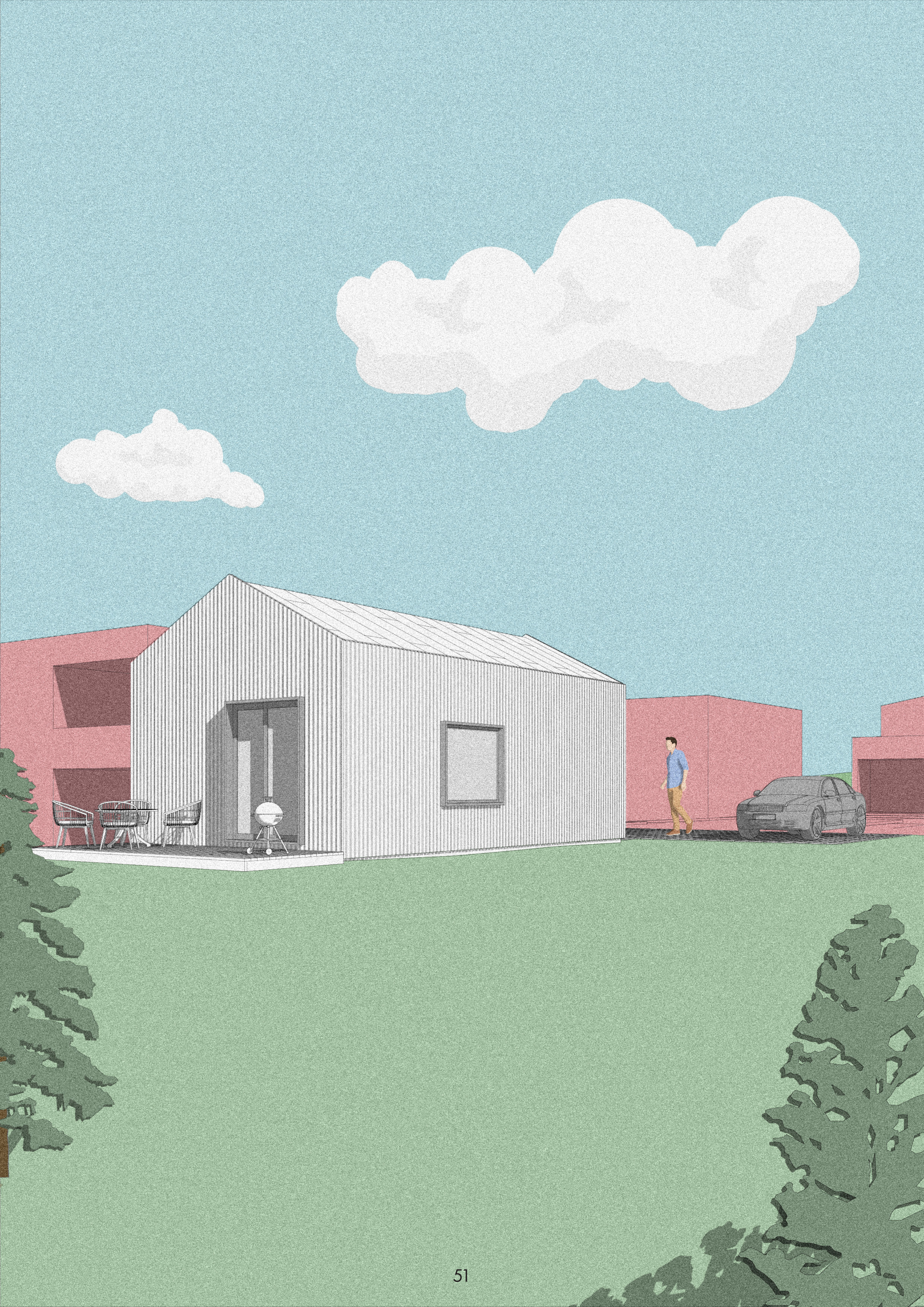
SINGLE INDIVIDUAL

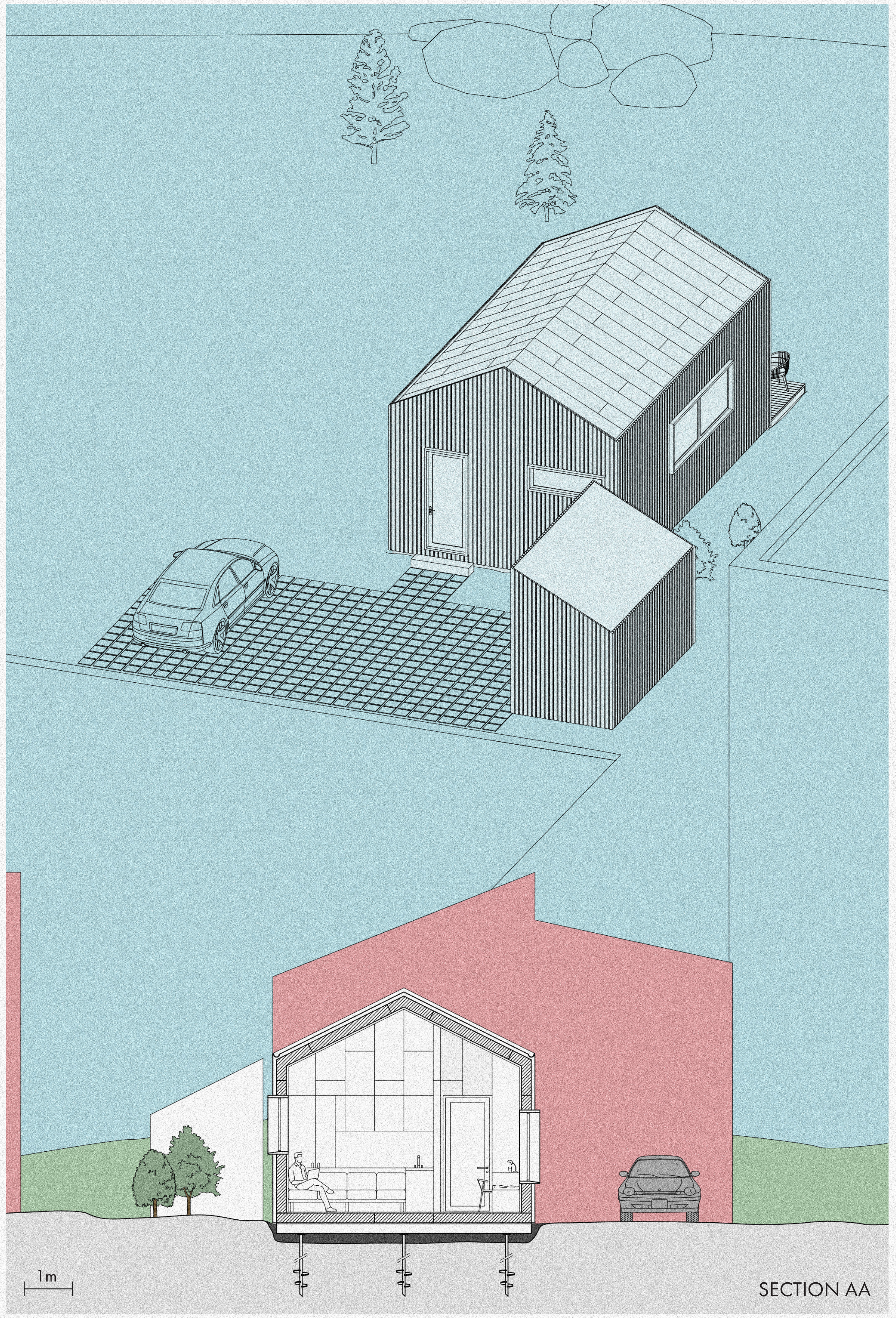
The first stage of the design is for a young single individual. The individual does not need a lot of space and is thinking in terms of what he can afford now. Since expanding the home at a later date is meant to be an easy process, this person can avoid taking large loans by building small now.
It is important to note that in the first stage, both the bathroom and the kitchen, the two main places that are more difficult to rearrange are designed well. In this project special consideration was given to these two spaces so they can work in all the stages without much change.

Gross floor area: 49 m2
Net floor area: 40 m2



STAGE 1 BUILDING MASS

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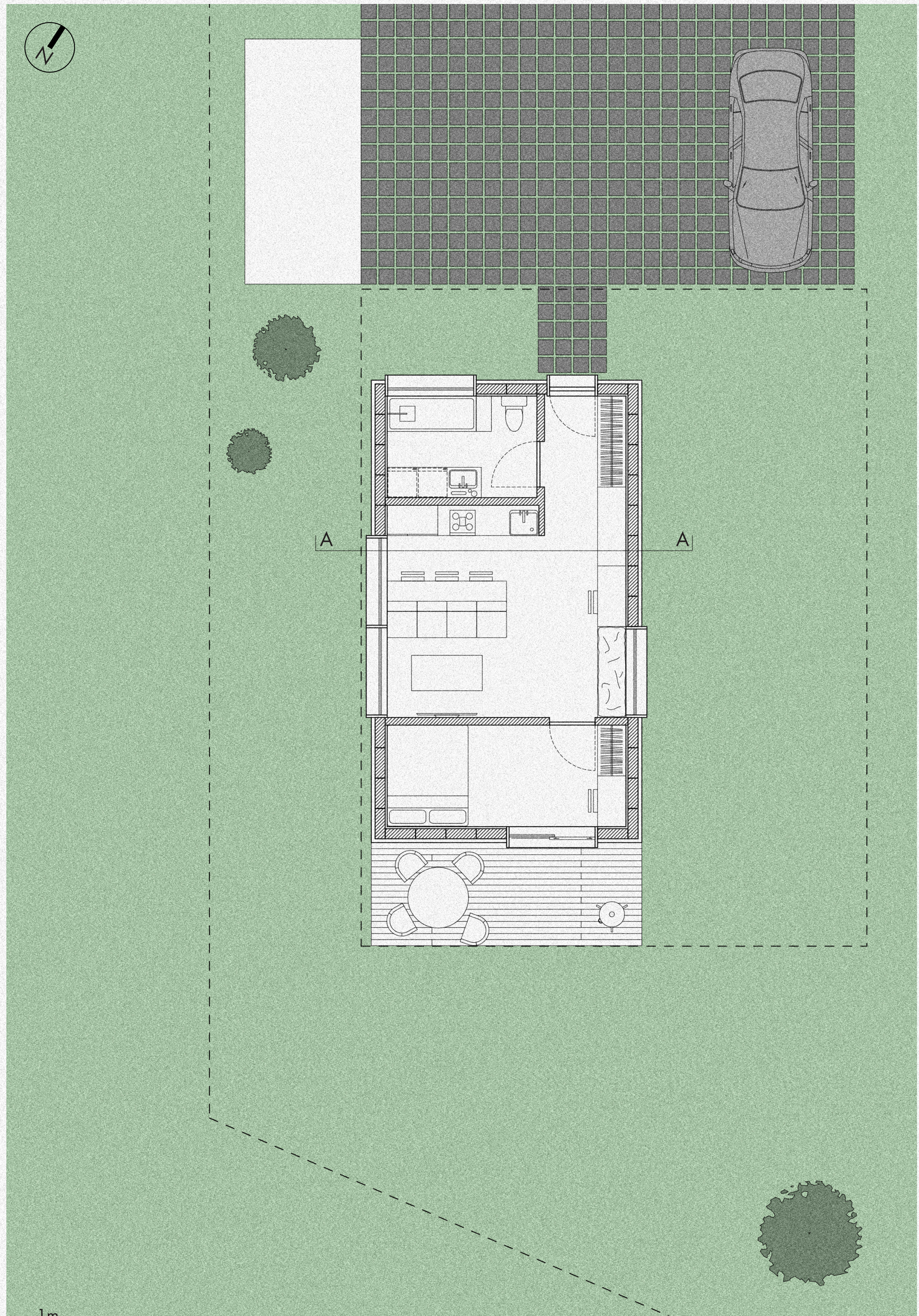
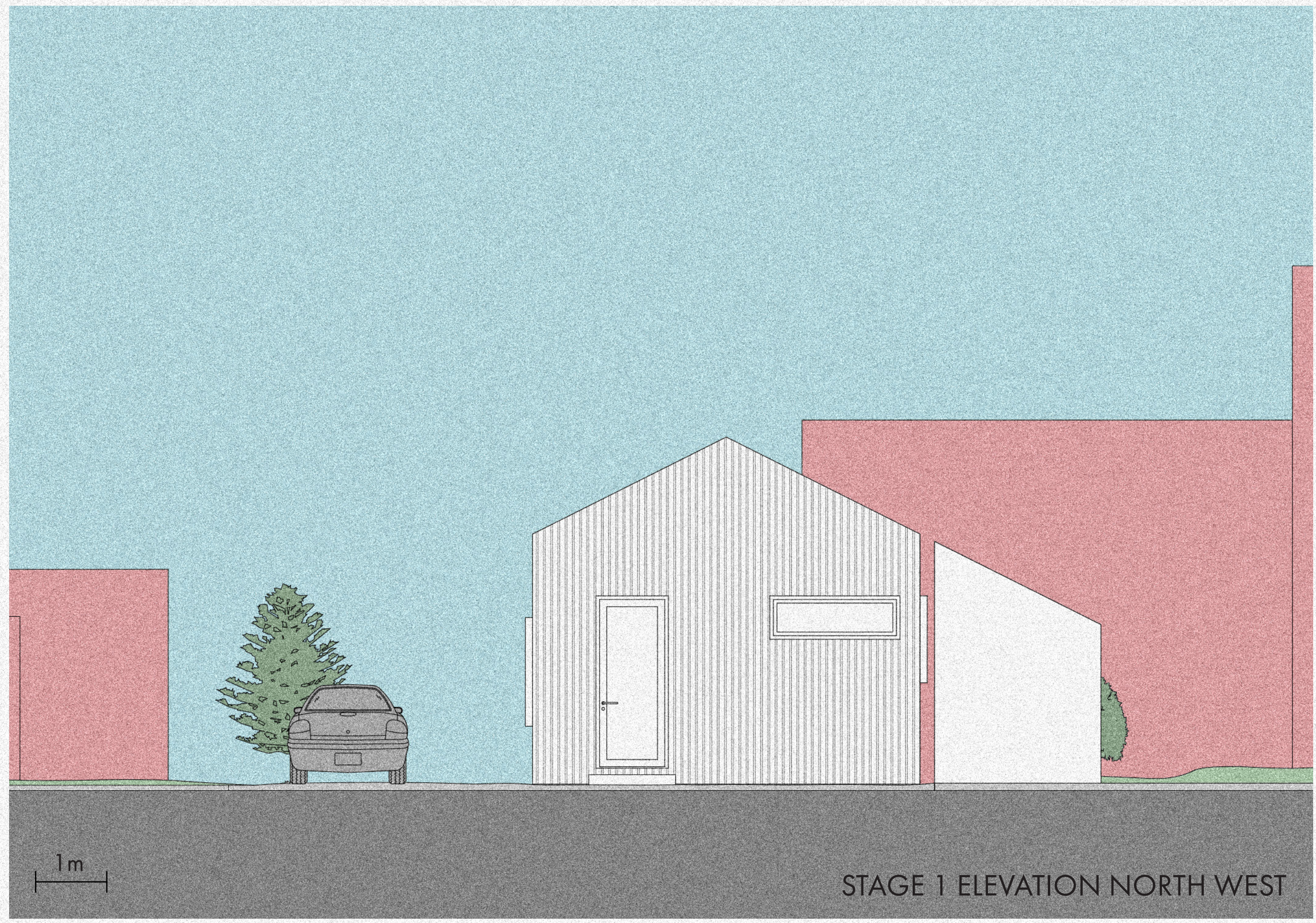


STAGE 1 FLOORPLAN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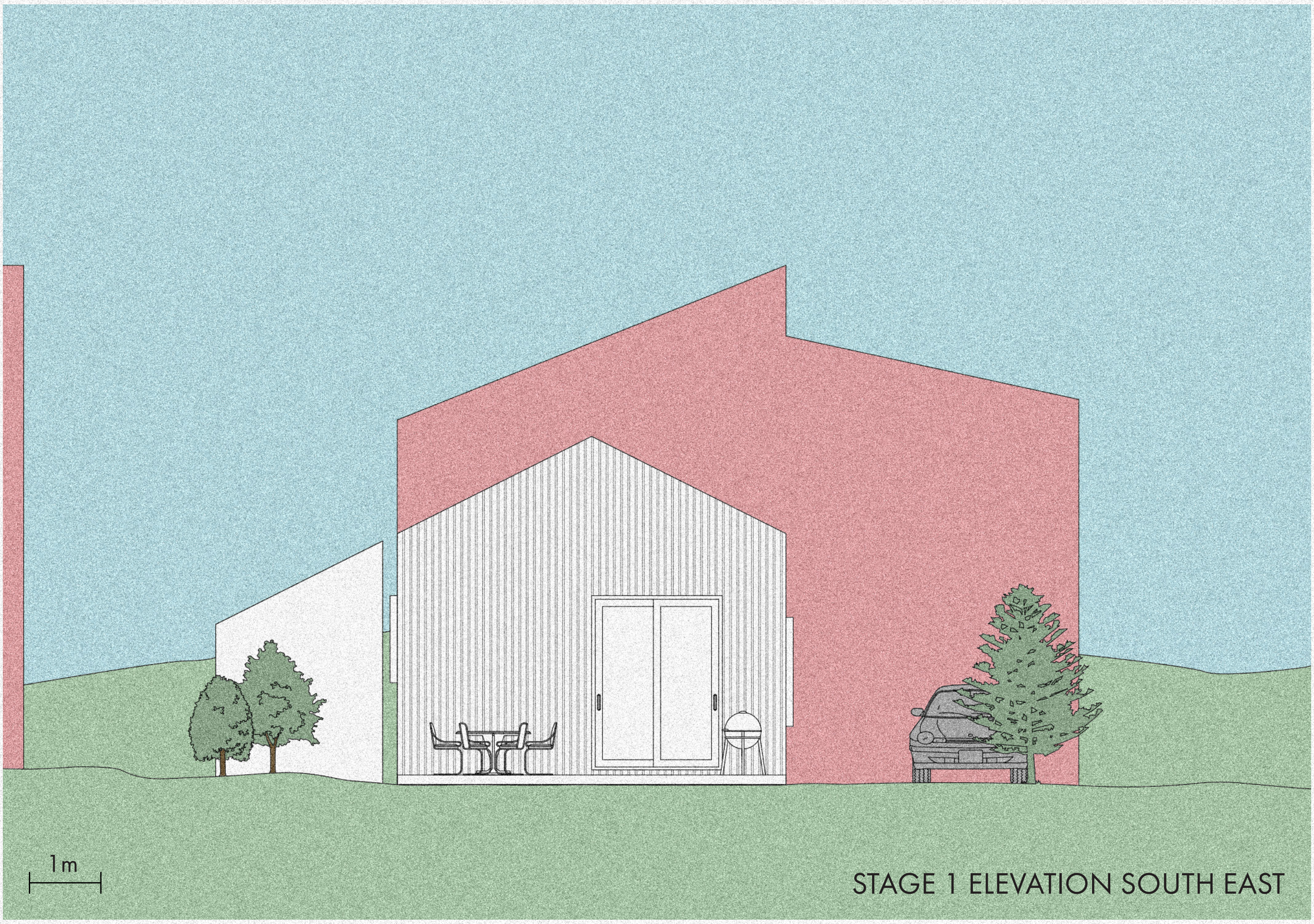
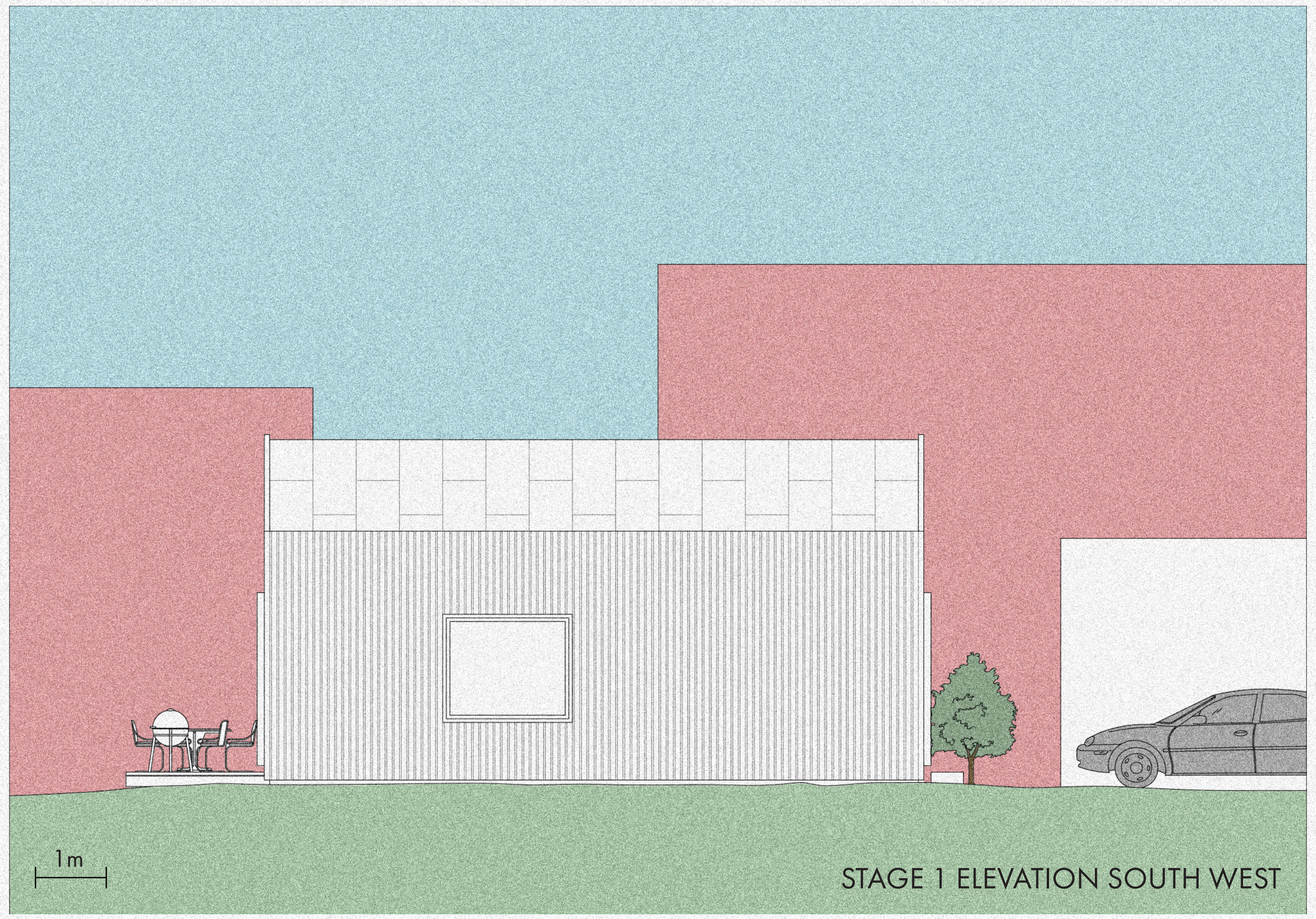
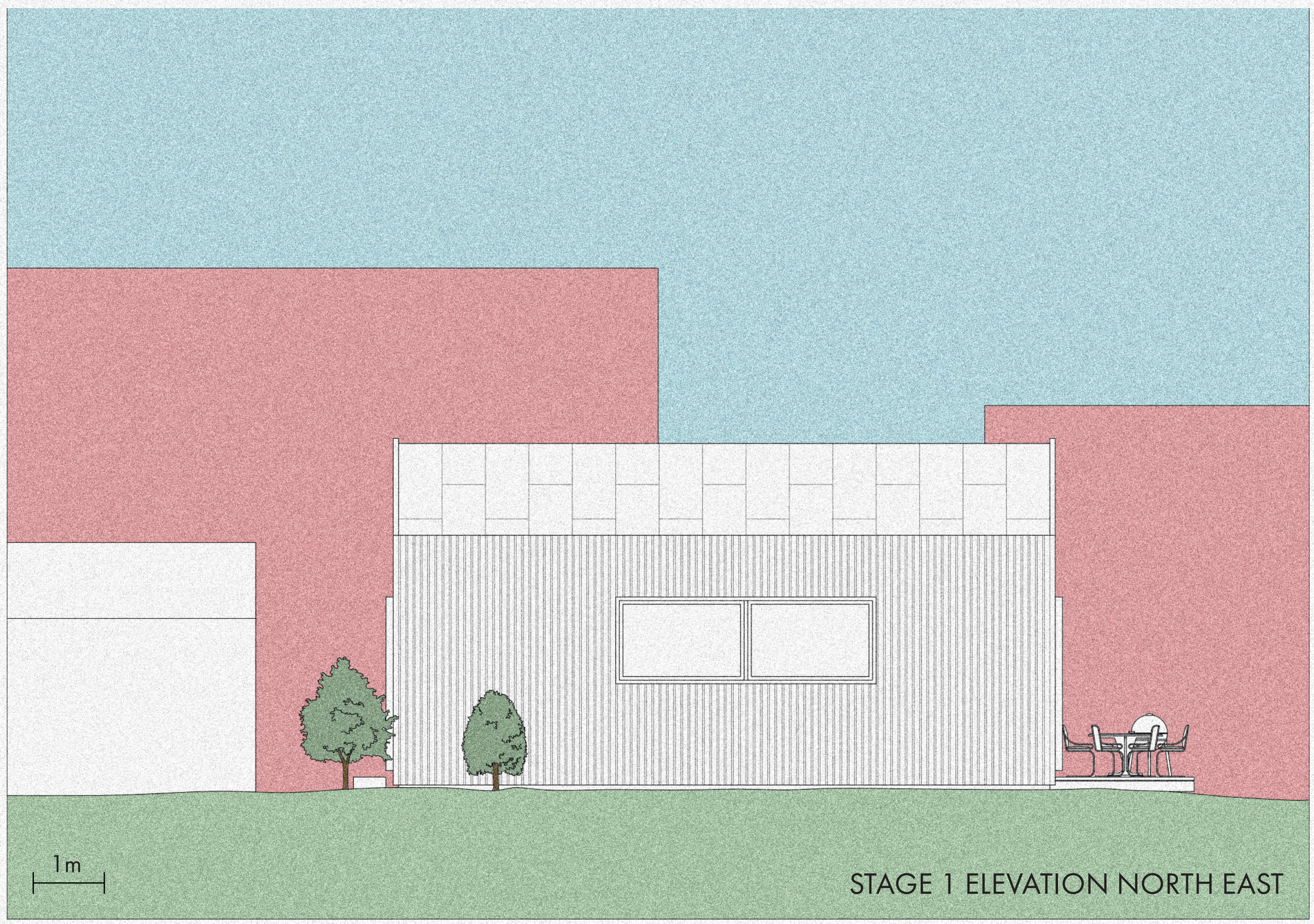
STAGE 1 ELEVATION NORTH WEST


1m
STAGE 1 ELEVATION SOUTH EAST


1m
STAGE 1 ELEVATION SOUTH WEST

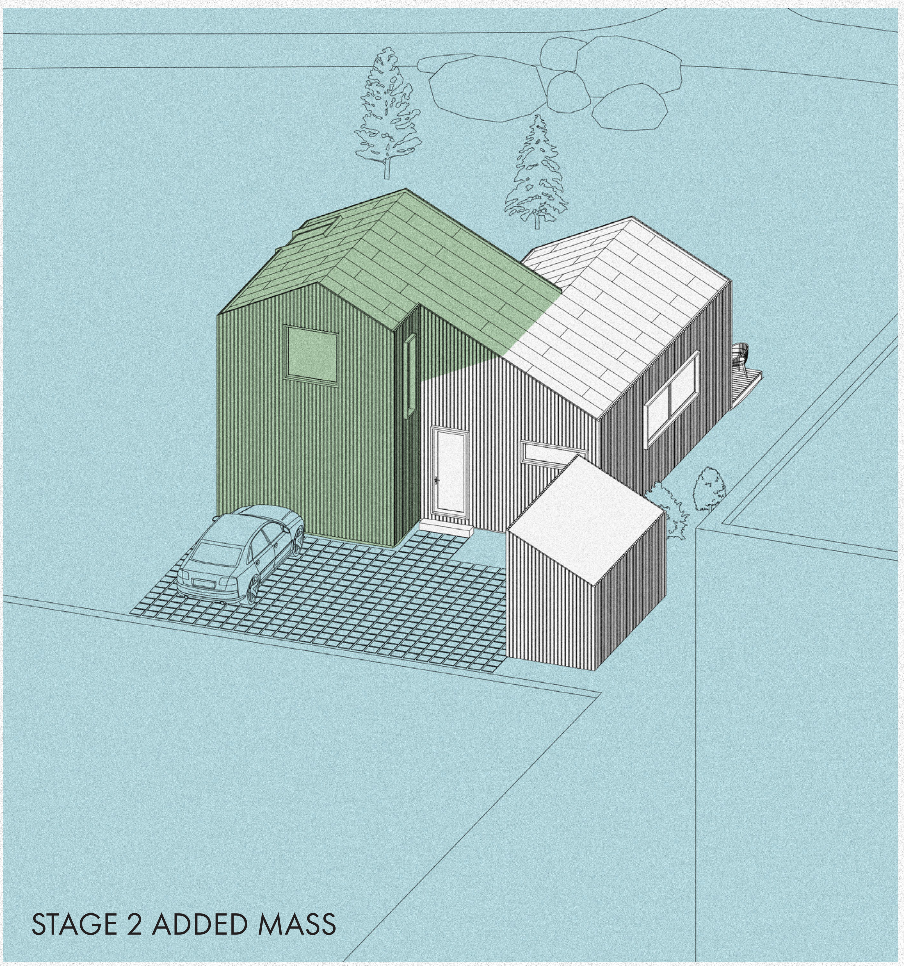

1m
STAGE 1 ELEVATION NORTH EAST

STAGE 2

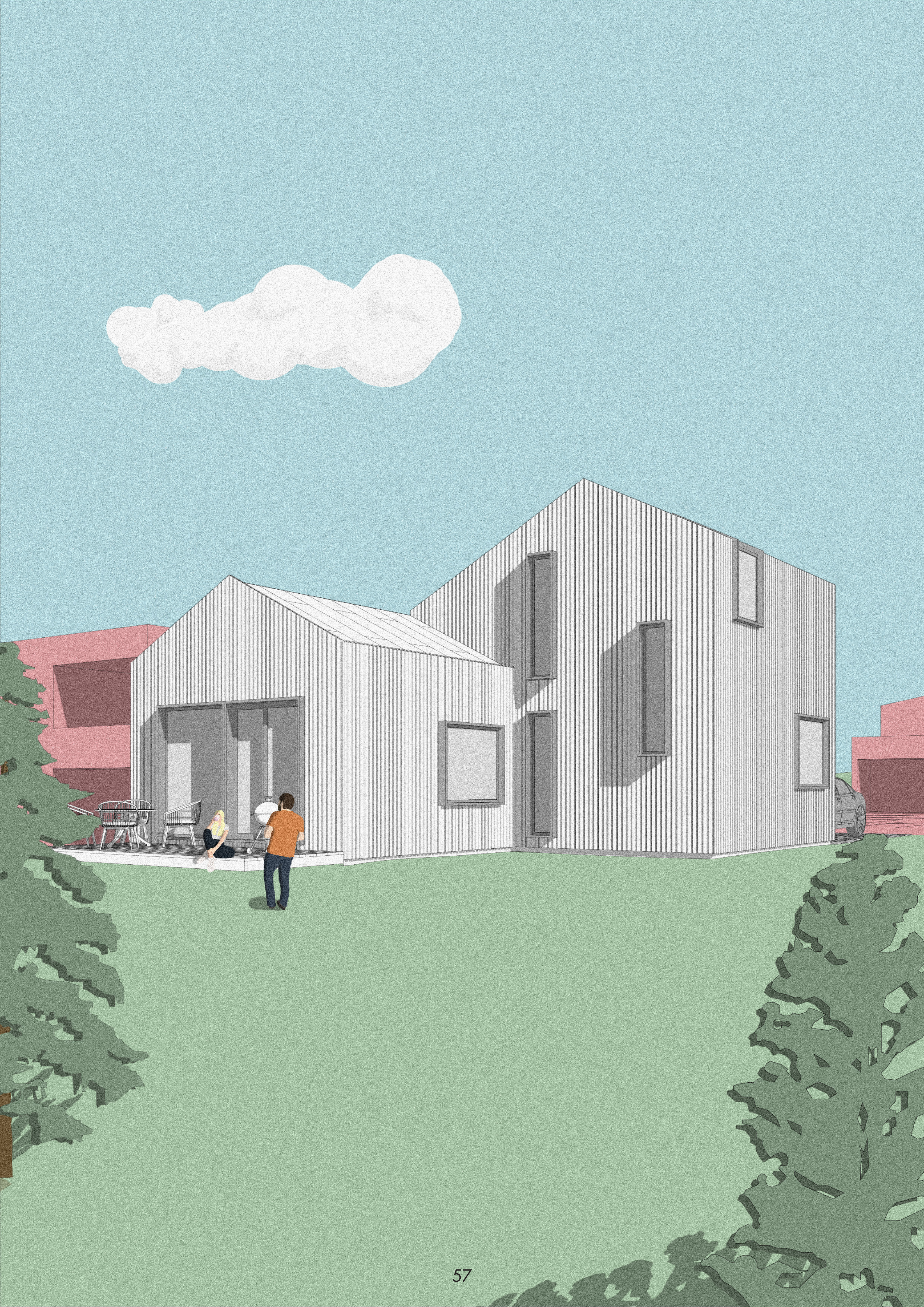
COUPLE

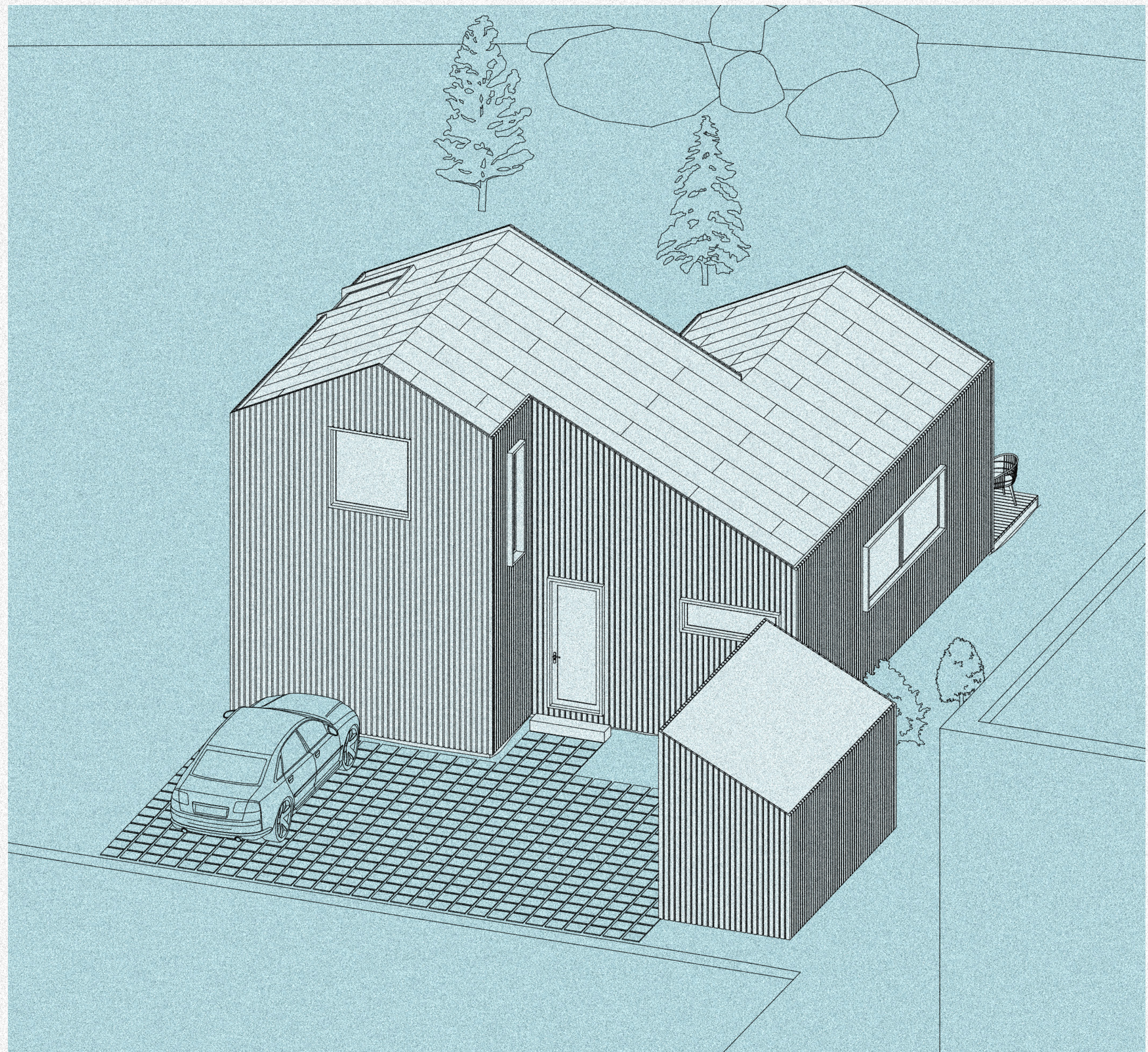
The second stage of the design is for a couple that intends to spend their life together. They combine their resources and add them to the home. They want a little better dining situation and some more space to stretch their limbs. This stage can last even if they have a single child up to a certain age. The bathroom does not change at all, and the kitchen receives an island. Additional mass on two stories is added to the North/ North-East part of the house.

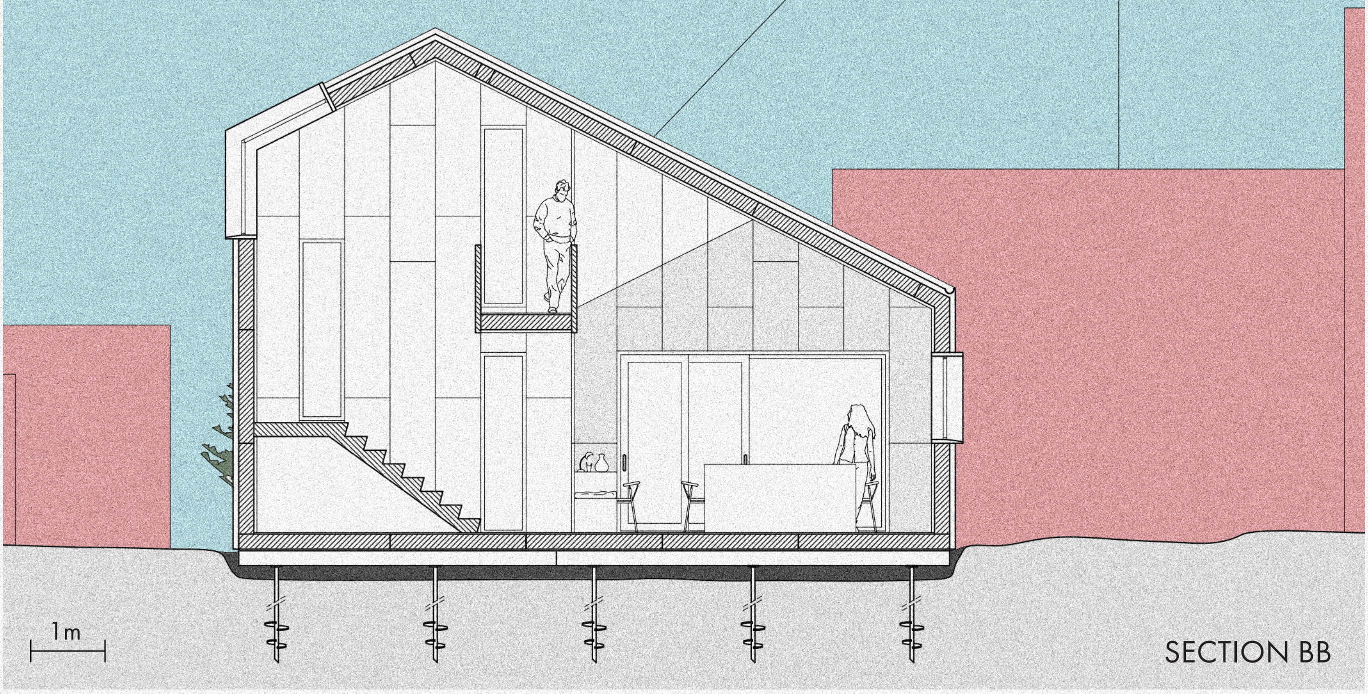
Gross floor area: 105 m2
Net floor area: 86 m2

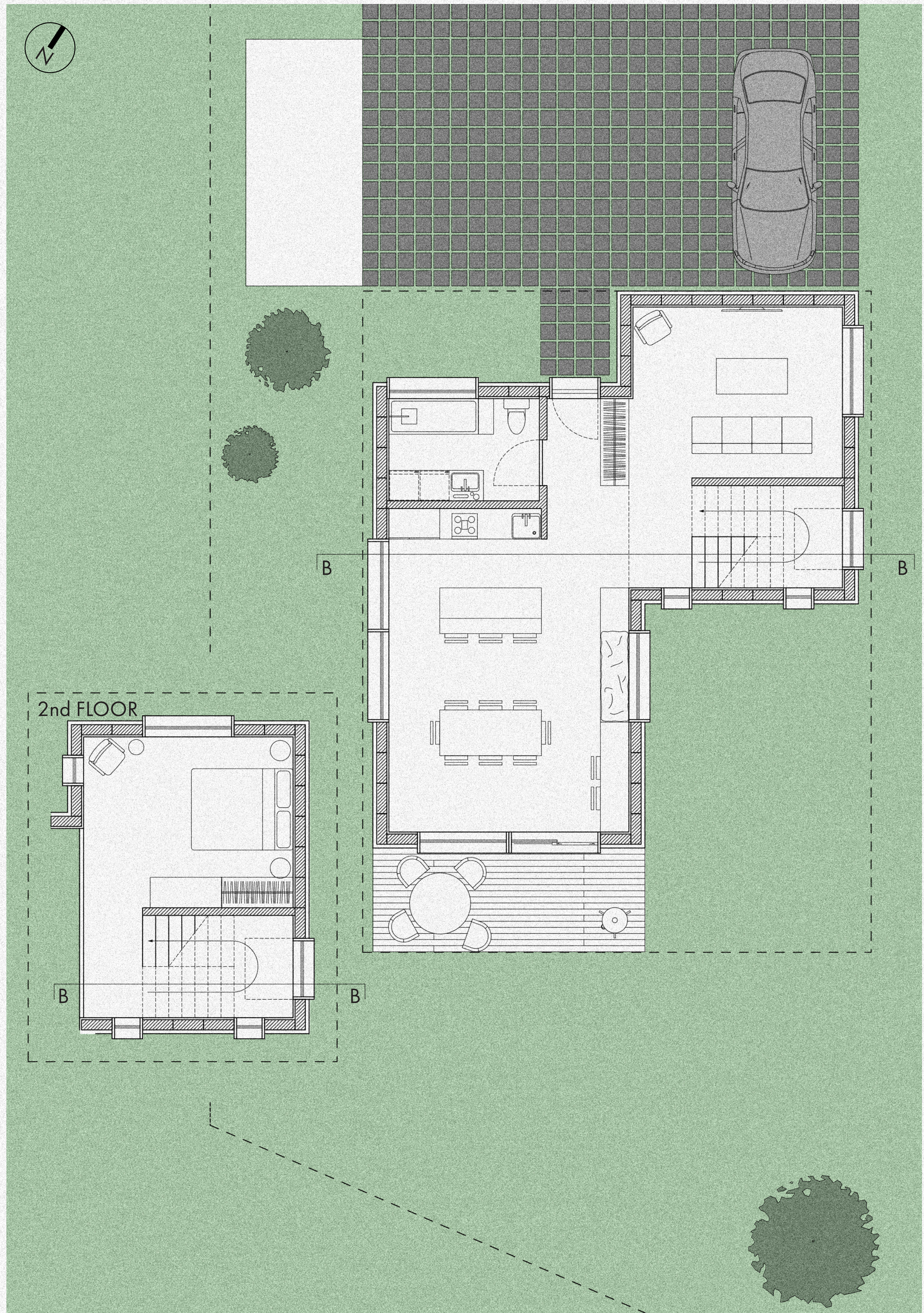


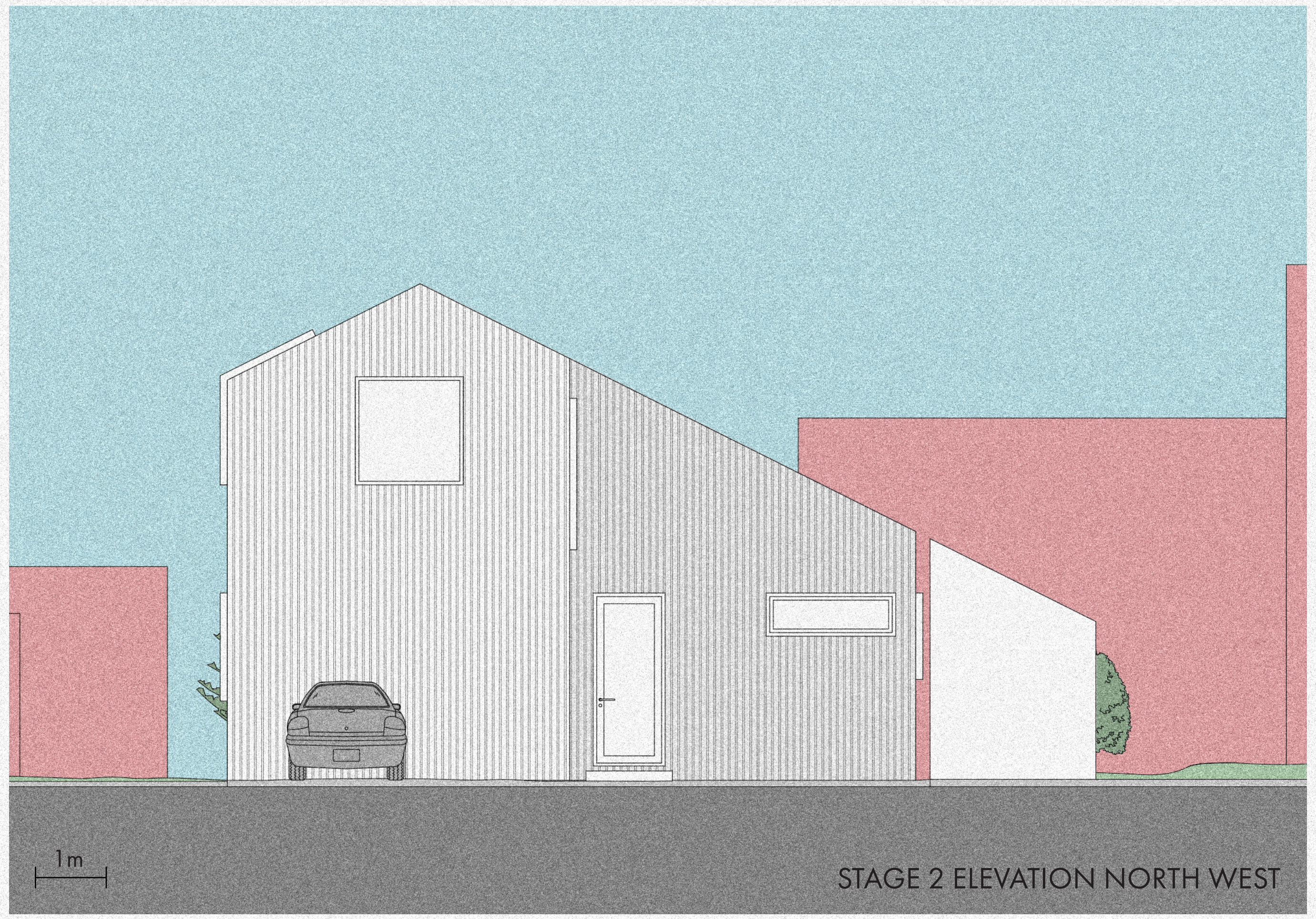
STAGE 2 ADDED MASS

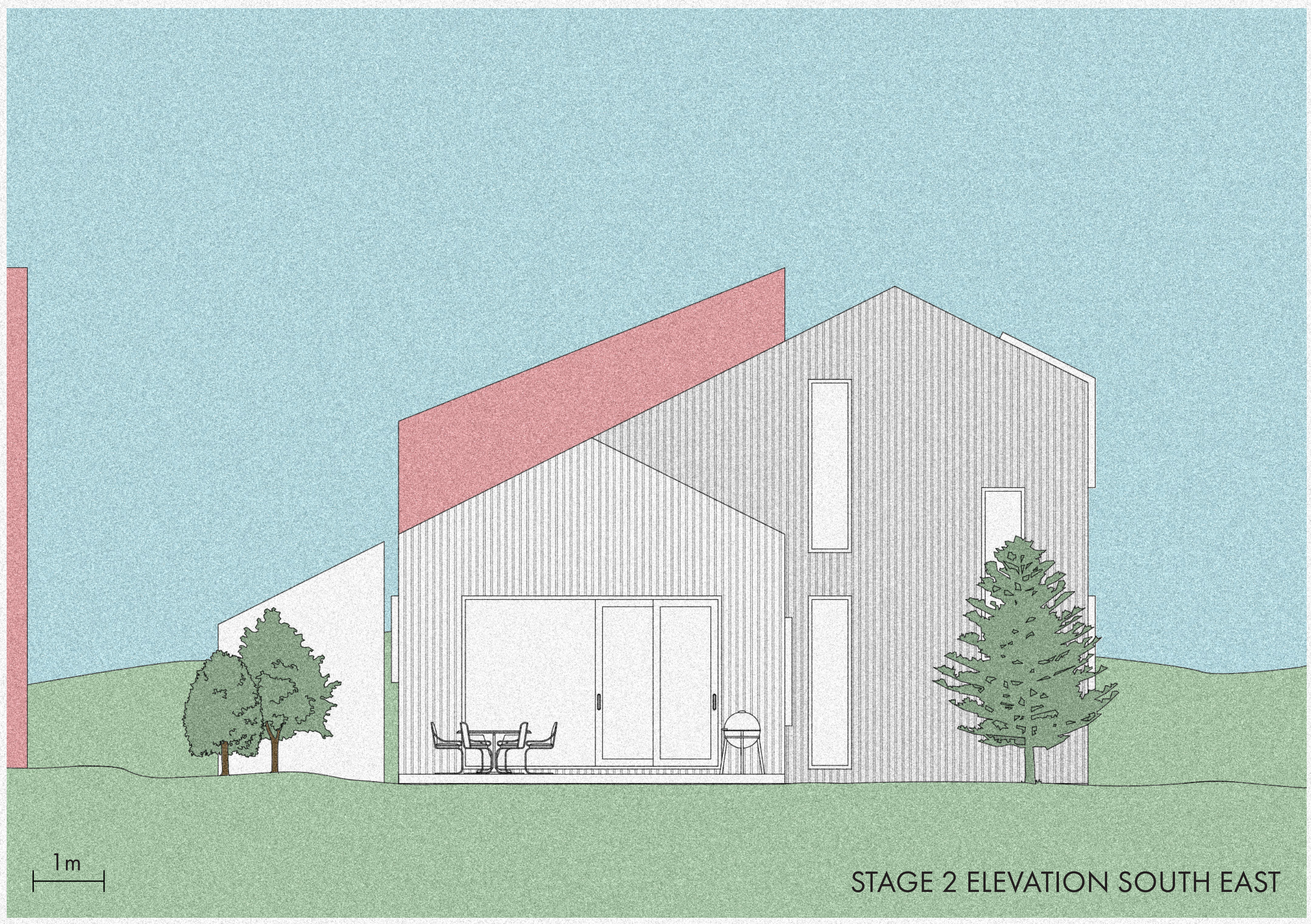


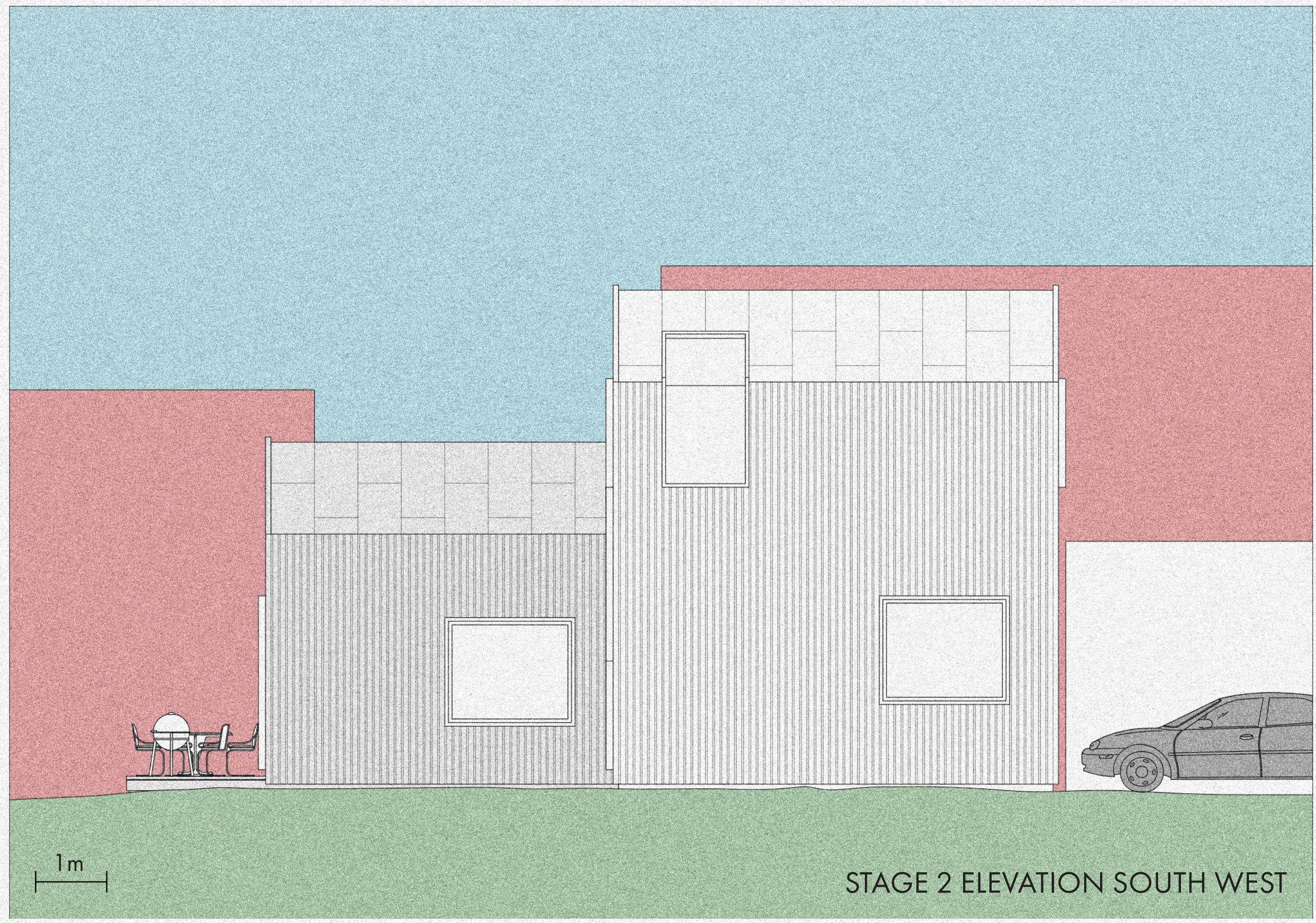


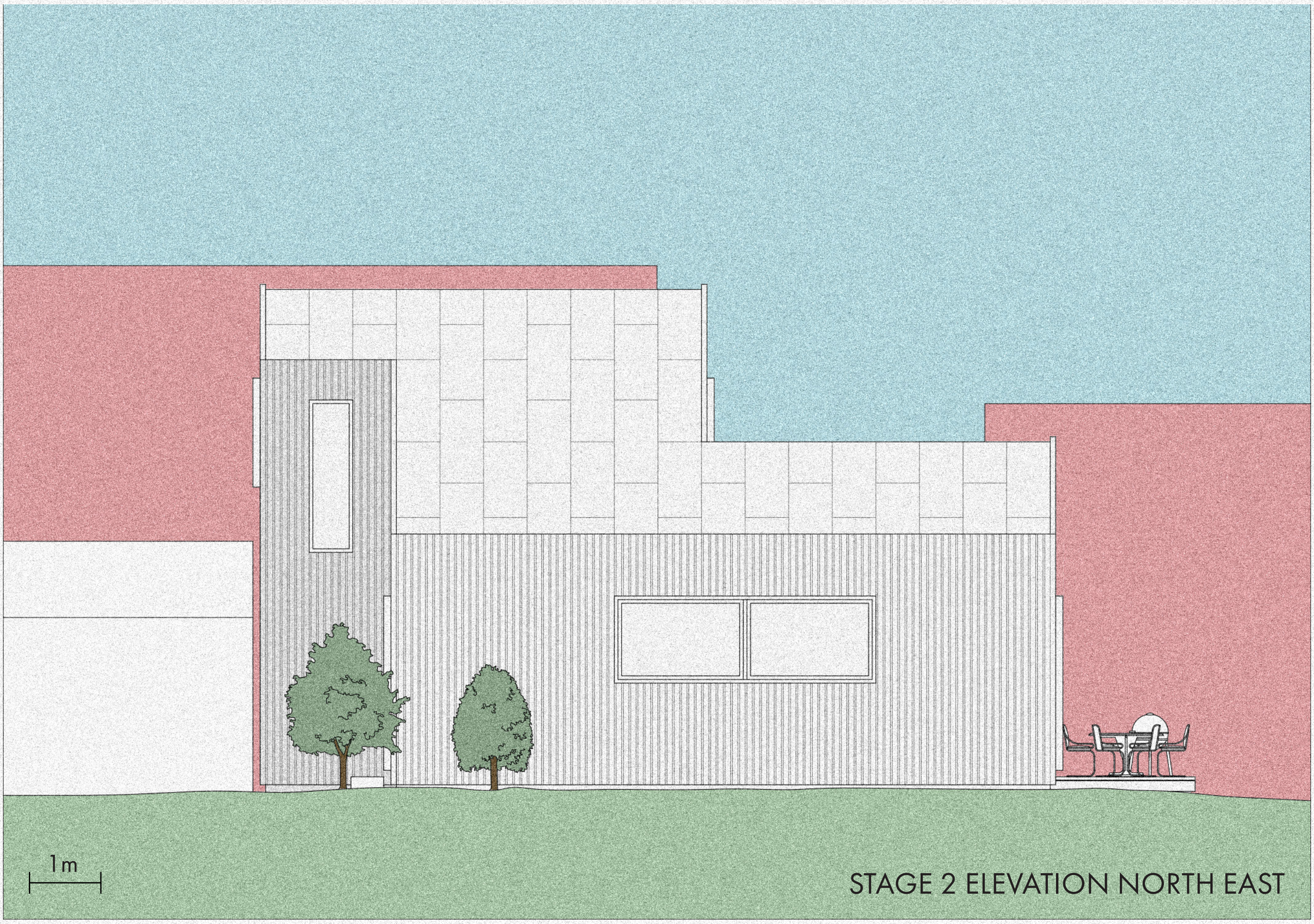

1m
SECTION BB


2nd FLOOR
B
B
B
B
1m
STAGE 2 FLOORPLAN


1m
STAGE 2 ELEVATION NORTH WEST


1m
STAGE 2 ELEVATION SOUTH EAST


1m
STAGE 2 ELEVATION SOUTH WEST

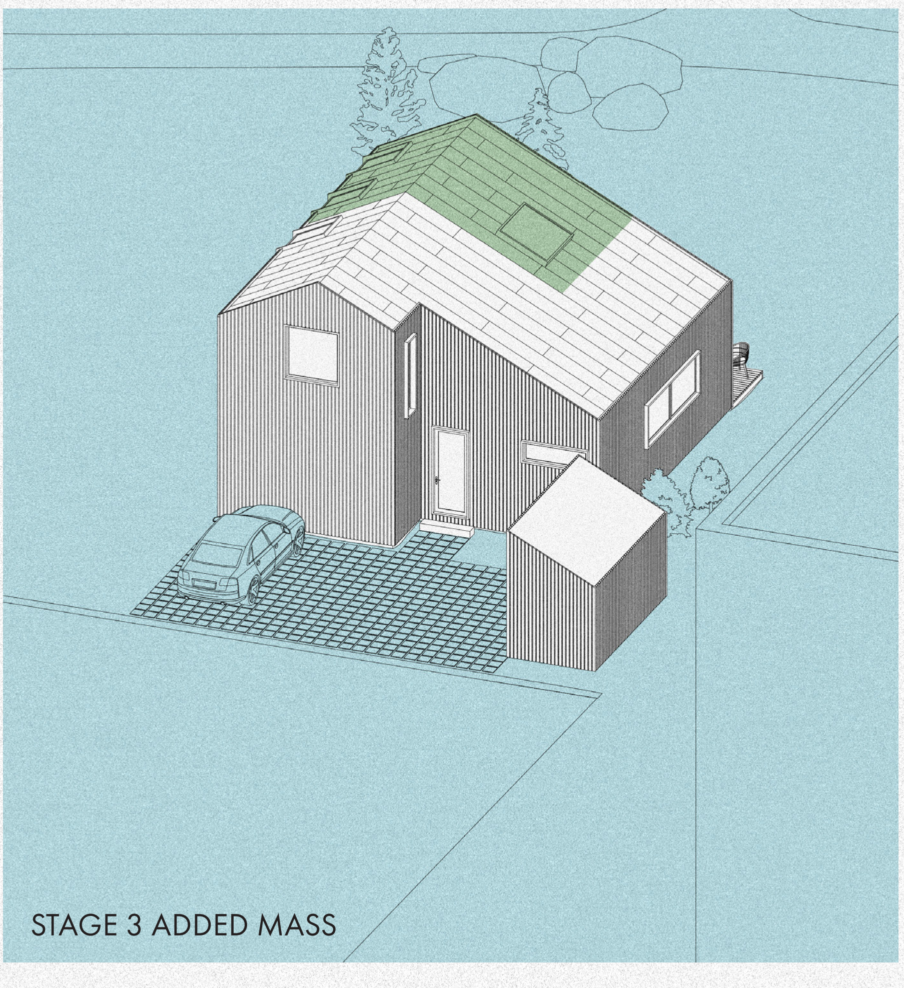

1m
STAGE 2 ELEVATION NORTH EAST

STAGE 3

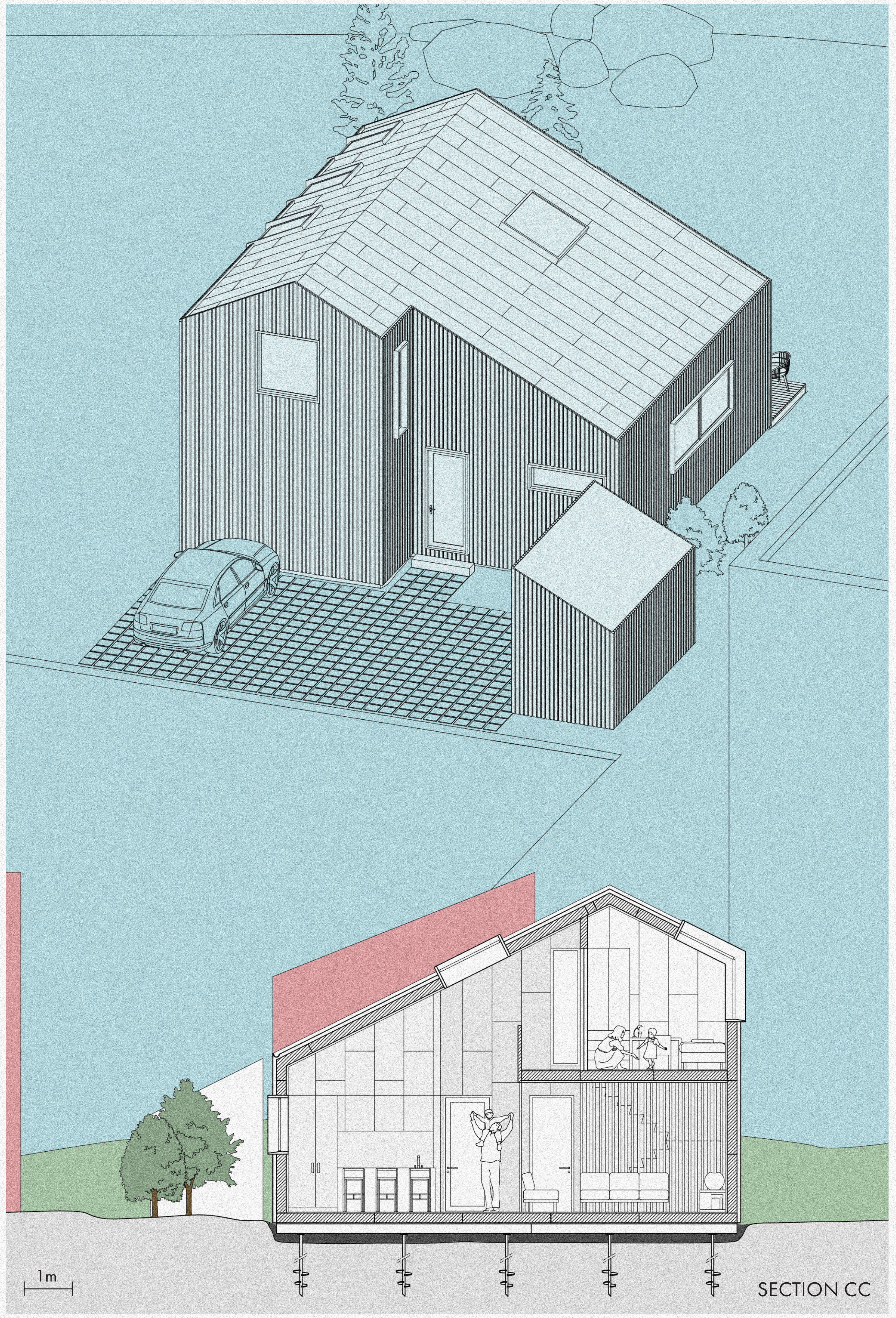
FAMILY OF FOUR

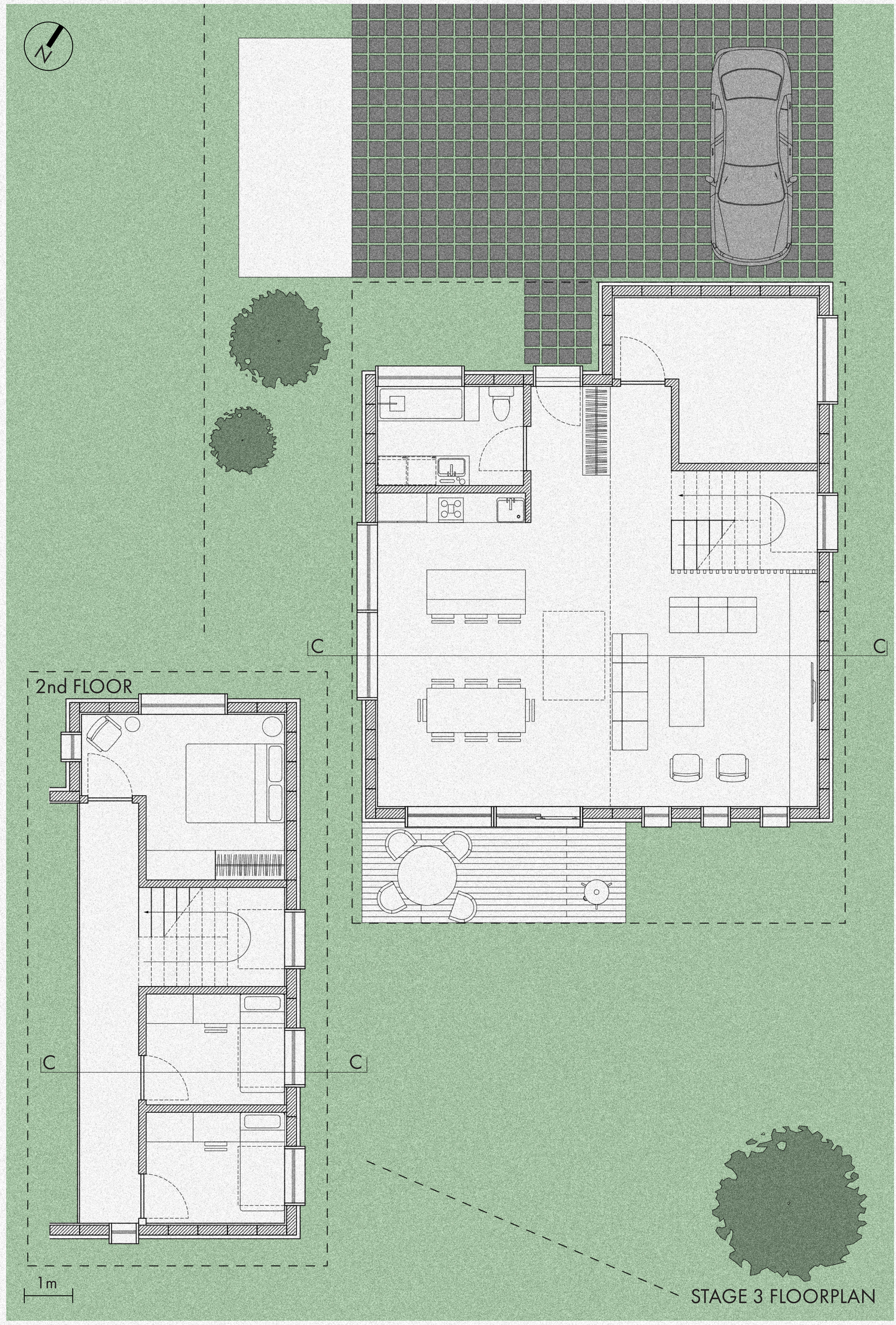
The third stage of the design is for a family of four. An additional two-story mass is added to the West corner of the building. The first floor expands the communal living space for the family while the second floor adds two children's bedrooms. A part of the first floor becomes an extra room, suitable as an office, a guest room but is intended to serv the family's future needs. When the children grow a bit older and need more room this room can become a bedroom while the two smaller bedrooms on the second floor are joined into one larger by removing the dividing wall between them. This floorplan has the potential to keep its form for a long time and serve as the family´s gathering spot even after the children move out and have kids of their own. The parents do not necessarily want to decrease the homes size until it is beneficial to do so.

Gross floor area: 148 m2
Net floor area: 126 m2

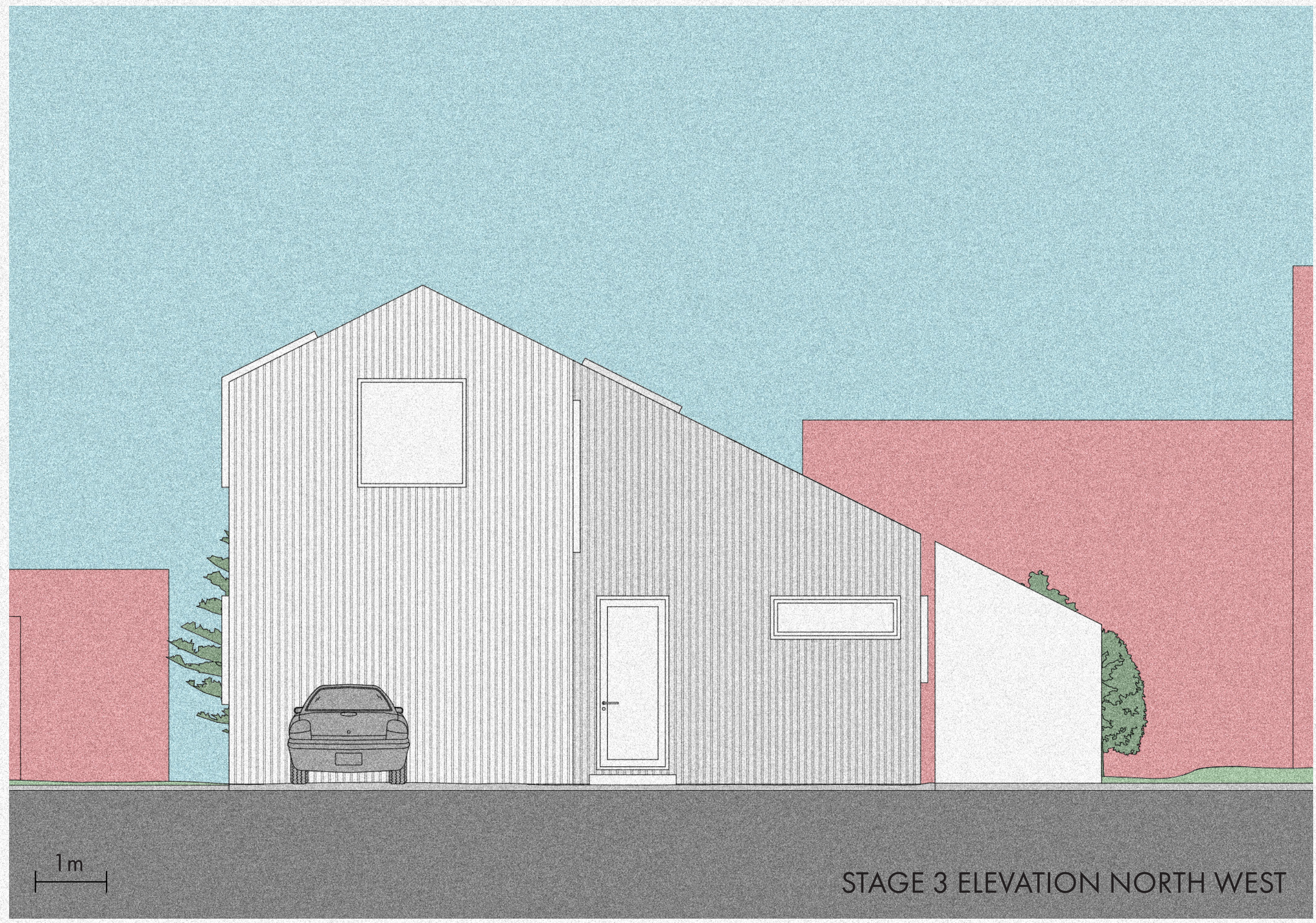


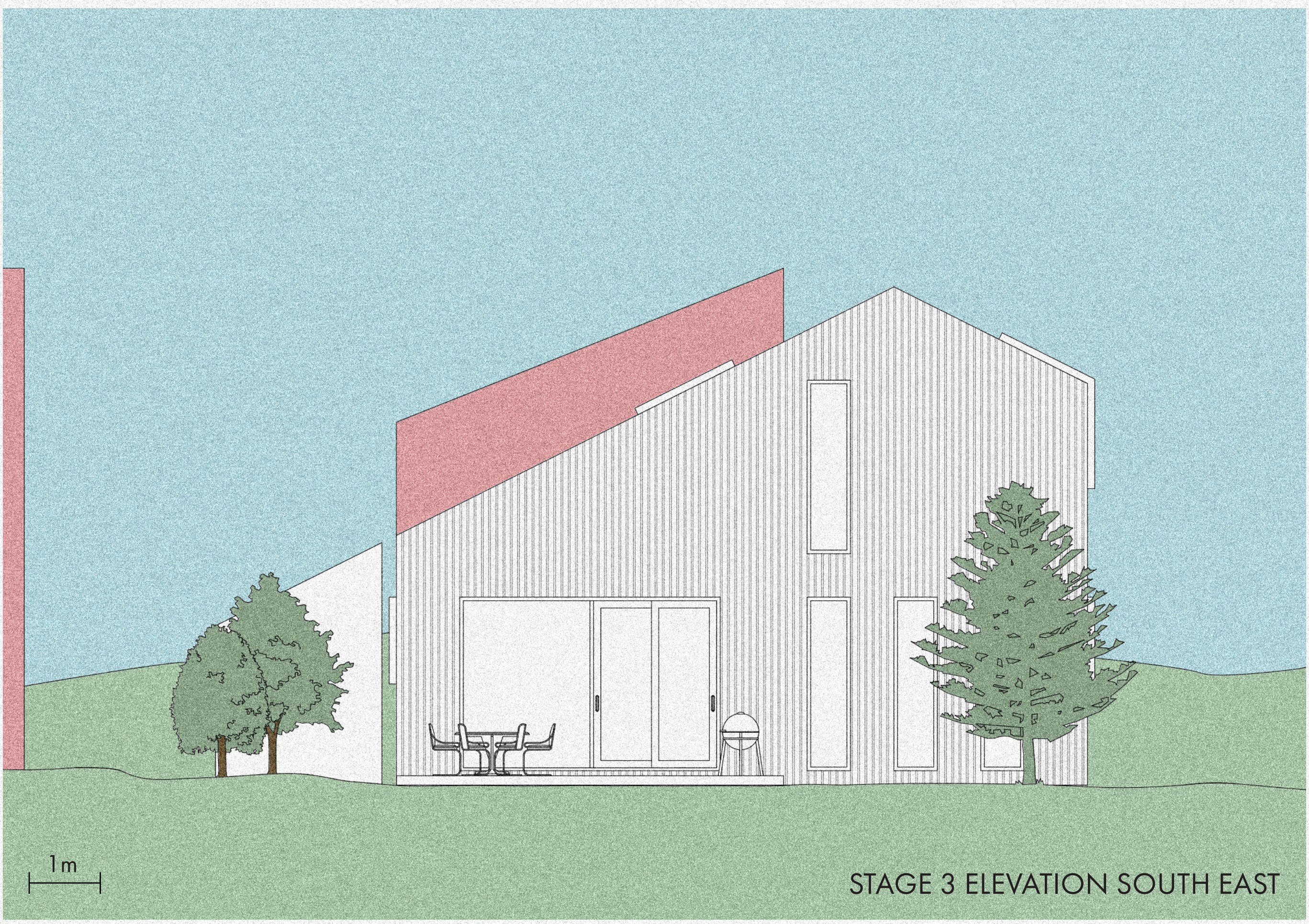
STAGE 3 ADDED MASS

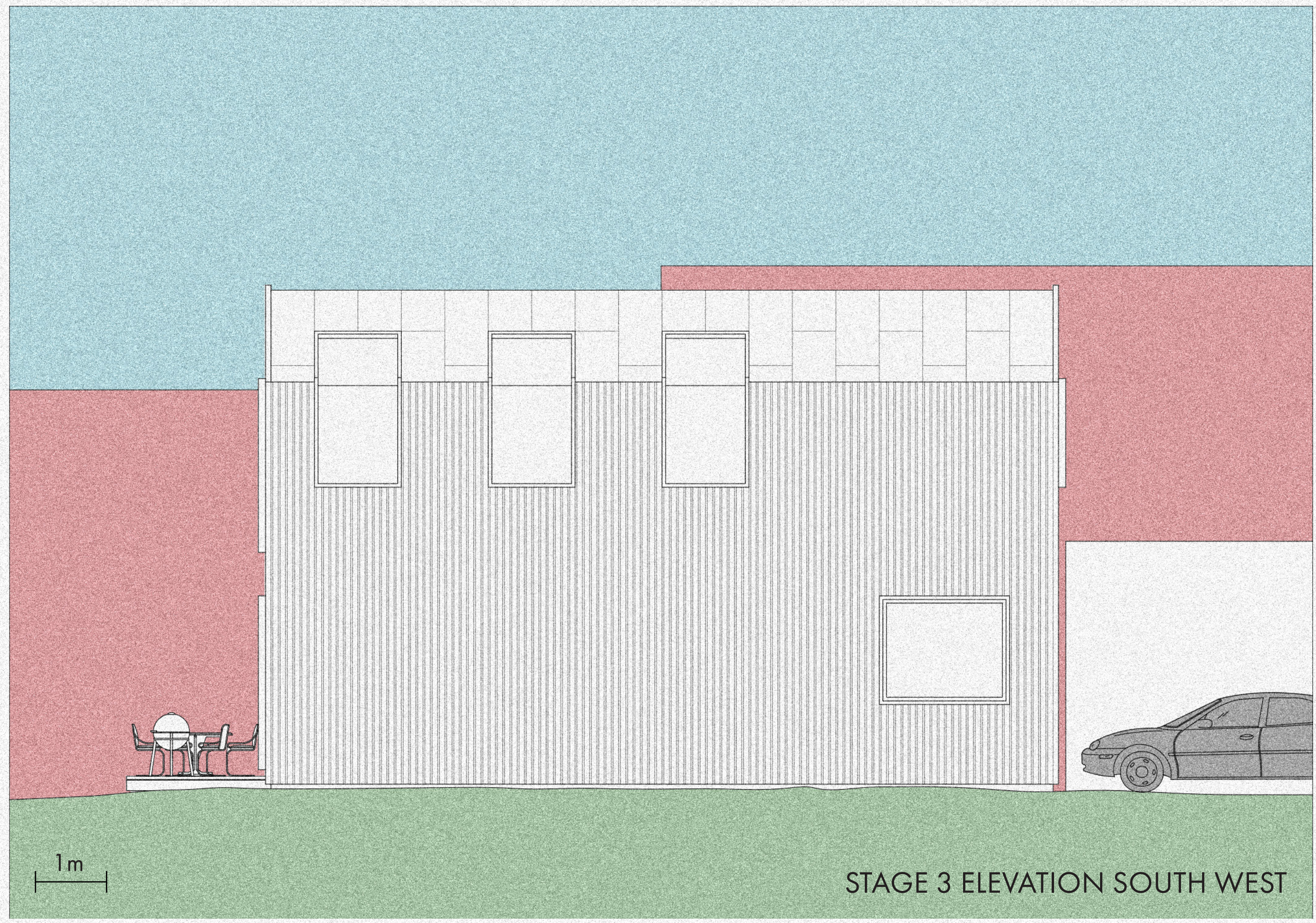

1m
SECTION CC



C
C
2nd FLOOR
C
C
1m
STAGE 3 FLOORPLAN


1m
STAGE 3 ELEVATION NORTH WEST


1m
STAGE 3 ELEVATION SOUTH EAST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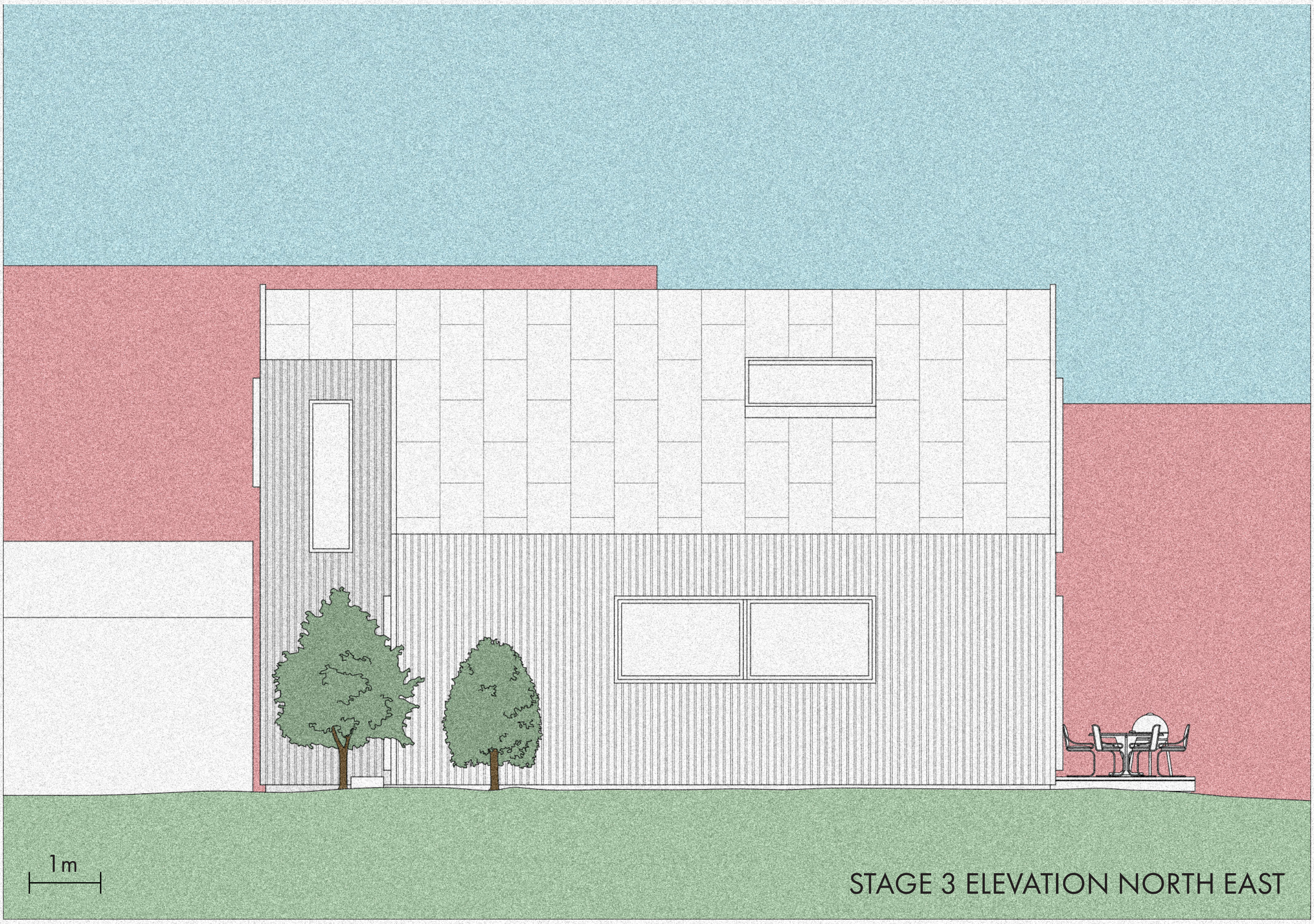
STAGE 3 ELEVATION SOUTH WEST

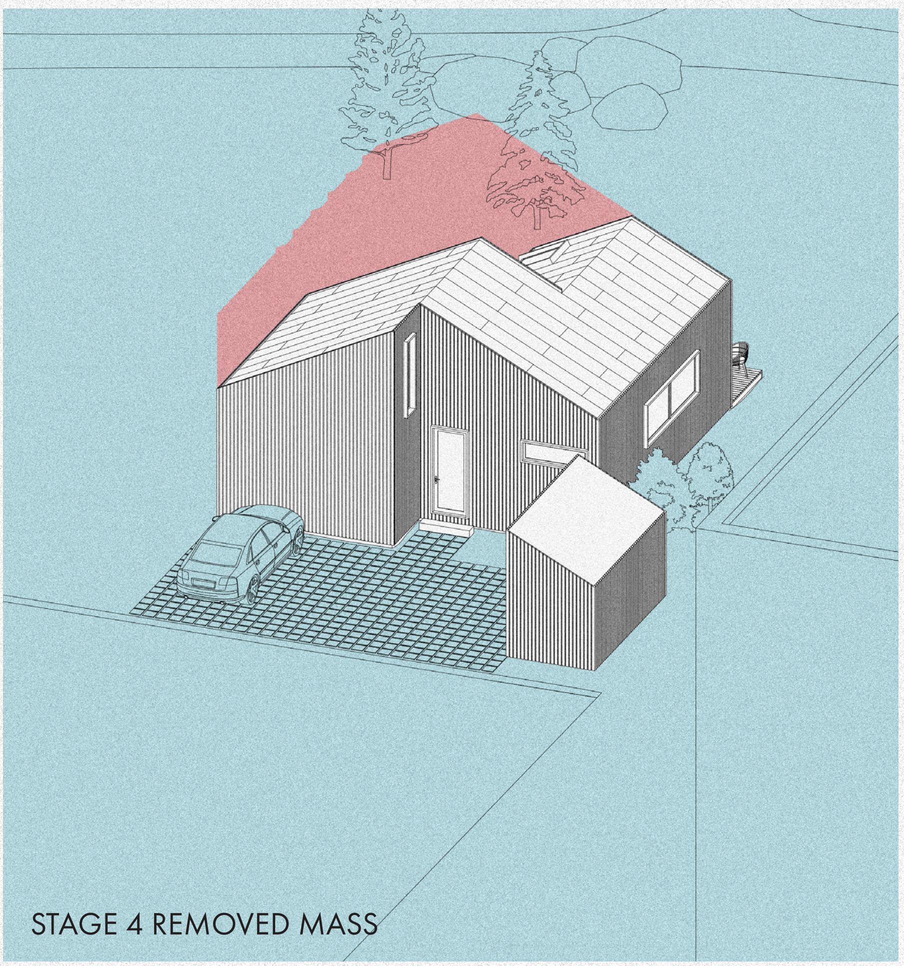

1m
STAGE 3 ELEVATION NORTH EAST

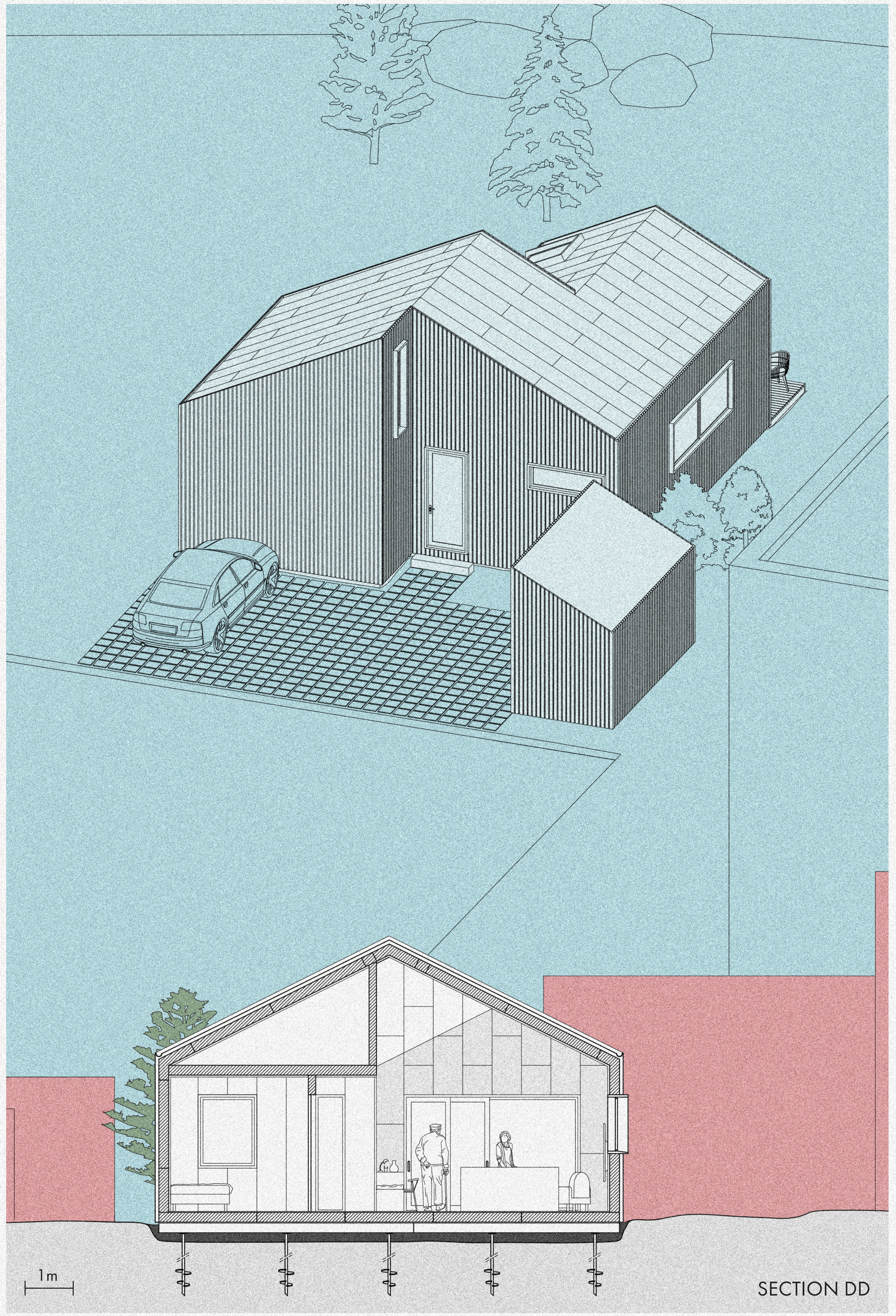
STAGE 4

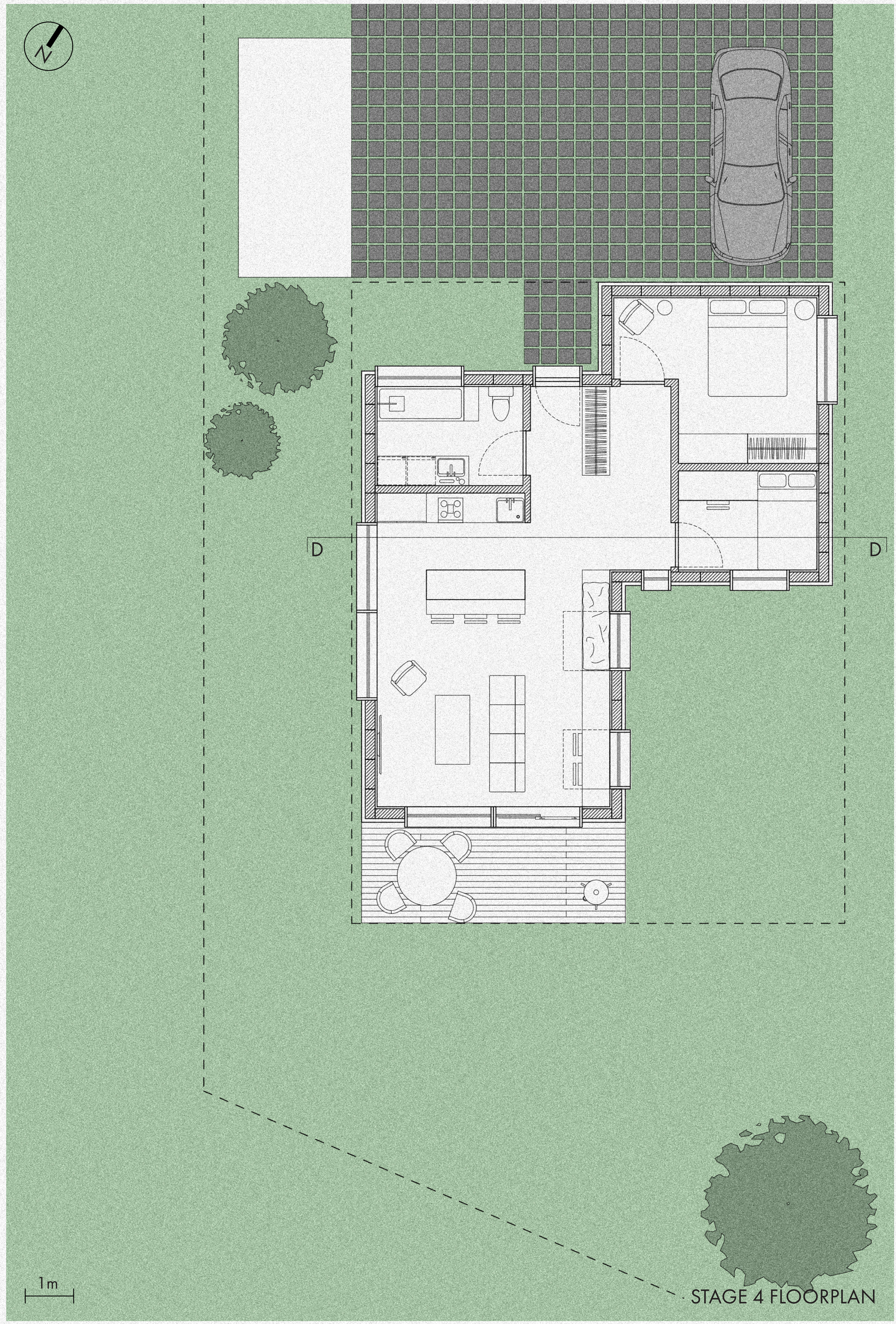
ELDERLY COUPLE

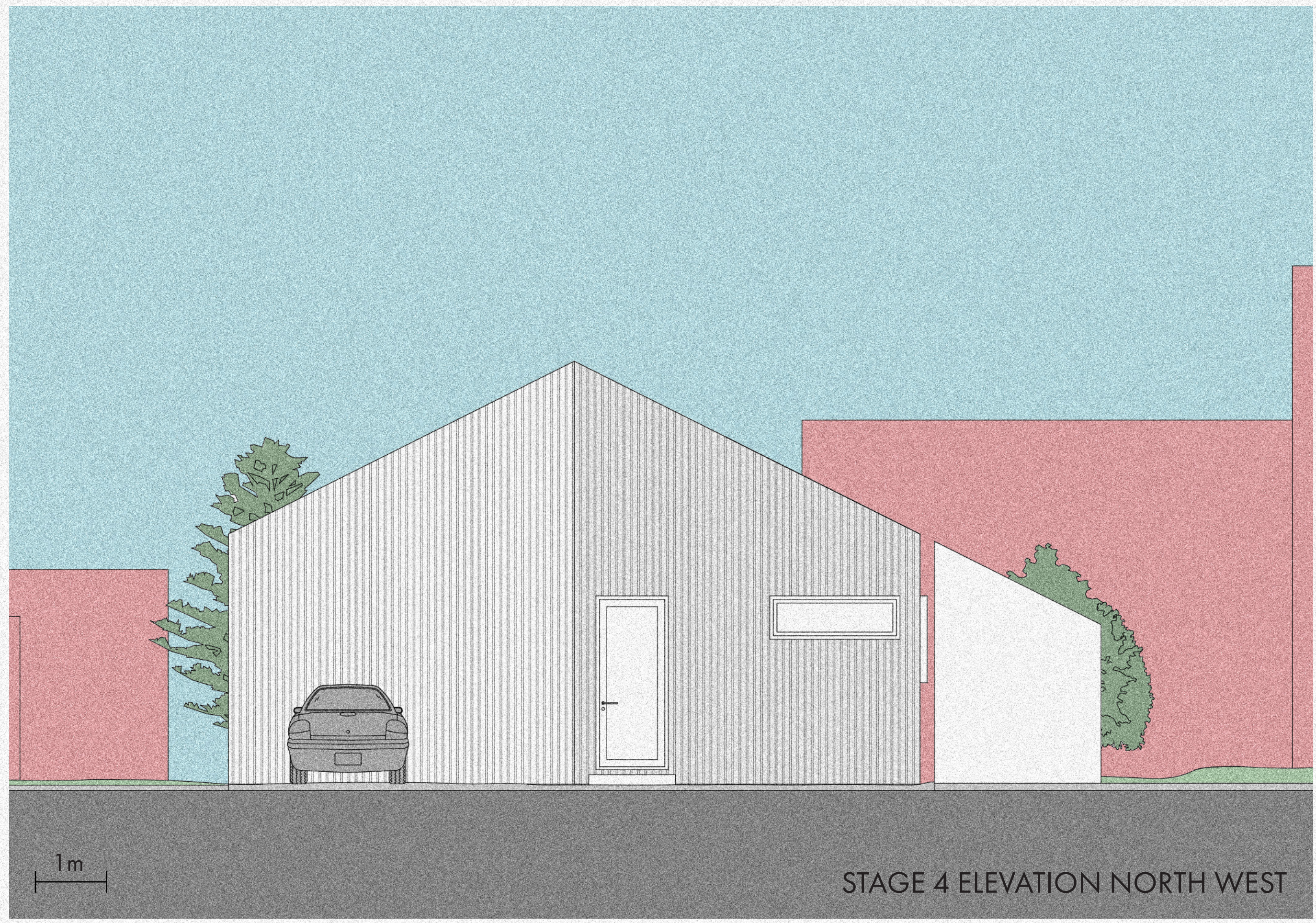
The fourth stage of the design is meant to meet the needs of an elderly couple. At some time in the future, the house will become too large for the elderly couple. Then it is time to scale it down. The kitchen and dining area are simplified, the living room moved and scaled down. The entire second floor is removed, and they are left with a bedroom and a small guest bedroom on the first floor. The excess building material can either be sold off or be a gift for their children to extend their own living situation.

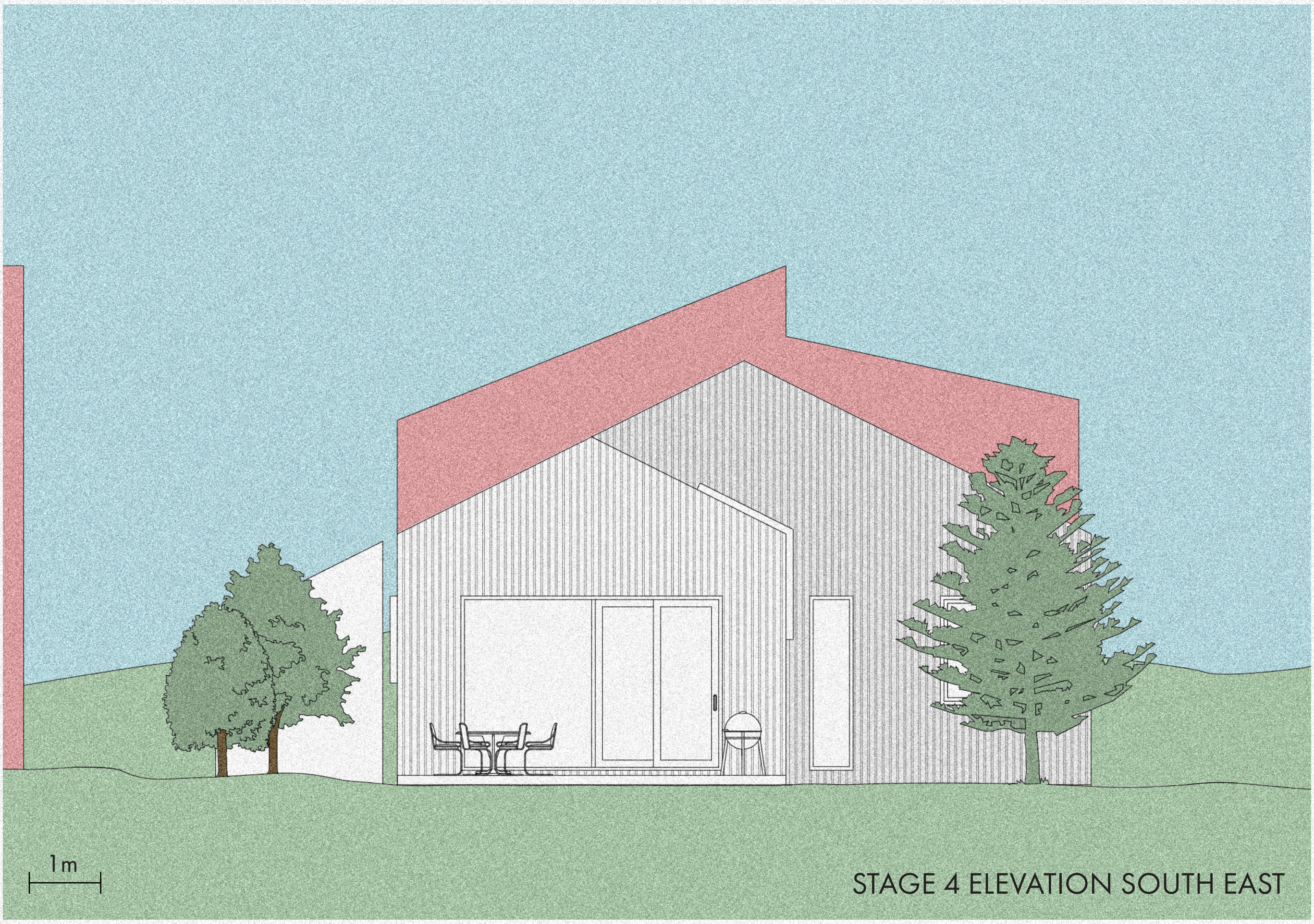
Gross floor area: 76 m2
Net floor area: 63 m2

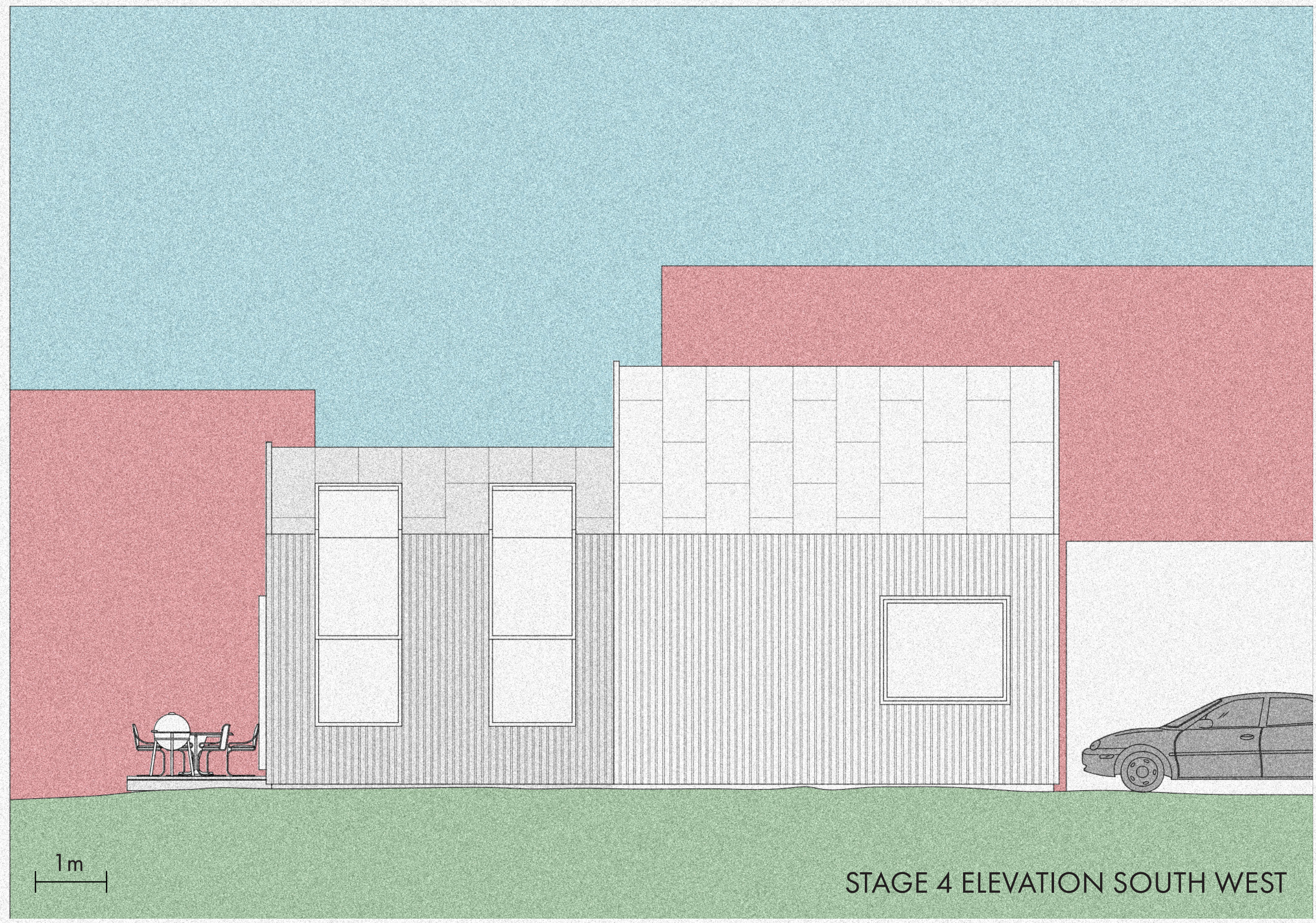


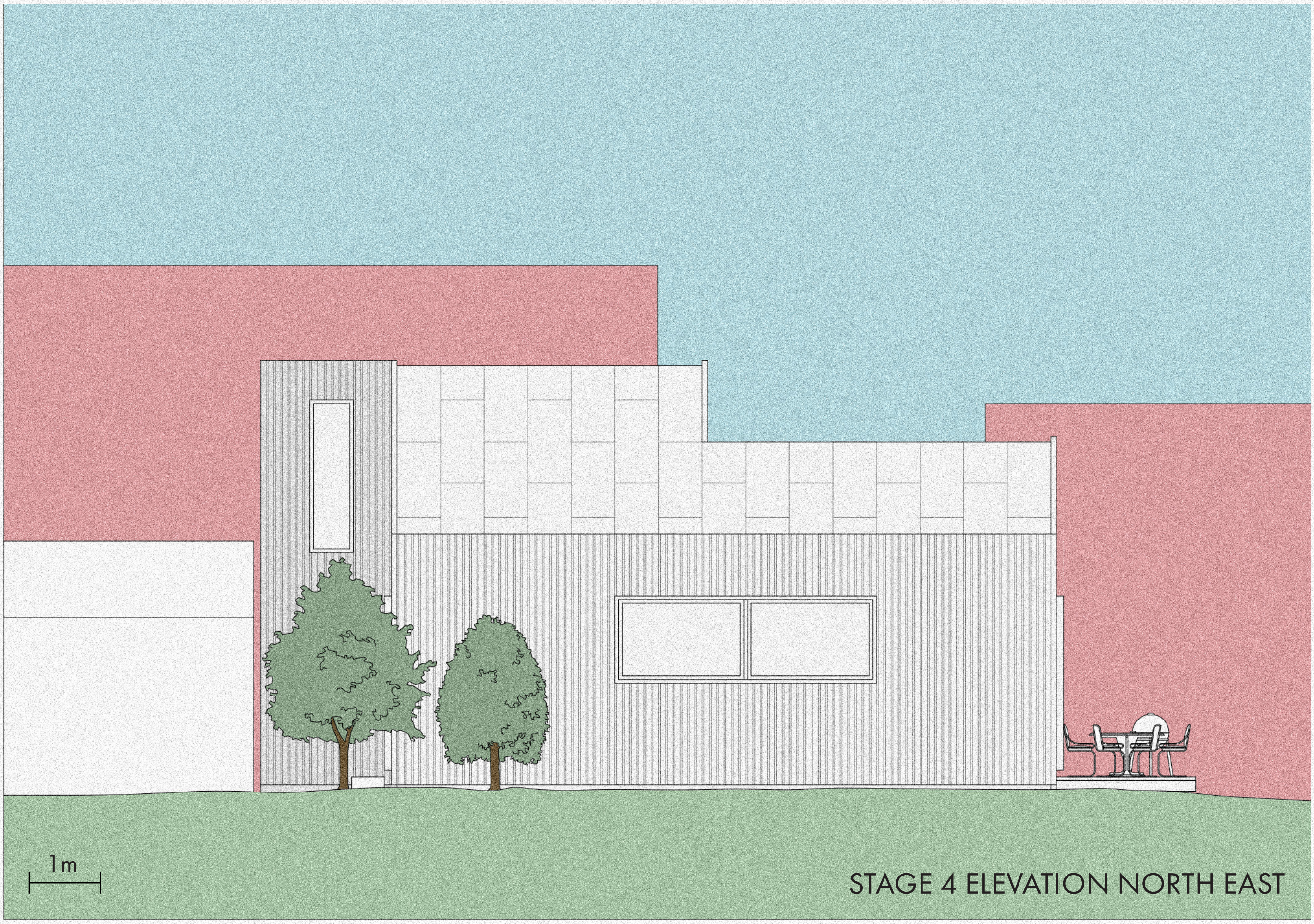

1 m
SECTION DD


N
D
D
1m
STAGE 4 FLOORPLAN


1m
STAGE 4 ELEVATION NORTH WEST


1m
STAGE 4 ELEVATION SOUTH EAST


1m
STAGE 4 ELEVATION SOUTH WEST


1m
STAGE 4 ELEVATION NORTH EAST

CONCLUSION

Taking everything into account, the author contends that circular economy will play a pivotal role in the future of the construction industry, driven not only by its environmental benefits but also its financial advantages.

This project focuses on providing a possible solution for ordinary individuals, especially those aspiring to establish their homes. It refrains from presenting a one-size-fits-all solution but instead aims to illuminate and disseminate information about a concept that could be a valuable addition to the array of options for home construction. However, it is crucial to acknowledge and address certain challenges inherent in this initiative.

The building system outlined in the preceding chapters is foundational and requires further development and testing to realize its full potential. Adjustments such as increasing the thickness of plywood sheets, enhancing the connection between modules, and potentially introducing extra wooden support beams may be necessary.

Furthermore, the concept of constructing within one's means and adapting the structure as spatial and financial needs evolve necessitates complete control over the building and site. This, however, poses a challenge to the viability of multi-apartment complexes, typically associated with lower costs. Additionally, in Iceland, purchased building lots often come with predefined parameters on the minimum and maximum allowable construction, wherein buyers effectively pay for the maximum built potential. This aspect would require reconsideration for successful implementation of the proposed concept. Another aspect worth exploring is the concept of "scaling down". Is it more financially prudent to sell the property at its peak and move to a smaller one, rather than downsizing the existing structure? The project refrains from providing definitive answers to such questions but seeks to raise them for contemplation. Furthermore, the issue of space and the availability of plots suitable for this type of construction warrants consideration. Designing with circular economy in mind is an intricate process, demanding a societal shift in both mindset and behaviour.

In conclusion, the exploration of the circular economy's potential in the building industry reveals not only its environmental and financial merits but also the intricate challenges that accompany its implementation. As we navigate the path towards more sustainable and economical construction practices, this thesis has sought to shed light on a concept that holds promise but requires further refinement and consideration. By acknowledging the complexities and uncertainties, we pave the way for future research, projects, and dialogues that will be instrumental in shaping a more sustainable and resilient future for the building industry. The journey towards circularity demands collective effort, innovation, and an unwavering commitment to redefining our approach to construction.

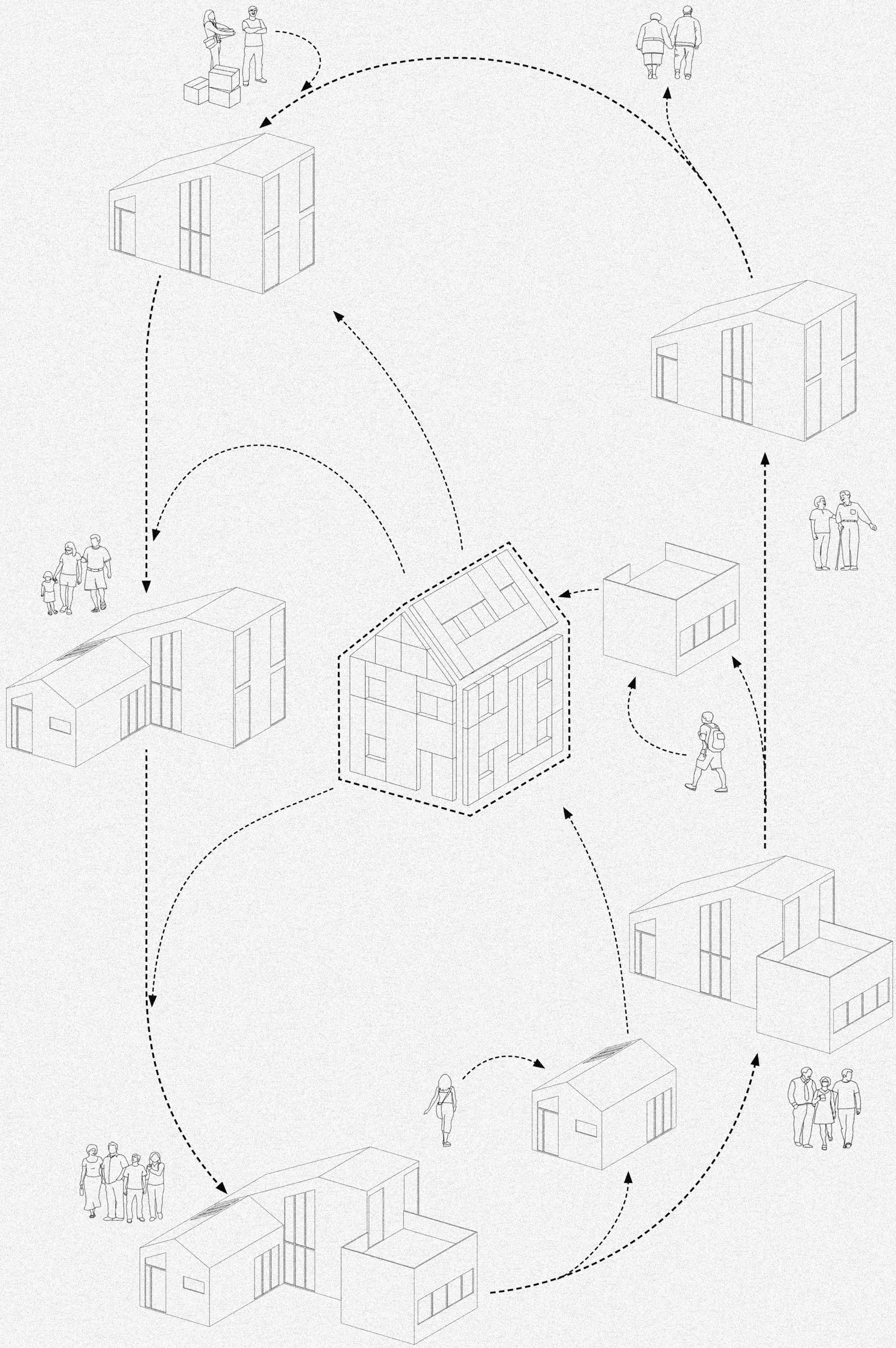


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IMAGE REFERENCES

Image 1:

https://www.rum.as/projekter/circle-house-2

Image 2:

https://gxn.3xn.com/wp-content/uploads/sites/4/2019/02/CircleHouse_ENG_2018.pdf
(Page 25)

Image 4:

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Image 3:

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Images 5-8:

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Image 10:

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Image 16:

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https://xframe.com.au/documents/xfs8.26---typical-details---shop-drawings---specifications.pdf
(Page 2)

APPENDIX: calculation for page 4

* Exchange rate of 1 EUR to 145.1 ISK is based on the day of calculation which is 7.th of August 2023 according to European central bank (ECB Euro Reference Exchange Rate: Icelandic Krona (ISK)). In order to keep the calculations clearer the numbers will be rounded to end in zero before a decimal number, e.g. 2.852,5 ≈ 2.850, 3.085 ≈ 3090.

AVERAGE INCOME FOR 25-34 YEAR OLD PERSON IN ICELAND

According to Statistics Iceland (Hagstofa Íslands) in 2022 the yearly average disposable income (after tax) for the age group 25-29 is 4.967.000 ISK or approximately 34.230 EUR*. That amounts to 414.000 ISK /2.850 EUR* per month.
The average disposable income for the age group 30-34 is 5.779.000 ISK./39.830 EUR*. That amounts to 481.500 ISK./3.320 EUR* monthly disposable income (Income by Sex and Age 1990-2022). Since these numbers are used to represent young adult, first time property buyers, the age groups and their respective income will be combined into one group by adding the two numbers together and dividing them by two. The average monthly disposable income for the age group of 25-34 is then calculated to be 447.750 ISK/3.090 EUR*.

RENT PRICES IN THE GREATER CAPITAL AREA OF ICELAND

Húsnæðis og Mannvirkjastofnun (HMS) is an institute dedicated to information on real-estates in Iceland. An article posted on their website on 17.08.2022 shows the average rent prices per sqm. in different areas of the greater capital area of Iceland. The most affordable place to rent a 2-room apartment cost 2901 ISK or 20 EUR* / sqm (Húsnæðis- og Mannvirkjastofnun).

AVERAGE COST-OF-LIVING IN ICELAND

At the time of calculation, the 7.th of August 2023, the average cost of living (excluding housing) in Iceland for a single individual is estimated to be 211.500 ISK or 1.460 EUR* per month (Umboðsmaður Skuldara).

PROPERTY PRICES IN THE GREATER CAPITAL AREA OF ICELAND

An article published on the news website visir.is on 31.05.20, the most affordable real-estate to buy in the denser part of the greater capital area of Iceland is located in a neighbourhood of Reykjavík called Bakkahverfi (Guðnason). A carto-scope webpage that tells the most up to date average prices of real-estates in the greater capital area of Iceland confirms that the average price for an apartment in that neighbourhood is 575.000 ISK or roughly 3960 EUR*/sqm (Vefsjá Matssvæða). This means that a 70m2 apartment should cost approximately 40.250.000 ISK or 277.390 EUR*.

MORTGAGE RATES IN ICELAND

For this project Arion bank will be used. It is one of the larger banks in Iceland and has an easy-to-use loan calculator. To get a loan from the bank a person needs to undergo payment capacity check to see how big of a loan it can take. The bank offers a free preliminary check on their webpage (Greiðslumatsreiknivél). An individual with a disposable income of 3090 EUR* that owns one car (anybody that has lived in Iceland will know that you need to own a car) has a payment capacity of 180.000-190.000 ISK or ca. 1240-1310 EUR per month. Arion bank offers three different loan types for housing. Non-indexed loans, inflation-indexed loans and mixed loans. Non-indexed loans are ideal for people who want to pay off their loans more quickly and avoid the cost of inflation accumulating on the principle. The repayments on these loans are generally higher to begin with compared to inflation-indexed loans, meaning that fewer people have the option of taking these loans. Inflation-indexed loans have initially lower repayments but take longer to repay the loan in full. Inflation is added to the principal and spread out over the loan period. It is possible to have fixed interests for five years but after that they become variable. Mixed loans are a mixture of both and can make the repayments become more even over the loan period. According to the loan calculator on Arion bank's webpage (Loans) this individual can only afford to take the mixed loan that consists of 25% as non-indexed loan and 75% as inflation-indexed loan over a period of 40 years. The first monthly payments are just under 1240 EUR. However, the monthly payments of these loans can easily change as they are connected to the inflation index and variable bank rates. It means that it is impossible to know how much the loan will grow over these 40 years. If inflation is estimated to be the same as it has been over the last 10 years, 3.8% (in August 2023) the total amount paid is estimated to be 988.280 EUR* or 4.2 times the loan amount. However, if inflation over the next 40 years rises to e.g., 7.6%, the average of the last 12 months (in August 2023) the total amount paid is estimated to be 2.163.820 EUR* or ca. 9.25 times the loan amount (see image to the right).

	Loan amount:	33.915.000	**Loan amount:**	33.915.000
Loan	**Loan 1**	**Loan 2**	**Loan 1**	**Loan 2**
	Non-indexed	**Inflation-indexed**	**Non-indexed**	**Inflation-indexed**
Loan amount	8.478.750	25.436.250	8.478.750	25.436.250
Structure of loan	25%	75%	25%	75%
Loan period	40y	40y	40y	40y
Annual interest	10,39%	3,24%	10,39%	3,24%
Type of interest	Fixed for 3 years	Fixed for 5 years	Fixed for 3 years	Fixed for 5 years
Method of payment	Equal payments	Equal payments	Equal payments	Equal payments
Estimated inflation*		3,8%		7,6%
Loan-to-value	21,25%	63,75%	21,25%	63,75%
Prepayment fee	Yes	Yes	Yes	Yes
Monthly payment	**79.785**	**95.331**	**79.785**	**95.904**
Monthy payment to calculate DSTI ratio	**79.785**	**124.722**	**79.785**	**125.472**
Annual cost ratio	**11,76%**	**7,22%**	**11,76%**	**11,14%**
Borrowing Costs				
Borrowing fee	0	0	0	0
Registration fee	2.700	2.700	2.700	2.700
Administration fee	9.995	9.995	9.995	9.995
Total cost	**12.695**	**12.695**	**12.695**	**12.695**
Loan minus costs		**33.889.610**		**33.889.610**
Total amount paid		**143.399.457**		**313.970.056**

SCREENSHOT FROM ARION BANK LOAN CALCULATOR IN ISK.

BUILDING COST IN ICELAND

Hannar is a company in Iceland that work mainly in consulting in the field of building management. On their webpage they offer a free simple calculator for building costs. The calculator is updated every three months to keep up with the latest numbers from the building industry. According to this calculator, each sqm of a one family timber house costs ca. 600.000 ISK/4.140 EUR*. This includes land prices based on the outskirts of the greater capital area of Iceland (Reiknilíkan Byggingarkostnaðar). By applying common sense, it is obvious that larger houses cost less per sqm and smaller houses cost more per sqm, since the price of the land is already included in the estimated costs. This means that if an individual wished to build a house on that land it would have to be larger rather than smaller to come close to the estimated price of 4.140 EUR/sqm.