BEYOND EFFICIENCY

A SUFFICIENCY FRAMEWORK

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MOTIVATION

IN RECENT YEARS, THE BUILDING SECTOR HAS FACED GROWING SCRUTINY REGARDING ITS ENVIRONMENTAL IMPACT, NECESSITATING INNOVATIVE APPROACHES TO SUSTAINABLE DESIGN AND CONSTRUCTION. AS ASPIRING ARCHITECTS, WE ARE DEEPLY CONSCIOUS OF OUR RESPONSIBILITY TO LEAD THE WAY TOWARDS A MORE RESPONSIBLE BUILDING PRACTICE.

THIS MASTER THESIS REPRESENTS OUR COMMITMENT TO THIS CAUSE, AND WE HOPE THAT IT CAN BE THE SEED THAT SPROUTS A NEW WAY OF PRACTICING ARCHITECTURE AND PUSHES THE BUILDING SECTOR TOWARDS A MORE SUSTAINABLE FUTURE.

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ABSTRACT

This master thesis explores the integration of sufficiency measures as a crucial component in the shift to a sustainable architecture practice, which now is mostly achieved through efficiency measures. Through the research of current design principles in sustainable architecture and case studies, this thesis develops a framework that presents strategic & design principles that can achieve the objective of including sufficiency in architectural design. With the use of an integrated design approach that includes sketching, modelling, life cycle assessments, simulations of light and structures etc., this thesis conceptualizes and exemplifies how efficiency, sufficiency and sufficiency aesthetics can be a part of a sustainable architectural design process.

The thesis is manifested through a small-scale architectural project, the transformation of a ruin on the Danish island, Langeland, that serves as an example of how to apply the framework and proves the effect of the strategic and design principles. The aesthetic approach of the framework and subsequent design seeks to redefine user expectations, promoting consumption that aligns with the Paris agreement. Furthermore, the design showcases how overlooked aesthetic potentials within materials can drive sustainable building practices. Using on-site, reused, biogenic materials and building process byproducts, the project unifies sufficiency and efficiency principles.

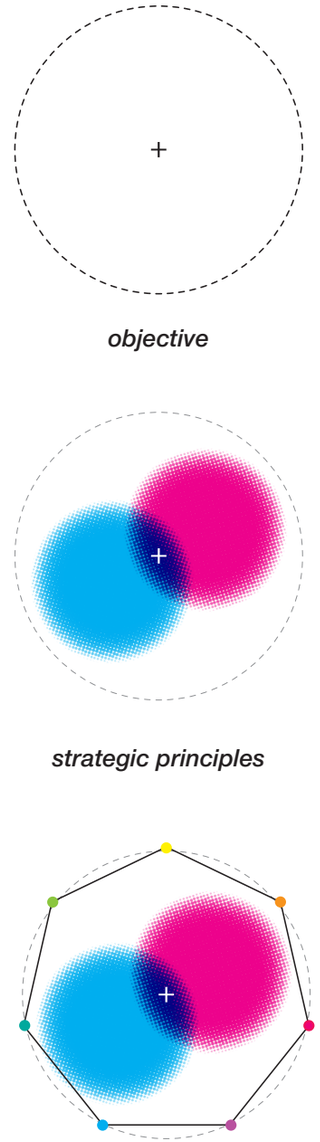
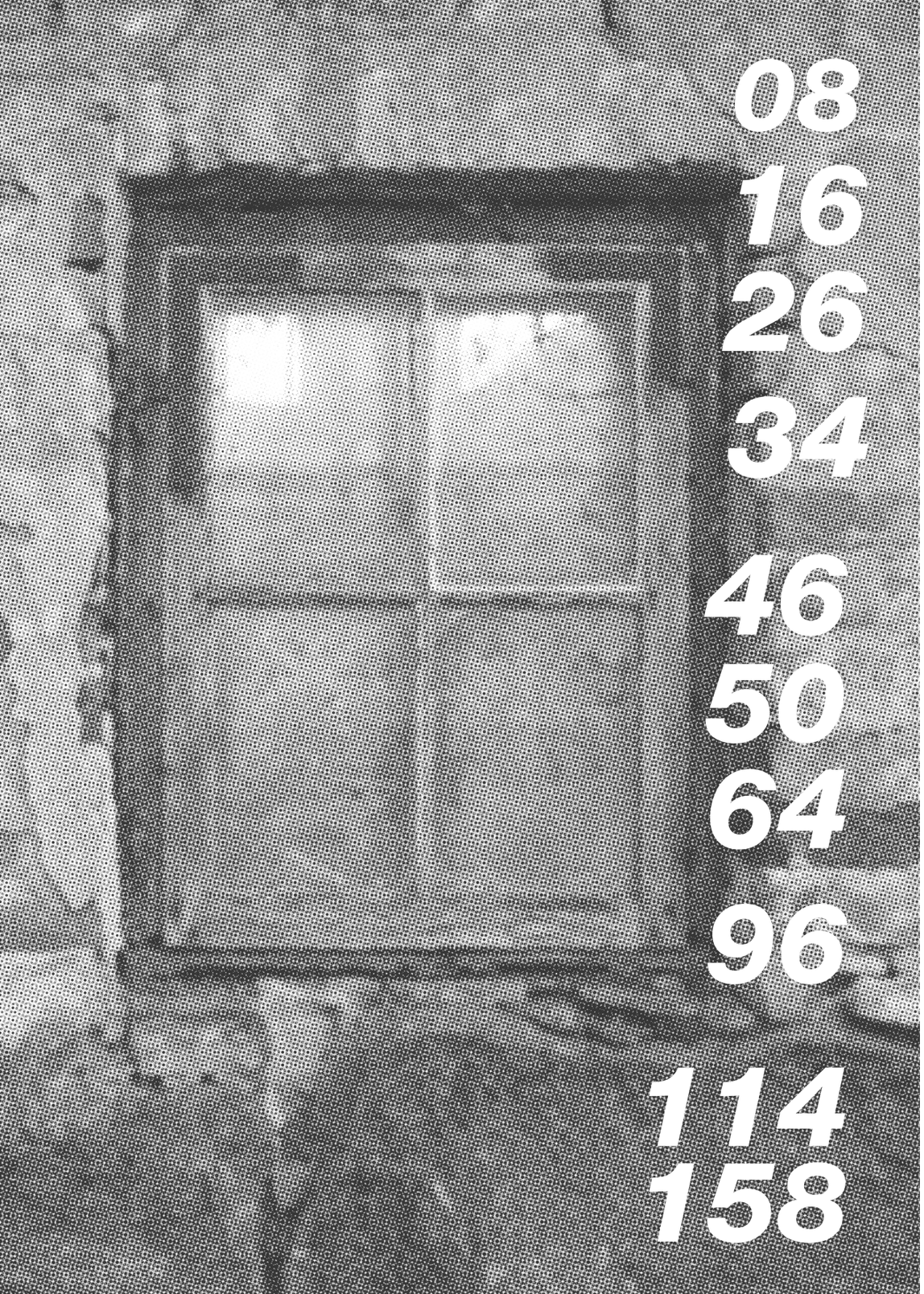


Fig. 01 *preliminary overview of the sufficiency framework.*



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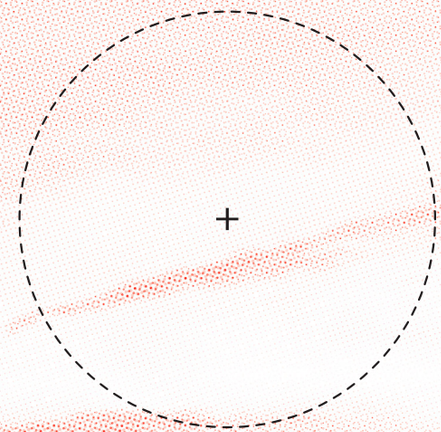
1.0 INTRODUCTION

STEP 1 OF THE SUFFICIENCY FRAMEWORK



objective
change user demand

BEHAVIOUR AND DEMAND

the rebound effect

The energy use per m² in Denmark over the last 30 years has been decreasing, due to buildings becoming increasingly energy efficient. Despite this, the total energy usage for heat consumption in Denmark has stayed the same in the last 30 years. Why?

ENERGY EFFICIENCY

When looking at energy usage for different classed buildings in Denmark, there is a vast gap between theoretical energy usage and the actual usage. A 2016 report documents that more energy efficient buildings use a lot more than theoretically expected, while the less efficient ones use less than expected. The differences in energy uses can be explained in part by the rebound effect. The rebound effect describes the tendency of energy consumption to rise as energy usage becomes more efficient, thereby neutralizing any energy savings that would otherwise have been achieved. (Gram-Hanssen and Rhiger Hansen, 2016).

MORE SPACE

Moreover, as buildings become more energy efficient, they grow larger. In 1980, the average area usage in residential buildings was 43 m²/person. Today, the number has risen to 53,7 m²/person (Danmarks Statistik, 2024). That is a 22% increase in m²/person over 44 years, and it shows no signs of stopping. As the heated floor area increases, energy efficiency measures are, once again, offset by the human inclination towards ever-rising consumption, as illustrated by Figure 2. Not only that, but the demand for more space has the added disadvantage of consuming more materials to build that space.

22%

INCREASE OF M²/PERSON SINCE 1980

CONCLUSION

ENERGY SAVING MEASURES ARE OFFSET BY USER BEHAVIOUR. IN ADDITION, USERS DEMAND MORE SPACE, THAT CONSUME STILL MORE ENERGY TO HEAT AND MATERIALS TO BUILD. IT IS INEFFECTIVE TO DESIGN A SUSTAINABLE BUILDING IF THAT BUILDING'S OCCUPANTS BEHAVE UNSUSTAINABLE, THEREBY OFFSETTING ANY CARBON SAVINGS THAT MIGHT HAVE BEEN INTENDED.

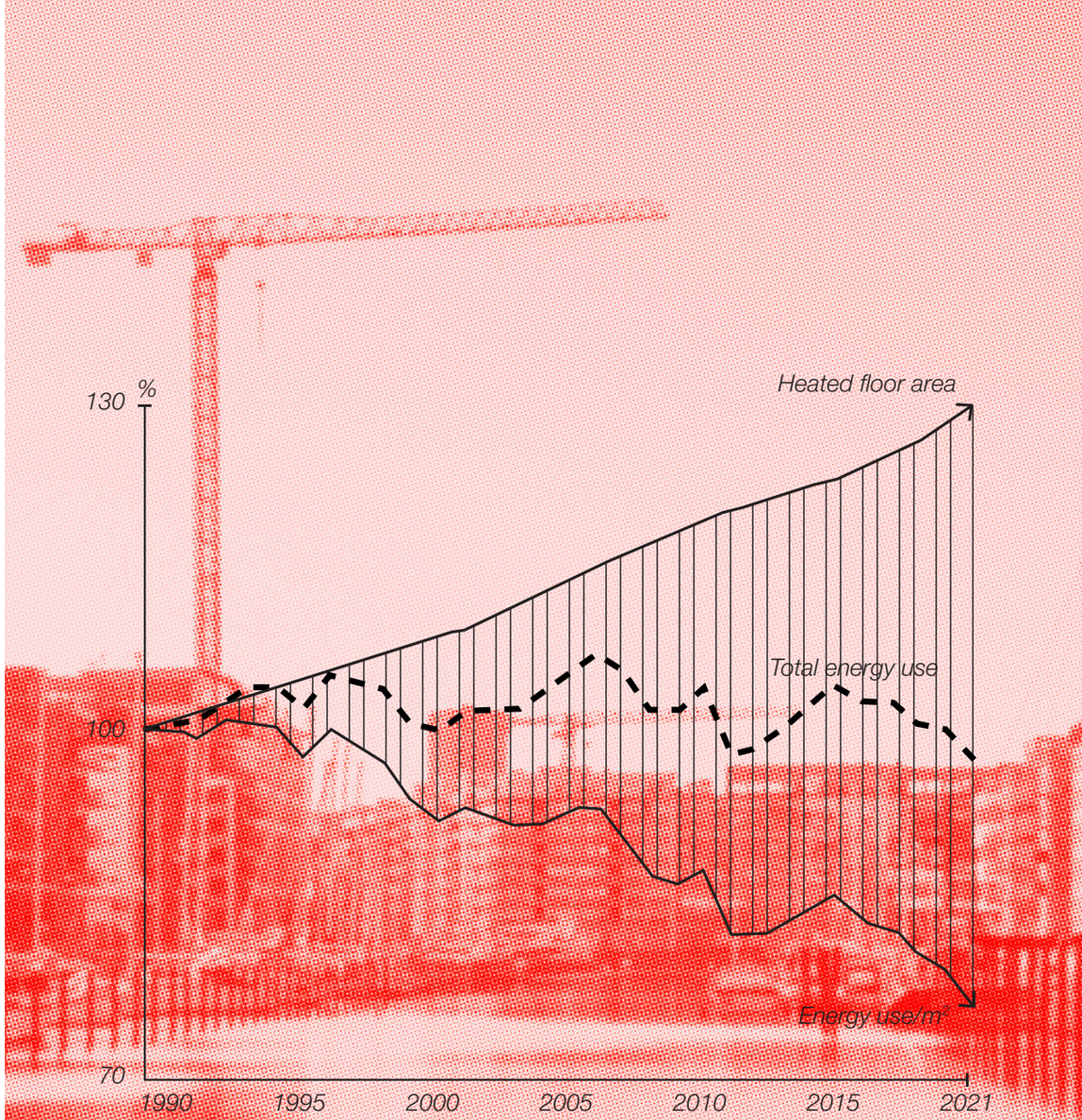


Fig. 02 *The energy use/m² has fallen, while the heated floor area has risen, so the total energy use has only very slightly fallen.*

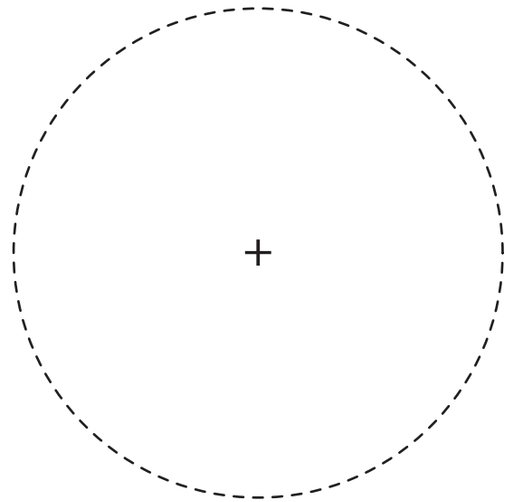
“In its quest for **efficiency and performance**, sustainable architecture has only made us want more – ***more buildings, more extraction, more stuff***. What if architects crafted ***new desires***, within planetary limits?”

- Barber, *2023*

OBJECTIVE

THE PROBLEM OF USER BEHAVIOUR AND EVER RISING DEMAND PERTAINS NOT ONLY TO THE QUESTION OF ENERGY EFFICIENCY AND USAGE. IT RIPPLES THROUGH EVERY ASPECT OF HUMAN ACTIVITY. IT IS IN OUR NATURE TO CRAVE MORE, MORE, MORE. AND YET, WE NEED TO CHANGE TO LIVE WITHIN THE CONFINES OF THE PARIS AGREEMENT, WHICH STATES THAT THE GLOBAL AVERAGE TEMPERATURE SHOULD NOT INCREASE BY MORE THAN 1,5°C.

ARCHITECTS HAVE THUS FAR MET THIS CHALLENGE IN PART BY DESIGNING EFFICIENTLY, WHICH IS COUNTERACTED BY USER BEHAVIOUR. BUT INSTEAD OF MEETING THE DEMAND FOR MORE AND MORE, IT IS TIME TO BREAK THE CYCLE AND CREATE ARCHITECTURE THAT CRAFTS NEW USER BEHAVIOUR THAT IS FOCUSED ON REDUCING DEMAND AND ENCOURAGING USERS TO LIVE WITH LESS. TO LIVE SUFFICIENTLY.

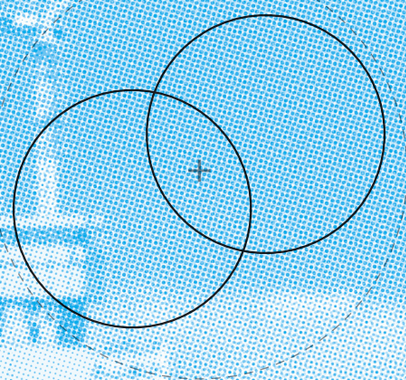


objective
change user demand

Fig. 03 *Step one of the sufficiency framework.*

EFFICIENCY

STEP 2 OF THE SUFFICIENCY FRAMEWORK



strategic principles
efficiency & sufficiency

EFFICIENCY

definition and strategies

Despite the challenge of efficiency measures, they have an important role to play in the sustainable transition of architecture. Efficiency is at the heart of the status quo of sustainable architecture.

ENERGY APPROACH

As outlined in the previous chapter, efficiency is partly concerned with reducing the amount of energy consumed in the use-phase of a building through optimized building components and technical installations. An efficiency approach is also about reducing the environmental impact by shifting to integrated renewable energy sources.

MATERIAL APPROACH

Efficiency is also implemented by reducing the carbon footprint of the materials used in the building industry. Environmental Product Declarations (EPDs) give industry professionals an overview over each material's environmental impact throughout its lifetime, making it possible to choose materials with a reduced environmental impact.

Material use is made further efficient by optimizing the number of times a material can be reused through the implementation of a circular use of materials and building components. Circular material use emphasizes multiple reuses of existing materials and building components to minimize the extraction of virgin materials. This is also applied on a building level where transformation of existing structures rather than demolition has gained popularity.

CONCLUSION

EFFICIENCY DESIGN IS CONCERNED WITH REDUCING ENERGY USE, RENEWABLE ENERGY, CHOOSING MATERIALS WITH A LOW ENVIRONMENTAL IMPACT AND CIRCULAR MATERIAL BY REUSING MATERIALS AND TRANSFORMING EXISTING STRUCTURES.

LIFE CYCLE ASSESSMENT

evaluating efficiency

The Danish building industry has implemented efficiency initiatives to comply with the Danish Building Regulations to reduce the industry's environmental impact. The initiatives are assessed through LCA, and the methodology has been translated into regulations to make building developers able to calculate and reduce climate impact building projects have.

DEFINITION

A Life Cycle Assessment is an analysis of the potential environmental impact of a building during its entire life cycle, from extraction of raw materials, through production, use, and eventually disposal or recycling, as illustrated by Figure 5. LCA can initiate a comparison between the environmental impact of various solutions and be used as a design driver in the design process, as well as a tool that ensures the climate impact does not exceed the maximum allowable limit values for CO_2 emissions.

In the Danish building industry LCA is used to calculate a building's environmental impact over a period of 50 years. Since the beginning of 2023, new building over 1.000 m^2 must not exceed the limit value of 12 kg. CO_2-eq./m^2/year as specified by the Danish Building Regulation. (BR18, 2023)

CONCLUSION

LCA IS CURRENTLY THE MOST COMMON WAY OF EVALUATING A BUILDING'S CLIMATE IMPACT AND OPERATES WITHIN THE SAME FRAMEWORK AS EFFICIENCY, FOCUSING ON MATERIAL AND ENERGY USE. THE LIMIT VALUE FOR LIFE CYCLE ASSESSMENTS IN THE DANISH BUILDING REGULATION IS 12 KG. CO_2-EQ./M^2/YEAR. IS THAT AMBITIOUS ENOUGH?

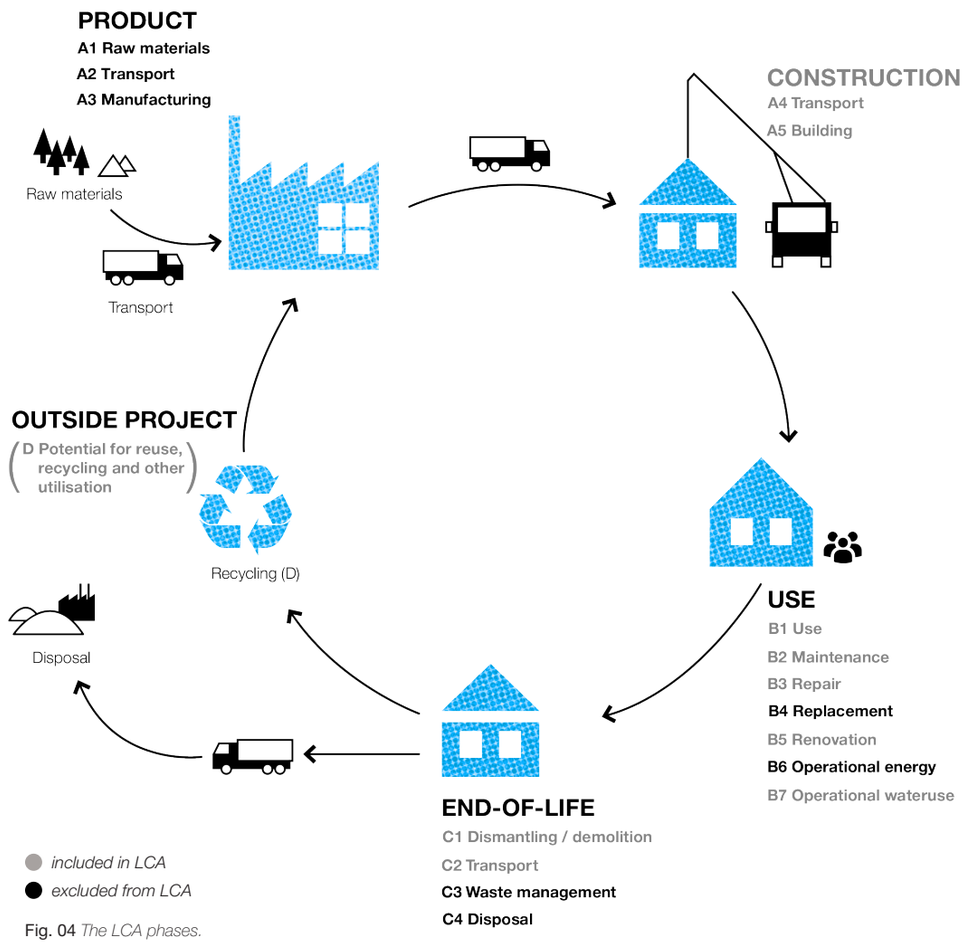


Fig. 04 *The LCA phases.*

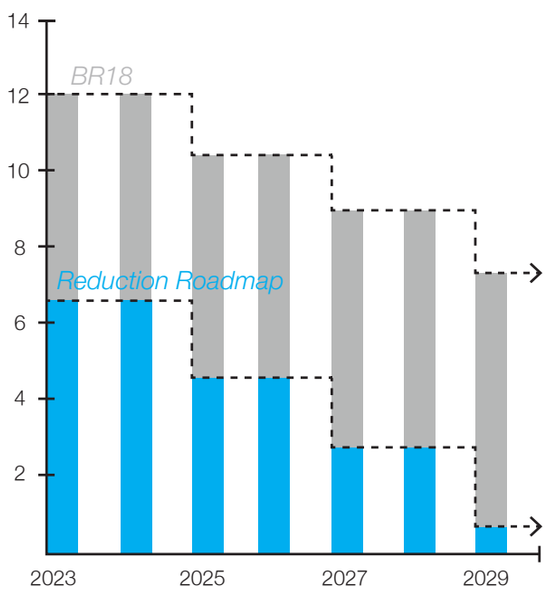
REDUCTION ROADMAP

adjusting the LCA target

Reduction Roadmap is an ambitious initiative developed by EFFEKT, Artelia and CEBRA, that translates the Paris Agreement into a LCA limit value for new buildings.

NEW LIMIT VALUE

The roadmap identifies the current CO_2 emissions from buildings in Denmark, the impact goal and the necessary rate of emission reduction to comply with the Paris agreement. It clearly states that the Danish building industry, even though many efficiency initiatives have been implemented, currently operates far away from the Paris Agreement. This means that it is necessary to reduce the emissions of greenhouse gasses significantly if the buildings are to be within the Paris Agreement's goals of a maximum temperature increase of 1,5°C. If residential construction continues at the same pace as today, CO_2 emissions must be reduced from 9,63 to 0,4 kg CO_2-eq./m^2/ year in 2029, which is a reduction of 96%, as illustrated by Figure 6. The current limit value being proposed by Reduction Roadmap is 5,8 kg. CO_2-eq./m^2/year. (Reduction Roadmap, 2023).



96%

SUGGESTED REDUCTION OF EMISSIONS

CONCLUSION

THE CONSTRUCTION INDUSTRY MUST REDUCE CO_2EQ EMISSIONS BY 96% IN THE NEXT 5 YEARS, WHICH PUTS SIGNIFICANT PRESSURE ON THE INDUSTRY'S ABILITY TO IMPLEMENT EFFICIENCY INITIATIVES.

Fig. 05 *Reduction of LCA limit value over time, as proposed by the Danish Building Regulation (BR18) and Reduction Roadmap.*

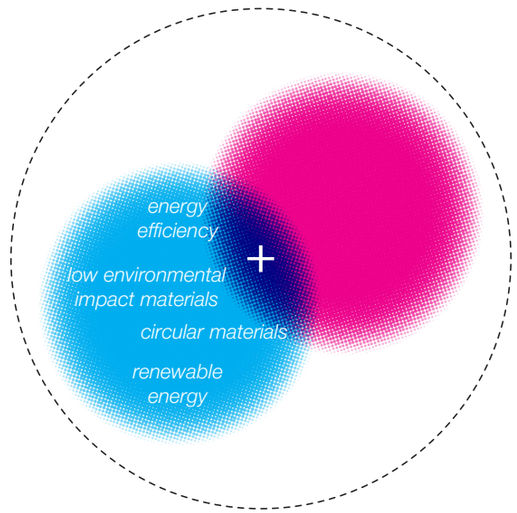
"The current legislation **limiting LCA to 12kgCO_2eq/m^2/year** is like setting a speed limit at 300km/h. **So high that it's pointless.**"

- Sinus Lynge, *EFFEKT & Reduction Roadmap*

EFFICIENCY

THE BUILDING INDUSTRY'S CURRENT WAY OF TACKLING THE CLIMATE CRISIS IS THROUGH EFFICIENCY APPROACHES. THESE INCLUDE REDUCING ENERGY USE, RENEWABLE ENERGY, CHOOSING MATERIALS WITH A LOW ENVIRONMENTAL IMPACT AND CIRCULAR MATERIAL USE. THESE STRATEGIES ARE MEASURED THROUGH LCA, ALTHOUGH THE CURRENT LIMIT VALUE IN BR18 IS NOT AMBITIOUS ENOUGH, WHICH REDUCTION ROADMAP OUTLINES. THE LIMIT VALUE MUST DECREASE DRASTICALLY, WHICH CALLS FOR RADICAL ACTION AND MIGHT BE UNLIKELY TO ACHIEVE THROUGH EFFICIENCY MEASURES ON THEIR OWN.

EFFICIENCY STRATEGIES ARE VERY IMPORTANT TO IMPLEMENT TO ACHIEVE A SUSTAINABLE BUILDING PRACTICE. YET, EFFICIENCY IS ULTIMATELY CONCERNED WITH MEETING USER DEMANDS. AS A RESULT, ILLUSTRATED BY THE REBOUND EFFECT, EFFICIENCY STRATEGIES ARE OFTEN OFFSET BY USER BEHAVIOUR. FOR EFFICIENCY TO TRULY FLOURISH, OTHER MEASURES MUST BE TAKEN INTO USE.

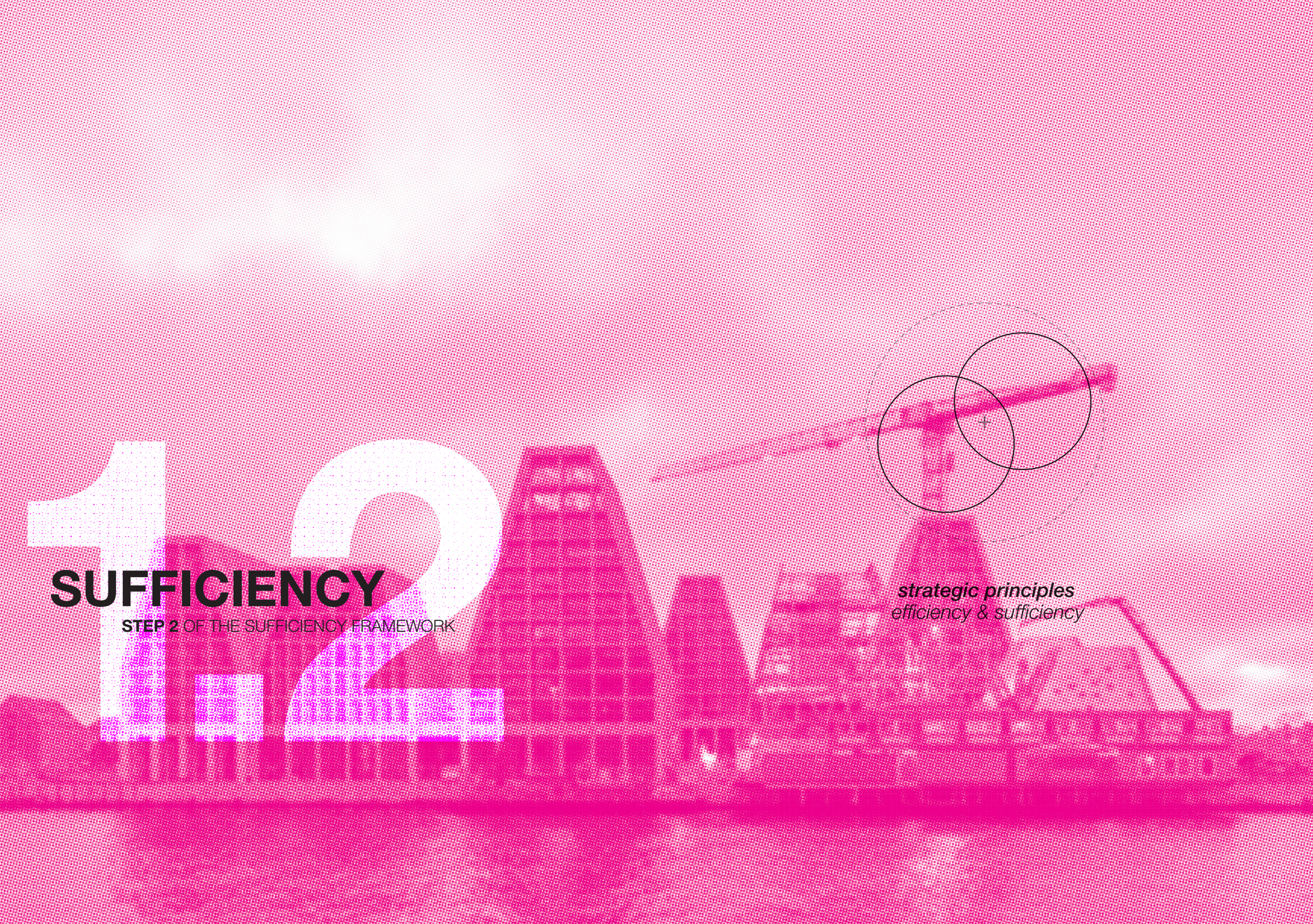


the approach
efficiency & sufficiency

Fig. 06 *First half of step two of the sufficiency framework.*

1.2 SUFFICIENCY

STEP 2 OF THE SUFFICIENCY FRAMEWORK



strategic principles
efficiency & sufficiency

SUFFICIENCY

the sufficiency imperative

March 16th marked Earth Overshoot Day for Denmark in 2024, meaning that after 76 days we had used our yearly share of the Earth's resources – the 6th country in the world to do so. This means that the rest of the year we use more resources than the Earth can naturally generate. And yet, Denmark is perceived as a forerunner for the sustainable transition (Geneva Environment Network, 2024).

THE NEED FOR CHANGE

By solely focusing on changing the way we build through efficiency and evaluating it with LCA while still demanding the same outcome; the same amount, the same comfort, the same luxury, and the usual aesthetics, we put unrealistic pressure on efficiency in the process.

The solution to this is sufficiency, which is a set of measures and daily practices that minimize the demand for energy, material, land, water and other natural resources. In this context, sufficiency emerges as a nuanced approach that seeks to strike a balance between meeting human needs and respecting the limitations of the natural environment. Rather than advocating for radical downsizing or deprivation, sufficiency challenges architects to rethink conventional norms of consumption and luxury, emphasizing the importance of moderation, adaptability and resilience (Barber, 2023).

CONCLUSION

REACHING THE GOAL OF REDUCING BUILDINGS' ENVIRONMENTAL IMPACT SEEMS FAR OFF WITH EFFICIENCY MEASURES ALONE. INSTEAD, THERE IS A NEED TO RETHINK WHAT WE EXPECT FROM BUILDINGS, WHICH IS WHAT SUFFICIENCY TEACHES. THE FOLLOWING CHAPTERS WILL DEFINE SUFFICIENCY DESIGN.

SPACE & COMFORT

living with less

We need to reduce the demand for energy and material consumption. How can sufficiency measures achieve this?

SPACE

The floor area per capita has generally been increasing in the last decades in the wealthier European countries. Denmark is, with a floor area of 53,7 m^2 per person (Danmarks Statistik, 2024), the least sufficient country in EU in teams of space, while the EU average floor area per capita is at 38m^2. To achieve the Paris Agreement's target of limiting global warming to 1,5°C and a fully de-carbonized global building stock in 2050, a 2021 report estimates that the global average space distribution should be 30m^2/person. (Saheb, 2021).

As a contribution to the transition towards a low-carbon society, the sufficiency approach, as a de-carbonisation strategy, reduces the demand for energy and materials. One aspect of sufficiency is space. The floor space of a building and its volume are drivers of its actual energy consumption. A general definition on implementation of sufficiency in buildings has been formulated as "the adequate space thoughtfully constructed and sufficiently equipped for reasonable use". (Bierwirth and Thomas, 2019)

COMFORT

Another sufficiency approach is Another sufficiency approach is to change the thermal comfort by decreasing the internal temperature in a building. This can contribute to a significant reduction in the energy demand and CO_2 emissions (Szałański et al., 2023).

A 2018 German study on the frequency distribution of winter temperatures in German rental flats shows that the indoor temperatures have been rising with advancing energy efficiency, and that the temperatures have been getting more constant in the new passive houses. In rentals from before 1978 the average winter temperature was 18°C, while it was 22°C in the passive houses. (Schröder et al., 2018) Reducing the indoor temperature have the potential of lowering the energy use with 6-8% per °C (Szałański et al., 2023).

30m^2

PER PERSON GLOBALLY.

> "There might be ways of crafting buildings and equipment that ***do not meet present needs*** [...], but that do ***enable and sustain much lower carbon ways of life***."
>
> – ***Shove,*** *2018*

This is another case of the rebound effect. It shows that people are arguably satisfied living in these older buildings with lower temperatures and a broader range of different temperatures, while the advancement in technology has led to higher temperatures.

LOW-TECH SOLUTIONS

It would be beneficial to reverse-engineer the technological approach to indoor comfort and instead focus on implementing low-tech solutions for indoor comfort control. Implementing low-tech solutions, such as passive design strategies, will contribute to energy savings by utilizing natural phenomenon, reduce the initial and maintenance costs by reducing the demand for technological building systems. Lastly it reduces the complexity (Preisler, Berger and Gasser, 2016). Furthermore, people are more likely to feel satisfied with the indoor environment, if given more adaptive opportunities (Zhang and de Dear, 2016).

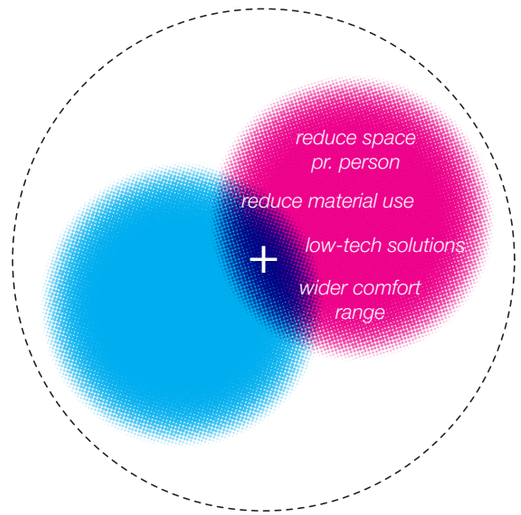
CONCLUSION

REDUCING SPACE, LIMITING MECHANICAL COMFORT CONTROL AND FOCUSING ON LOW-TECH CONTROL OVER COMFORT IN THE SUFFICIENCY APPROACH TO DESIGN CAN LEAD TO SIGNIFICANT CHANGES IN ENERGY AND MATERIAL USAGE. THEREBY CAUSING SIGNIFICANT REDUCTIONS IN THE CARBON FOOTPRINT OF THE BUILDING SECTOR. THESE ARE VERY CONCRETE SUFFICIENCY SOLUTIONS THAT CAN BE USED TO DIRECTLY DECREASE CONSUMPTION.

SUFFICIENCY

SUFFICIENCY DESIGN IS CONCERNED WITH CHALLENGING THE STATUS QUO AND THE WAY WE INTERACT WITH BUILDINGS TODAY. USER EXPECTATION IS NOT THE MAIN DRIVER FOR SUFFICIENCY, UNLIKE EFFICIENCY. SUFFICIENCY ADVOCATES FOR LESS. THE AREA WE INHABIT SHOULD BE REDUCED TO 30M²/PERSON, OUR COMFORT ZONE SHOULD BE CONTROLLED WITH LOW-TECH SOLUTIONS AND WE SHOULD NOT EXPECT TO HAVE ALL OUR NEEDS MET IN A BUILDING.

BUT IN A WORLD WHERE CHOICES AND PROGRESS ARE DRIVEN BY ADVANCEMENTS, WE MUST FIGURE OUT HOW SUFFICIENCY CAN BE A COMPELLING APPROACH FOR ARCHITECTS, DEVELOPERS, AND USERS. THIS IS WHERE AESTHETICS COMES INTO PLAY.



the approach
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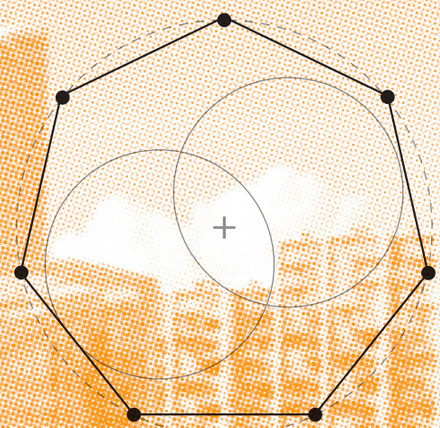
Fig. 07 *Second half of step two of the sufficiency framework.*

SUFFICIENCY AESTHETICS

STEP 3 OF THE SUFFICIENCY FRAMEWORK



design principles
sufficiency aesthetics

SUSTAINABILITY AESTHETICS

state of the art

Before sufficiency aesthetics are characterised and developed, the current landscape of aesthetics must be surveyed. As of right now, sustainability aesthetics are a result of the sustainability mitigation solution, which relies on efficiency. It is characterized by a focus on sustainable material choices and energy optimization strategies, to achieve a low result in life cycle assessments. To define the term closer, the following will examine the current landscape and trends of sustainable aesthetics in Danish architecture.

BIOGENIC MATERIALS

It is by now a well-known fact that material use has a significant environmental impact and that the use of materials such as concrete and steel needs to be reduced significantly. These are materials that we have relied heavily upon until now, so what do architects replace them with? One material presents itself as the obvious choice: timber. Timber is the most versatile material in terms of structural properties and aesthetic appeal when judging by climate impact. It performs very well in life cycle assessments, and it is present in most contemporary projects. Vandkunsten is a studio that is well known for timber projects, such as Skråningen (2019) in Lejre or Lisbjerg Bakke (2018) in Aarhus. Other biogenic materials such as hay, straw or clay are being utilized in insulation.

REUSE

Another sustainable choice that is becoming more common is reused materials. While they may not be load-bearing, they offer a significantly lower climate impact than their newly manufactured counterparts. This is creating an interesting new aesthetic, where materials are used in new ways: as in the case of Lisbjerg, a Lendager project that reuses roof tiles as façade cladding (see Figure 8). Reusing materials also adds patina to a building from its inception; material imperfections add history to a new building.

Fig. 08 *Lisbjerg by Lendager (2022). Photo by Giedre Skucaite.*

Fig. 09 *The Silo by Cobe (2017). Photo by Rasmus Hjortshøj.*

TRANSFORMATION

More than just reusing materials, projects that reuse whole structures are becoming increasingly popular. These transformation projects use existing buildings and renovate them to accommodate a new usage or update them. Many transformation projects originate in industrial buildings that are no longer in use. By adding and changing these, an interesting effect takes place where the contrast between old and new is highlighted. Such is the case with Cobe's project The Silo, that utilizes an old industrial concrete structure by mounting a new façade on it and renovating the interior for residential use (see Figure 9). Here, the industrial heritage is contrasted by a new steel façade. The same is true for Copenhagen Contemporary, transformed by Dorte Mandrup from an industrial hall to a museum space. Here, the industrial exterior is largely preserved, whereas the interior has been renewed. Both projects reveal an interesting aesthetic, that is concerned with respecting the old structure and retaining its character in the new structure, while also creating a contrast between new and old.

CONCLUSION

THE CURRENT STATE OF SUSTAINABILITY AESTHETICS IS DIRECTLY LINKED WITH EFFICIENCY SOLUTIONS AND IS CHARACTERIZED BY USING BIOGENIC MATERIALS, REUSING MATERIALS, AND TRANSFORMING EXISTING STRUCTURES. SUSTAINABILITY AESTHETICS MUST BE BROADENED TO INCLUDE SUFFICIENCY. BUT WHAT CHARACTERIZES SUFFICIENCY AESTHETICS? THE FOLLOWING SECTIONS WILL EXPLORE THIS.

SUFFICIENCY AESTHETICS

a case study

To describe what a sufficiency approach might look like aesthetically, the following will present a case study of House 14a by Pihlmann Architects, built in 2023. (Pihlmann, 2024). This project has an exemplary approach to sufficiency aesthetics. The house, located in Copenhagen, was originally built in 1951 and is a classic example of a post-war house. The transformation creates an interesting dialogue between the remnants of the original elements, reused elements placed in a new setting and virgin materials.

Fig. 10 *Photo by Hampus Berndtson.*

MATERIAL ASSEMBLY

The interior wall and ceiling cladding is made up of plywood panels with variating patterns and colour hues that seem to be sourced separately from each other, disregarding traditional aesthetics that would be concerned with using matching panels. Likewise, the wooden flooring is made up of a very untraditional joining of plywood panels, herringbone flooring, and wooden planks. This contrast is not hidden – on the contrary, it is emphasized through very distinctive and impromptu transitions that seem to have been done ad hoc on-site with the available materials. This creates an aesthetic that seems less concerned with perfection and more interested in non-traditional material meetings between imperfect surfaces.

Reused bricks are used as detailing and lintels, looking rough and worn, still covered in the mortar from the bricks' previous lives. These stand in stark contrast to the virgin bricks in the building, as well as the smooth surfaces of the plywood panel. This is an interesting choice to draw attention to the worn quality of a material that would otherwise be a waste product or cleaned thoroughly before reuse. Instead, the worn-down material is embraced and tells a story of circularity.

MATERIAL APPROACH

The material selection is carefully considered, not only regarding carbon footprint, but also delves deeper to unlock the inherent functional and aesthetic potential within each element. Each surface and component transcends its environmental impact, becoming active participants in solving specific tasks. This meticulous approach minimizes waste while optimizing performance. Using the material bank available to them, House 14a by Pihlmann explores the potential of fusing past and present and not disregarding any building component but finding a functional and aesthetic use for every element, creating a very thoughtful yet unpolished aesthetic.

Fig. 11 *Photo by Hampus Berndtson.*

Fig. 12 *Photo by Hampus Berndtson.*

CONCLUSION

HOUSE 14A REVEALS AN INTERESTING AESTHETIC, THAT ALMOST SEEMS LIKE A MATERIAL COLLAGE TECHNIQUE, RESULTING FROM USING MATERIALS TO SOLVE SPECIFIC PROBLEMS. THE FOCUS IS ON USING THE MATERIALS AVAILABLE ON SITE, IMPORTING AS FEW VIRGIN MATERIALS AS POSSIBLE AND ON EXPOSING MEETINGS BETWEEN MATERIALS.

POTENTIAL OF IMPERFECTION

wabi-sabi, chaos & order

In today's architectural landscape, buildings are very often expected to be flawless, with pristine surfaces and sleek lines. But in this search of the perfect, the value of imperfections is overlooked and forgotten. A change in the aesthetic qualities of materials and how they are put together is necessary to move towards a more sustainable use of materials, to question the conventional idea of beauty.

WABI-SABI

One philosophy of beauty in the unfinished and imperfect is the Japanese philosophy know as wabi-sabi. Today's standard understanding of how and when a building is finished has resulted in generic mass-produced architecture that emphasizes perfect and quick solutions through technology and an adaptation to machines. We rarely emphasize the potential of unfinished and imperfection in architecture, where the building elements are not hidden away by layers of mortar, paint and seamless joints.

Wabi-sabi as a philosophy in architecture can address the beauty of natural and raw materials with imperfections, simplicity, irregularity, and patina. Embracing these principles in architecture will decrease consumption of materials, which purpose is only to serve as a finish on construction elements (Koren, 1994). A more conscious philosophy on imperfections can serve a more holistic approach towards the aesthetical evaluation; in the material choice and amount, and how the different materials will be put together. This also includes utilizing the inherent potentials of reused materials and their aesthetics.

Fig. 13 *an example of wabi-sabi, Koldinghus. Restored by Inger and Johannes Exner. Photo by S. Juhl.*

CELEBRATE THE BROKEN

A Japanese practice that exemplifies the spirit of wabi-sabi is the restoration of broken pottery with gold or silver lacquer, also known as kintsugi. In this way, the cracks and faults are emphasized rather than masked, and the repaired fragments are a part of their history and their beauty. A repair technique of Kintsugi called Yobitsugi also introduces other pieces to fill the gaps. This is done if you don't have all the pieces needed for the repair, and it can reveal an even greater contrast and celebration of its history. (Herbert F. Johnson Museum of Art, 2008).

Inspired by the practice of Kintsugi and Yobitsugi, damaged architectural structures can be repaired in this way to utilize the inherent value of the structure, make it usable again, all while celebrating its history through the contrasting elements and signifying the importance of reuse and transformation through its aesthetics.

CHAOS AND ORDER

Inherent in the reused materials, reused structures and lack of finishes in the meetings of materials lies an accompanying visual chaos. This chaos gives richness to the atmosphere through the patina of the reused materials and structures, and the history that they bring with their aesthetics. The exposure of joints between materials and the imperfect surfaces also gives an awareness and deeper understanding of the material composition of the building.

But to fully unleash the potential of the imperfections and their visual chaos, it needs to be balanced with order. While the chaos revives the architectural dimension and gives it and individual dimension, order will evoke the feeling of harmony (Rubinowicz, 2000). Using ordering principles in design will allow the chaos of imperfections to coexist within an ordered, harmonious whole. These ordering principle are axis, symmetry, hierarchy, datum, rhythm and transformation (Ching, 2007).

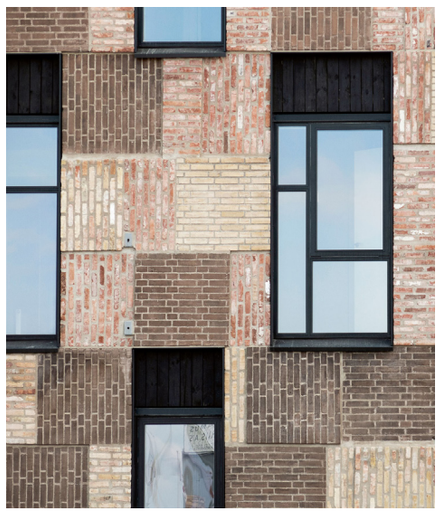


Fig. 14 *putting chaos in order, Ressourcerækkerne. Architect: Lendager. Photo by Nicholas Duxbury Ransome.*

CONCLUSION

TO MOVE TOWARDS A NEW UNDERSTANDING OF SUSTAINABLE AESTHETICS, WE SHOULD EMBRACE THE PRINCIPLES OF WABI-SABI BY NOT COVERING JOINTS AND SEAMS UP, VALUE THE IMPERFECTIONS OF MATERIALS AND EMBRACE THE CHAOS OF REUSE WHILE STILL DESIGNING IN HIGH QUALITY WITH THE HELP OF ORDER.

SUSTAINABLE TECTONICS

durability, adaptability & beauty

Tectonics and sustainability in architecture are interconnected through bringing together structure, function, and aesthetics in an ever-shifting balance between harmony and chaos. 2000 years ago, Vitruvius wrote De Architectura, where he defines architectural quality through the Vitruvian triad: Firmitas (structure), utilitas (function), venustas (beauty). Seeing tectonics through the Vitruvian lens can unlock a new approach to sustainable architecture with sufficiency aesthetics.

FIRMITAS AND UTILITAS

Vitruvius viewed firmitas as the structural aspect of a building, including material selection and the building's components, and is also commonly translated to structure or durability. The latter, durability, is an integral element of sustainable architecture. The least we can do when building new structures and depleting the planet's finite resources is to create structures designed for longevity that can withstand changing times. The materials that are put into the new structures need to be carefully designed for disassembly and in terms of durability against the weather and use, so that they keep their value as much as possible. It also includes fluctuating aesthetic sensibilities and user needs – therefore, durability can only be achieved by also designing adaptable buildings. The concept of utilitas is preoccupied with the functionality of a building, or a building's function.

In a contemporary framework that is concerned with sustainable building practices, there is no more sustainable choice to make other than preserving the existing building mass. To achieve this, buildings must be structurally sound and durable (firmitas) but equally important: adaptable. Today many buildings are derelict and falling into ruin because their original purpose is no longer in demand. Therefore, it is essential to create adaptable buildings can that stand the test of time by being transformed over time.

VENUSTAS

In Vitruvius' world view, venustas described beauty. The contemporary understanding of the term is about the spatial and aesthetic experience of architecture. The role of aesthetics for achieving durable, adaptable buildings cannot be understated. Aesthetics is arguably the most front-facing corner of the triad, determining how users and the broader public respond to the building. (Vitruvius Pollio et al., 1999).

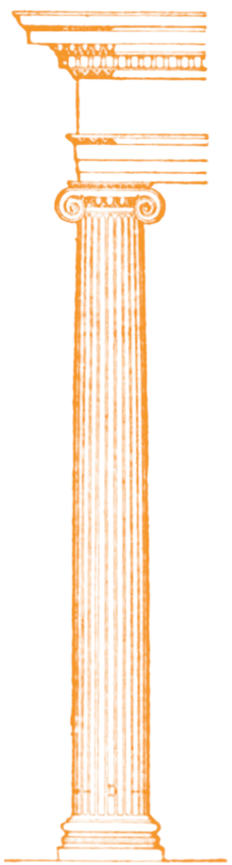


Fig. 15 *from De Architectura.*

BEAUTY OF SUFFICIENCY

The current tendency of prioritization on energy efficiency leads to thicker dimensioned walls, floors, and roofs. This entails that the structural elements become objects covered and hidden by thick layers of insulation and gypsum board. Instead, it should be questioned whether cladding is necessary in some circumstances and whether it might not lead to an interesting aesthetic that prioritizes sufficiency.

The intersection of durability and adaptability can be expressed through materials. As the case study of House 14a documents, reusing worn materials with patina can tell a story of a time past and create a feeling of connectedness with the past and future lives of a building, creating an understanding of the durable as well as adaptable nature of architecture. Adaptability through materials is especially apparent in material joints. Creating visible, reversible joints that are seemly done ad hoc and impromptu on the building site with the available building materials creates a visual representation of the fact that the building or building component will one day be disassembled and reused in a new context.

Fig. 16 *adapting a ruined structure to modern use. Koldinghus. Restored by Inger and Johannes Exner.*

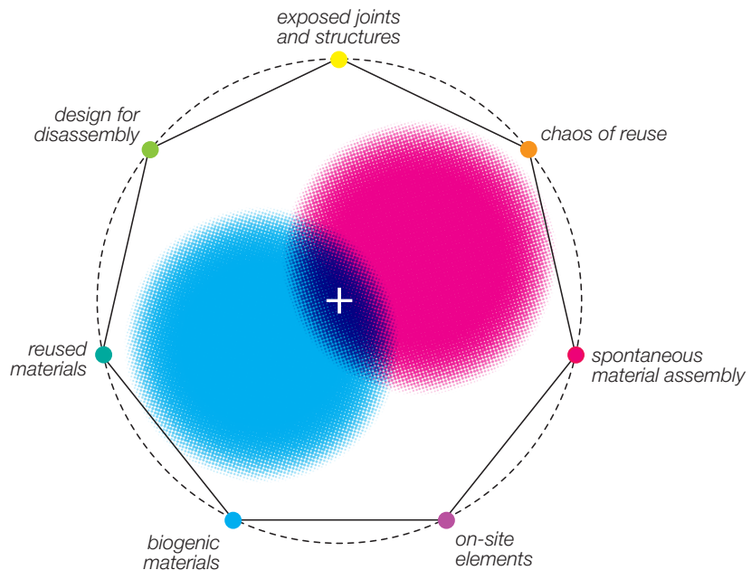
CONCLUSION

TRANSLATING FIRMITAS INTO DURABILITY AND UTILITAS INTO ADAPTABILITY REVEALS A WAY OF BUILDING THAT PRIORITIES THE LONGEVITY OF A STRUCTURE AND THEREBY MINIMIZING THE EXTRACTION OF RAW MATERIALS. BEAUTY IS NECESSARY TO SWAY THE OPINION OF THE PUBLIC AND CHANGE USER EXPECTATIONS. THE BEAUTY OF EFFICIENCY SHOWS A NEW AESTHETIC THAT DOES NOT COVER UP, EMBRACES ALL MATERIALS AND CREATING JOINTS THAT ARE DESIGNED FOR DISASSEMBLY WITH VISIBLE, REVERSIBLE JOINTS.

SUFFICIENCY AESTHETICS

THE WAY WE PERCEIVE BUILDINGS IS CRUCIAL TO HOW WE UNDERSTAND HOW THEY OPERATE AND WHAT WE EXPECT OF THEM. THE APPEARANCE OF A BUILDING SUBCONSCIOUSLY INFORMS THE USER OF HOW COMFORTABLE THEY CAN EXPECT TO BE WITHIN IT. WITH A NEW AESTHETIC APPROACH, DUBBED SUFFICIENCY AESTHETICS, THE IMPLEMENTATION OF SUFFICIENCY MEASURES CAN BE ACCEPTED BY THE USERS AND THE RESULT OF EFFICIENCY STRATEGIES CAN BE MAXIMIZED.

THE SEVEN DESIGN PRINCIPLES CAN BE APPLIED TO ARCHITECTURE PROJECTS TO ACHIEVE SUCCESSFUL IMPLEMENTATION OF EFFICIENCY AND SUFFICIENCY STRATEGIES.



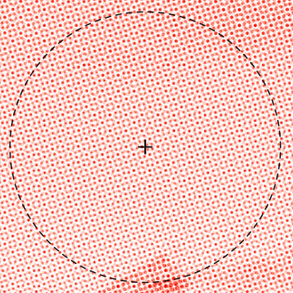
the strategy
sufficiency aesthetics

Fig. 17 *Step three of the sufficiency framework.*

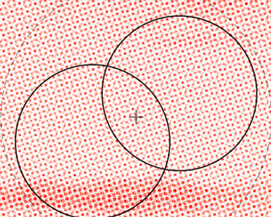
11

THE SUFFICIENCY FRAMEWORK

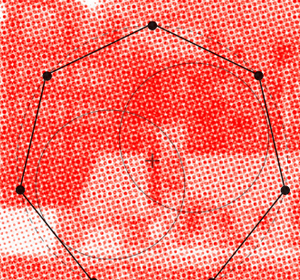
FINAL OVERVIEW OF THE SUFFICIENCY FRAMEWORK



objective
change user demand



strategic principles
efficiency & sufficiency



design principles
sufficiency aesthetics

THE SUFFICIENCY FRAMEWORK

THE BUILDING INDUSTRY'S CURRENT SOLUTION TO LIMIT GREENHOUSE GAS EMISSIONS LIES WITHIN EFFICIENCY, SUCH AS ENERGY EFFICIENCY OR USING MATERIALS WITH LOW GLOBAL WARMING POTENTIAL: QUANTITATIVE APPROACHES. BUT IN THE WESTERN WORLD WHERE CONSUMER DEMAND AND EXPECTATIONS ARE EVER-RISING, EMISSIONS SAVED ARE CANCELLED OUT BY USER BEHAVIOUR. SUFFICIENCY AND EFFICIENCY ARE EQUALLY IMPORTANT BUT MUST WORK IN PARALLEL: SUFFICIENCY MEASURES CAN UNLOCK THE FULL POTENTIAL OF EFFICIENCY STRATEGIES AND VICE VERSA.

THERE IS A STRONG PRECEDENT FOR THE IMPLEMENTATION OF EFFICIENCY MEASURES THROUGH LIFE CYCLE ASSESSMENTS, ENERGY CALCULATIONS AND INDOOR CLIMATE SIMULATIONS, AND ARE THEREFORE REASONABLY UNCOMPLICATED TO QUANTIFY. SUFFICIENCY, ON THE OTHER HAND, REQUIRES A MORE QUALITATIVE APPROACH AND THERE ARE NO CURRENT GUIDELINES FOR SUCCESSFUL IMPLEMENTATION. SO HOW DO WE ACHIEVE A CHANGE IN USER BEHAVIOUR? THROUGH AESTHETICS, THAT SHOULD BE USED AS DESIGN CRITERIA.

USING THE SEVEN PROPOSED PRINCIPLES OF EXPOSING JOINTS AND STRUCTURES, CHAOS OF REUSE, SPONTANEOUS MATERIAL ASSEMBLY, ON-SITE ELEMENTS, BIOGENIC MATERIALS, REUSED MATERIALS AND DESIGN FOR DISASSEMBLY, WILL RESULT IN A BUILDING THAT IS NOTICEABLY DIFFERENT FROM THE STATUS QUO OF AESTHETICS. SIGNALLING TO THE USER, THAT THIS IS NO ORDINARY BUILDING AND A REDEFINITION OF HEALTHY AND HAPPY LIVING.

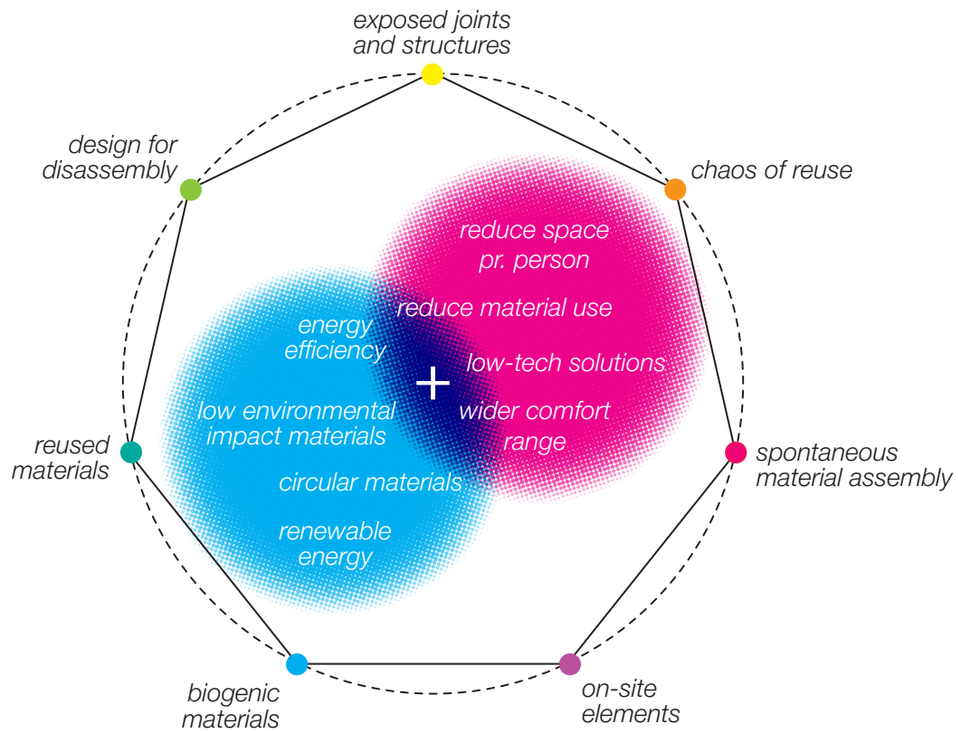


Fig. 18 *The sufficiency framework.*

SITE ANALYSIS
LINDELSE MØLLE

Fig. 19 *pictures from the site.*

INTRODUCTION

validating the sufficiency framework

With the sufficiency framework established, this thesis will proceed to validate it through an architectural design process and presentation. The following will introduce the motivation for choosing this particular site and the potentials it holds for the application of the framework.

PROJECT DESCRIPTION

In the small town of Lindelse, located on the island Langeland, an old traditional mill is a local gathering point. Next to the mill lies an old farm ruin, which the locals wish to transform into a meeting point for cultural and local activities. This transformation of this ruin is the focal point for applying the sufficiency framework. The project site was the subject of a 2023 Realdania competition, where architects were invited to send in sketch proposals. This competition outlined a program that this thesis will re-purpose in the interest of saving time for working on the framework and subsequent design process.

SITE POTENTIALS

Lindelse Mølle has been chosen due to several reasons, both practical and aesthetical. First off, with it being small-scale project of 300m^2, it has a manageable size, which allows time for designing details, joints and comprehensive material choices that is necessary to apply the framework. Additionally, with the program already in place, time that would otherwise have been spent on creating the project brief, can be spent on developing and detailing the design.

The aesthetical considerations have revolved around the project being a transformation task, which is already in line with the framework. Furthermore, this opens the possibility for interesting material compositions between the existing structure, reused materials and biogenic materials. The ruin also presents itself as a simple and low-tech structure, which aesthetically and functionally lines up with the goal of sufficiency to introduce more simplicity into architecture.

Fig. 20 *map of Denmark, with the site marked.*

CONCLUSION

THE PROJECT SITE, LINDELSE MØLLE, WILL BE USED AS THE FOUNDATION FOR PROVING THE OPERABILITY OF THE SUFFICIENCY FRAMEWORK. THE SITE ALREADY HAS A LOOSE PROGRAM AS WELL AS A SMALL SCALE AND INHERENT POTENTIALS TO SERVE AS A GOOD USE CASE FOR THE SUFFICIENCY FRAMEWORK.

Fig. 21 *Lindelse. 1:10.000*

LINDELSE MØLLE

site description

South of the Langeland's main city, Rudkøbing, is a small town with 300 inhabitants named Lindelse. On the periphery of the city lies an old farm with a mill. The farm is comprised of an inhabited farmhouse, the ruin of the old stable and a smaller ruin of the old henhouse. The old stable will be the main point of departure for this project, with a secondary focus on the old henhouse.

SITE LAYOUT

The mill is out of service but well maintained and open to the public. It serves as a destination for locals and tourists. Just north of the mill is the farmhouse, which is privately owned by a family that owns both the ruins and the mill. The stable footprint mirrors the farmhouse and was originally used for livestock. The southern and smaller ruin used to be a henhouse built just next to the road leading into the site. The whole area is secluded with only a few close neighbours and the site itself is placed on hilly terrain, the highest being the hill which the mill sits on and the lowest on the eastern side of the former stable. Surrounding the site on the northern side are many old and relatively large trees, while open fields stretch along the southern direction. The site is located just off the roads leaving Lindelse making it easily accessible by both cars, pedestrians and cyclists.

HISTORY

The original mill was constructed on the site in the 1600s, but it was replaced in 1809 by a larger and more industrialized Dutch windmill. In 1826, that mill burned down, but it was rebuilt and nicknamed "Phoenix Mill", meaning that it arose from the ashes. The farmhouse, located adjacent to the mill, was built 1823. For decades, the mill was closed to the public but after the present owners took ownership in 2020, a mill guild was formed and since then, the guild has created a community surrounding the mill and farm. The guild opened the mill to the public in 2021. Today the mill is listed, and it serves as a cultural and social platform for locals and visitors looking to participate in various activities and events, from musical events to social dining. (RealDania, 2023).

CONCLUSION

THE PROJECT SITE IS MADE UP BY FOUR STRUCTURES: THE MILL, AN OCCUPIED FARMHOUSE AND TWO RUINS. THE TWO RUINS ARE THE OBJECTS OF THE UPCOMING DESIGN PROCESS, WITH A PRIMARY FOCUS ON THE STABLE RUIN

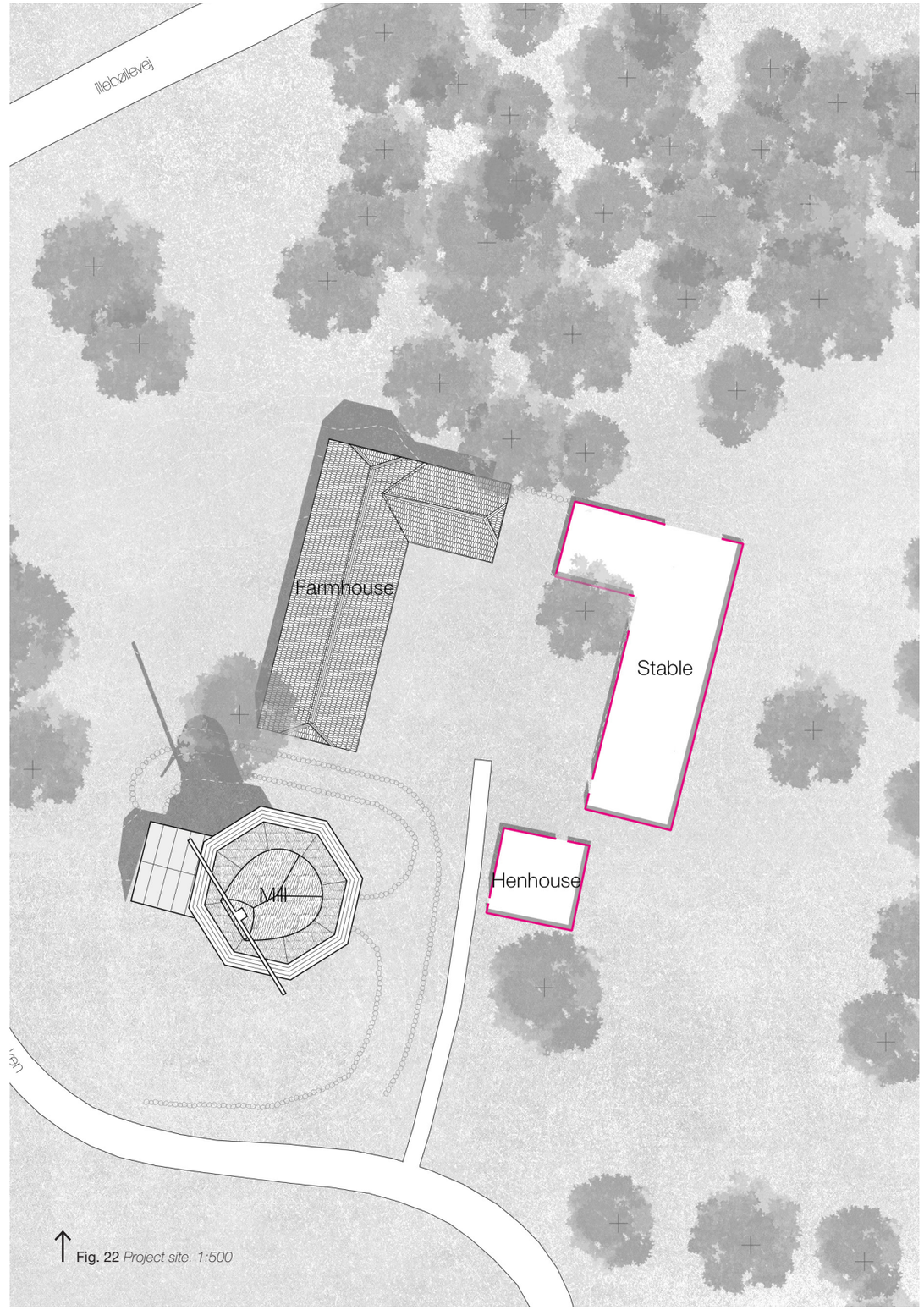


Fig. 22 *Project site. 1:500*

PROJECT PROGRAM

vision for the ruin

The vision for the ruin is to create a visitor and cultural destination, that frames the existing community surrounding Lindelse Mølle. The activities around the mill have seen support from the local community but are currently challenged by the cramped space in the historic mill, an uninsulated building envelope, and the lack of facilities.

NEW GATHERING SPACES

The desire is to create a local gathering place with opportunities for activities for locals and visitors. Lindelse Mølle is a destination for visitors, while also being privately owned property, therefore there should be a clear demarcation of private and public (RealDania, 2023). The vision for the main stable ruin is for it to house a community space operated by the mill guild. The space will become the primary place for the activities arranged by the mill guild, as well as a place where the mill guild can invite the local community for various gatherings. The structure should house a kitchen and public bathroom facilities.

The small ruin will become public accessible, serving as a space where tourists can take a break and relax in connection with their visit to the historic mill.

CONCLUSION

OVERALL, LINDELSE MØLLE WILL OFFER A WIDE RANGE OF CULTURAL, ARTISTIC, MUSICAL, AND HISTORIC ACTIVITIES, APPEALING TO BOTH LOCALS AND TOURISTS, MAKING THE MILL AN ATTRACTIVE GATHERING SPACE.

Fig. 23 *activities at the site.*

SITE EVALUATION
condition

Today the stable stands as an unmaintained and decayed structure only giving a small glimpse into what it used to be. It is important to establish the condition of the site to determine its potentials.

WALLS

The remnants of what was once the external brick wall of the stable is in varying condition, some places it is well-preserved, while other areas have completely deteriorated over the years, leaving behind a wall with holes and large gaps. The wall is fully bricked with two layers. The window gaps, some still with remnants of wooden frames, are still open and supported by either a wooden beam or arched bricks. Given the state of decay the ruin currently is in the external wall is not considered to have any load-bearing properties.

The henhouse's wall- and roof structure is in a more deteriorated state than the stable ruin. Half of its structure is fully bricked and double layered, while the other half is a timber framed ("bindingsværk" in Danish). The bricks are in decay, while the timber frames are almost completely deteriorated. None of the structures in the henhouse are considered to have load-bearing properties.

FOUNDATION

The stone foundations of both ruins seem to be in a good condition. Due to the height of the stable's foundation on the eastern and northern facade it is a very significant element of the ruin. Stone foundations of this type is an outdated technique of making foundations dating back thousands of years, therefore there is a larger incentive to prolong its lifetime by restoring it and using it as foundation for the architectural intervention, accentuating the dialogue between old and new structures.

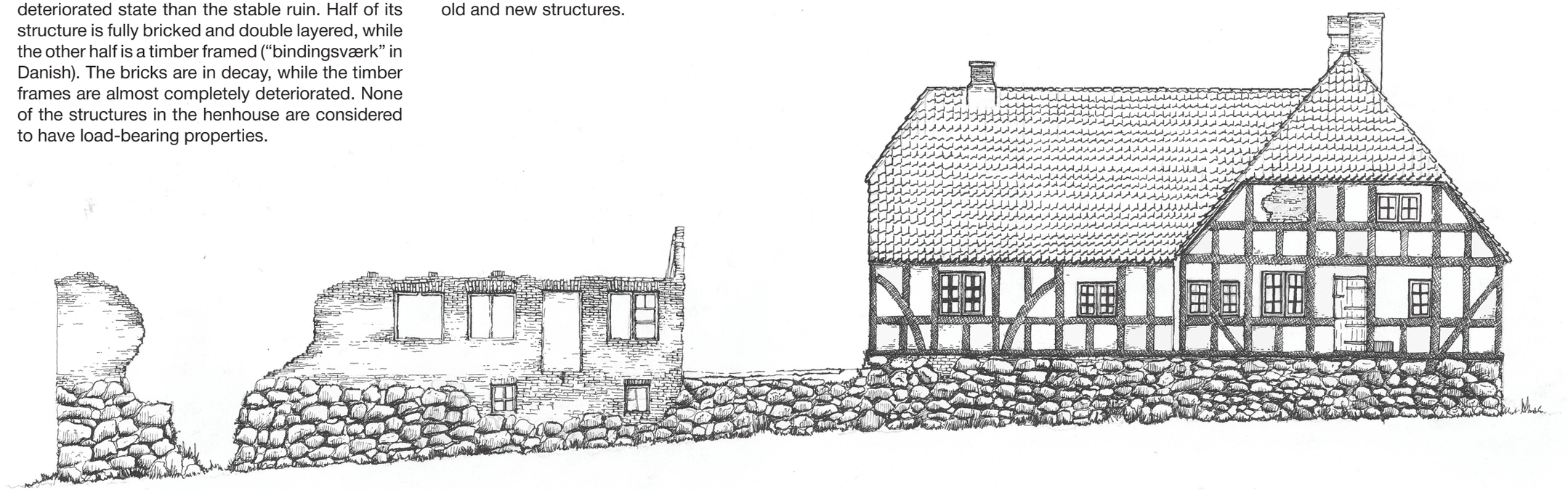


Fig. 24 *north elevation of the current state of the ruin and farmhouse.*

SITE EVALUATION

materials

Exploration of the available materials present on site provides a valuable overview of the potential for their reuse in the design. By creating an overview of these materials, insight is gained into which items might be feasibly reintegrated into the new design and which are unsuitable due to their condition.

LOOSE ELEMENTS

Various materials are scattered around the site surrounding the ruin. The materials are in varying conditions ranging from quite deteriorated to virgin materials and are illustrated and described on figure 25. Some of the materials still has potential of being reused, such as bricks or non-loadbearing wood, while others' lifetime is too short to be implemented or the material contains health hazardous substances and therefore cannot be used, such as the roof sheets from the old henhouse. The specific application and selection the various materials will be described in the design process.

CONCLUSION

THE STRUCTURES CONVEY A CULTURAL AND HISTORIC NARRATIVE. NEITHER THE STABLE WALLS NOR THE HENHOUSE WALLS ARE PRESUMED TO HAVE LOAD-BEARING CAPACITIES BUT MAY BE UTILIZED IN OTHER WAYS. THE STONE FOUNDATIONS ARE STILL USABLE AND IN FINE CONDITION. VARIOUS MATERIALS, BOTH USED AND NEW ARE SCATTERED AROUND THE SITE. THESE CAN BE USED IN A NEW STRUCTURE.

1. Untreated construction wood
2. OSB boards
3. Deteriorated construction wood
4. Various wooden elements
5. Trees of various sorts
6. Eternit roofing sheets
7. Broken yellow bricks
8. Damaged red bricks
9. Red clay roofing tiles
10. Perforated red bricks

Fig. 25 *available on site materials.*

2.1 DESIGN PROCESS

METHODOLOGY

integrated design

The methodology (the integrated design process) and relevant methods used over the course of this project are described and discussed in the following.

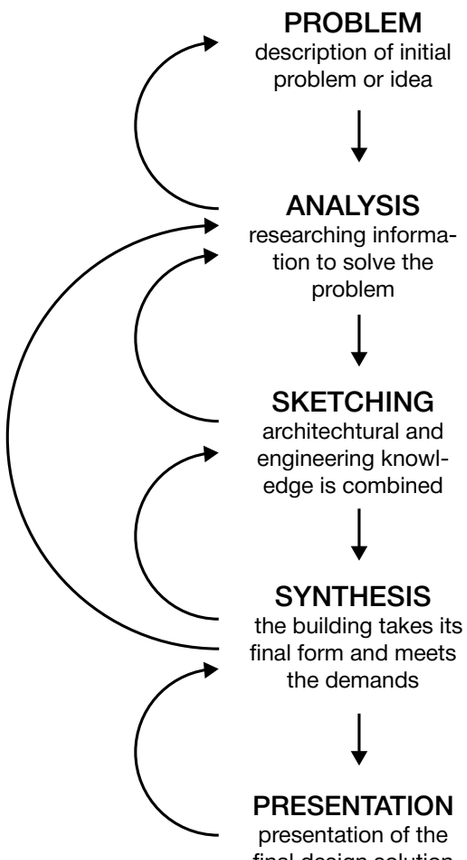


Fig. 26 *IDP*

IDP
The Integrated Design Process (IDP) is a methodology that integrates knowledge from both engineering and architecture to address often highly complicated problems with regards to building design. The architecture, design, functionality, indoor climate, energy consumption, technology and construction are all incorporated into the five phases of the integrated design process. The iterative nature of the methodology and interdisciplinary approach addresses both aesthetic, functional and technical aspects resulting in mature design solutions of high quality. Figure 26 shows the interconnectedness of the five steps but serves as a simplification of the iterative design process, where each step gives knowledge to the next while also emphasizing that new knowledge influences old. (Hansen and Knudstrup, 2005).

QUALITATIVE/QUALITATIVE DATA
Quantitative and qualitative approaches to data collection were applied throughout the project to investigate in-depth aspects of various phenomena related to the overall framework by collecting and analysing both written and visual data. Various theoretical standpoints from articles, books and papers have been used to collect comprehensive and nuanced information to support the project's framework and concepts.

LCA
Life cycle assessments were conducted to evaluate the potential environmental impact of various design proposals. The software, Real-time LCA, was used to make the life cycle assessments throughout the design process. The assessments were conducted on both a macro component level and on a building level.

SKETCHING AND MODELLING
Throughout the design process both hand and digital sketching were used as a tool for applying the theoretical framework on design initiatives through an iterative process, which created a dynamic process where design and theory developed interdependently.

ENSCAPE
Real time renderings and visualizations were used throughout the design process, connecting theoretical concept to visual representations. This fosters the seamless development of both design and theory, where each informs and strengthens the other.

SITE VISIT
A visit to the project site served as a crucial part of developing a visual and conceptual understanding of the project site, character and context.

BE18
Energy performances were evaluated through calculations made in Be18. The focus of the evaluation of energy performance were from a sufficiency standpoint, where the effects of various comfort temperatures were compared regarding the final energy consumption.

KARAMBA3D
Structural analyses were made in the parametric structural tool Karamba3d to allow for the integration of an iterative approach to the structural part of the design. The focus of the evaluation of the structural analysis was the total mass of materials needed for a sufficient structure with well utilized elements.

HONEYBEE RADIANCE
To evaluate the daylight conditions in various design proposals, honeybee radiance was used to calculate the Spatial Daylight Autonomy for ensure the daylight condition corresponded with the minimum requirements from BR18. Furthermore, the Daylight Factor was also calculated to evaluate the ratio of daylight inside compared to outside.

UBAKUS
Ubakus were used to calculate the u-values of every building component along with evaluating moisture conditions in each building component.

CASE STUDIES
Case studies were used as a method through research and analysis of existing buildings and design solutions that could generate new ideas and foster solutions to similar design problems. They have been used to varying extents, from getting inspired by a single visual detail to doing in-depth analysis of a project.

TRANSFORMATION STRATEGY

ruin approach

STRATEGIES

As outlined in “Evaluation of ruins” the ruins have been determined as being structurally unsound. According to the sufficiency framework, on-site structures and element should be reused. Then it stood to reason that the ruins should either be disassembled, and its materials be reused or the ruins should be transformed into a new structure, reinforced, detached or perhaps a mix of the two: a question of addition and subtraction.

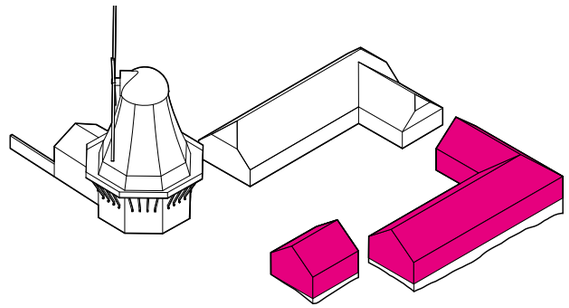
Three strategies were formulated, see Figure 27. While determining which strategy to use, it was also necessary to consider the building envelope of the new structure. Many options were considered, most of them focusing on strategy 2 and 3. It was felt that, where possible, the ruin should be preserved to showcase the historical nature of the structure, since simply reusing the materials would not achieve this as visibly. Furthermore, expending energy to disassemble the materials, simply to use them in the same place seemed futile and wasteful.

In the end, the stable was decided to follow strategy 2, detaching the new structure from the ruin. Strategy 3 in variously involved reinforcing and expanding the ruin’s walls, meaning that materials usage would not be reduced. Additionally, by placing the new structure behind the ruin, it could act as a backdrop, highlighting the ruin.

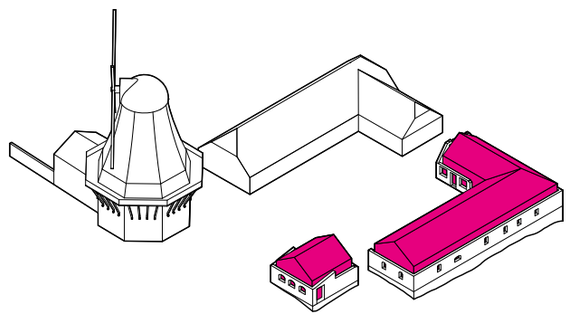
The henhouse was wished to be an open, light timber structure, unheated and uninsulated. With the structure being so dilapidated, it was decided that the henhouse should follow strategy 1, only preserving the foundation, but reusing the bricks from the walls.

CONCLUSION

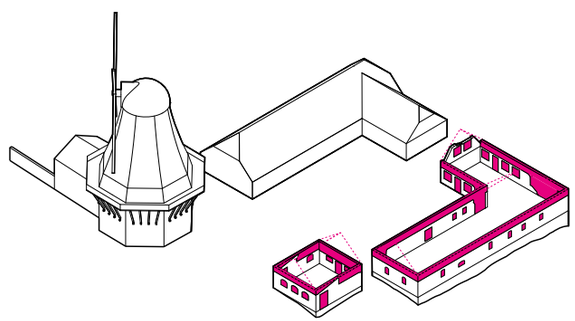
THE STABLE’S FOUNDATION AND WALLS WOULD BE PRESERVED, AND THE NEW STRUCTURE WOULD BE DETACHED AND ACT AS A BACKDROP TO THE RUIN. ONLY THE HENHOUSE’S FOUNDATION WOULD BE PRESERVED, THE WALLS’ BRICKS REUSED.



Strategy 1: *Preserving just the foundation. The ruins will be disassembled and their materials will be reused.*



Strategy 2: *Preserving the ruins and foundation. The new structure will be detached from the ruin.*



Strategy 3: *Preserving the ruins and foundation. The new structure will be integrated with the ruin, which will most likely need to be reinforced.*

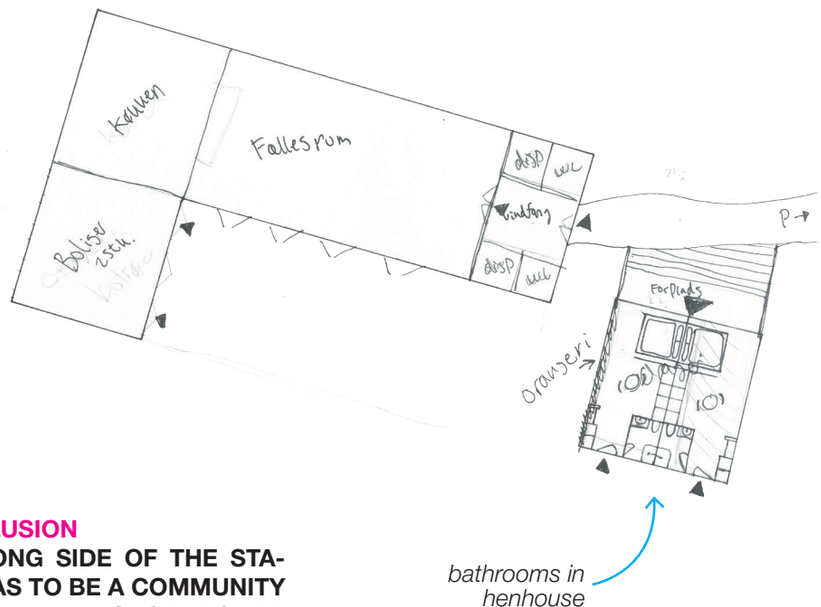
Fig. 27 *transformation strategies.*

PROGRAMMING

the ruins' functions

Most of the building's program was given beforehand: the stable should house a multifunctional community hall (including the kitchen) with limited access and freely accessible bathroom facilities. The henhouse was to house a visitor space, freely accessible.

That left the west wing of the stable to be freely programmed. Ateliers, hostels or short-term rentals were considered. In the end, it was decided to make it a two-storey, long-term apartment for a family of 4, as a challenge to design a well-functioning apartment on a small footprint - a demonstration of sufficiency.



CONCLUSION

THE LONG SIDE OF THE STABLE WAS TO BE A COMMUNITY SPACE AND HOUSE TOILET FACILITIES, THE WEST WING OF THE STABLE A LONG-TERM APARTMENT AND THE HENHOUSE A FREELY ACCESSIBLE VISITOR SPACE.

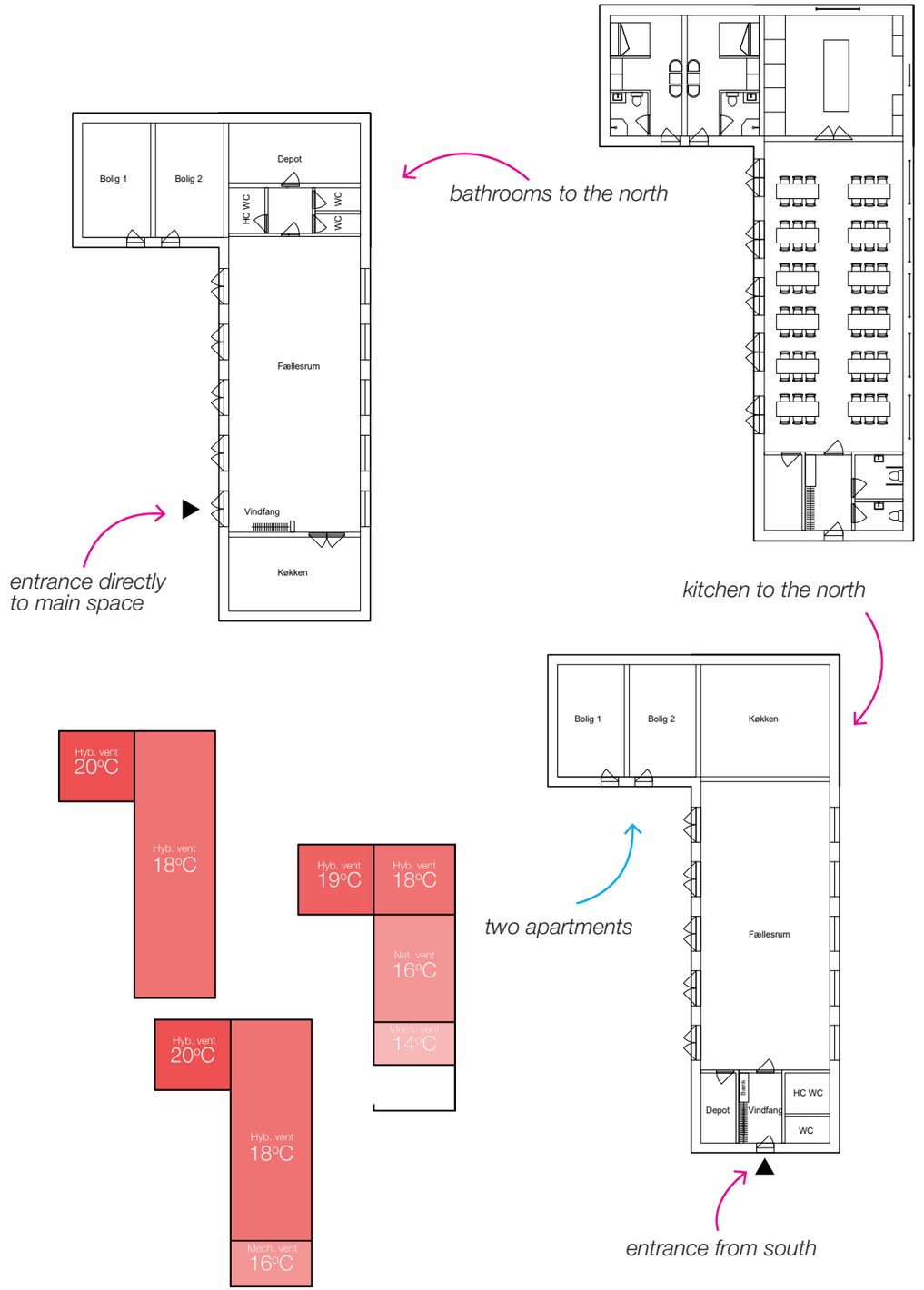


Fig. 28 *design process: floor plans and climate zones*

SHAPING THE STABLE

the overall form

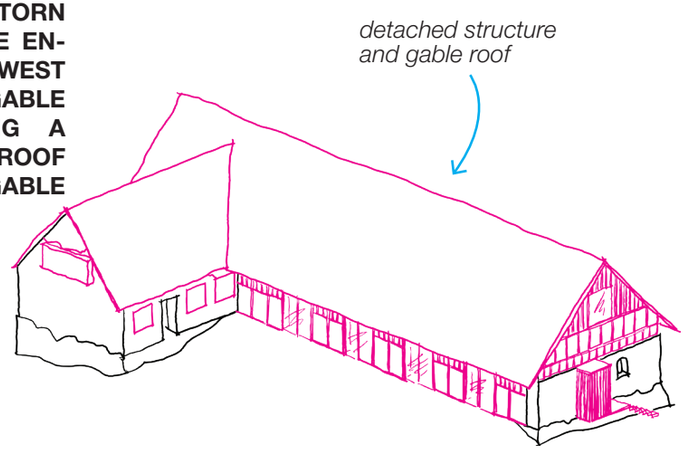
The west facade was wished to be perforated by double doors, that can swing open and allow free access in and out in the summer months. This part of the facade is detached from the rest. Therefore, it was decided that this part of the ruin would be demolished, since the window gaps would most likely weaken the remaining structure considerably. The bricks from this part of the ruin would be reused.

The entrance was to be south facing, since the site is reached by cars, pedestrians and cyclists from this direction. Though, in the interest of preserving the south face of the ruin, the entrance was placed south-west, where the wall would be demolished regardless, so this seemed logical. In this connection, the gable of the new structure was pushed back, creating a transitional space for visitors to shelter from wind and rain.

The roof shape went through several iterations. The gut feeling was to have a gable roof, but in the interest of testing all possibilities, angled and flat roofs alike were tested. After these tests, the gable roof remained the best option, due its simplicity seeming more at home on a unpretentious site. Additionally, it created a harmony in the structure, by drawing a line, north to south, down the centre axis of the building and revealing the interior logic of the building that would also, by far and large, become mirrored down the centre axis.

CONCLUSION

THE WEST FACADE WAS TO BE OPEN WITH SEVERAL DOUBLE DOORS AND THEREFORE TORN DOWN TO BE REUSED. THE ENTRANCE WAS TO BE SOUTH-WEST FACING AND THE NORTH GABLE PUSHED BACK, CREATING A TRANSITIONAL SPACE. THE ROOF WAS DECIDED TO BE A GABLE ROOF.



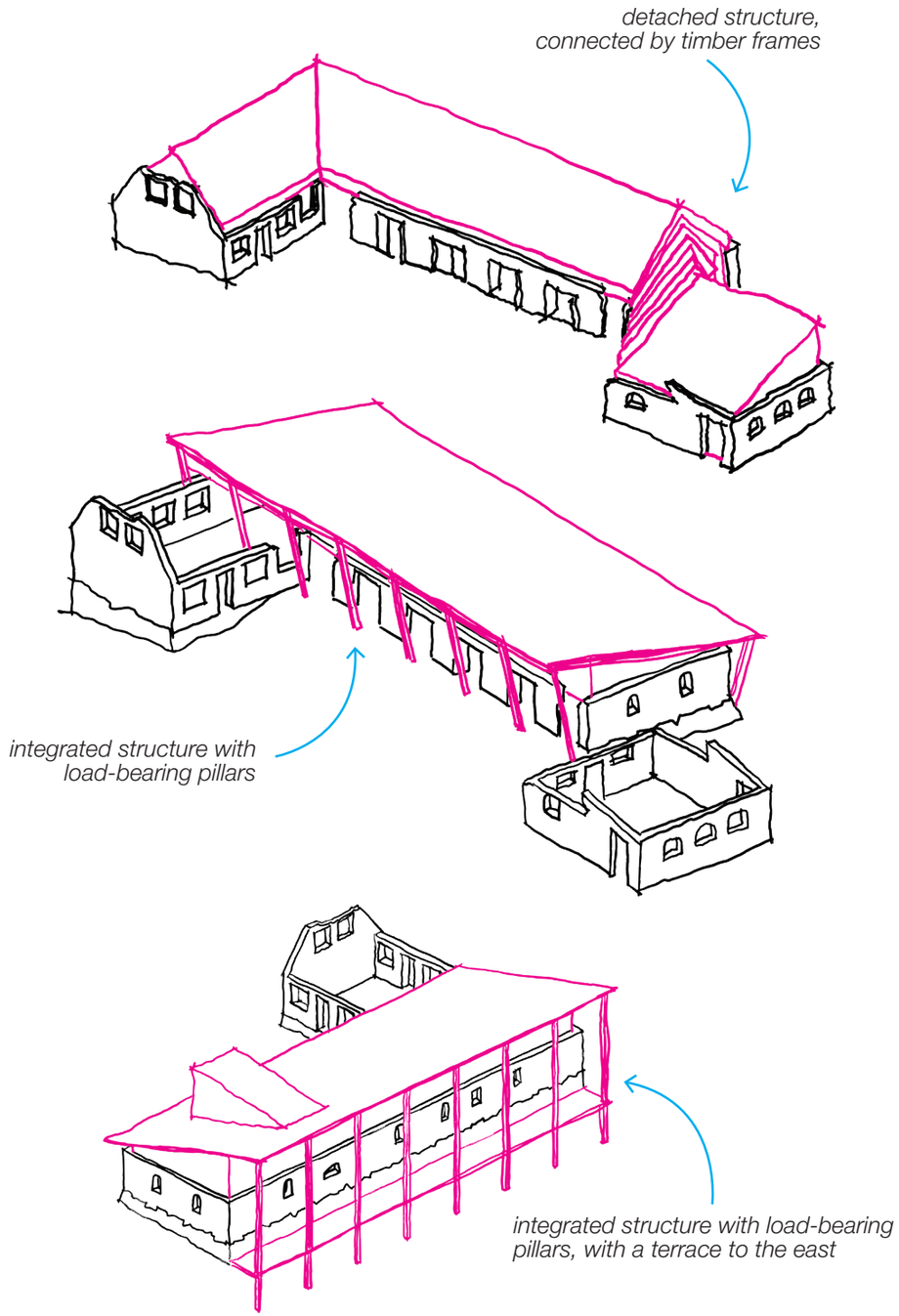


Fig. 28 *design process: sketches.*

FACADES

materials

The facade cladding went through many phases. For a long time, a reused brick facade was considered. But this facade did not distinguish itself from the ruin enough. The two structures melded together, but a certain level of contrast was wished for. Instead, timber was considered. First, painted with a dark red or green hue. But this treatment seemed unnecessary, and in the end, the timber become untreated. It was decided that timber from the building process would be sourced to fill out a pre-planned facade grid. Thereby achieving the perfect blend of chaos of reuse as well as order and a regular rhythm. The timber would stand in contrast to the light bricks of the ruin, creating the perfect backdrop. The facade grid was implemented on all exposed walls, clearly communicating the building's concept of being encapsulated by the ruin. The gap between wall and roof was an equal part of the grid, this time horizontal to communicate the change in building level.

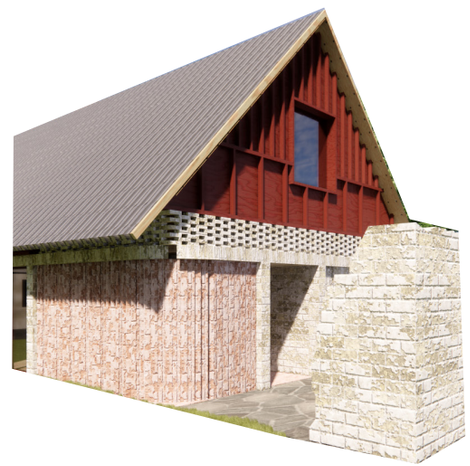
The gable roof was clad with a zinc roof, owing to the lightness of the material, especially visually; seeming to float over the structure and ruin. The sides of the roof were stretched to protect the top of the ruin from the elements.

roof overhang over entrance zone

exposed roof structure

facade grid with reused wood

reused brick facade



east facade dominated by ruin

painted green timber facade

roof sheets creating a dark backdrop to ruin

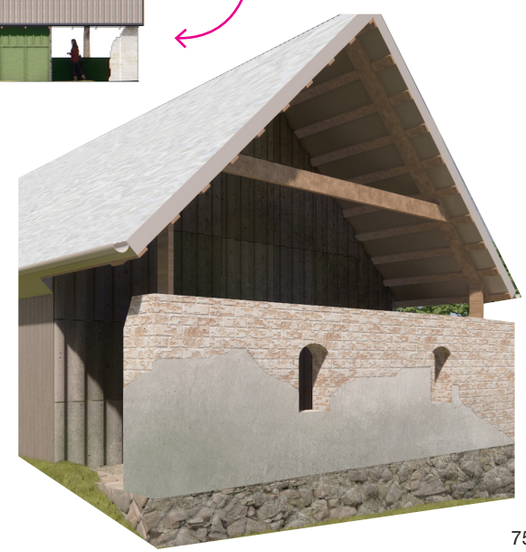


Fig. 29 *design process: facade renders.*

FACADES

building envelope

The expression of the south and west facade of the community space was by and large decided, as described previously. Only the exact placements of the openings were left to be decided. To enable different levels of ventilation, both doors and a smaller window could be open and allow for both single sided and cross ventilation, through windows on the east facade.

The east and north facades would be the least seen, as users and visitors would have little reason to walk around this part of the building. This, combined with the diminished option for daylight, lead to the decision to make few interventions in the eastern face of the ruin, leaving it as a testament to times gone by.

In the northern gable was a large gap in the brickwork. The method for filling this was through several iterations, in the end landing on a single window to create a viewpoint from inside the community hall and allowing light to filter into the kitchen.

CONCLUSION

THE FACADES WERE TO BE CLAD WITH TIMBER SCRAPS FROM THE BUILDING PROCESS, WITHIN AN ORDER IMPOSED BY A FACADE GRID. THE ROOF WAS DECIDED TO BE OF ZINC DUE TO ITS LIGHTNESS AND FLOATING QUALITY. THE EAST FACADE WAS TO BE WITHOUT INCISIONS, THE ONLY DISCERNIBLE INTERVENTION BEING THE WOODEN HORIZONTAL BAND, WRAPPING AROUND THE ENTIRE BUILDING. THE GAP IN THE NORTH FACADE WAS TO BE CLAD IN THE TIMBER GRID.

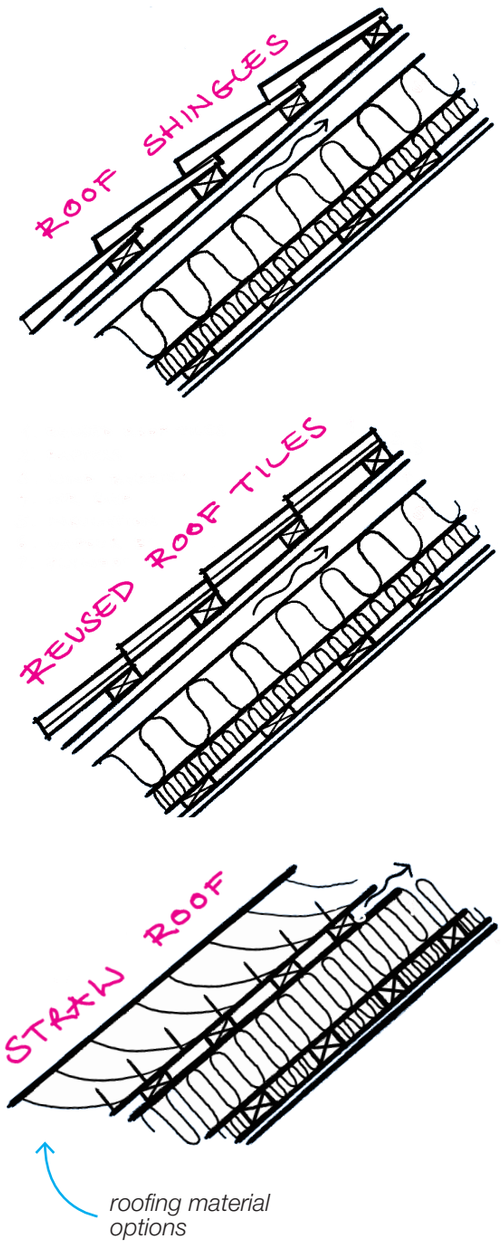


Fig. 30 *design process: roof sections*

fenestration options

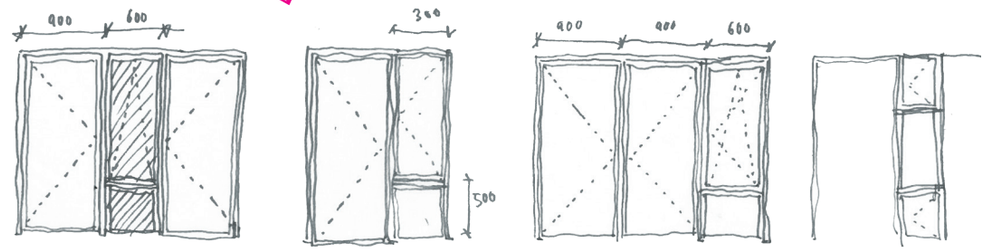


Fig. 31 *design process: window sketches*

material study. cladding the north facade

Fig. 32 *design process: visualisation*

placement of openings in west facade

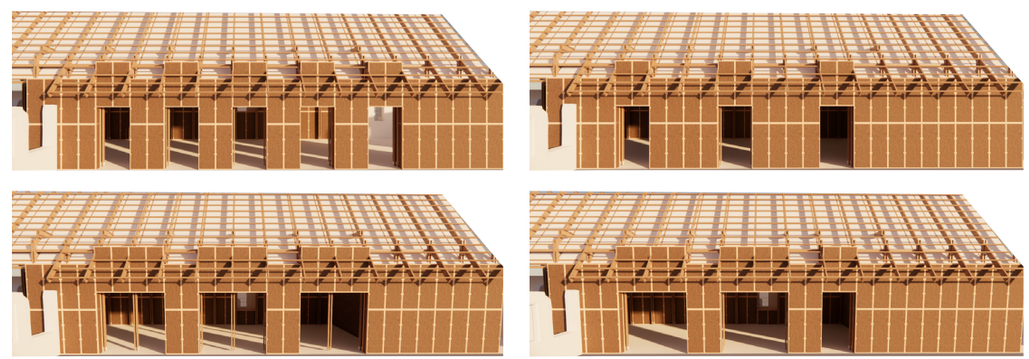


Fig. 33 *design process: renders*

INTERIOR

walls & roof

The interior of the community hall was developed in large part around a modular wall system. With reference to the sufficiency framework, the interior wall was wished to be visible, not hidden away by eg. plywood. Therefore, the insulation is visible from the inside. The straw insulation is treated on the interior side to make it fireproof. Several other insulation options were considered, such as hempcrete and wood fibre. This module system was shifted on wherever there are openings, such as the windows on the east facade.

Several options were considered for the floor material, such as reused bricks and wooden blocks in varying patterns, embracing the chaos of reuse. In the end, wood was chosen as a light and warm material to contribute a more welcoming feeling to the space.

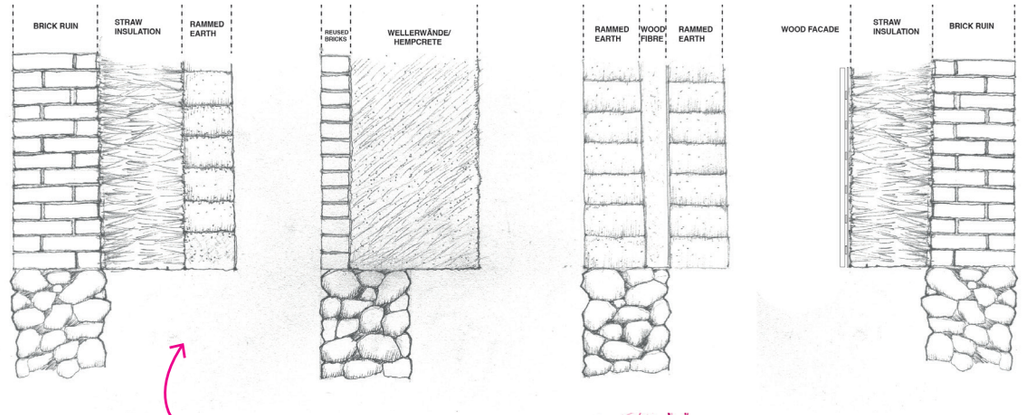
early iterations

study of floor material

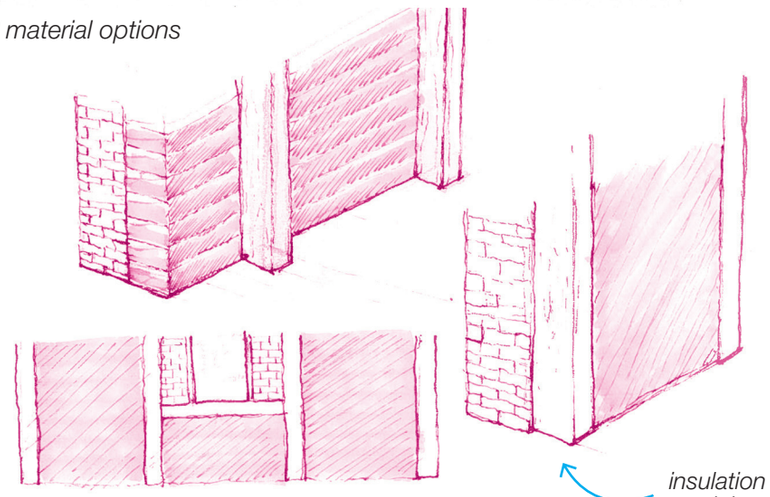
Fig. 34 *design process: renders*

CONCLUSION

THE INTERIOR WAS DESIGNED TO EMBODY THE SUFFICIENCY FRAMEWORK, WITH THE WALL STRUCTURE EXPOSED, AS WELL AS THE JOINTS IN THE CONSTRUCTION AND USING ONLY REUSED OR BIOGENIC MATERIALS. THESE MATERIALS ARE CAREFULLY ASSEMBLED TO COMMUNICATE THE CHAOS OF REUSE AND INTERESTING MATERIAL MEETINGS.



wall material options



insulation modules

Fig. 35 *design process: sketches.*

study of east window openings

STRUCTURAL DESIGN

timber sizes & strength

STRUCTURAL ANALYSIS

The approach to the structural design of the building started with the choice of material. Timber was chosen as the primary structural material as it was sufficient to solve the structural needs of the scale of the design, while having a lower environmental impact.

The approach taken in the design of the construction also considered the availability of materials in the project area. This led to the decision to design and dimension using standard pine elements. This constraint meant that the design had to be based on standard-sized elements (45mm x 45, 70, 95, 120, 145, 170, 195, 220, 245, 270, 295mm) without significant or demanding special cuts.

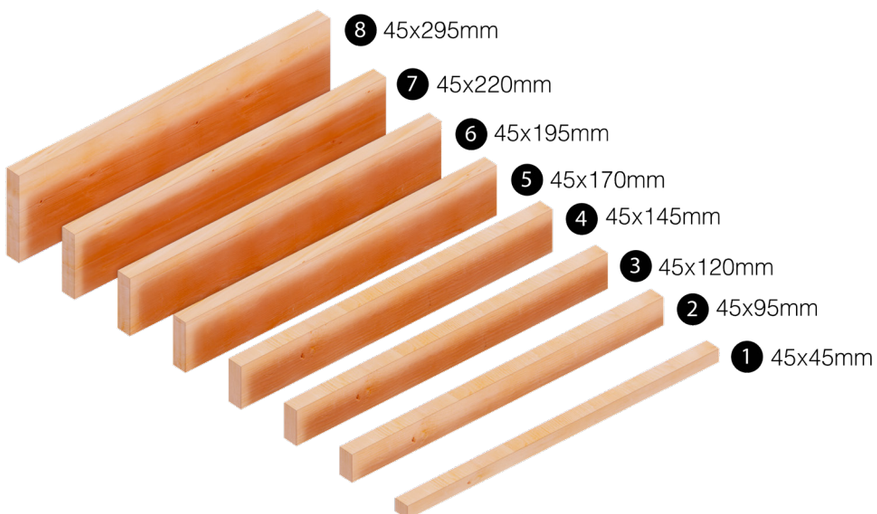


Fig. 36 *timber element sizes.*

STRENGTH CLASSES

As a principle, the design aimed to utilize lower strength grade timber to optimize resources in a more holistic and sympathetic approach. Given the project's smaller scale, with lighter loads and spans, it wouldn't be logical to use the highest strength grades. These could be better allocated to more demanding projects. Hence, the design was based on using timber of strength grades C18 and C14. However, this means the timber will exhibit more imperfections in appearance, such as a larger number of knots.

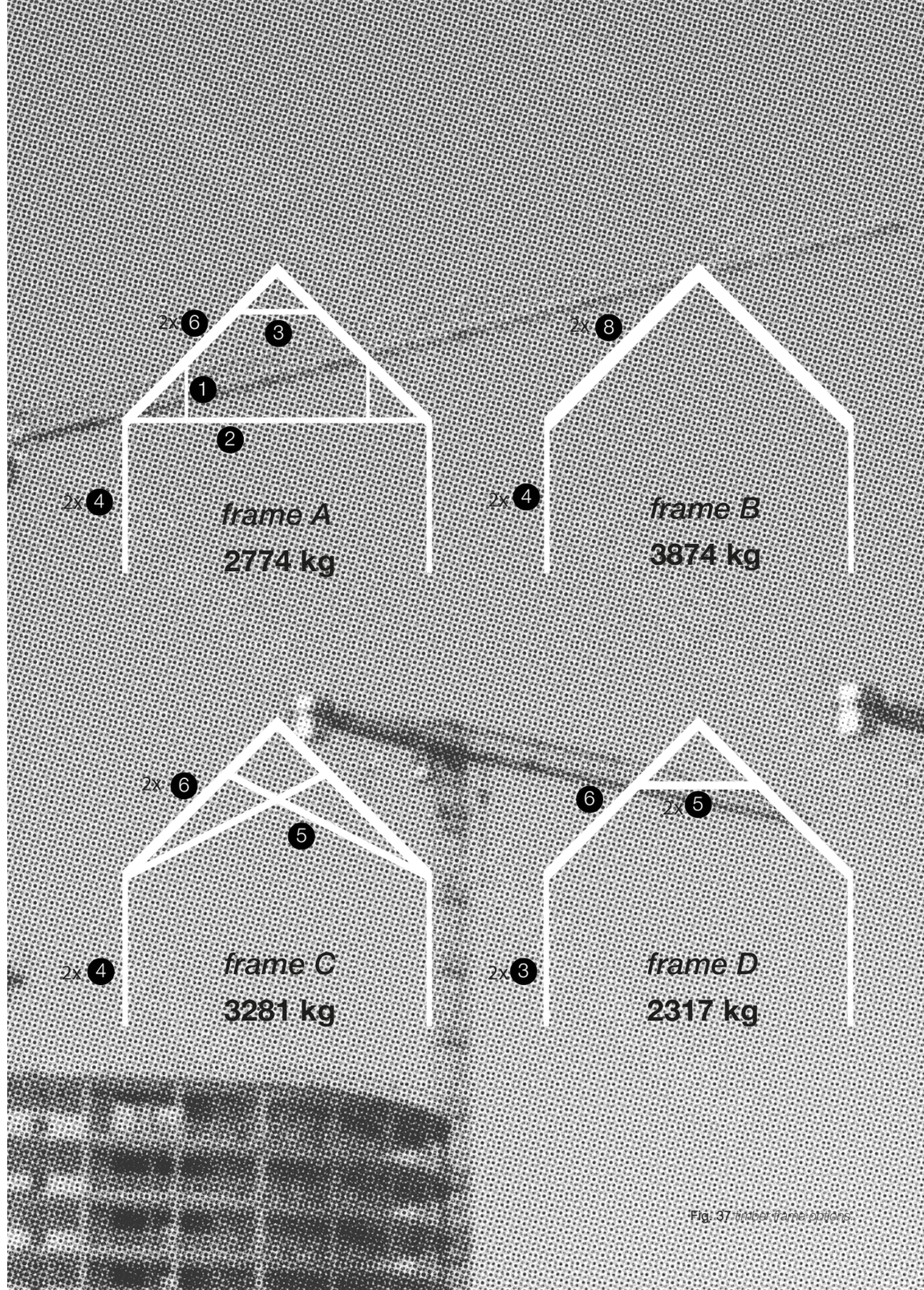


Fig. 37 *timber frame options.*

CONSTRUCTION

structural analysis

FRAME DESIGN

In the process, the design was based on a single frame in the construction of the common room. The premise was that the frame construction should stand on its own independently of the ruins and walls, and it should be visible inside.

The individual frame was designed according to ultimate limit states with dominant snow loads.

No significant consideration was given to designing for fire loads beyond aiming for a maximum utilization rate of 70%.

The most significant and determining criterion in the selection of the frame design was the total mass of timber used. A parametric Karamba3D script was developed to estimate the total material mass as different parameters for each frame were adjusted. In each frame type, the following parameters were changed to optimize utilization rates and minimize the necessary material usage (standard cross-section for each element, distance between each frame, frame height, strength class).

The script would also provide a utilization rate of each element in the form of a colour code. Green if the timber element was reasonably utilized (10-70%), yellow if it was minimally and inadequately utilized (<10%), and red if it was over-utilized, meaning under-dimensioned (>70%).

CONCLUSION

FRAME TYPE D WAS CHOSEN BASED ON A LOWER REQUIRED MASS. ALTHOUGH THE LARGER TIMBER ELEMENTS HAD TO BE SPLIT UP AND IT ALLOWED FOR A THICKER ROOF LAYER FOR A LARGER AMOUNT OF INSULATION WITHOUT THE NEED FOR OVER-DIMENSIONING THE RAFTERS IN HEIGHT.

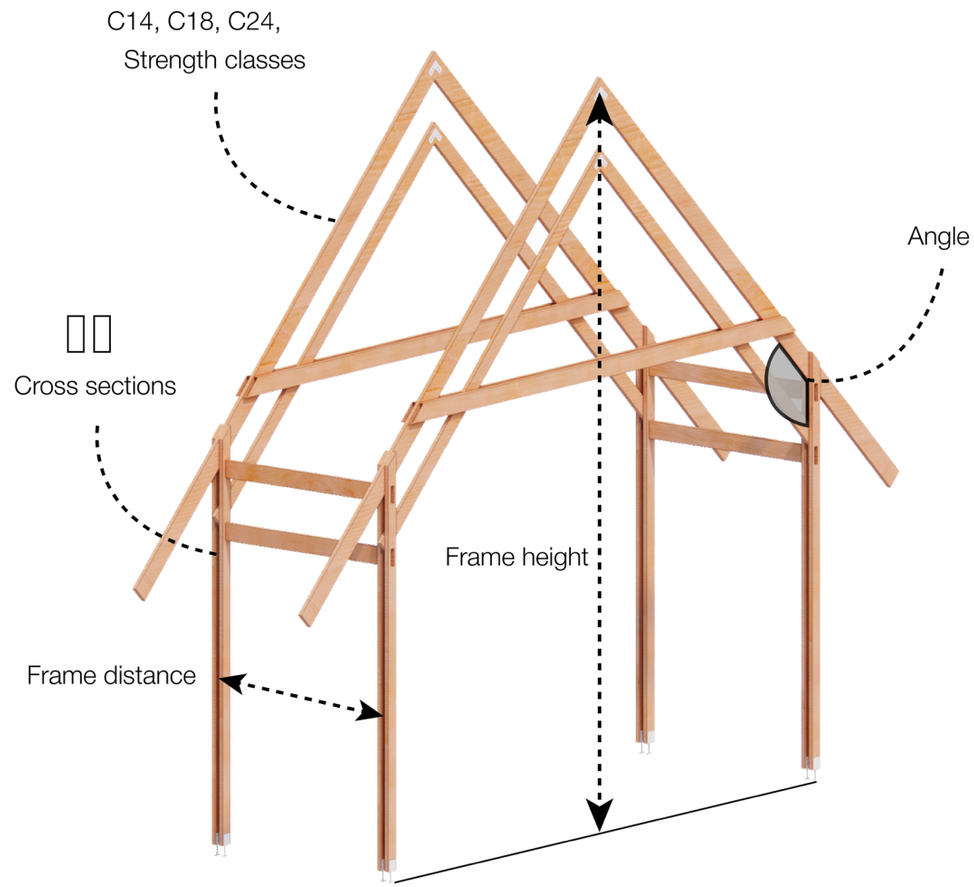


Fig. 38 *the parameters included in the Karamba3D-scripts, which were changed to optimize the structure to lower the mass. this would ensure an optimized and sufficient use of the material.*

APARTMENT
interior and exterior

The purpose of the apartment was to house a young family with two grown-ups and one or two children on 80 m^2 (60 usable m^2), making it an exercise in tiny living and in optimising the floor plan. Utilizing the space wisely was key.

Just on the other side of the partition between community space and apartment is the communal kitchen. Therefore, the family was given the possibility to access that kitchen, so they are free to use the whole community space as a dining space, play space or otherwise. That allowed most of the ground floor to be given over to a family dining and socialising space and a wall-mounted fold-out bed for the parents.

The first floor was given over to the children's bedrooms, prioritising giving them their own rooms, so they can retreat if so wished. A desk on the landing is placed for the parents to work from home. A double height space extends the staircase, giving amble light as well as audio- and visual connection between up- and downstairs.

CONCLUSION

OPTIMISING THE APARTMENT'S FLOOR PLAN WAS KEY. THIS WAS DONE BY CAREFULLY WEIGHING THE PERSONAL NEED FOR PRIVACY AND SOCIALISATION BY THE FUTURE TENANTS AS WELL AS TAKING THE COMMUNITY SPACE INTO USE AS AN EXTENSION OF THE APARTMENT.

Fig. 39 *exterior render of apartment. design process.*

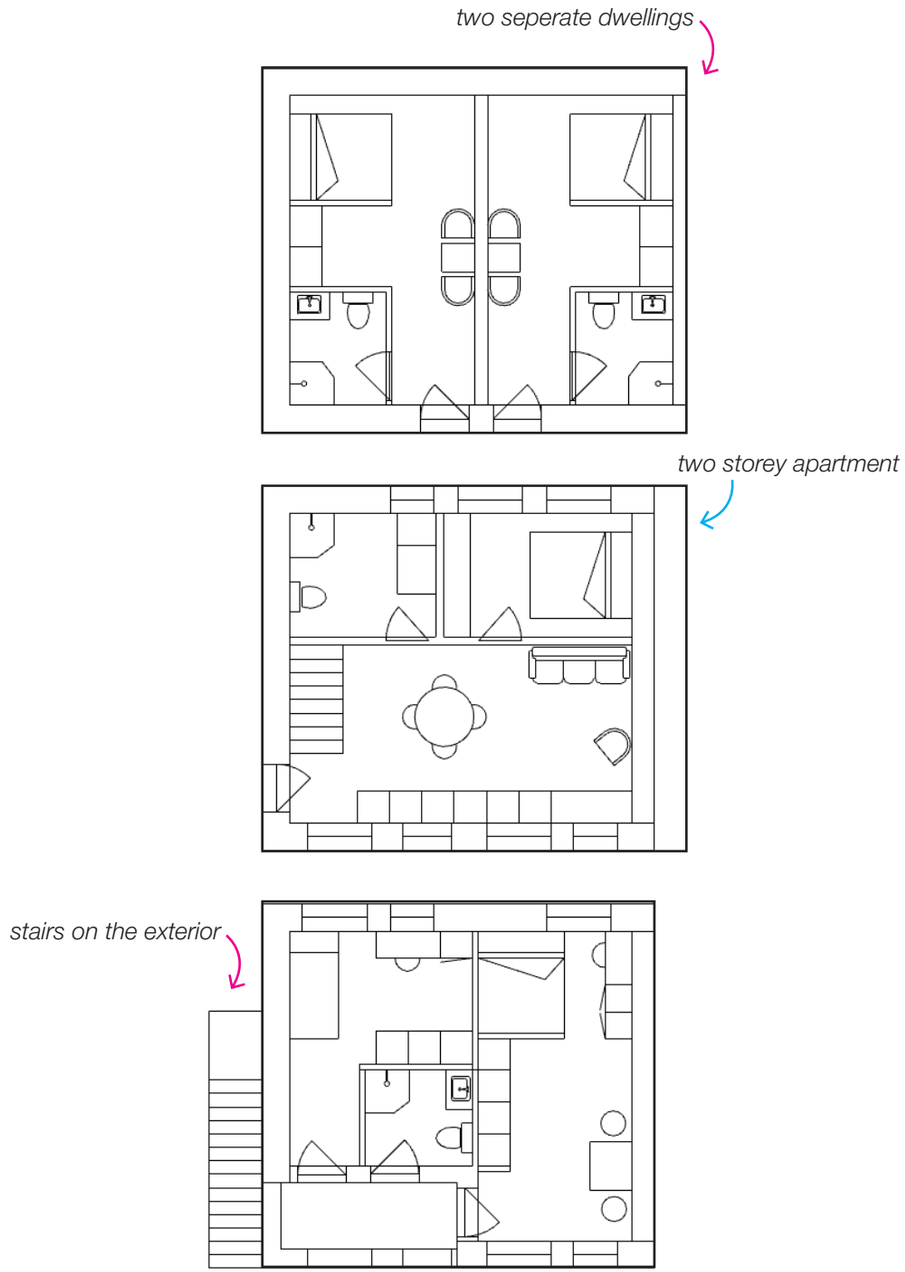


Fig. 40 *apartment plans. design process.*

HENHOUSE

The henhouse was intended as a light timber structure for visitors to the site, where they can rest, and information boards can be displayed.

Most of this the design process in project is concerned with materiality and this henhouse was a chance to practice design in the “formgiving” tradition. The first several options were more closed volumes, to offer shade from the wind and rain to visitors. But it was more prioritised to create an open structure, and so it became more open and solar panels were added, both as a functional addition - but also signalling to visitors arriving to the site by foot the importance of renewable energy.

CONCLUSION

THE HENHOUSE WAS DESIGNED AS AN OPEN STRUCTURE FOR VISITORS, WHERE THEY CAN REST AND READ INFORMATION ABOUT THE SITE AND MILL.

solar shading device

opening the volume

reused timber facade

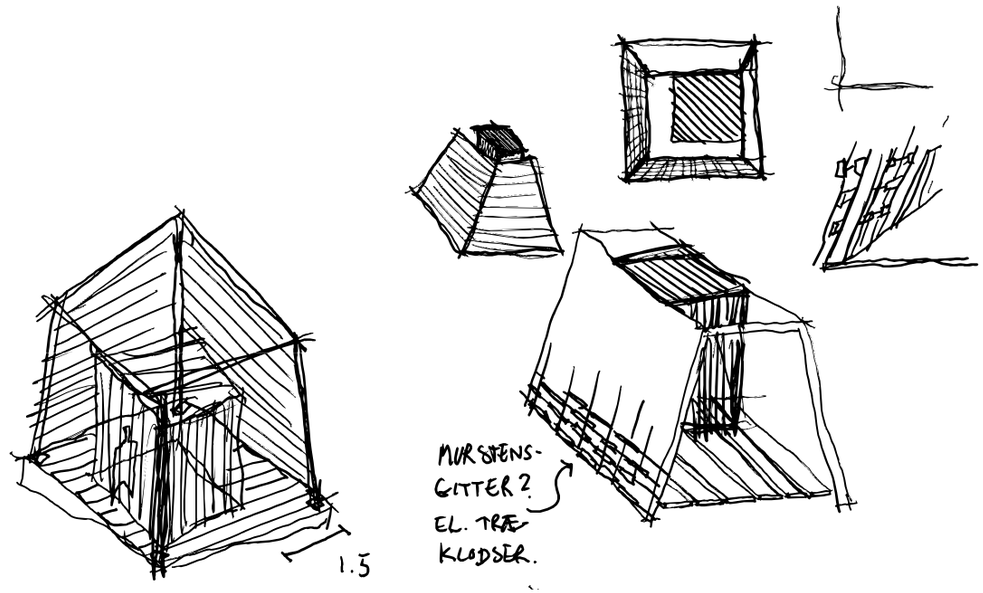


Fig. 41 *henhouse sketches. design process.*

closest to final design

Fig. 42 *henhouse renders. design process.*

MATERIALS

selection process

Various material combinations have been tested throughout the design process, in a simple graphical way to enable various quick iterations. The combinations can be seen in Figure 45 which focuses on the external wall material, that intertwines with the existing ruin structure and on the roof material. Combination six was chosen to serve as a foundation for further detailing of the façade. The zinc roof was chosen because of its light and cold aesthetics, which compliments the ruin structure. Furthermore, it was chosen due to its light weight that results in less load on the construction, reducing its dimensions. Wood cladding was chosen giving that brings a light aesthetics contrasting to the existing ruin brick wall. The wood was chosen to be untreated so it would be as close to its natural aesthetic as possible.

1. Untreated construction wood
2. OSB boards
3. Deteriorated construction wood
4. Various wooden elements
5. Trees of various sorts
6. Eternit roofing sheets
7. Broken yellow bricks
8. Damaged red bricks
9. Red clay roofing tiles
10. Perforated red bricks

Fig. 43 *on site materials.*

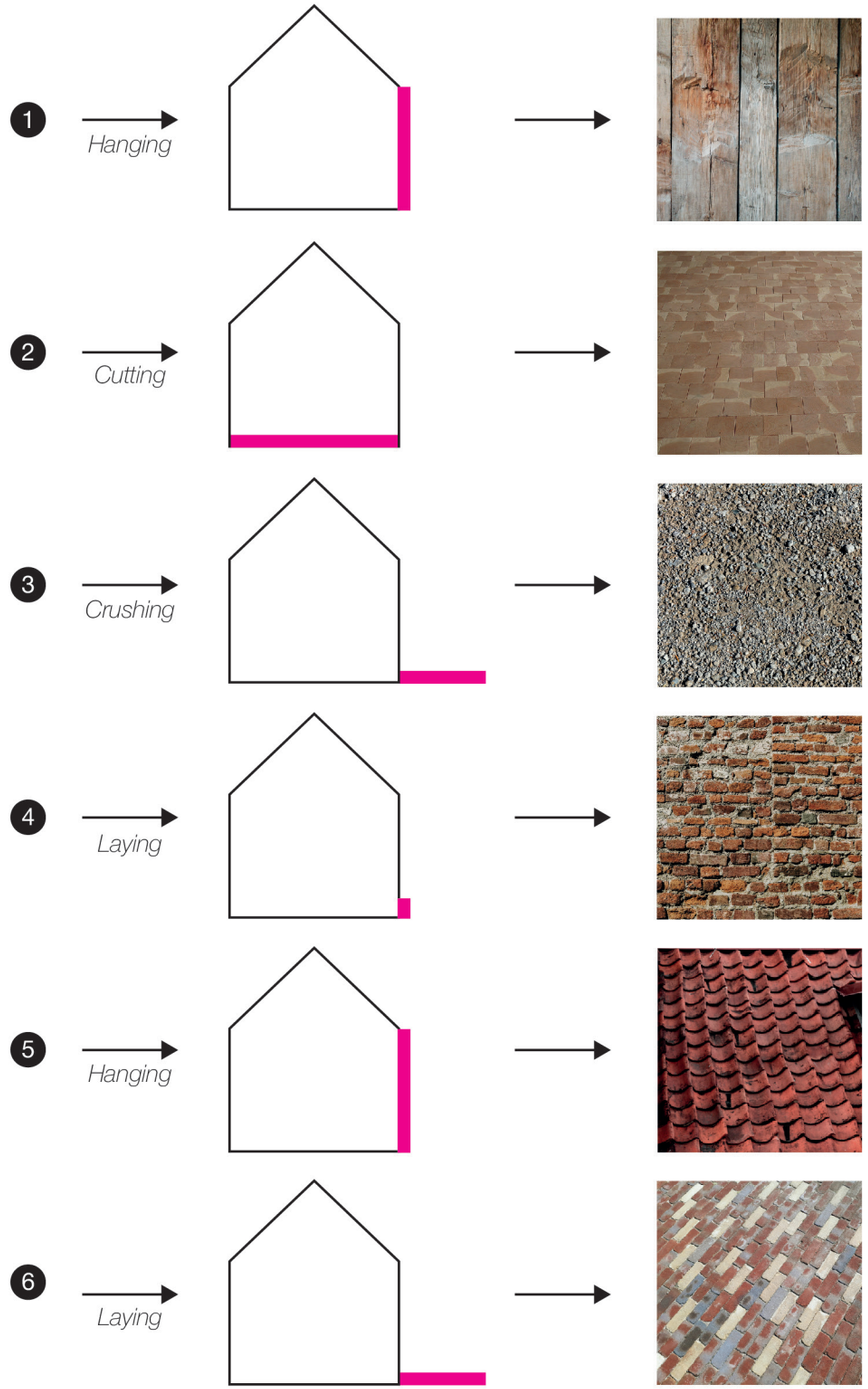


Fig. 44 *material application.*

1

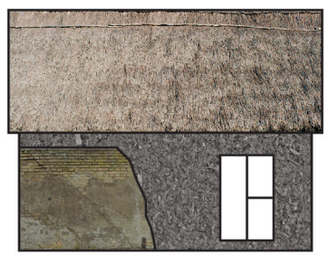
Thatched roof

Reused bricks

2

Thatched roof

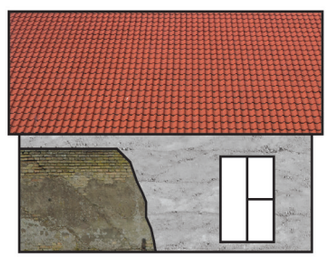
Hempcrete



3

Roofing tiles

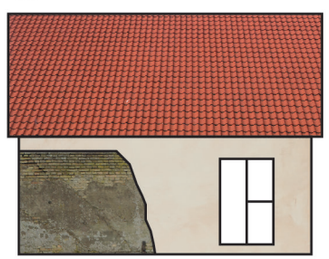
Rammed earth



4

Roofing tiles

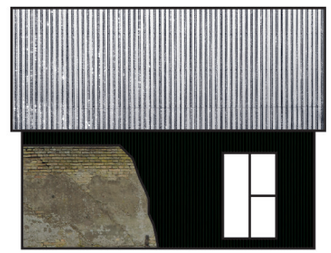
Lime plaster



5

Zinc roof

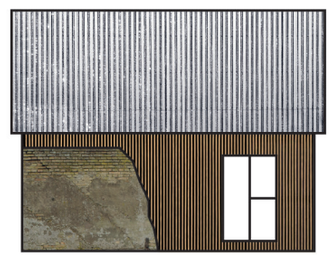
Painted wood



6

Zinc roof

Wood cladding



7

Wood shingles

Concrete

8

Wood shingles

Red bricks

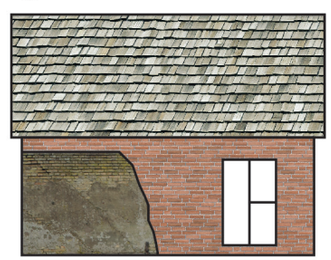


Fig. 45 *material application.*

DAYLIGHT EVALUATION

SPATIAL DAYLIGHT AUTONOMY

Spatial daylight autonomy assesses whether a space receives sufficient daylight on a plan during a period and with a lower threshold for lux. The calculation method was used to evaluate whether the plane received sufficient daylight corresponding with the minimum requirement from BR18. The simulation was done during all daylight hours and with a lower threshold of 300 lux 0,5m above ground and for each evaluation grid at least half of the daylight hours must receive at least 300 lux or more.

The first iteration sees sufficient daylight in the dwelling, therefore the common room will now be focused on. The spatial daylight autonomy shows there is insufficient daylight conditions in the common area, therefore the design will be iterated on. By adding two windows in the existing window holes on the eastern façade, the spatial daylight autonomy shows that more than half of the floor area has at least 300 lux in half of the daylight hours.

DAYLIGHT FACTOR

Daylight factor assesses the ratio of the level of daylight inside and the level of daylight outside under a overcast sky. Under those condition a daylight of 2-3 % on the plane is considered as a sufficient level of daylight.

The first iteration uses the same model to evaluate where the daylight needs to be improved by placing more windows or increasing the existing window area and shows that the overall daylight factor is sufficient with a smaller area being a bit less daylight. To resolve this matter, it was decided to make the windows in the new façade larger, making the ruin more visible from inside the building.

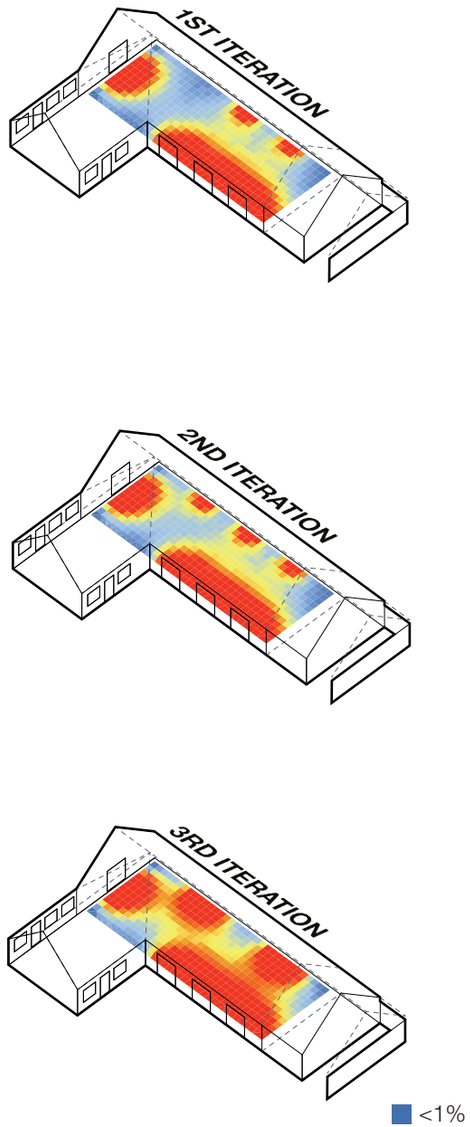


Fig. 46 *daylight factor simulation.*

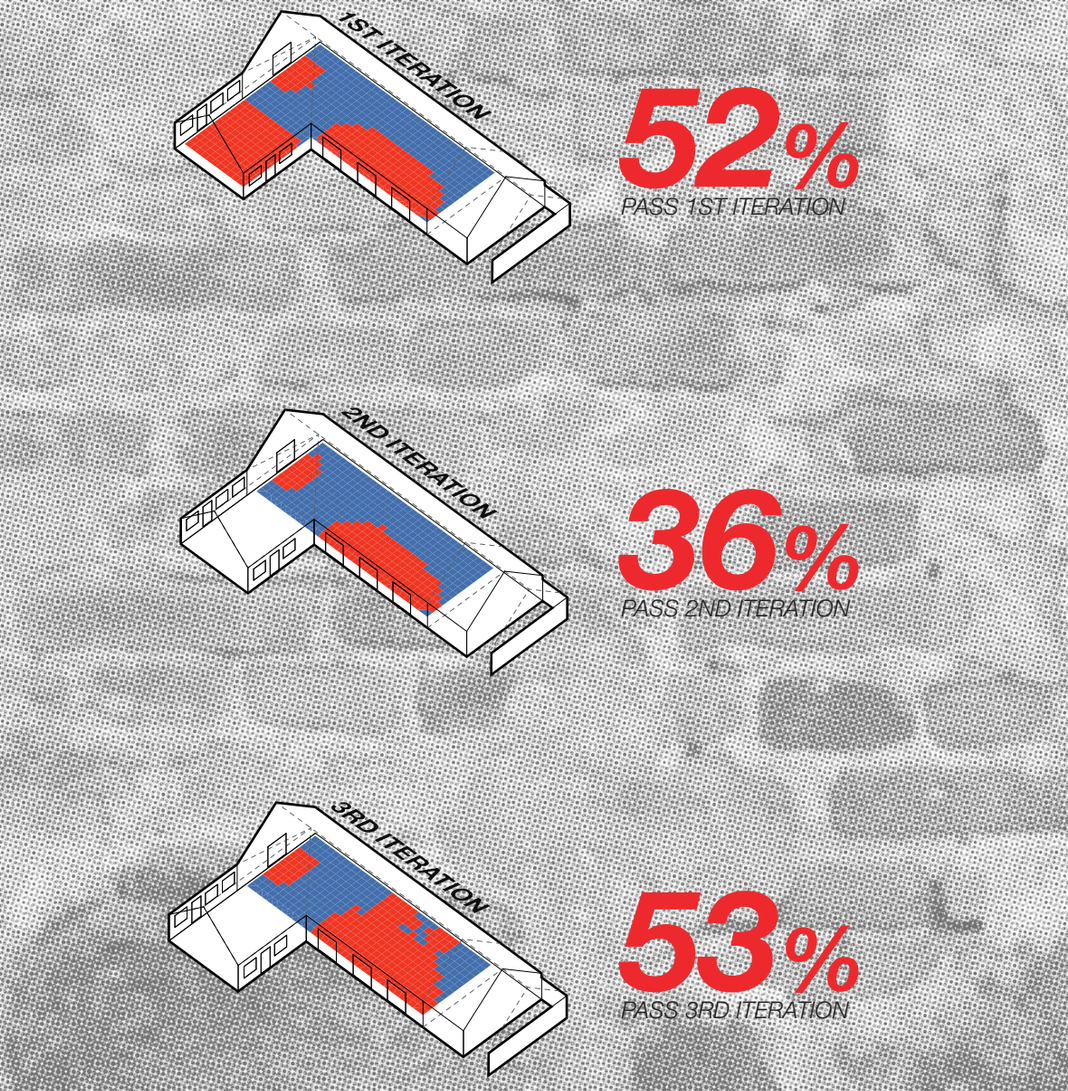


Fig. 47 *spatial daylight autonomy simulation.*

FRAMEWORK-METHOD-SOLUTION

The framework presented in this thesis served as a guidance for the transformation of the ruin. To ensure that the design would follow the principles of the framework, each strategic principle and design principle would be connected with at least one design solution. A key method would then be placed in the connection between each principle-solution pair to also demonstrate and ensure the use of all methods. For the sake of simplicity, this diagram does not represent a complete list of all design solutions, nor does it show all methods used in each design solution.

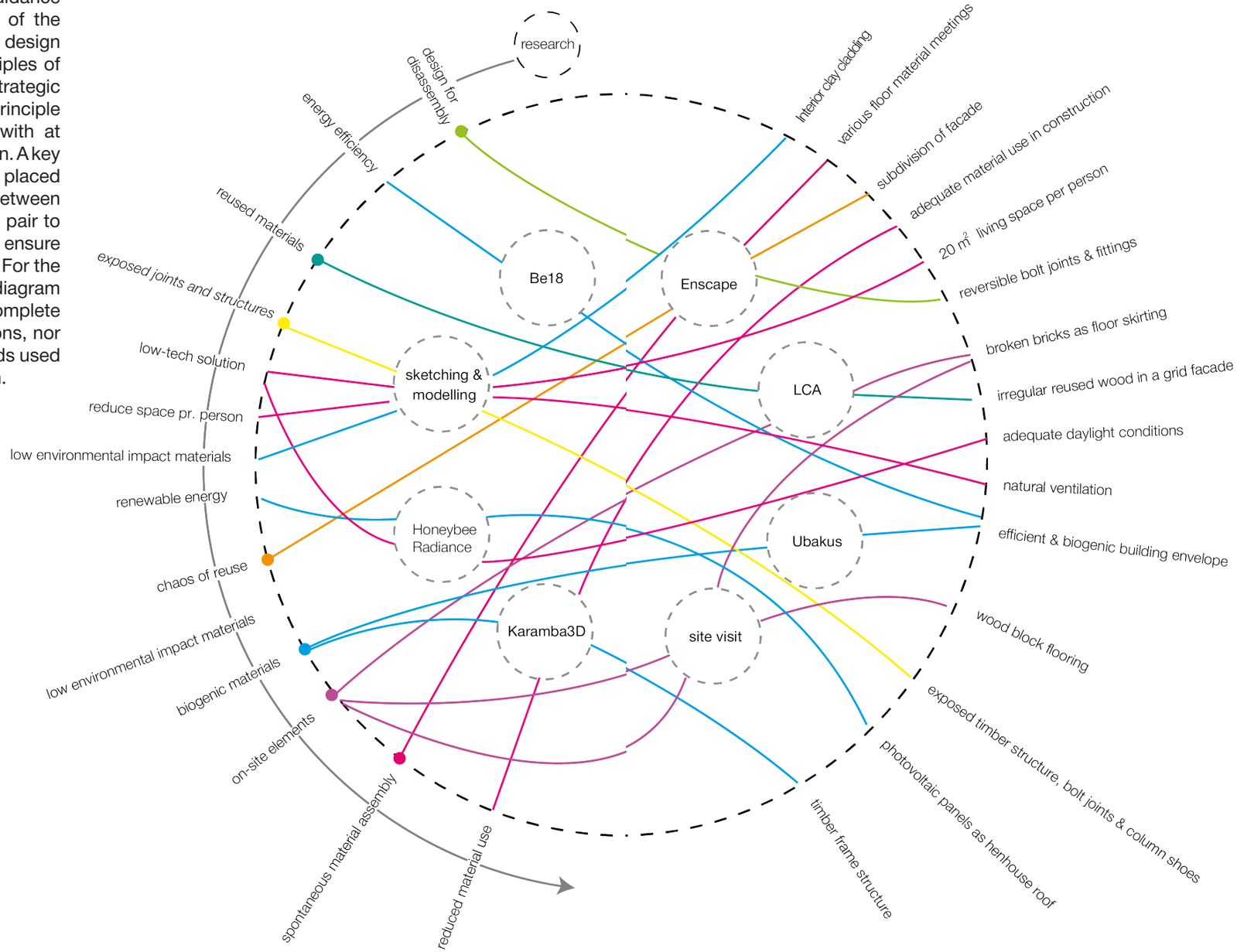


Fig. 48 *methods, framework and solutions.*

02

LCA PROCESS

LCA STRATEGY

cases & scenarios

In the following section two cases will be developed to serve as a foundation for an investigation through comparison of various design scenarios. The purpose of the two cases is to be able to compare the design scenarios with cases that have the same baseline model and system boundary. The three scenarios relate to various approaches regarding the sufficiency framework.

CONVENTIONAL BUILDING
Case 1 is a representation of a conventional building method, with the use of carbon heavy materials such as bricks, concrete and steel. The specific u-values and materials used can be seen in Figure 49.

CONVENTIONAL SUSTAINABLE BUILDING
Case 2 is a representation of a conventional building method regarding u-values and indoor climate, but it utilizes unconventional building materials, which has been chosen based on various cases with a low carbon footprint. (Garnow et al., 2023).

SCENARIO 1
Scenario 1 uses the same building model as case 2, but it explores the implementation of sufficiency measures regarding thermal comfort by calculating the heating and electricity consumption in Be18 through a variation of the average room temperature. Scenario 1 assesses how a decreased average temperature affects the global warming potential.

SCENARIO 2
Scenario 2 uses the same variation of the average room temperatures as scenario 1 but explores sufficiency measures through a variation of u-values, by utilizing the existing ruin structure. The scenario assesses the effect of reducing insulation materials by increasing the u-values.

SCENARIO 3
Scenario 3 is a development of scenario 2 and explores the effect of implementing sufficiency space measures by minimizing the footprint. The scenario assesses the correlation between the number of materials used and the footprint that the carbon emissions are distributed onto.

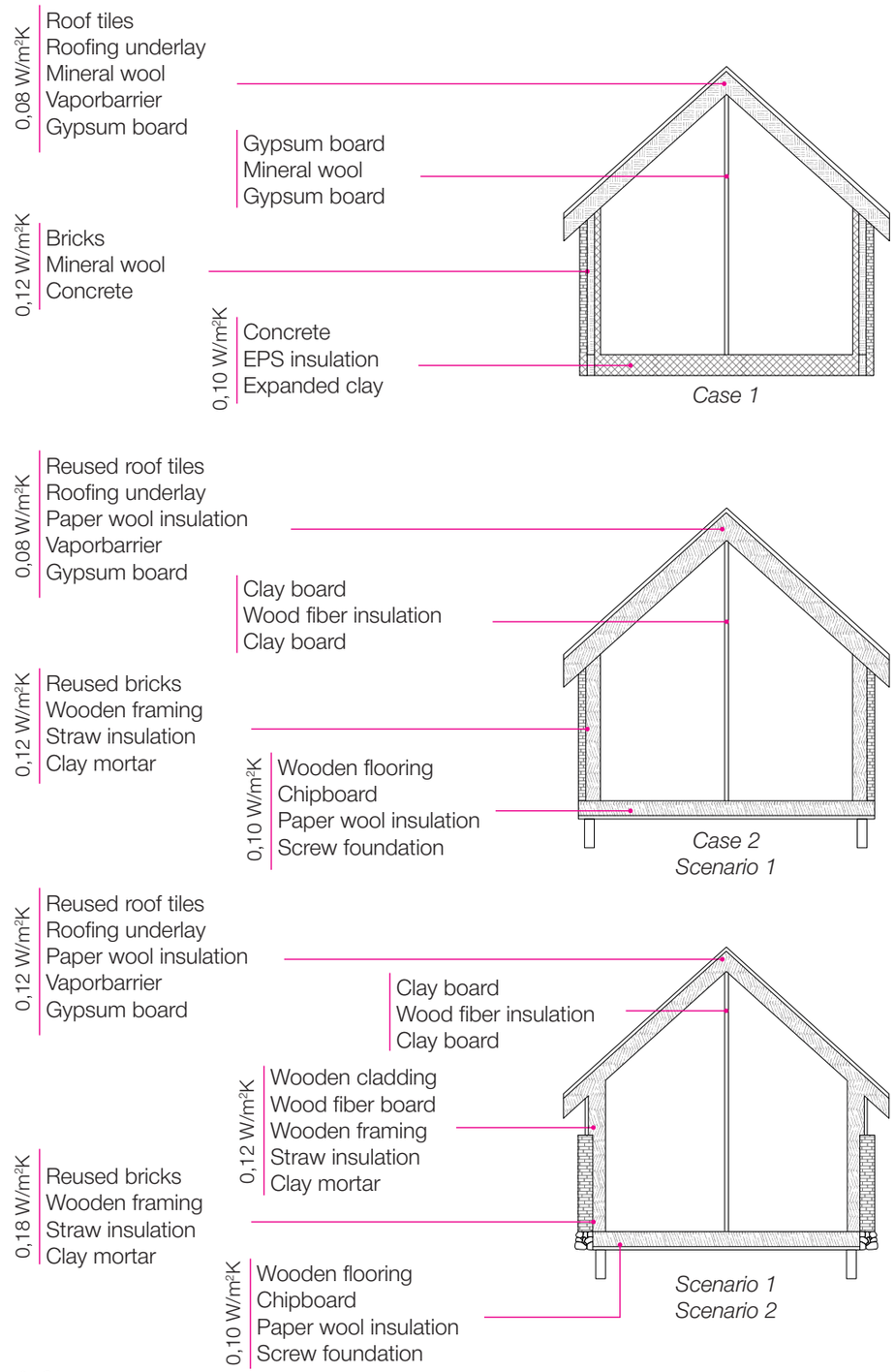


Fig. 49 *LCA cases and scenarios*

ROOM TEMPERATURES

yearly average temperature

As the theory see page 30 concluded, decreasing the room temperature with just one degree plays a significant role in lowering a buildings energy use. This will ultimately result in decreased emissions from energy during use phase when making an LCA. The room temperature is a yearly average temperature meaning that occasionally it will be hotter or colder. Since the energy simulation software Be18 only can use one average temperature, different strategies of dividing the building into zones with different average temperatures, will be used to calculate one area based weighted average temperature ranging from 20°C-15°C degrees. The room temperatures will be used throughout the design process to calculate the heating and electricity consumption, which ultimately will be used as input for the life cycle assessment.

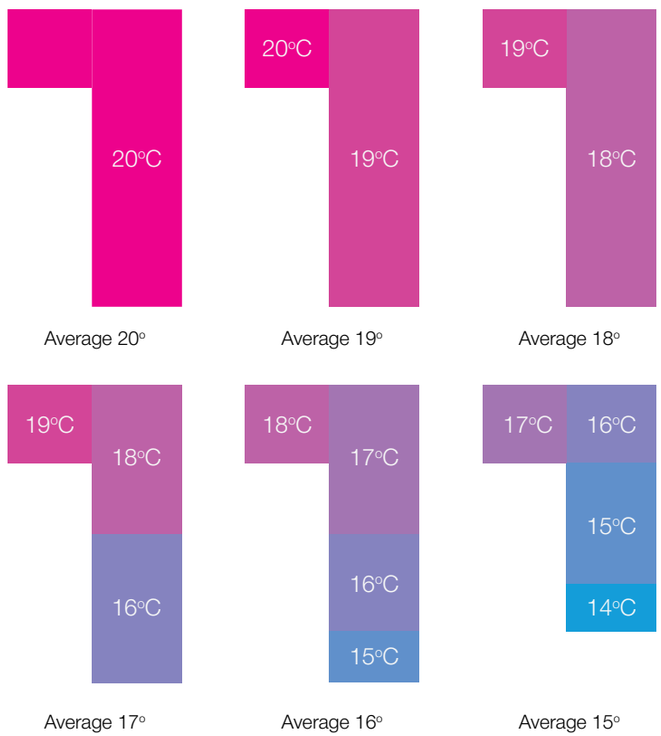


Fig. 50 *temperature zones*

ENERGY CALCULATION

electricity & heating

As seen in Figure 51 the electricity and heating consumption is lowest in case 1 and highest in scenario 2 and 3. The conventional building method of case 1 results in a heating demand of 29,9 kWh/m²/year, due to the high thermal capacity of concrete. The conventional sustainable building has less thermal capacity because of its light inner surfaces, therefore having a heating demand of 31,3 kWh/m²/year. Scenario 2 and 3 has the highest heat loss, due to the higher u-values, ultimately resulting in a higher heating demand.

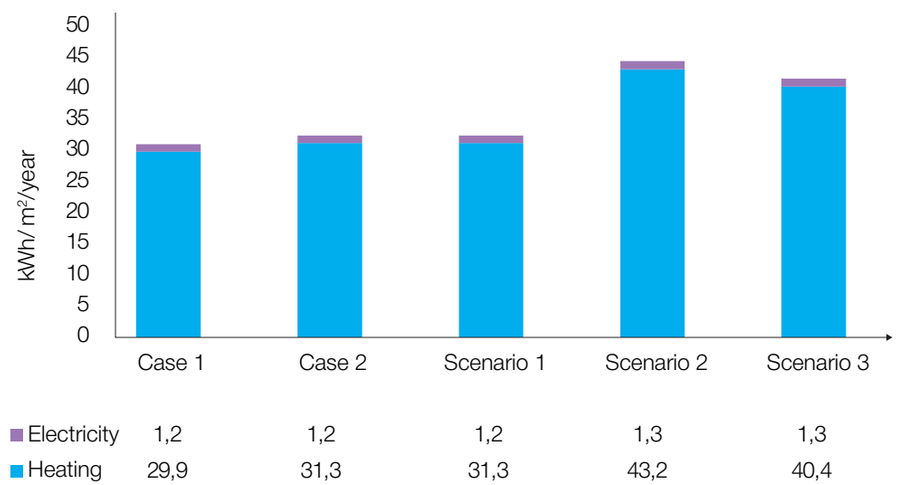
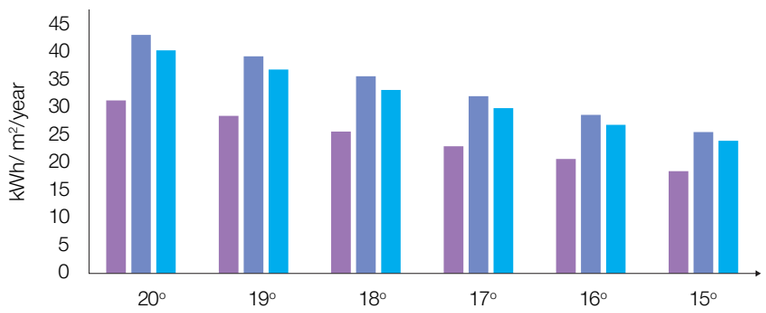


Fig. 51 *Electricity and heating consumption*

ENERGY CALCULATION

electricity & heating

Figure 52 shows a comparison of the scenarios with the variation of room temperature calculated prior. The figure is showing a decrease in heating demand by lowering the average room temperature with just one degree. As seen on page 30 many older buildings have an average temperature of 18°C, so therefore the heating consumption from scenario 1 could be lowered by 17,90% by decreasing the average room temperature from 20°C to 18°C.



	20°	19°	18°	17°	16°	15°
Scenario 1	31,3	28,5	25,7	23	20,7	18,5
Scenario 2	43,2	39,3	35,7	32,1	28,7	25,6
Scenario 3	40,4	36,9	33,2	29,9	26,9	24

Fig. 52 *energy demand for heating, using varying room temperatures.*

SYSTEM BOUNDARY

components & phases

The system boundary for the life cycle assessments is defined by building components and life cycle stages. The building components are external walls, roof, inner walls, and foundation and the life cycle stages are production A1-A3, use-phase B4 and B6, and end-of-life C3 and C4.

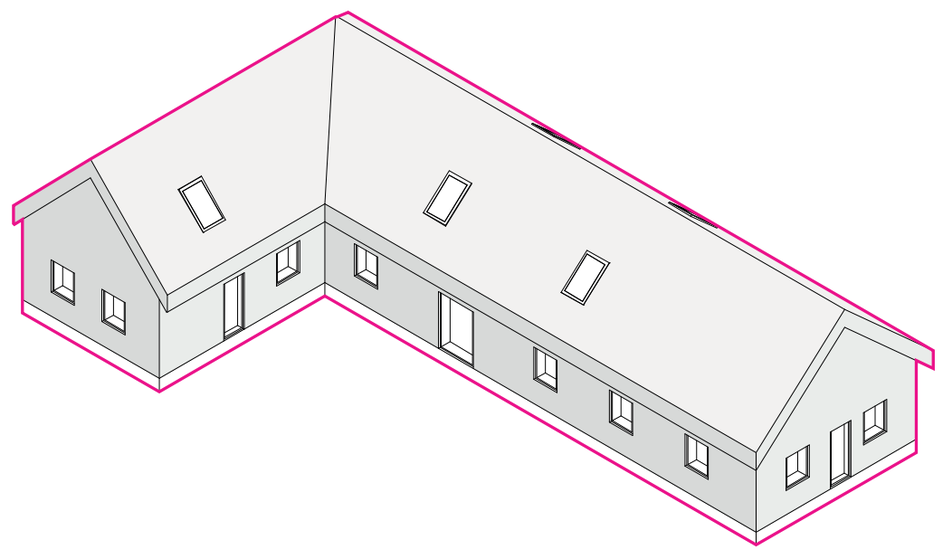


Fig. 53 *system boundary.*

CASES & SCENARIOS

global warming potential

A life cycle assessment for the two cases and three scenarios has been calculated through Real-Time LCA. The calculation gave the results for the global warming potential for both cases and all the scenarios (see figure 54). In the figure all the instances have the same average room temperature.

The advantages of choosing low carbon materials becomes evident as case 2 has a carbon footprint that is more than half of case 1. The global warming potential for scenario 2 and 3 is increased from scenario 1 due to the higher heating demand, even though scenarios 2 and 3 uses less material for insulation.

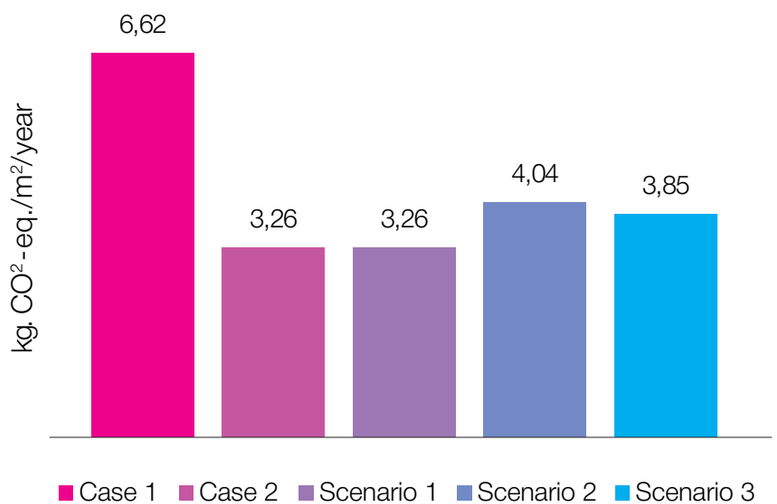
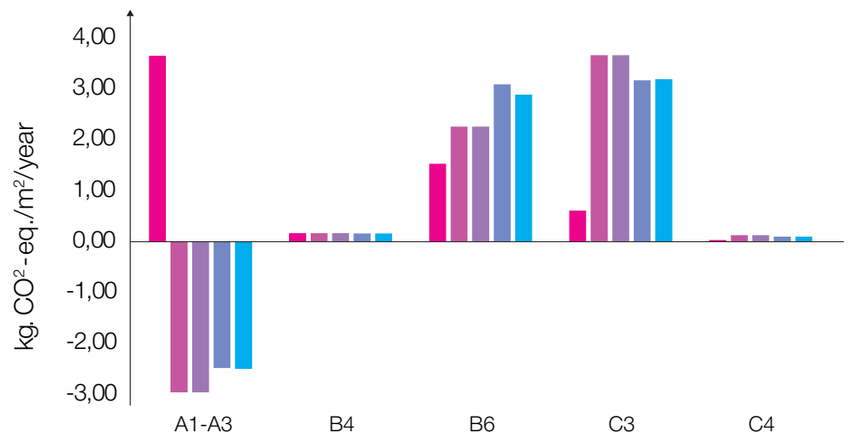


Fig. 54 *GWP for cases and scenarios*

LIFE CYCLE STAGES

global warming potential

The global warming potential for each life cycle stage is shown in figure 55. Case 2 and scenarios 1-3 all has a negative impact in the production stage, due the carbon sequestering potentials of materials used such as straw and paper wool for insulation, and wood elements for construction. Scenario 2 and 3 has a higher CO_2-eq. in production stage (A1-A3), than scenario 1 due to the use of less biogenic material mass, but therefore also a lower impact in the end-of-life stage (C3 and C4). As the heating demand is higher for scenario 2 and 3 the use phase emission (B6) from the commissioning energy is significantly higher.



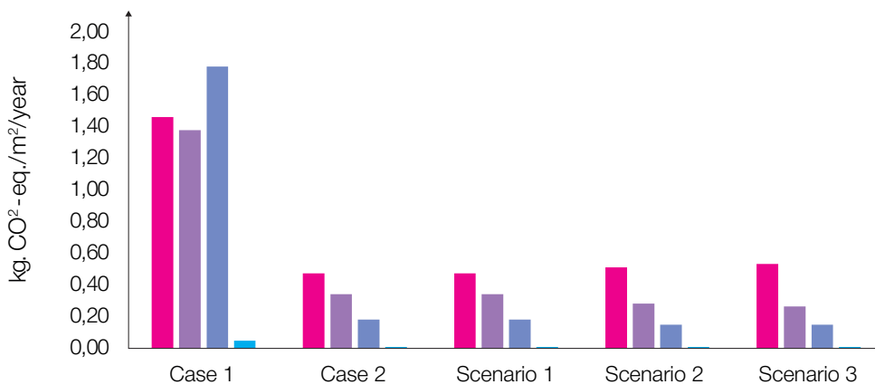
	A1-A3	B4	B6	C3	C4
Case 1	3,65	0,17	1,53	0,61	0,03
Case 2	-2,96	0,17	2,26	3,66	0,13
Scenario 1	-2,96	0,17	2,26	3,66	0,13
Scenario 2	-2,48	0,16	3,09	3,17	0,10
Scenario 3	-2,50	0,16	2,89	3,19	0,10

Fig. 55 *GWP of life cycle stages*

MACRO COMPONENTS

global warming potential

An evaluation of the impact for each macro component is shown in figure 56. Choosing biogenic materials and reused materials over conventional significantly decreases the GWP for each of the macro components used for the building. In case 1 the conventional concrete foundation is the macro component with the highest impact, whereas the low carbon solutions have external walls as highest impact. The impact from external walls increases from scenario 1-3, which is due to scenario 2 using virgin wooden cladding on some of the façade. Even though wood is a low carbon material the GWP is still higher than any kind of reused material. Scenario 3 sees an increase from scenario 2 due to the decrease in square meters of floor area that the GWP can be distributed onto.



	Case 1	Case 2	Scenario 1	Scenario 2	Scenario 3
External walls	1,46	0,47	0,47	0,51	0,53
Roof	1,38	0,34	0,34	0,28	0,26
Foundation	1,78	0,18	0,18	0,15	0,15
Inner walls	0,05	0,01	0,01	0,01	0,01

Fig. 56 *GWP for macro components*

MATERIALS

global warming potential

The macro components from scenario 1 have been expanded in figure 57 to show the impact of each of the materials used for the scenario. Unlike the conventional building case the scenario have the highest impact from the external wall. The largest share of GWP in the external wall comes from the windows when using low carbon and reused materials. In the roof the paper wool insulation sits on the largest share of GWP due to the large amount of biogenic carbon released in the end-of-life phase.

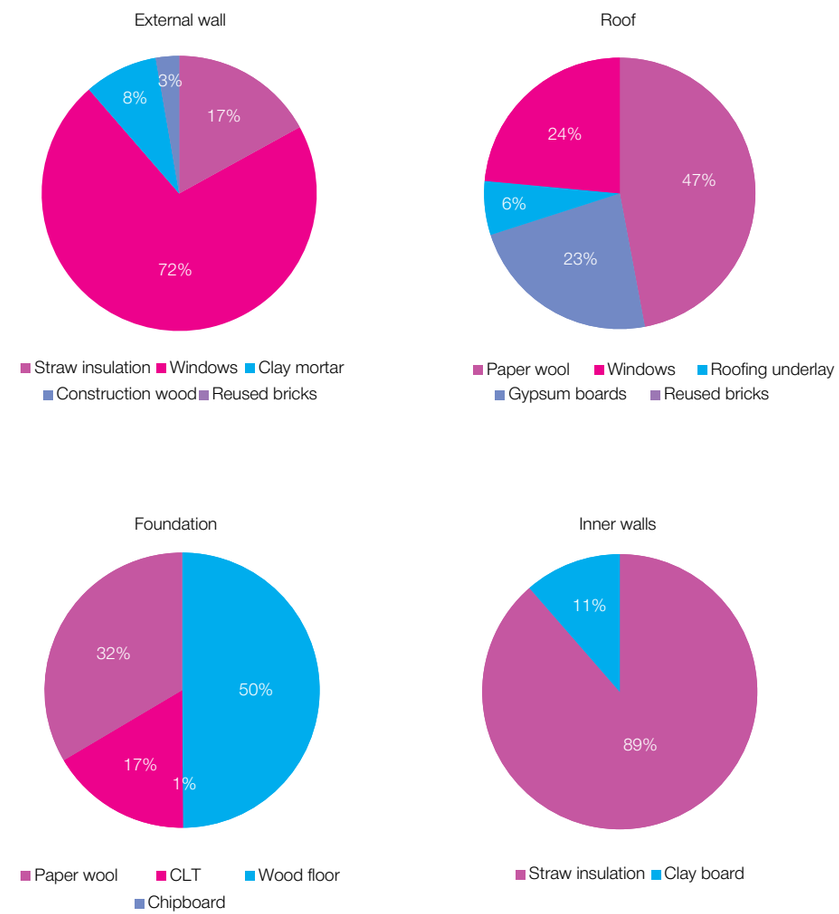


Fig. 57 *GWP materials by building components*

BUILDING FOOTPRINT

global warming potential

The evaluation of the results from figure 56 has led to the exploration of how the size of the heated floor area influence the GWP when divided with the heated floor area. The results are illustrated in figure 58 where scenario 2 has a lower GWP pr. m^2 than scenario 1 due to less insulation in the macro components. Scenario 3 has a higher GWP pr. m^2 than scenario 2 even though the total GWP for materials in scenario 2 is 10437,83 kg. CO_2-eq. and 9100,03 kg. CO_2-eq. for scenario 3.

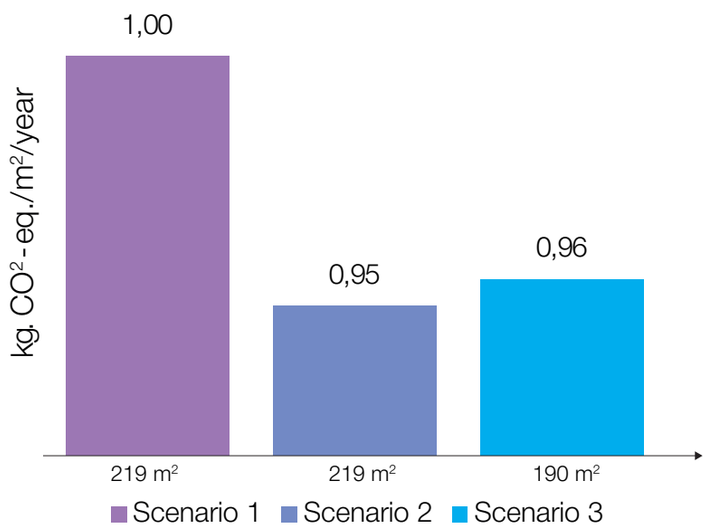


Fig. 58 *GWP for materials*

THERMAL COMFORT

influence on B6 stage

The emissions from buildings use phase is heavily impacted by the commissioning energy, so lowering the room temperature with a few degrees has a huge positive impact on these emissions. Lowering the room temperature see figure 59 from 20°C to 19°C reduces the commissioning energy emissions with 9,30% and lowering with one more degree down to 18°C reduces the emissions with 17,70%.

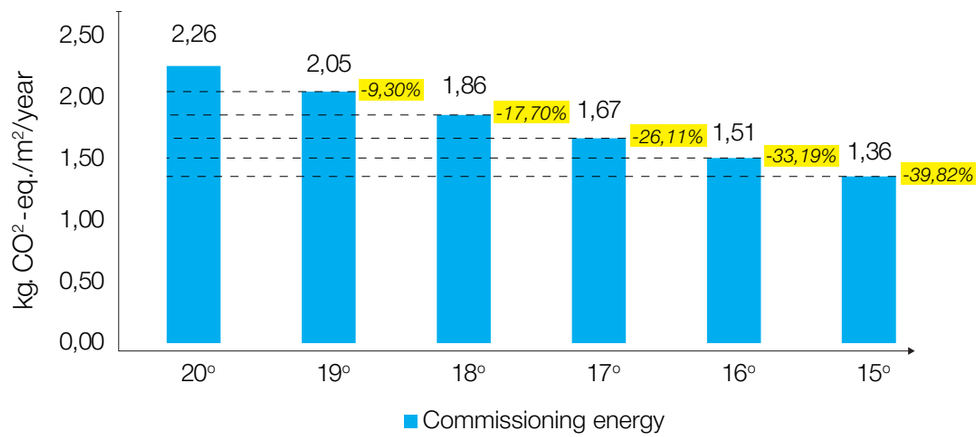
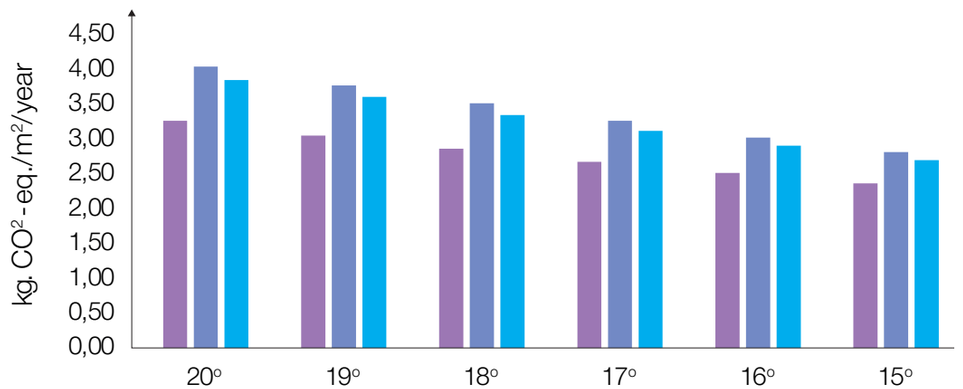


Fig. 59 *GWP for commissioning energy*

DESIGN TEMPERATURE

global warming potential

Increasing the u-value of a macro component to account for a decrease in room temperature, increases the total GWP (see figure 60). Since all the scenarios uses low carbon insulation materials such as paper wool and straw, removing a proportion of the mass lowers the GWP from materials insignificantly compared to the increased heating demand, as a result of an increase in heat loss.



	20°	19°	18°	17°	16°	15°
Scenario 1	3,26	3,05	2,86	2,67	2,51	2,36
Scenario 2	4,04	3,77	3,51	3,26	3,02	2,81
Scenario 3	3,85	3,61	3,35	3,12	2,91	2,70

Fig. 60 *GWP for cases and scenarios, using varying design temperatures.*

POTENTIALS OF LOW-TECH

global warming potential

Decreasing the number of technical installations has a positive impact on a buildings GWP see figure 61. Implementing a low-tech solution which reduces the technical installations for heating, cooling and ventilation to half reduces the GWP for energy by 1,33% and 26,32% for materials.

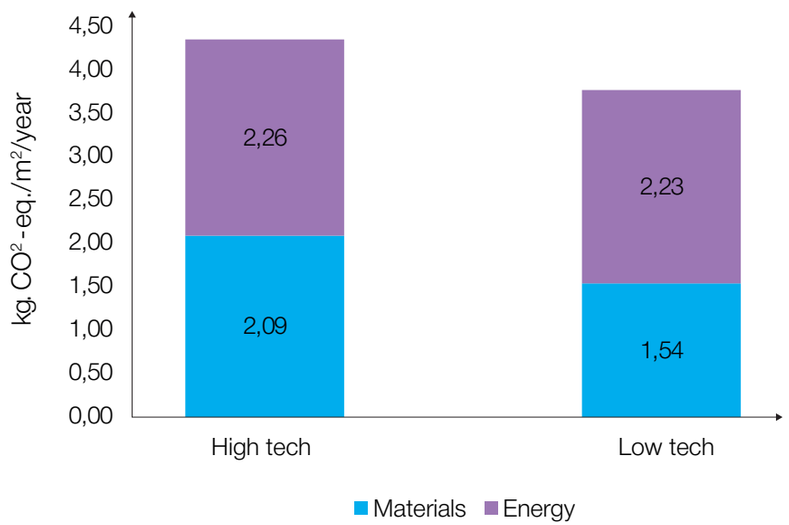


Fig. 61 *GWP for materials and commissioning energy.*

LCA PROCESS

FROM SCENARIO 1, LOWERING THE AVERAGE ROOM TEMPERATURE BY JUST A FEW DEGREES SIGNIFICANTLY DECREASES THE GWP FROM THE B6 STAGE.

FROM SCENARIO 2, INCREASING THE U-VALUES BY USING LESS INSULATION MATERIAL SIGNIFICANTLY INCREASES THE HEATING DEMAND, WHICH ULTIMATELY INCREASES THE B6 STAGE. THE REDUCTION IN GWP FROM PRODUCTION PHASE A1-A3 BY USING LESS INSULATION MATERIAL, WHEN USING LOW CARBON INSULATION MATERIALS, DOES NOT ACCOUNT FOR THE INCREASE IN THE B6 STAGE.

FROM SCENARIO 3, REDUCING A BUILDING FOOTPRINT REDUCES THE NUMBER OF SQUARE METERS WHICH THE TOTAL GWP CAN BE DISTRIBUTED ONTO, THEREFORE INCREASING THE GWP WHEN USING THE UNIT AS PER THE BUILDING REGULATIONS.

LIFE CYCLE ASSESSMENTS RESULTED IN THE POTENTIALS OF SAVING A LOT OF CARBON BY IMPLEMENTING LOW-TECH SOLUTIONS THAT CAN REPLACE SOME HIGH-TECH SOLUTIONS.

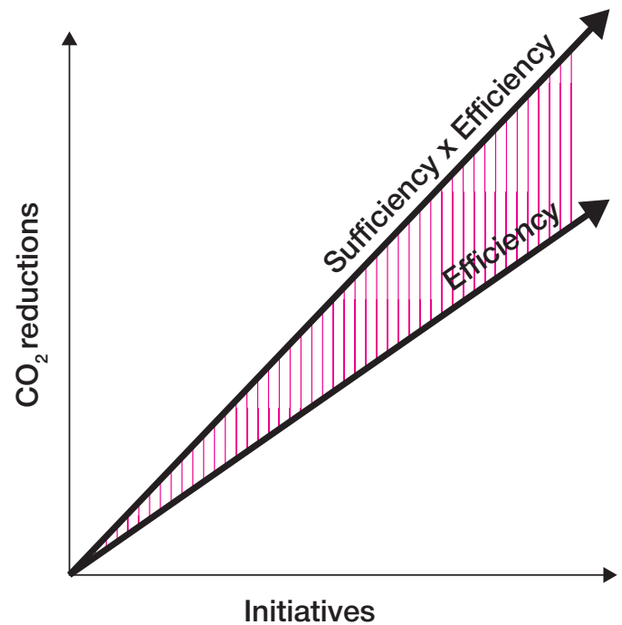


Fig. 62 *conceptual effect of the sufficiency strategic principles.*

DESIGN
PRESENTATION

Fig. 63 *render from north-east.*

site introduction

The mill still stands tall on the site on the man-made hill supported by stone walls similar to the stone foundations. When arriving, the former henhouse, now a pavilion, is first to come to sight. The pavilion allows visitors to have a rest while visiting the historic mill. The site is accessible by car, bike and as a pedestrian. The parking facilities make the site more accessible, while paths make for effortless circulation. The community hall encloses the courtyard, recalling the original stable structure in footprint and form.

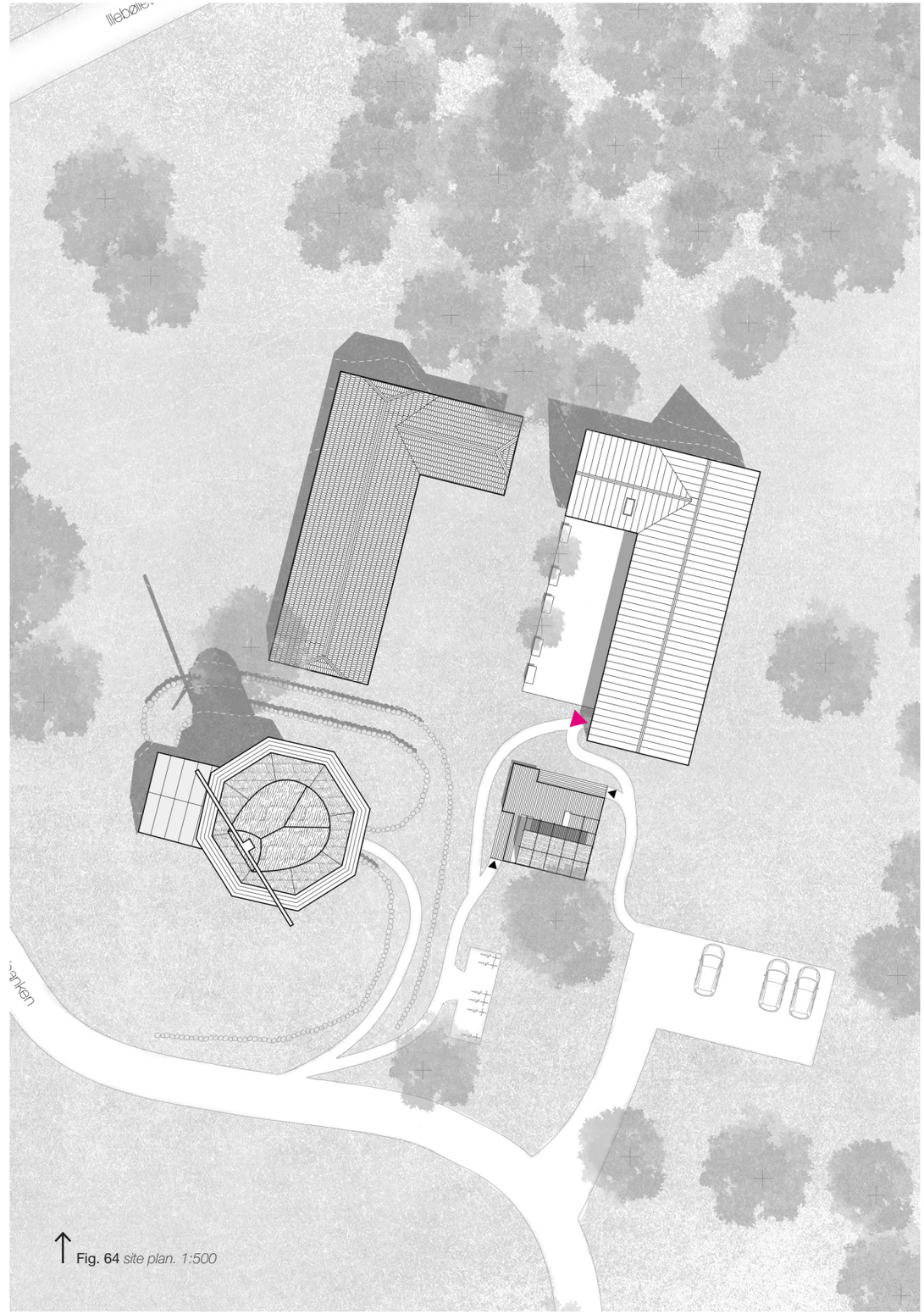


Fig. 64 *site plan. 1:500*

The old and new façades intertwine in a subtle story, told through a patchwork of repurposed wooden elements from the building process and site, in a grid creating an order of chaos, while the ruin stands a capsule of time and history. The wooden façade creates a backdrop behind the ruin and elevates the roof to create the illusion of an almost light floating roof. The henhouse pavilion with its light wooden structure becomes a contrast to the ruin, while the mill in the background gives the site its characteristic identity.

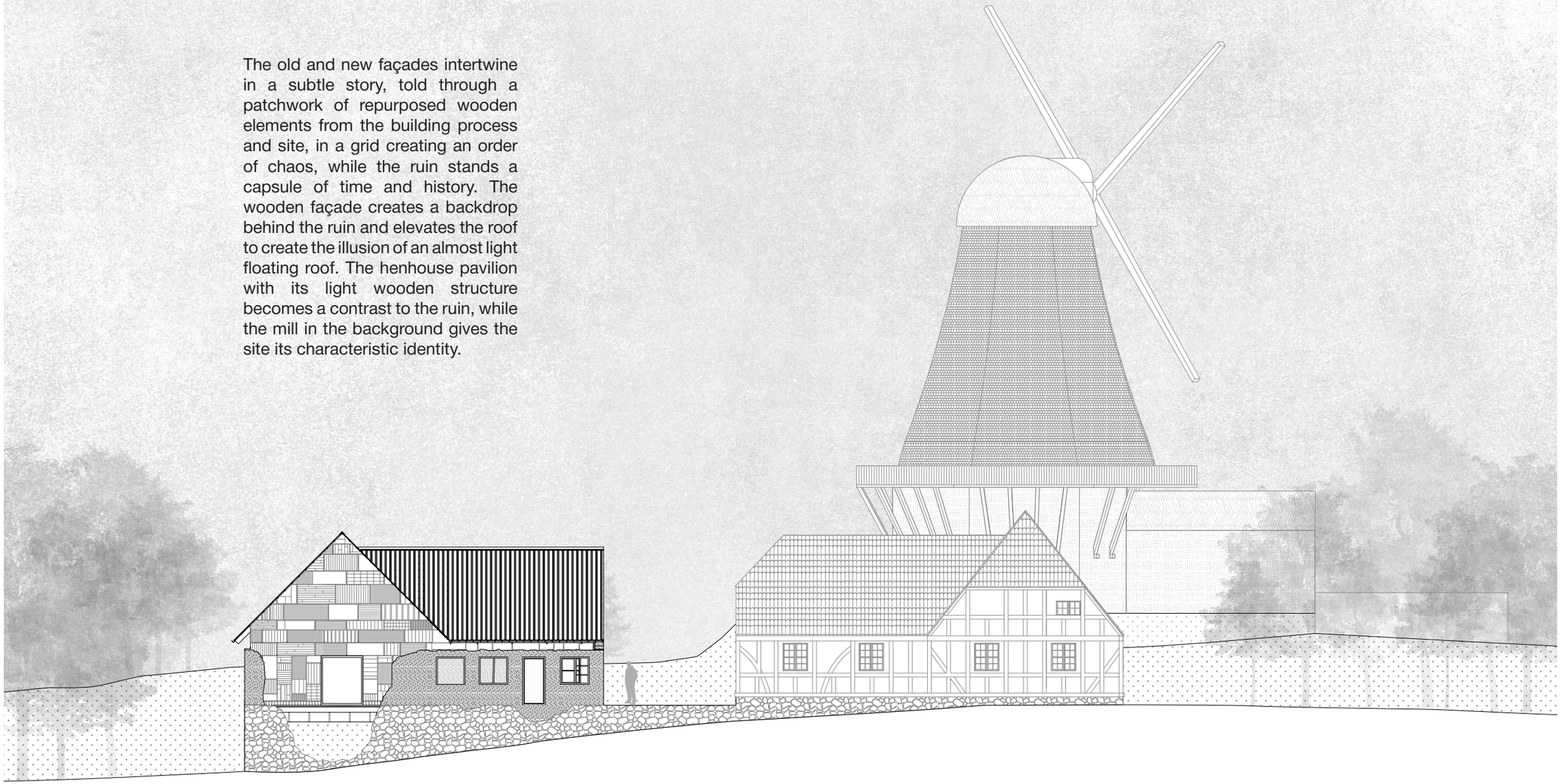


Fig. 65 *north elevation. 1:200*

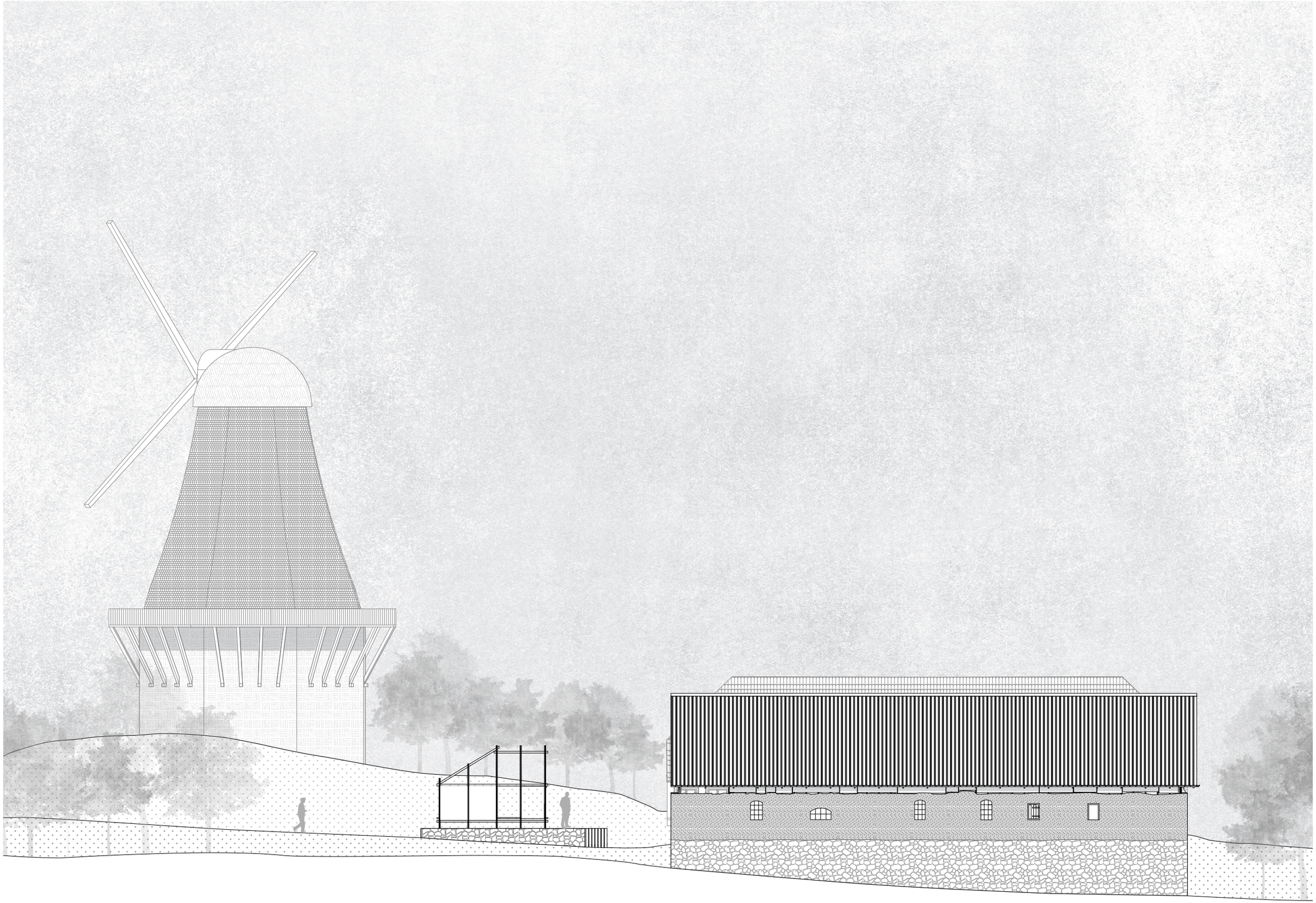


Fig. 66 *east elevation. 1:200*

Fig. 67 *west render.*

entrance

At the entrance to the community hall, the narrative of old and new is expressed by the new structure distancing itself from the ruin, creating a space where two time periods can be explored. The roof structure latches onto the ruin, creating a sheltered space that serves as a transition from outside to inside, while the uncovered roof construction gives a glimpse into the tectonic aspects of the exposed joints. The façade towards the entrance leans inwards, accentuating the entrance to the community hall. The aesthetic that emerges from the façade, which is clad with repurposed wooden elements spontaneously assembled, expresses that only what is sufficient should be expected from the spaces within.

Fig. 68 *entrance render.*

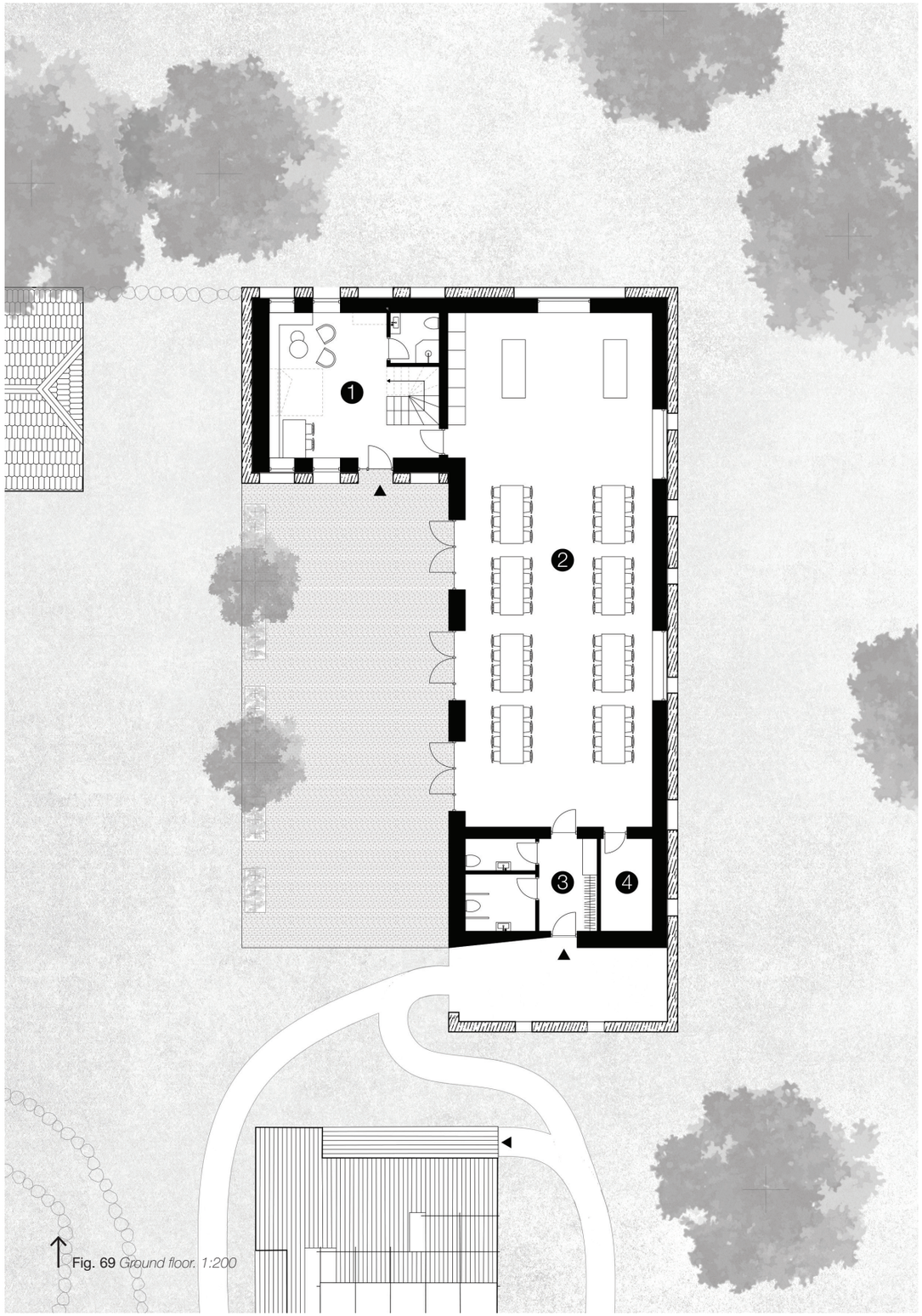
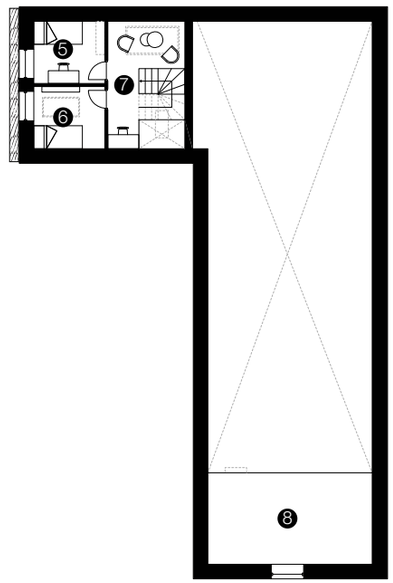


Fig. 69 *Ground floor. 1:200*



1 Living room 40 m²
2 Community hall 140 m²
3 Entrance 8 m²
4 Storage 9 m²
5 Bedroom 10 m²
6 Bedroom 10 m²
7 Office/living 16 m²
8 Storage 30 m²

Fig. 70 *First floor. 1:200*

building layers

Figure 71 exposes the layers of the design starting from the ruin and foundation. On top of the ruin sits a wooden deck with screw foundation, then the wall elements are placed on top, enveloped by a wooden façade, followed by load bearing construction elements and lastly enclosed by the roof.

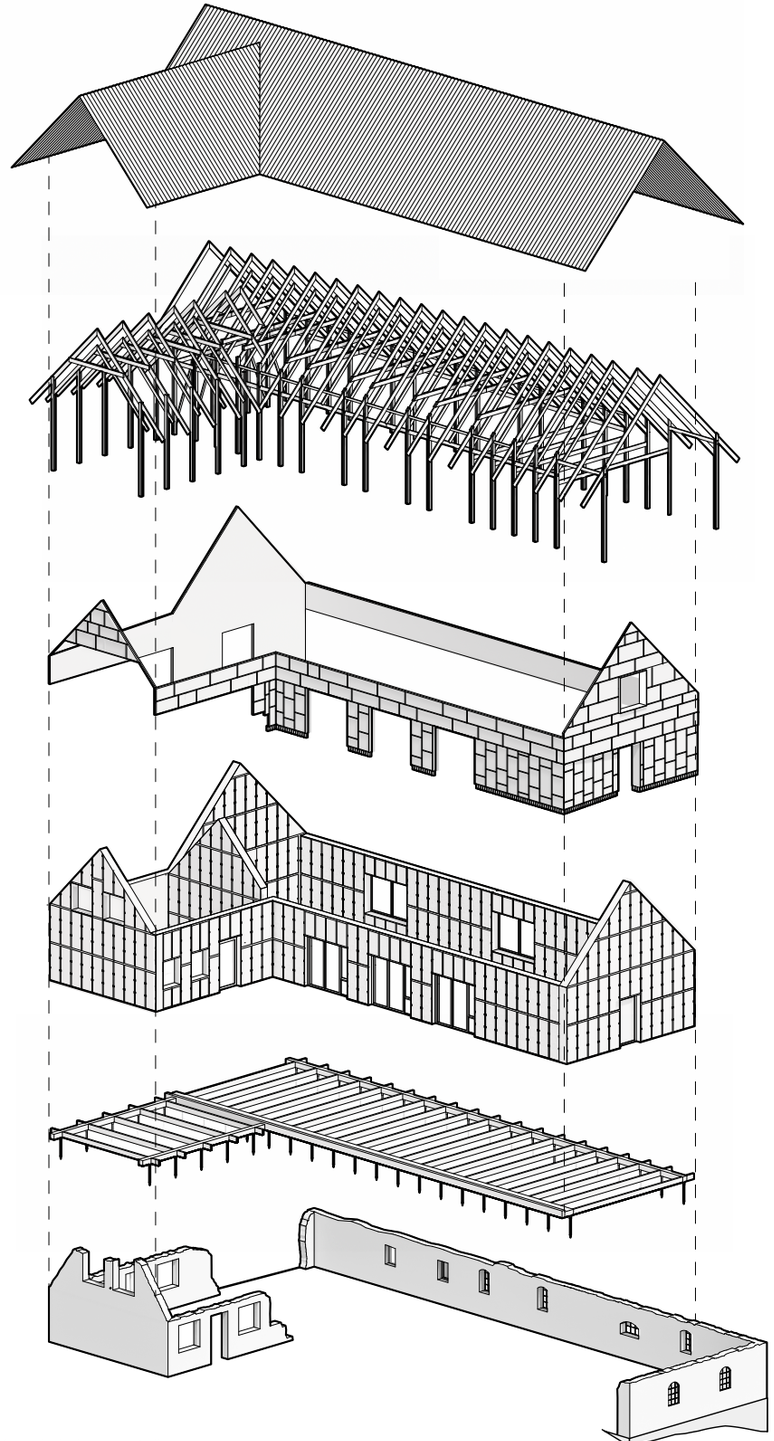


Fig. 71 *exploded concept diagram.*

Fig. 72 *interior render.*

The community hall is an open space capable of hosting various events. The space overlooks the surrounding nature to the north from the elevated terrain inside the existing ruin structure. The entrance is an unheated and publicly accessible space before entering the community hall, creating a series of contrasting zones – from open to enclosed to open again.

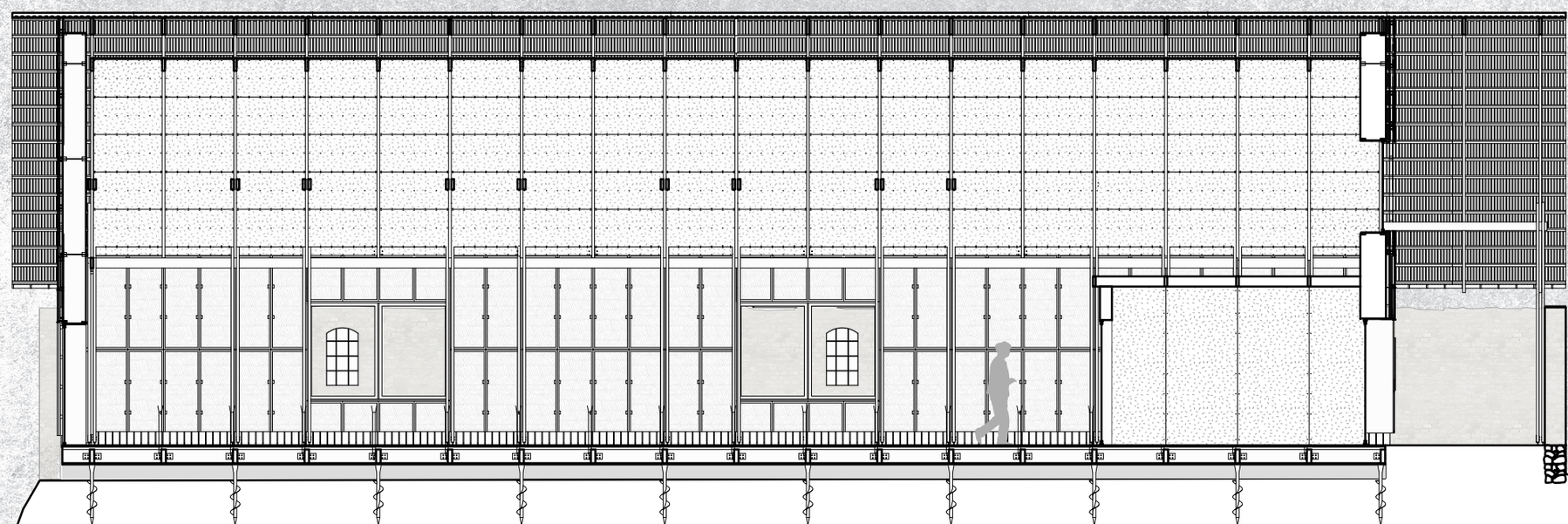


Fig. 73 *longitudinal section. 1:100*

scenarios

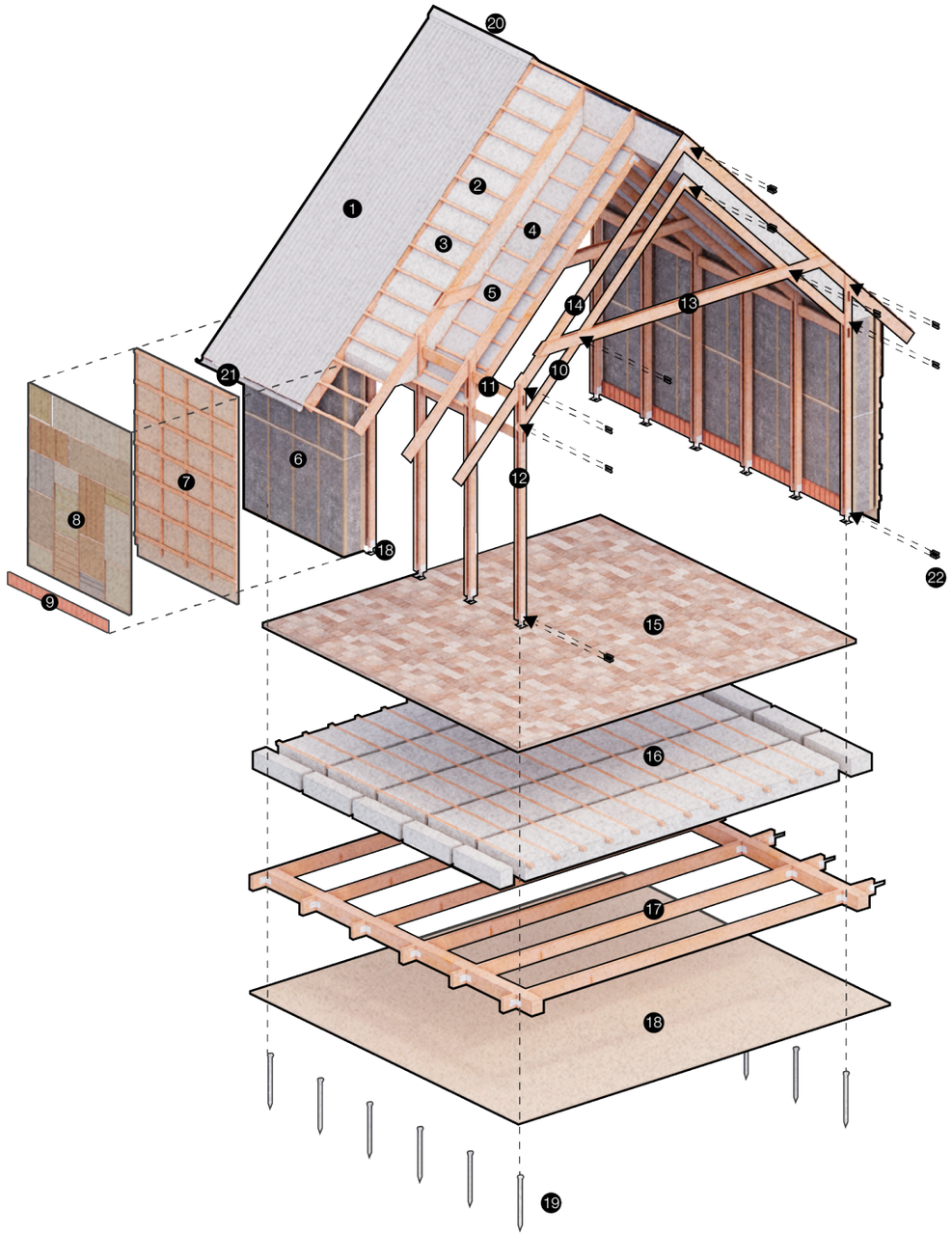
The community hall, with its open plan layout, is designed to host various events illustrated on figure 74. As exemplified through four scenarios, multiple events can take place at the same time. The first scenario is an art exhibition in the first half of the building while the other half still is capable of hosting smaller gatherings. The second scenario shows the potential plan layout of a larger social gathering with a stage and dance floor, and where the courtyard is being utilized to expand the size of the community hall. In the third scenario the capacity of the community hall is pushed towards its absolute limits with a large social gathering, where the courtyard is being used for seating. In the fourth scenario the community hall has been transformed into a theatre.

Fig. 74 *scenarios*

materials

The indoor surfaces in the community hall are plastered with textured clay, giving the walls a rough and unpolished finish. The wall modules are visible wooden framing elements dividing the wall into a grid system. The ceiling is covered in nothing but raw gypsum boards that give a rough and honest aesthetic that emphases the beauty of unfinished surfaces. The walls and floor are transitioned by the floor skirting, made from on-site bricks. The floor is made from wood blocks cut from trees that were growing inside the ruin, a trace of what once was there.

Fig. 75 *interior render.*



1. Reused trapez zink sheets
2. Roof laths
3. Paper wool insulation
4. Laths for ceiling
5. Gypsum board
6. Straw insulation modules & clay plaster
7. Wood fiber board withwooden strips
8. Reused wood in grid
9. Reused bricks
10. Bottom rafters (45x145)
11. Support beams (45x170)
12. Columns 2x(45x120)
13. Rafter tie beam 2x(45x170)
14. Top rafters (45x195)
15. Wooden block floor on chipboard
16. Floor joists
17. CLT with angle brackets
18. Wood fibre wind barrier
19. Screw foundation
20. Roof ridge
21. Gutters
21. Bolts

Fig. 76 *exploded diagram showing construction elements*

low-tech solutions

Various low-tech solutions have been implemented in the final design. The purpose of the solutions has been to minimize the final energy use by reducing the need for energy through manually operated building systems. The adaptive principles seen on figure 77 are all manually controlled to increase the users influence on the indoor climate, which will ultimately result in an indoor environment which is expected less of and a higher degree of satisfaction among the users. The low-tech solutions are also a representation of the overall architectural expression of the low-tech materials which the building is made of.

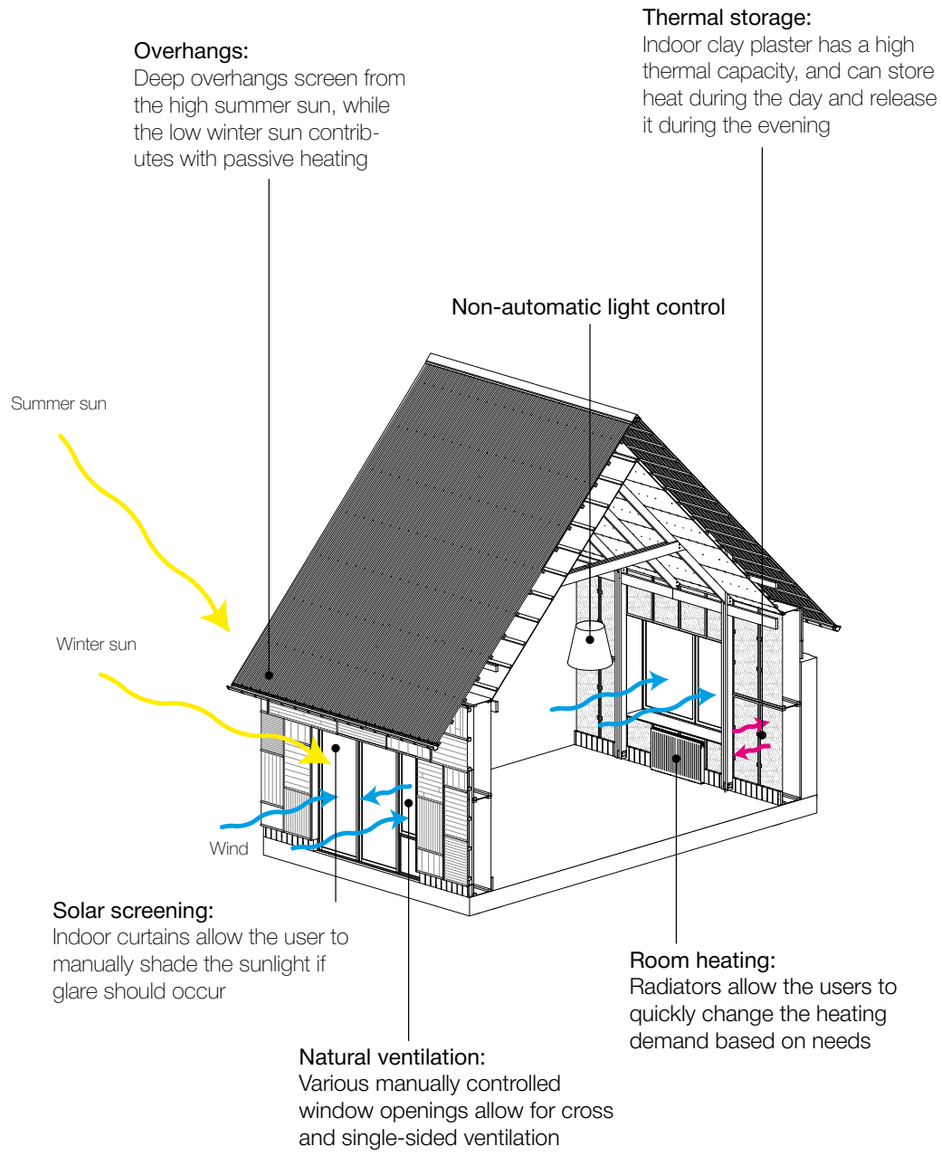


Fig. 77 *low-tech strategies.*

apartment

The apartment expresses a simple way of living, where social time is prioritized. The materials are a mix of virgin conventional materials, on-site materials, by-products, and reused materials. The walls and ceiling are covered in unpolished gypsum board, showing screws, production labels and joints. Integrated furniture in plywood optimises space use while giving warmth to the room. Above the dining table hangs a suspended acoustic panel made from eelgrass, with the purpose of both improving the acoustic quality and create zoning. The entrance to the apartment is covered by surface made from on-site red bricks, while the remaining part of the surface is covered with a plywood board creating a seamless transition from the entrance to living space.

Fig. 78 *apartment render.*

The section through the apartment shows its compactness in a simple but well-distributed apartment. The section further gives a glimpse into what sufficient housing potentially could look like. The apartment shares a wall with the community hall and differences and similarities between the apartment and the community hall are shown.

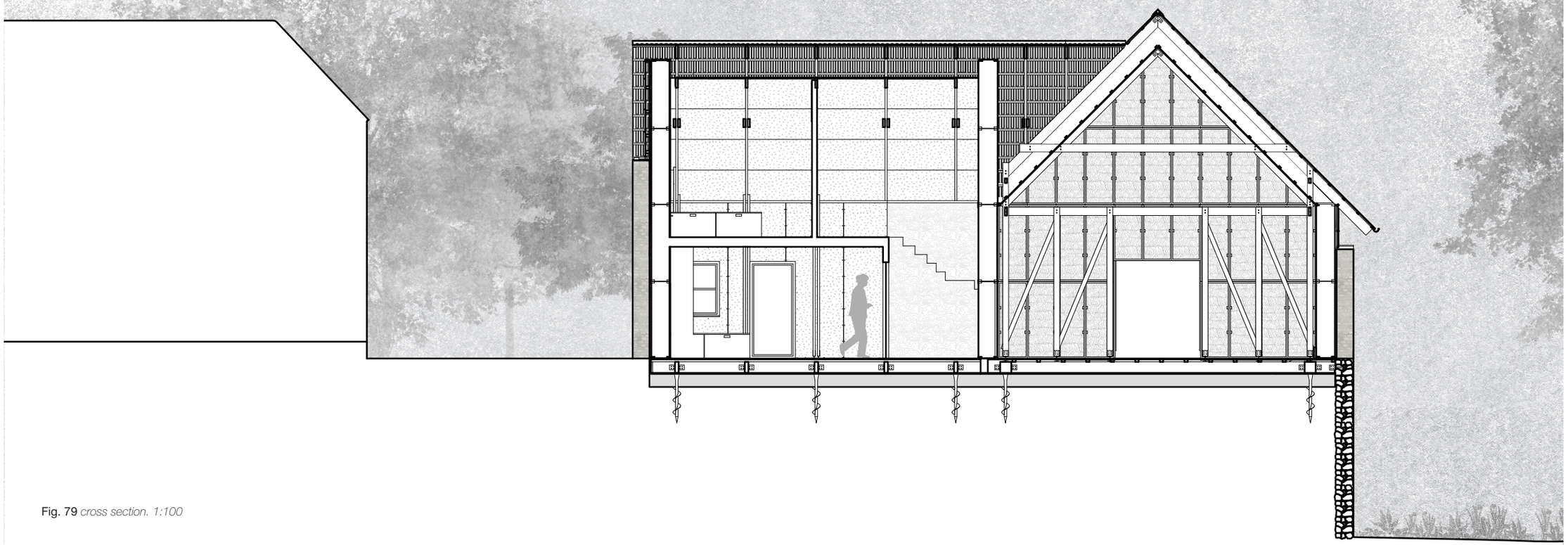


Fig. 79 *cross section. 1:100*

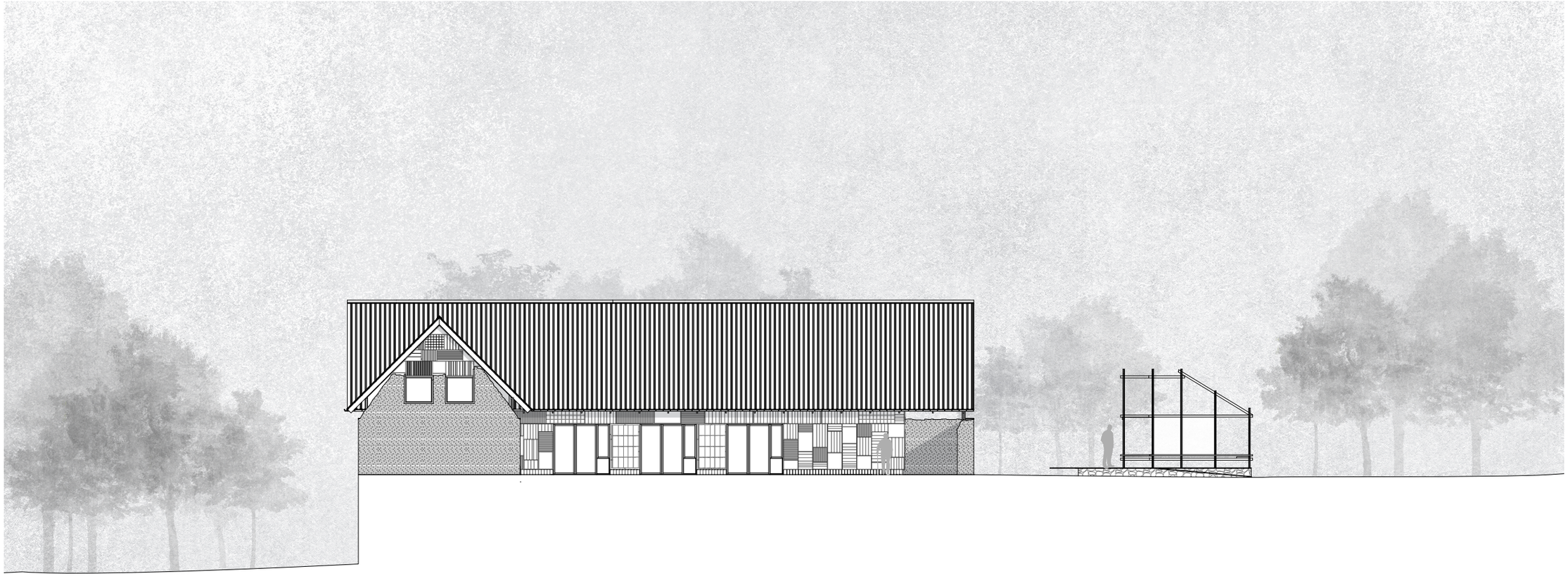


Fig. 80 *west elevation. 1:200*

Fig. 81 *south elevation. 1:200*

pavilion

The pavilion is placed on top of the foundation formerly housing the henhouse. The pavilion is made from a light and open construction made from wooden elements with visible joints and connections. On the roof of the pavilion south orientated solar panels are placed. The purpose of the pavilion is to serve as a publicly accessible space, where visitors to the mill can have a rest while enjoying the view to the mill, community hall and the surrounding nature.

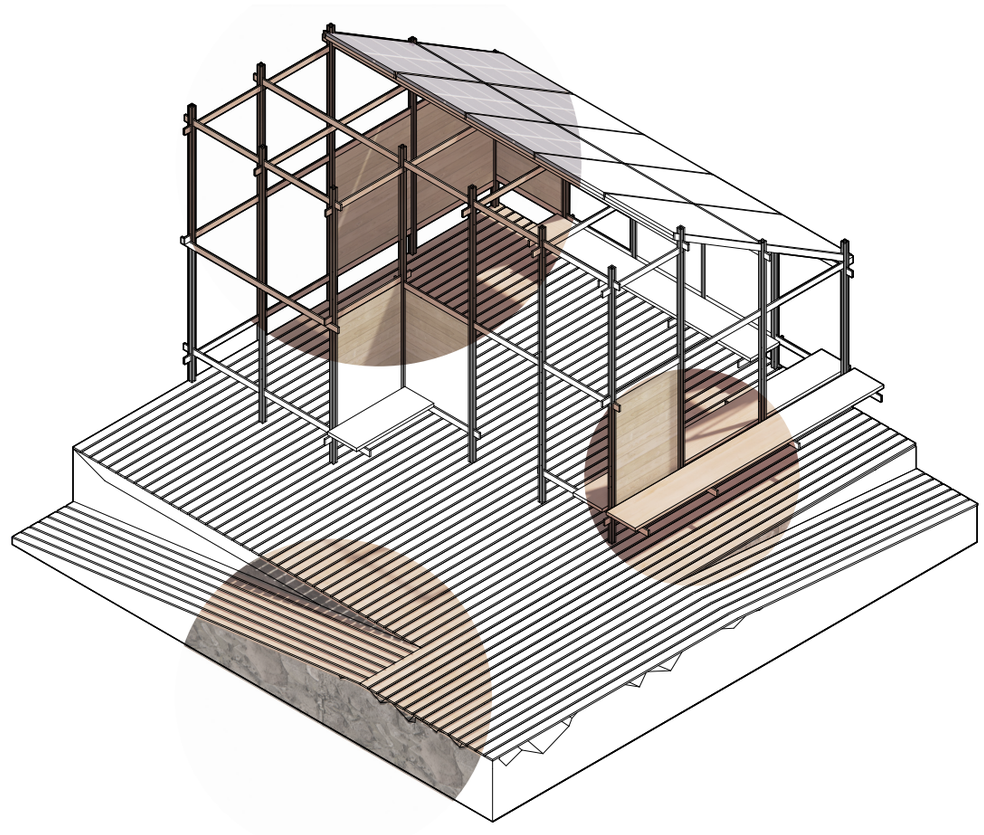


Fig. 82 *isometric diagram of henhouse pavilion.*

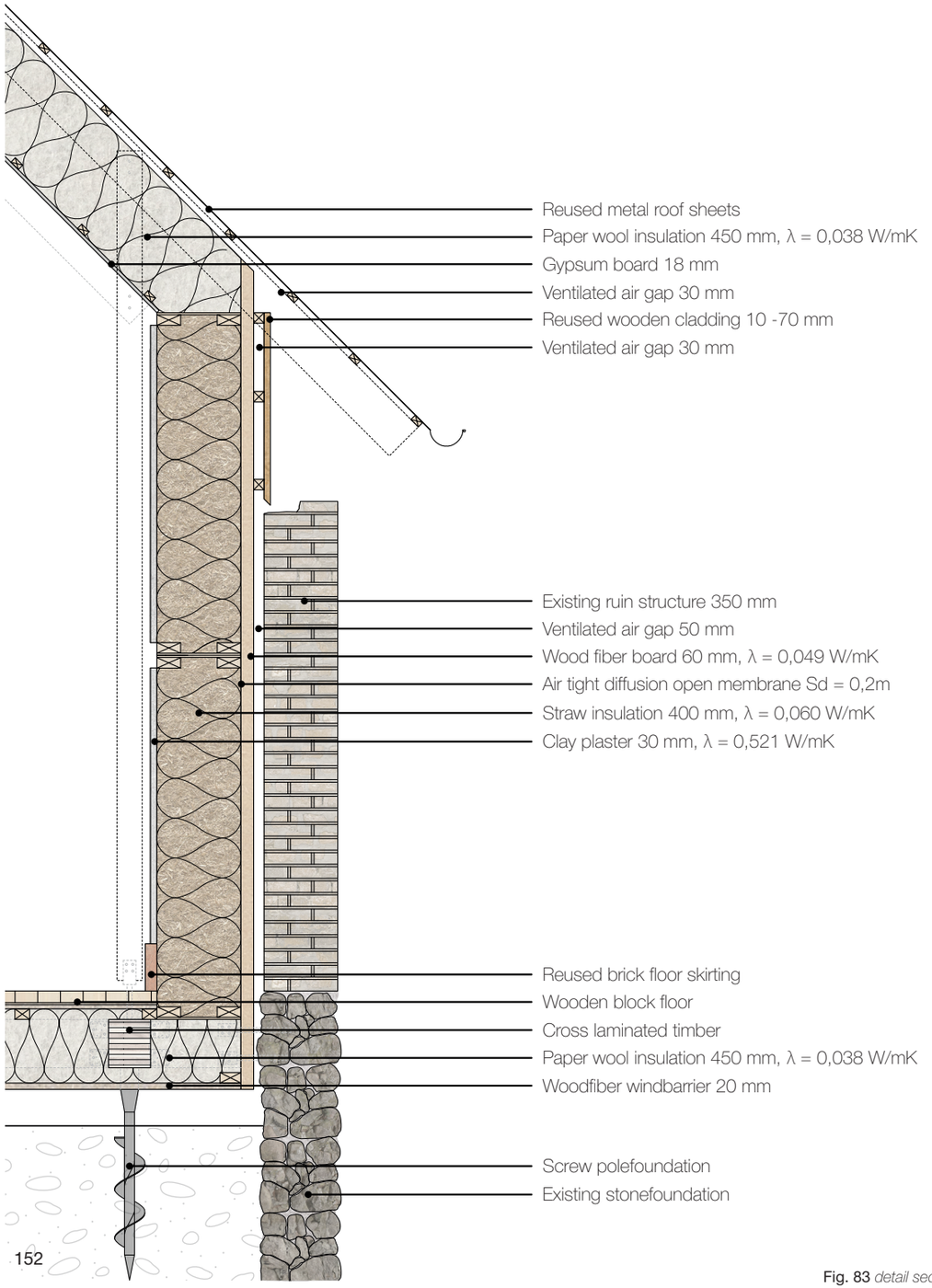


Fig. 83 *detail section 1:25*

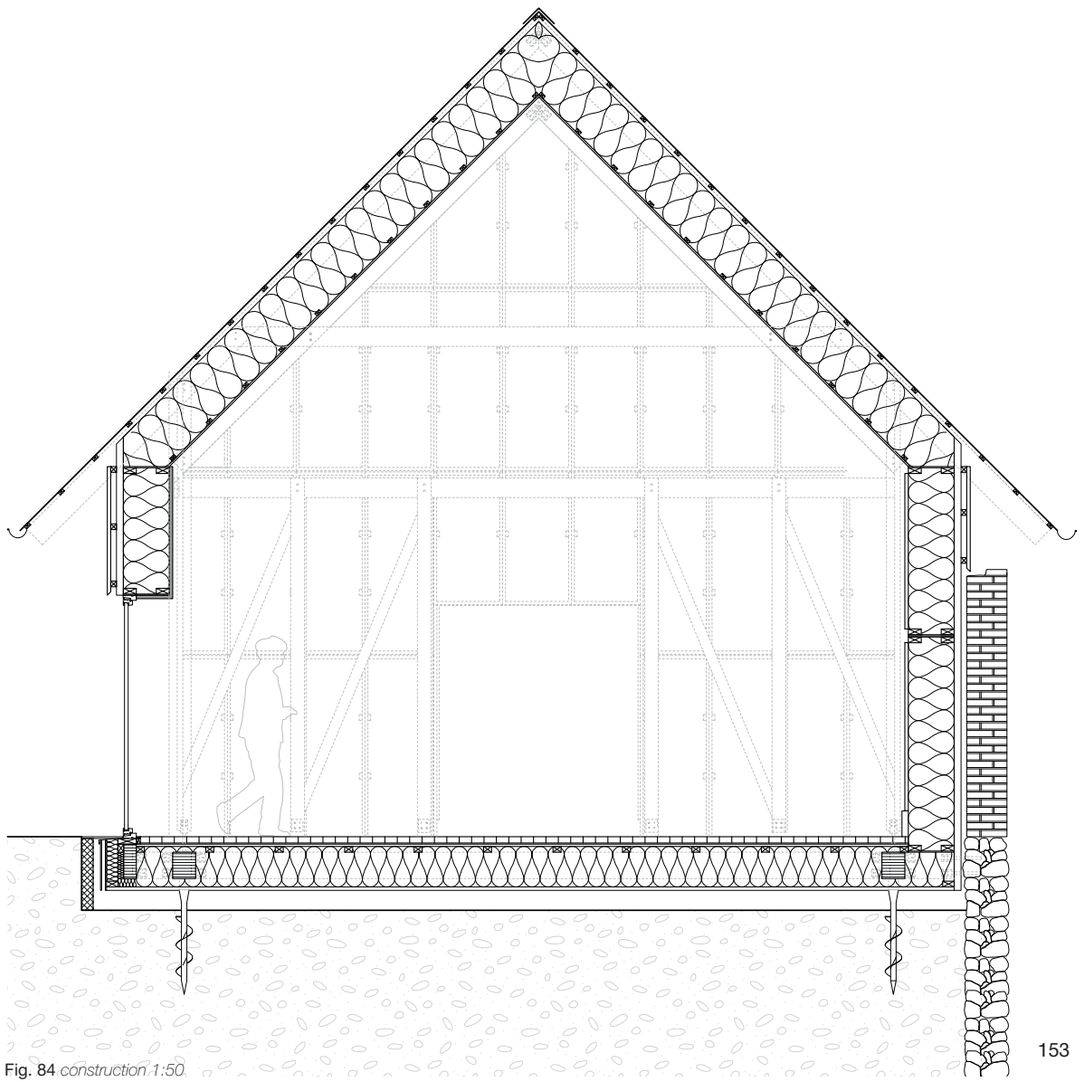


Fig. 84 *construction 1:50*

impact of framework

The impact of sufficiency measures on a building's carbon footprint becomes evident in the comparison of the final design and the benchmark cases. The final design utilizes sufficiency measures of thermal comfort and densification of the space. It is important to note that the approach to sufficiency aesthetics would see a larger gap to efficiency, if the macro components were more detailed, as sufficiency aesthetics sees no need for materials whos' purpose is only to hide construction elements and joints, which in many cases has a negative impact on a buildings carbon footprint.

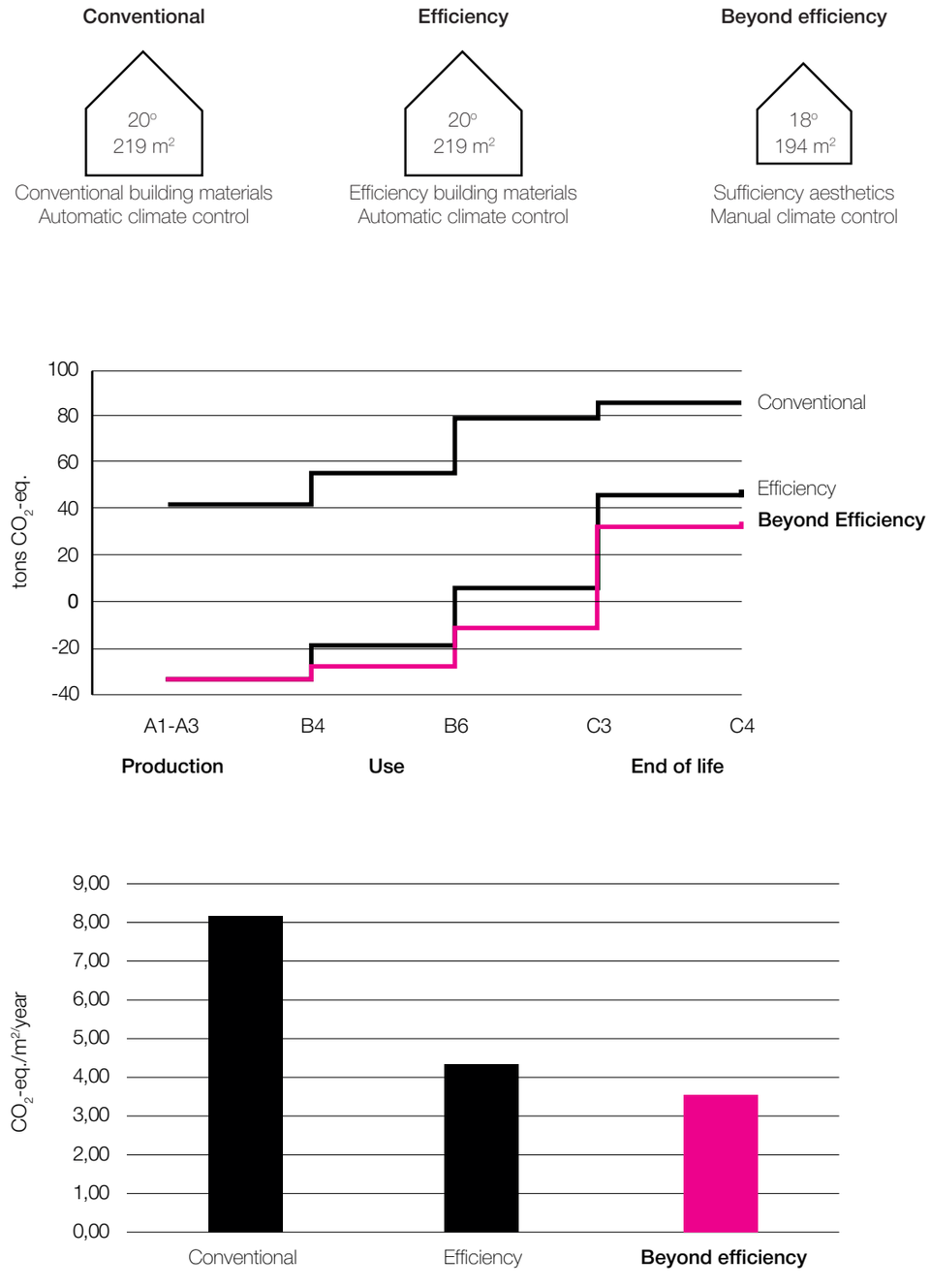


Fig. 85 *effect of the sufficiency framework.*

Fig. 86 *east facade render.*

new & old

The façade visualisation from east shows the ruin walls and stone foundation. The old brick wall and the stone foundation constitutes the primary façade expression. Behind the ruin wall is the light wooden cladding made from various repurposed elements, that together with the zinc roof seemingly float, giving a light expression contrasting the ruin brick wall and stone foundation.

3 OUTRO

CONCLUSION

This master thesis is a proof of concept that sufficiency measures can be considered in many projects to truly unlock the potential of efficiency. The design demonstrates the success of sufficiency initiatives through life cycle assessments and addresses aesthetics as the pivotal factor for the successful implementation of the initiatives. The aesthetic approach, when successfully applied, strives to recalibrate what we as humans expect from architecture and question what is sufficient for human well-being. Pushing towards more sustainable building practices the project should be considered an example on how to utilize overlooked aesthetic potentials, serving as a supplementary approach to existing sustainable building practices. This project has implemented efficiency, sufficiency, and sufficiency aesthetics to challenge today's standard building practices.

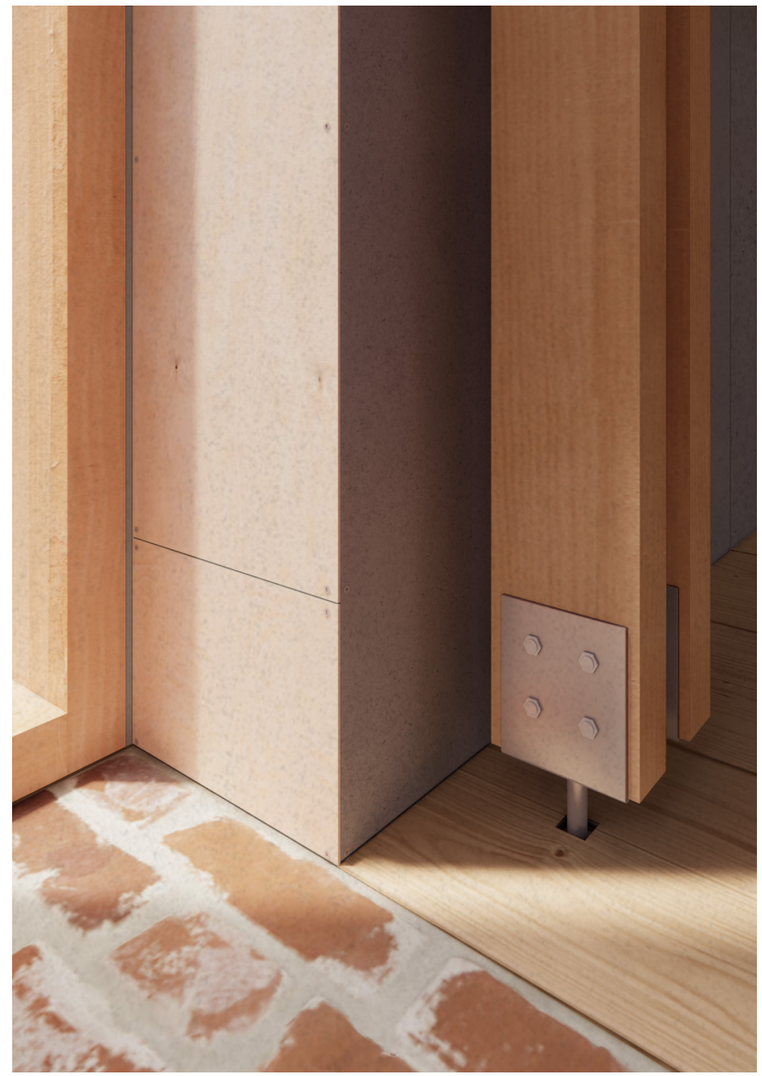


Fig. 87 *east facade render.*

REFLECTION

THE SUFFICIENCY FRAMEWORK

This master thesis delved into sufficiency as a supplement to efficiency initiatives and found that both concepts are essential to achieve a sustainable building practice. Though perhaps their application should depend on building typology.

Efficiency initiatives focus on reducing the environmental impact of a building and can be quantifiably evaluated through life cycle assessment, thereby offering a more universally applicable approach where standard benchmarks can be set, and more easily compared to other buildings. Sufficiency, on the other hand, focuses on reducing the demand for resources and energy, to align the demand with sufficient consumption. This makes sufficiency initiatives more difficult to quantify as they are more subjective to project specific conditions. The sufficiency initiatives should vary depending on the specific project, regarding scale, typology, economic factors, functionality and geographical conditions.

For instance, a large office building in an urban context will should have different sufficiency initiatives than the ones applied in this master thesis. The impact of the sufficiency initiatives would also vary depending on the specific project. The consumption of floor area per person in dwellings has been one driver for the motivation behind the framework, but the result of implementing that sufficiency principle might look different for an office building.

ON-SITE MATERIALS

The transformation of the ruin has proved the validity and aesthetic potential of the framework, for instance regarding the material availability. During the site, an overview of existing on-site materials was constructed and was used to make assumptions regarding the quantity and quality of the materials. With the overview of the on-site materials, it was also assumed that there would be a sufficient supply of all the reused materials needed for the final design. In a real-world setting, a true material bank should be established, instead of presuming one, as that would create fertile ground for an arising from ad hoc solutions to concrete problems for individual surfaces and joints. Creating an aesthetics more based on the materials already existing on site or developed as byproducts during the construction process, emphasizing the specific conditions related to the site, context and construction process.

REUSED MATERIALS

The current methodology behind calculating the impact of reused materials is based on the cut-off method. The calculation behind the method prerequisites the environmental impact of each life cycle stage to be counted for in the life cycle stage they are initially produced in. This means that all impacts are allocated to the first cycle and other use cycles account for 0% of impact from the first cycle. This encourages building developers to reuse existing building materials to reduce the total carbon impact. This methodology is beneficial for reducing the carbon emissions from buildings, but it does not consider the potential environmental gains from assembling components with the intention of being reused for the next cycle. On the other hand, the end-of-life method considers this, as it is the opposite of the cut-off method. The end-of-life method allocates all the environmental impacts of the life cycle stages to the last use cycle, based on a principle that building components will be reused after the first cycle. This encourages building developers to design with the intention of disassembly for future cycles, where the last cycle must pay for the initial carbon emissions. The two opposite methods make it difficult to consistently evaluate a buildings environmental impact if to regard both the use of reused materials and disassemble principles. This master thesis has been using the cut-off method for calculating the impact of the reused materials, meaning that the principles of design for disassembly emphasised throughout the project and used for many of the virgin materials used, does not benefit the final environmental impact of the project in a life cycle assessment perspective.

Besides the methodologies other factors also plays a role when evaluating the impact of reused materials. The embedded value of the materials from the initial cycle must align with the use in the subsequent cycles not to waste the inherent potential of the material. Within this master thesis the objective has been to reuse materials as direct as possible making the best of the inherent capabilities utilizing the embedded value. The storing and transformation of materials between cycles has not been considered in this master thesis but serves as in important aspect in the supply chain of reused materials. Reusability refers to the measures needed before assembly and disassembly, the separation between user and owner refers to agreements of selling a service rather than a product, and design complexities related to the use of reused materials, are also all aspects to carefully consider when using reused materials. (De Wolf, Hoxha and Fivet, 2020).

Another aspect of reused materials is the perspective of the supply chain of reused materials since it mostly relies on the demolition of existing building stock. The tendencies within the building industry to choose transformation over demolition reduces this supply and hinder the use of existing materials for new projects. Some of the materials used in this master thesis most likely comes from demolished building stock, which means that this architectural project and the success of the implementation of reused materials is partly dependent on the demolition of existing building stock.

BIOGENIC MATERIALS

The shift towards reducing the carbon impact of buildings has led to innovation in building technology with the purpose of implementing more biogenic materials instead of concrete and steel. Biogenic materials are favoured over conventional materials due to their ability to store the carbon they remove from the atmosphere during their life cycle, which inevitably will be released back into the atmosphere during the decay of the material. This process is accounted for in the current life cycle assessment methodology and therefore provides an overview of the biogenic carbon flow within each life cycle stage. The ability to remove and store carbon is called carbon sequestering and the ability of any biogenic material to sequester carbon is directly connected to the biomass growth. The biomass is influenced by the rotation period of any biogenic material and considers the time it takes for the material to have the same biomass as when extracted. Therefore materials like timber have a longer rotation period because it grows slower and cannot be seen as carbon neutral within a short time horizon. Hence when deciding which biogenic materials to include in the building, it is important to prioritize materials with a short rotation period, such as straw, hemp and eelgrass, which all has great insulation properties and aim to only use timber for structural purposes. (Hoxha et al., 2020).

In this master thesis timber is the primary material for structural and stabilizing purposes, but paper wool which is a timber-based product has been used as insulation in the roof and foundation, where other fast-growing materials such as straw, hemp or eelgrass could have substituted the paper wool as insulation. Biogenic materials need land to grow on and giving that land is already in scarcity, the allocation of land for building materials must align with other sectors that also need land allocation, such as food, infrastructure, and energy. Lastly, carbon sequestering relies on future innovations on carbon capture technologies to truly be effective in maintaining a safe concentration of carbon in the atmosphere.

FUNCTIONAL UNIT

The carbon impact on any building is measured per square meters per year in current life cycle assessments. This unit has been set to evaluate and compare various life cycle assessments across building sizes and typologies and generally serves as a fair unit for comparison. The life cycle assessment made in this master thesis and with the current unit resulted in misleading information regarding one of the scenarios actual carbon impacts. The scenario seemed to perform worse than its successor, but this was due the decreased gross-floor area which the total carbon emissions could be distributed onto. Reflecting upon this, another unit such as per person, could have been introduced in this master thesis to compliment the current unit as densification has been favoured to align with the framework.

CLOSING WORDS

THIS MASTER THESIS CONCLUDES OUR EDUCATION IN ARCHITECTURE AT AALBORG UNIVERSITY. WE WOULD LIKE TO THANK OUR SUPERVISORS RUNA T. HELLWIG AND ENDRIT HOXHA FOR THEIR COOPERATION AND GUIDANCE THROUGHOUT THE ENTIRE PROJECT. AFTER SOME EVENTFUL AND TOUGH, YET FULFILLING YEARS, WE TAKE WITH US KNOWLEDGE AND COMPETENCIES THAT HAVE MADE US READY TO TACKLE PROBLEMS IN A PROFESSIONAL ENVIRONMENT. WE WILL REMEMBER THE THOUGHTS BEHIND THIS THESIS IN OUR COMING PROFESSIONAL CAREERS AND DO OUR PART TO PUSH ARCHITECTURAL PRACTICES TOWARDS MORE IMPACTFUL SUSTAINABLE INITIATIVES.

THANK YOU FOR TAKING THE TIME TO READ OUR THESIS.

- MAGNUS, MORTEN & NINA

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