a TINY SOLUTION to a BIG PROBLEM

HOW TINY HOMES COULD BENEFIT YOU, SOCIETY, AND HOW THEY COULD PLAY THEIR PART IN CLIMATE CHANGE COMMUNICATION

MASTER THESIS
ARCHITECTURAL ENGINEERING
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DTU

The pdf has hyperlinks to refer back to the table of content, but they seem to work only on a PC or Adobe reader for some reason.

A Tiny solution to a big problem.

How Tiny Homes can benefit you, society,
and how they could play their part in
climate change communication.

En lille løsning på et stort problem.

Hvordan Tiny Homes kan gavne dig og samfundet
- og hvordan de kan spille en rolle i
climate change communication.

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This dissertation research came from a very personal place: a combination of my love for architecture, sustainability, and the Tiny Home that I call home since starting my studies in Denmark. I aimed, and achieved, to combine these three things and situate architectural design in a broader context. The thesis I present here would not have been the same without the input of various people I would like to thank.

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I'm sure I will forget some people - I'm also running out of space on the page and I can't mess up the layout! So thank you!!!

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ABSTRACT

Humanity has a big problem on their hands called climate change. It is affecting everyone and it is everyone's responsibility to do their part. Whether that is eating less meat, revolutionizing solar power, or looking at sustainable industry from the perspective of .. a Tiny Home.

This thesis explores the value of Tiny Homes to individuals, society and the environment. The thesis will address how Tiny Homes can help transitioning to a sustainable society and what role they could help play in climate change communication, preparedness and mitigation.

The methodology used is the so-called "research by design". A Tiny Home design is developed in parallel with the research, this creates a link between research and practice. The thesis is built up in steps. Every step has a research phase, connected to architectural design. The first step is a literature study on Tiny Homes and the development of a concept design. The second step looks at the created Tiny Home design from a sustainability framework in order to improve it. The last step in this thesis is focused on Climate Change Communication & how the design relates to this.

Building a Tiny Home instead of the traditional concrete home will save 90.000 kg CO_2 eq – or as much as a Danish person would save if he never used an airplane. 40% of all households are 1-2 people. Looking at the surroundings of Copenhagen, if 40% of newly build homes would be Tiny Homes this would save 72 million kg CO_2 eq – or 2800 football fields with trees.

The review on exiting research shows the potential Tiny Homes have. If you live in a Tiny Home benefits have been shown to include freedom in time, a stronger connection with family and community, and an overall growth in knowing what a person's true needs are. Living in a Tiny Home teaches you… how to be enjoy life. Additionally the thesis isolated the importance of interior design – including in this outdoor space, to create a quality and a mentally healthy home. Regardless of size these principles can be applied in an apartment building or a villa.
For society Tiny Homes can not only create a financially accessible housing market. The thesis showed low level job opportunities in a sustainable construction industry and an opportunity for quick testing and experimentation in low carbon housing development.
The thesis emphasizes the importance of healthy materials. It has been shown previously that the European union spends 82 billion yearly on building related illness. Coincidentally many of these healthy materials happen to be sustainable & low carbon. The strong interior design and healthy design bring the construction industry back to human centric buildings.
Questionnaires show a high acceptance to integrate Tiny Homes in neighborhoods with preference for local architecture and wooden houses. Tiny Homes create a more diverse neighborhood, contributing to a stronger social sustainable community. They require the human centric urban design that post Corona epidemic political landscape is talking about. as their small space forces people outside more.

Tiny Homes are very visible in media and the streets, creating a dialogue and showcasing what a sustainable lifestyle can be and look like. With a bit of effort they could be used to educate the public about climate change. It seems now is the time to purposefully include Tiny Homes in urban planning and legislation, and make living in them an accessible lifestyle, and building them a low carbon industry.

ABBREVIATIONS & SYMBOLS

Biophilic Design
A concept in architecture of including nature in the build environment, and the variety of benefits connected to this for people.

LCA
Life Cycle Assessment

IEQ
Indoor Environmental Quality – a general term

Methodology
The *methodology* is the general research strategy that outlines the way in which research is to be undertaken and, among other things, identifies the methods to be used in it.

KPI
Key Performance Indicators - A term mostly used in business to describe the parameters that show how well a company/team is performing. In this thesis we broaden it to describe parameters that can help analyze a house's performance, this includes quantitative and qualitative data.

GWP
Global Warming Potential – A term used in life cycle analysis software, it refers to the calculated carbon footprint/GHG.

GHG [CO2e.]
Greenhouse gasses – all gasses responsible for climate change. Also referred to as Carbon or carbon emissions. Units are expressed in carbon dioxide equivalent, the most present GHG.

IPCC
The Intergovernmental Panel on Climate Change – the team of the united nations responsible for assessing the science related to climate change. They publish regular reports on the current data available on climate change and future projections as well as mitigation and adaptation options.

NAP
National Adaption Plan – A lot of countries have set up a cohesive plan to prepare their country for the changes climate change will bring.

Mitigation
A term generally referring to Climate change, and specifically how we can reduce GHG and stop the planet from heating to a critical point.

Adaptation
A term generally referring to Climate change, it means the preparedness for the local changes in our climate that are coming. How we can change our infrastructure and lifestyle to adapt to this changing climate and weather.

VRE
Variable Renewable energy – renewable energy source such as wind or solar that do not have a stable continuous supply. As opposed to geothermal or hydroelectric for example.

DIY
Do It Yourself – a popular term for any self made project, from bookshelves to houses.

ADU
Additional Dwelling Unit – a common used legal construct in America and Australia. This allows owners to have a send smaller living unit on their property. The exact regulations are dependent on local zoning.

List of figures

Table of Contents

INTRODUCTION THESIS

On a personal note, I did not realize the full importance of architecture in climate change before writing this thesis. I thought building sustainably would be enough. Through research and discussions with people in the field, I saw that both concepts are connected - but hardly the same. I also realized how big the impact is of the construction world on our environment. Today 1/3 of energy related Green House Gases (GHG) comes from buildings, and 2/3th of GHG can be directly related to household lifestyle. (Carvalho, 2019) (Silva, 2020) (European Comission, 2019) (Stuart Capstick, Radhika Khosla, and Susie Wang, 2021) This will be visible in the difference in focus in part 1 versus part 2&3 of the thesis.
My drive for doing this thesis came from buying my own Tiny Home to be able to study in Denmark. I wouldn't say it gave a positive bias: I was confronted with water leaks, mold, ants, wasps and legal hurdles that balance out all the positive aspects. But it did give me experience!
What I thought would be the biggest hurdles in Tiny Home Living actually became some of the best parts of this adventure. I realized living small is very easy with good design. For instance, composting toilets are not scary but pretty awesome (they don't smells at all !).
But what I thought would be easy - finding a place to stay - turned out to be the biggest challenge of all!

I had **two goals** with this thesis. The first was to help find a way to **provide good, healthy, accessible homes to people**. The second is aimed at **climate change action and communication**. I personally believe that in order to win the battle against climate change everyone of us has to look at our own field of work, expertise and lifestyle, and change what we can there.

Research questions

1.What is the value of Tiny Homes, to you, to society and to the environment? How does this reflect in a design? Building a design concept from literature study and a general architectural knowledge.

2.How is the design improved when framing it in a sustainable context?

3.Can architecture be a tool for climate change communication? How to best communicate the findings of the thesis?

Methodology = research by design

The methodology is based on research by design. It is a methodology that allows to work with the uncertainties of the future, especially when handling complex environmental challenges. Politics, economics, climate change migration – these are all uncertainties that affect architecture. Research by design avoids the typical linear approach of research to conclusion. There is a wide diversity in approach for this methodology due to its design component. (Roggema, 2016) (Gaver, 2012)

The methodology in the thesis is based on my design experience studying architecture. Starting any new project, you always have your basic knowledge you can draw upon. Additionally you will have a specific research project, a building to make. From there a creative process starts, and while art is not definable by any means, our training taught us to design in several steps. You start from an empty page with a few lines and - through an often messy process - a concept is created. In the next steps this concept is built upon and refined, or sometimes even changed drastically and turned upside down.

This thesis will add research to these design steps. From an empty page a concept design will be created based on the research on the Tiny House movement and all its aspects. This research is mainly done by exploring literature.
Then as climate change is a pressing concern, and something we have to apply in all fields, the second part will be focused on pillars of sustainability, and investigate, analyze and improve the design from these angles.
The third part will then focus on Climate Change Communication. And explore how a Tiny house could contribute. After all a message that misses its audience isn't worth much.

These different design steps will each add new knowledge, cause changes,… and this structure emphasizes a process that is not finished. More steps could be taken. An essential part of design is knowing that it is never finished, even if you can't work on it forever. A house is part of society, bound to change with times, and its resilience lies in the flexibility to adapt. Therefore it is also important to mention that the design presented in the next pages is just one option. It is not aiming to be your perfect home, or thé perfect Tiny Home. It is aiming to give a scientifically researched sustainable design, one that can be used by DIY builders, or maybe by lawmakers to support inclusion of Tiny Homes in their communities.

Finally a word on graphics. Architecture is a graphic medium, while research usually is text based. Both have their own values - but they can be a hard mix. To facilitate this, graphs and sketches are incorporated in the text to create links to the design process. Furthermore, based on Climate Change Communication research, throughout the text important findings have been translated into *info*graphics, allowing not only for the information to be more easy to grasp, but also for whomever wants to, to be easily used in third party's presentations.

Thus the thesis aims to address the challenge of climate change in its design of a Tiny Home. Looking at 3 stakeholders: you, society and the environment.

STEP 1. CONCEPT DESIGN OF A TINY HOME

The first part of the thesis will focus on creating the concept design based on literature research of Tiny Homes and a general background knowledge of architecture and engineering.
First research will be presented and analyzed. This research will be connected with design of “Tiny Step”, the name we gave our Tiny Home. Finally the concept will be presented in 2 posters.

LITERATURE STUDY INTEGRATED DESIGN OF TINY HOMES

The literature study will first answer the question ‘What is a Tiny Home?’. Then look into its impact on you, society and the environment.

WHAT IS A TINY HOME (4p) + 2p. pictures. 6p total.

This section will look at the roots of the tiny home movement. Why are people motivated to change lifestyle? It seems, surprisingly, that care for the environment is not a major motivator, even if it is a consequence. And then we’ll take a closer look at the question: ‘what is the essence of a tiny home?’.

- The Tiny House movement is slowly taking over the world

The Tiny House movement has become increasingly popular in media. Netflix and tv shows like *Tiny House Nation* or YouTube channels such as *Living Big in a Tiny Home* brought a niche way of living to the public eye and it has been received with unexpected success. (Tiny house nation, *Tiny house luxury*) (Mangold and Zschau, 2019)
Ikea, which has been praised before for making affordable furniture that works in small spaces, has presented a Tiny Home. You can buy one from Amazon for around 40.000 dollars, but you will have some work to finish and furbish the house. Harvard and Yale have both popped up designs as well. (AMAZON, 2019)(UN Environment programme, 2018) (Curbed, 2020)(Green Matters, 2020) (Robinson, 2016)

Roots and expansion worldwide

The movement has its roots in end 90’s early 2000 in the US with the book *The Not So Big House: A Blueprint for the Way We Really Live* (Mangold and Zschau, 2019) and Jay Shafer, regarded as founder of the Tiny House Movement (Weetman, 2018). Both address the problem of affordable housing introducing small houses to the public, focusing on quality rather than quantity. After the stock market crash/global economic recession in 2008 Tiny Homes have exponentially exploded in western landscape. (Mangold and Zschau, 2019) They are an established, if mostly non-legal, part of American architecture. In 2015 Tiny Houses in Australia where in their infancy, 3 years later they went viral (Weetman, 2018) and the last years the movement has slowly been setting roots in Europe.

Tiny Homes wear many hats

Tiny Homes have many functions. They are known mostly as residential homes, but often they are used as B&B’s, a step-up home, accessory dwelling unit (ADU) for aging parents, holiday home, a work studio or student housing. They can be considered on their own or as an add-on to a traditional








Top – Ikea Tiny Home
(Green Matters, 2020)

Underneath – Harvard Tiny Home
(Robinson, 2016)

Bottom left – Living big in a Tiny house Instagram

Bottom right – Yale Tiny Home
(UN Environment programme, 2018)

Top – Heijmans One step up Home (TinyHouseTalk, 2015)

Underneath – Heijmans One as B&B on an empty plot (Fastcompany, 2016)

One the left - Moving into my T-pod ready to study at DTU!

On the right top – Tiny Hotel (Homecrux, 2018)

On the right bottom - Backyard office (Convene, 2018)

Bottom left – Refugeehouse designed by Tiny House Belgium (Tiny Houses, 2018)

house, providing flexibility necessary to accommodate changing needs of owners. (Weetman, 2018) They have been investigated as temporary relief homes for disaster zones, an alternative to nursing homes, and as a way to address homelessness. (Mangold and Zschau, 2019) Tiny Homes as a modular or prefab construction have been used in the tourist industry for places such as hiking shelters. (Carvalho, 2019)

Literature and research : in full development

There is still a limited amount of academic sources. Therefore this thesis will look at worldwide literature and tie it back to specific European circumstances later in the design. While the attention Tiny Homes have been getting has earned them recognition in the architectural landscape, they are still not understood completely. There is much to learn from the unique challenges Tiny Houses face and their influence in lifestyle change. (Kilman and College, 2016) (Boeckermann, Kaczynski and King, 2019)

- 37 m^2 - The maximum Tiny Home size?

The increase in housing size and its impact on energy use

Over the last decades we have seen a trend in increasing housing size across America, Australia and Europe. The construction industry and everything around it has a large stake in human impact on the environment. Environmental impact has doubled since the 1950s due to increased house size. (Boeckermann, Kaczynski and King, 2019)(Danmarks Statistik - BOL106, 2021) (EU Buildings Database, 2016) Today 1/3th of energy related Green House Gasses (GHG) comes from buildings, and they are responsible for over a 40% of EU energy consumption and 40% of resource use. (Carvalho, 2019) (Silva, 2020) (European Comission, 2019) Over 50% (54%) of people live in cities. City activities are 70-75% of consumption of natural resources. In 2017 there where 7.6 billion people on earth – it is predicted that number will rise to 10.2 billion in 2050. (Silva, 2020)

GHG and energy already hidden in our built environment

We should also consider that the current built environment contains an enormous amount of energy and GHG already embedded. Following this we should carefully consider and prioritize renovation and reconversion rather than demolition and rebuilding. If and when we construct new building, we should do it conscious of the impact this makes. (Ferreira Silva *et al.*, 2020) (BuildDigiCraft, 2020)

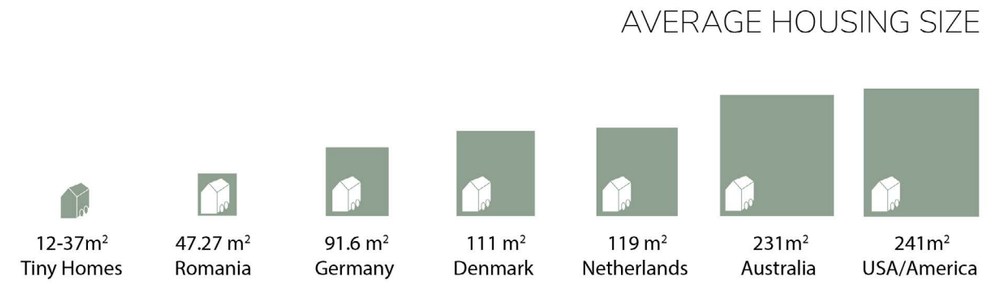


Figure 1 The average size of residential buildings in different countries [m^2] Sources: (Danmarks Statistik BYGV06, 2020) (EU Buildings Database, 2016) (Weetman, 2018) (Living Big In A Tiny House, 2018b) (Boeckermann, Kaczynski and King, 2019)

Tiny Homes have an inherent advantage to traditionally sized homes. In literature they are usually put at a maximum of 400 sqft or, rounding off, 37m² in size. (Weetman, 2018) (Mukhopadhyay, 2020) So per definition they contain less material, less material waste, therefore less embodied energy and embodied carbon. Being small, often mobile houses also easily open up the industry to prefab and modular construction. However size is far from the only defining factor in Tiny House design.

- Why do people "go Tiny" ?

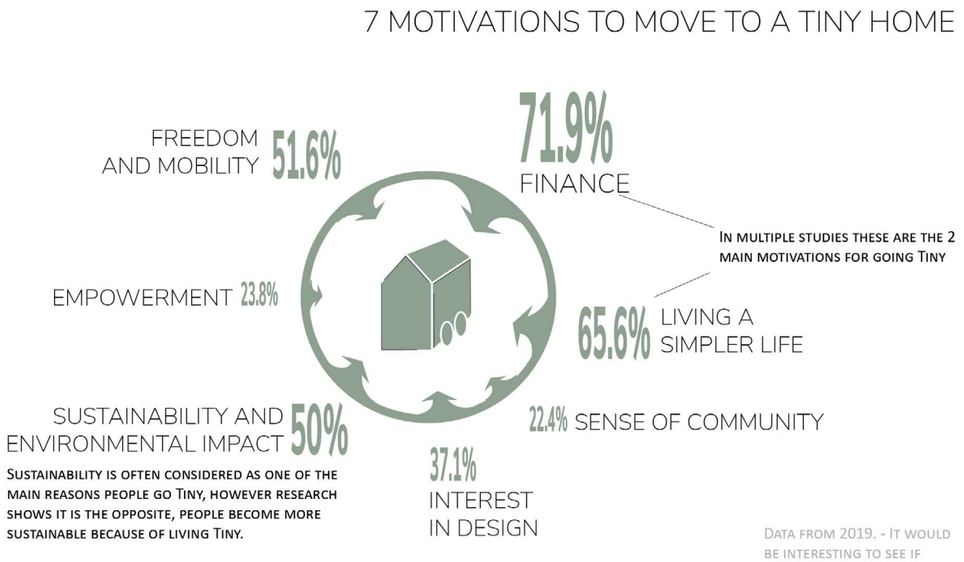


Figure 2 – 7 motivations people 'go Tiny' based on (Mutter, 2013) (Boeckermann, Kaczynski and King, 2019) (Weetman, 2018)

Seven motivations to 'go Tiny'

A study by Mutter identified motivations to "go Tiny". (Mutter, 2013) These motivations were then used for another study covering 64 people mostly located in America. The study showed that the most important motivation for people to go and live in a Tiny Home was financial (71.9%). (Boeckermann, Kaczynski and King, 2019) A similar study in Australia indicates finance as a first motivator and living green as the second. It also emphasized that Tiny House living gives space to people to question consumerism society. (Weetman, 2018)
The desire to live a simpler live away from consumerism, and the freedom to not be attached to one location are a close second and third. The study also found that the only correlation between motivation to live Tiny and satisfaction in the home lies in the ability to come to a simplified lifestyle. Sustainability and environmental impact was 50/50 low versus high motivation for people. (Boeckermann, Kaczynski and King, 2019)

Stumbling upon Tiny Homes rather than looking for them

A study based on in depth interviews with 30 people found that Tiny House owners didn't actively seek out the lifestyle. People more often than not stumbled upon the idea of Tiny Homes. Following

individual struggles they reexamined their lives and made the jump in lifestyle change. (Mangold and Zschau, 2019) This study examined 5 motivations similar to the previous one, excluding the environmental and sustainability aspect. The demographics of both studies conducted mainly in America show a high percentage of people with capital and/or higher education and predominantly white. (Boeckermann, Kaczynski and King, 2019) (Mangold and Zschau, 2019) The demographics of the Australian study showed mostly singles or couples in their 20' and 30's. (Weetman, 2018)

While the Tiny house movement is often linked with living ecologically, it seems the true motivations of moving Tiny are more complex. For the design of Tiny Step to be successful the main motivations, finance and simpler living, have to be prioritized. **(The graphs of the studies can be found in Annex X)**

- The essence of a (Tiny) Home? A story on homelessness

This thesis focusses on residential Tiny Homes, however Tiny Homes have many applications as mentioned before. The Tiny Home movement starts from the concept of creating affordable homes for everyone and Tiny Homes have been adopted as (transitional) houses for the homeless in many different forms. Building for the homeless creates a lot of questions such as what is the essence of a home? Can it be transitionary? **What makes a house human? What makes a house a home?** (Jay Shafer, 2020) (Living Big In A Tiny House, 2018b)

The success and challenges of Tiny Home villages for the homeless in the US

Different studies have shown that sheltering the homeless is not only ethical and humane but also more cost effective. Thus it seems there should be a strong incentive to address the problem – however to different extents homelessness is still a part of society. (Mingoya, 2020)
In the US there are several examples of how the homeless problem has been tackled privately using Tiny Houses in their most essential form: a cabin that offers a place to sleep, security and privacy. (Mingoya, 2020) (Evans, 2020)
These initiatives are usually put up illegally. While it has been shown that government support is essential for the long term survival of homelessness projects, legalization itself can be a problem too. A salvaged Tiny Home can be put up for 3000 to 8000$, while a legalized house has to follow building codes and starts at a minimum of 18000$. (Jackson *et al.*, 2020) (Mingoya, 2020) (Evans, 2020) A better balance between law and the urgency of homelessness should be found.

Advantages

There are a few clear advantages connected to these settlements compared to other solutions.. Traditional housing often lacks the social structure that can be essential to helping chronically homeless people, not just on a physical level but also mentally and emotionally. Shelters have many limitations, where strict rules- often requiring people to leave and return at a certain time- provide no stability or security. (Mingoya, 2020)
The Tiny Home settlements create a level of independence, responsibility and community that allow people to build up their live again on a financial, emotional and mental level. (Jackson *et al.*, 2020) (Mingoya, 2020) However the **question of social justice remains**, what is a humane home? Is heating, cooling and electricity enough? Or is a private bathroom essential? The debate is still open. (Evans, 2020)

– Tiny Homes for the LA streets – need for a safe, private and homy environment

A Tiny Homes story in LA gives a clear example.[1] The city of LA faces a homelessness crisis affecting over 28.000 people. Half of them spend their nights on the streets. Elvis Summer realized talking with people living on the streets that the support they needed to get back on their feet was quite simple: a safe place to sleep, access to a plug and storage. He started a crowd funding, the 1200$ goal was quickly reached and a 100.000$ was gathered.
Very small Tiny Homes (~4m²) on wheels were build, with natural ventilation, a small solar power element, a heating element and a lock on the door. The houses look very homy, and the paintings on the back make them into individual pieces of art representing the owners.
The morning the city of LA announced their 2 billion dollar plan to end homelessness all the houses where seized. Just a few where saved but they are not allowed to be used now. (SBS, 2017) (Elvis Summers, 2021) (ReasonTV, 2016)

Around 2 years later LA announces it's finished village for the homeless: *hope for the valley*. A video tour starts promising, showing a beautiful park. When the camera turns wired fences give the impression of a prison, not helped by the guard at the gate who has to check for contraband. Inside the compound we find a very designed and industrial looking environment. Bright blue and red surfaces on a grey background of fences and gravel. There is no nature, no plants or decoration, nothing architecturally to give depth, nothing to make the place come alive. The houses are shared by 2 or 3 people, undermining the primary need of safety. (Corbett, 2021) ('Hope of the Valley', 2021)

There is a big contrast between the personal contact and knowledge in the interview with Elvis and the way homelessness is generalized in *hope for the valley*. They talk about numbers instead of stories and people, which results in a lack of humanity and equality. With 40 units and 75 beds, they build tiny houses but not Tiny Homes.

- Conclusion

When designing a Tiny Home it is important to consider that financial motivation and the desire to live simpler far outweigh any environmental concerns. While a Tiny Home is characterized by m², it is not the defining element. They have strong roots in the search for an accessible home that doesn't make someone go bankrupt, a search for minimalism, but more importantly, they try to answer the question what makes a house a home. While this is still open for debate, some essentials can be found in every DIY build: A roof over your head, a cozy warm and safe place to rest, and last but not least every house made is a piece of art made from love.

1 A short disclaimer. Most of this thesis is based on scientific research and literature. This example comes from a collection of articles & YouTube videos.

Tiny homes for the Homeless

Top - Banned tiny homes of LA (ReasonTV, 2016)

Underneath – Dignity Village homes (Mingoya, 2020)

Left – Tallahassee Tiny Homes (Jackson et al., 2020)

On the right – Tiny Hotel (Homecrux, 2018)

Bottom left – - Hope for the valley ('Hope of the Valley', 2021) 2018)

IMPACT ON YOU

This section will take a look at the impacts choosing to go Tiny can have on *you*, both the positive and the negative. This includes a closer look at financial impact and the freedom a Tiny Home can give, the lifestyle impact of a simpler life. A closer look at how optimized interior design makes a quality environment even if it is Tiny. And the engineering challenges that come with such a small space.

- Personal finance & hidden cost

Tiny Homes come at a lower cost, resulting in financial freedom. Especially DIY builds can drive the prices very low: sometimes as low as even a couple thousand euro's. However many hidden costs are tied to the construction and living in a Tiny Home. The industry is still developing and thus not as reliable yet when it comes to pricing as traditional housing. (Jackson *et al.*, 2020) This is mostly due to their unclassified nature, making it hard to get insurance or a loan. (Kilman and College, 2016)

Prices

All over the world affordable housing is in high demand and hard to find. (Haffner and Hulse, 2021) The average housing prize of sold properties in Denmark early 2021 was 2 590 000 DKK (348.165,91 Euro). ((Danmarks Statistik - BYG42, 2021)

The cost of a Tiny Home is in sharp contrast to those numbers. The prefab unit developed in an Austrian study costs approximately 21.000 euro's for 15m^2, 32.000 euro's at carpenter price. This is the price for the raw build not appliances and operational systems. (Leindecker and Kugfarth, 2019) Companies are selling finished houses with starting prices at 50.000 or 100.800 euro's. (Inropa Greenbuild, 2021) (TinyHouseLiving, 2021)

DIY

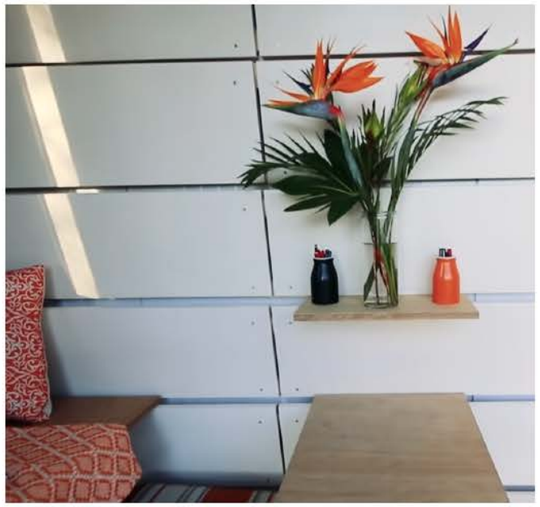
A way to keep prices lower is to build the home yourself, the DIY community is a big part of the Tiny Home movement and YouTube is full off tutorials and vlogs, ranging from van conversions to Tiny Home construction. A DIY build can start at 800 $ or a couple thousand dollar. Often DIY builds are sourcing materials secondhand which can not only make a big difference in cost, but makes for a more environmentally friendly home as well.

Building DIY takes time and requires new skills. For those daunted by the task, different systems of 'building blocks' are coming on the building market. These aim to build a house almost closer to Ikea style, fast, no health risks in construction and environmentally friendly. One of these is the ReBlock system. (REXCON System, 2021)

The DIY aspect of building a house is also a social event, where people help each other out to learn new skills. Working parties are held to build together. Nevertheless building a house is also an intensive undertaking that carries it's own stress. (Living Big in a tiny house, 2017) (Living Big In A Tiny House, 2018b) (Living Big In A Tiny House, 2018c)

Loans and insurances can be hard to find

Many hidden costs are related to buying a Tiny house. Since Tiny Homes are not included in regulations, the consequences are that there are often no loans or financial support structures available. (Kilman and College, 2016) This means most Tiny Home owners need to be able to put the full sum upfront, making tiny houses only an option for people with capital. In the US you can only get a loan for your Tiny Home if the company making it is RV certified. (Recreational Vehicle / Mobile Home) As



Top - A staircase that is a kitchen and laundry too

Top right - A wall that allows easy hanging of shelves or even a table.

Middle - A bathroom with fold out composting toilet

Middle right - A couch with storage for university, sewing and luggage

Bottom - A downstairs bedroom + open loft design

(Living Big in a Tiny Home, 2020) (exploring alternatives, 2020)

a comparison people can buy a house at 3.5% up front. (Kilman and College, 2016)
In Europe this is slightly different, buying a house at a fraction of the cost is usually not possible. In Denmark you have to pay 20% of the price up front and 80% will be covered by a loan. Since a Tiny Home is smaller and cheaper it would be easier to fund it. The interest rate fluctuates but is often quite low (under 5%). There is also the option to pay only interest for the first 10 years, stalling repayment of the capital: this gives young families the opportunity to invest in their children first. (Realkredit Denmark, 2021)
Getting insurance on a Tiny Home can be very difficult as there is no standard to follow. Additionally if your house isn't legal you won't have an address. (R. Zwarteveen, personal communication, 14.7.2019)

Higher cost of living?

A small house comes with less space, which means one will buy less new clothes or house decoration: there simply is no space for it. Yet, there still is a concern for a higher cost of life. For instance: a smaller house means also a smaller fridge and freezer, resulting in more trips to the grocery store. The time and money spent on this can be significant. (Ford and Gomez-Lanier, 2017) This is a problem mainly faced in America, a country known for food deserts (Hinrichs and Lyson, 2007) Some newer suburbs in Europe that are also more car reliant face the same concerns. (M. Lane, personal communication, 18.5.2021). But in Europe, living with a small fridge is more a problem of comfort than substantial extra cost.
Then again, most cities don't have dedicated spaces for Tiny Home dwellings. As a result, Tiny Home owners see themselves banned to rural areas. Which results in an increased budget for mobility.
Both these examples show the hidden costs in living Tiny, which are more due to urban planning than to the Tiny Home itself. (Jackson *et al.*, 2020) (Evans, 2019)

- How Tiny Homes optimize interior design

Due to the lack of space Tiny Homes have become an exercise in optimizing interior design. Research isolates the main interior design principles based on a comparison to slum homes. Post Corona pandemic research also pointed out how outdoor space is an essential component to living small that is not always addressed in the designs.

Social challenges in a Tiny space

While Tiny Home owners generally adapt to their smaller space very fast there is a reduced privacy creating physical and emotional difficulties that should be addressed. The Corona epidemic has brought the problem of small housing in general to light. The solutions proposed lie mostly in flexible design. Thus the *Tiny Step* design should find solutions in optimized architecture. One constraint that is harder to solve: it is very hard to host people in a Tiny Home. No matter how smart the design, bringing many people to your home will be a difficult undertaking. (Kilman and College, 2016) (Thompson, 2021) (Peters and Halleran, 2020)

The importance of interior design

The design of Tiny Homes is a unique learning experience that is focused on optimization of space and fulfillment of an individual's needs. These are elements that do not only apply to tiny architecture but contribute to turning any house into a home. Interior design is still often seen as a luxury for those who can afford it, often inspired by expensive mansions of celebrities. The Tiny Home design stresses the fact that interior design is not just important, it is *needed*. It is described as an evolution in architecture, optimizing space by multifunctional custom designs. (Hutchinson, 2009) (Peters and Halleran, 2020) (Zaher, 2020)

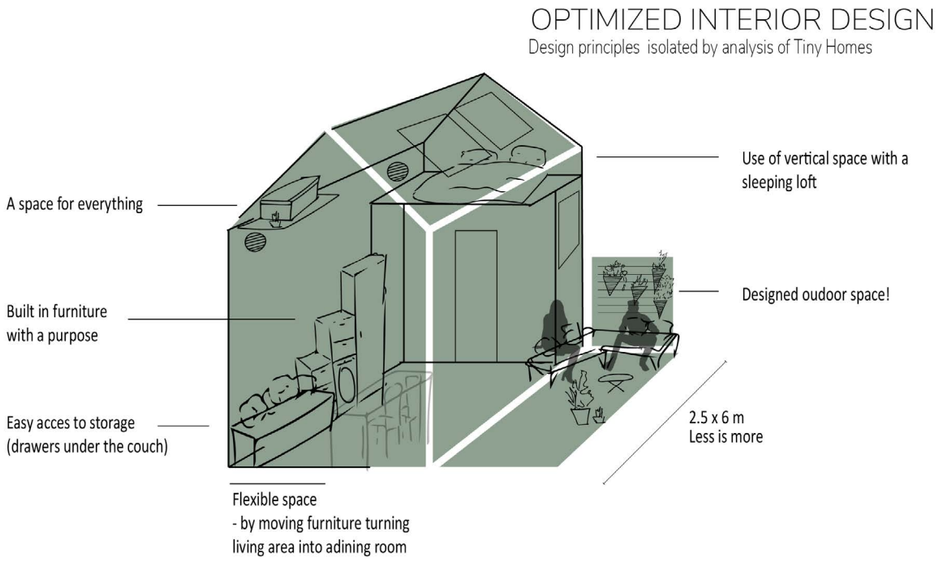


Figure 3 Design principles for optimized interior design in Tiny Homes from the following research: (Anggraeni and Herlily, 2020) (Peters and Halleran, 2020) (Zaher, 2020) (Rassia, 2020)

A Tiny House or a Tiny Home? – Isolating design principles

A study investigating the relationship between Tiny Homes and slums in north Jakarta identifies specific design differences. While Tiny Home owners choose a specific life style, the people in slums end up there out of need. A smart interior design will allow for a maximized use of the available space so that even though the home is tiny, it doesn't feel that way. The majority of the residents that were interviewed think that the Tiny Home movement could be a solution to tackle their housing issues and make their neighbourhood more livable. (Anggraeni and Herlily, 2020)
One similarity found between Tiny Homes and slums is that double duty rooms make for a house with less privacy. If your living room also serves as a bedroom, you will need to live on a schedule with your housemates.
"Less is more" was another similarity. To live Tiny means to minimize and be very deliberate of what comes into the house. Anything that isn't necessary will end up as clutter making life more difficult. Organization and easy access are critical to make this process easier. In Tiny Homes built in furniture plays a huge role in this.
The *difference* between Tiny Homes and slum homes lies first of all in the comfort level such as the indoor kitchen and plumbing. Taking a closer look at design, one of the biggest differences is the use of vertical space in Tiny Homes. This can for example eliminate the double duty rooms, by creating sleeping lofts. (Anggraeni and Herlily, 2020) (Peters and Halleran, 2020)
Post Corona research also pointed out how outdoor space is an essential component to living small that is not always addressed in the designs. Even before the Corona Pandemic we already spent 90%

of our time indoors. A space that is large enough, functional and attracts people to be outside should be an essential aspect of any home. (Peters and Halleran, 2020) (Zaher, 2020) (Rassia, 2020)

- Spatial & engineering challenges – indoor environmental quality (IEQ)

Designing a Tiny Home comes with bigger engineering challenges as it needs to pay closer attention to the indoor climate. Proper construction, design, material choice, furniture and ventilation all play an important part in this.

Road transport limits

Tiny Homes are typically on wheels, or transportable. This means they have space constraints for mobility. In Europe the maximum dimensions for free road transport are 2.55m wide, 4m high and up to 16.5m in length. In reality, most Tiny Home trailers are no longer than 8.4m long. Bigger transport is possible with the necessary permits and regulations, but these bring an extra cost to the project. Some countries will allow larger dimensions: in Austria 5m wide is allowed. (International Transport Forum, 2013) (Leindecker and Kugfarth, 2019) (p. De Keuster, personal communication, 27.6.2021) Some Tiny Homes will circumvent these measures using houses that fold open upon arrival at the site. (Stinson, 2018) (UN Environment programme, 2018)

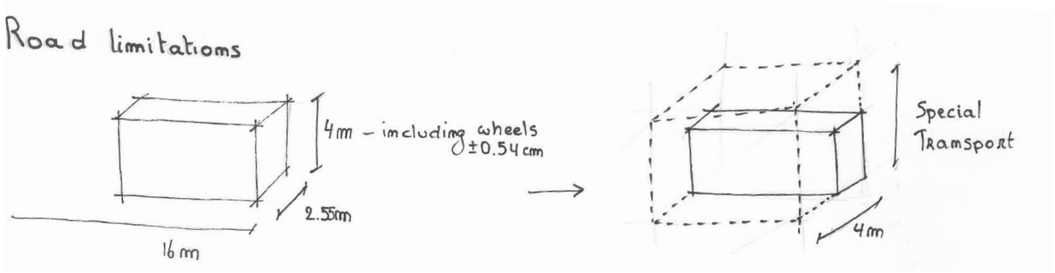


Figure 4 Sketch illustration of limits for dimension of road transport

Toxicity of indoor air quality in Europe

In industrial countries we spend about 90% of our time indoors, where concentrations of pollutants can often be 2 to 5 times higher than outdoors. These pollutants or VOC's – volatile organic compounds – often come in the form of harmful particles or gasses emitted by construction materials such as varnishing and wood treatment products. (Ford and Gomez-Lanier, 2017)(US EPA, 2019) (Klepeis *et al.*, 2001) (European comission, 2003) This includes furniture too, though there is less research on that. It has been shown that the most polluted room in a house is often the baby room – the room where all furniture and decoration is usually newly bought. (Pickett and Bell, 2011) (Lakestani *et al.*, 2013) Candles are an overlooked source of indoor pollution releasing toluene and benzene. (Sustainable buildings course DTU, personal communication, 2019) And some indoor air particles contribute to global warming. For example refrigerators and air conditioners are known to emit CFCs, who are known for depleting the ozone layer. (Ford and Gomez-Lanier, 2017)
With their small volume these concentrations can get even higher in Tiny Homes, making indoor environmental quality – IEQ – become even more important. We'll look into some important points that will influence the design.

Tiny size can skew results for calculations and appliance control.

This emerges from a study on two Tiny Homes in Montana – a state in the US with a cold and dry climate with temperature range from -18˚C till 27˚C.
Both houses are made traditionally without special attention to materials, sustainability, zero energy goals,…. The houses couldn't comply to some standards purely because of the way they are set up. For example infiltration is calculated using exposed surface/volume ratio, and the size of a Tiny Home completely skews those results. (Mukhopadhyay, 2020) Looking at the energy use of a home - energy frame - expressed per m^2. If a Tiny Home uses 1000 kWh/year and is $20m^2$. This will give and energy frame of 50 kWh/year m^2 – too high for passive standards. While a traditional home would be around $150m^2$, with an energy frame of 20 for passive building, the total energy would be 3000. A Tiny home is still a house that needs to provide the same electricity for a fridge, hot water,… So the fact that the values are expressed per m^2, makes it almost impossible for Tiny Homes to reach the same energy frame, even if they in absolute numbers, are better.
Operational control of the house also faces some challenges in a small space. Most appliances for heating and cooling are dimensioned for bigger houses. The small volume of a Tiny Home will make it react stronger to a change in temperature. (Mukhopadhyay, 2020)

Humidity → mold → asthma

As Tiny Homes are tiny, the construction is easier to control and thus the building will have less cracks for air/wind to come through. With low infiltration in a small volume, moisture control becomes a critical element for IEQ. Humidity is a big problem in Tiny Homes. (Mukhopadhyay, 2020) A small space has a large influence on the amount of water in the air per volume. Humidity has to be kept between 20% - 70% at all times to prevent mold and other health related problems. (Mukhopadhyay, 2020)

Ventilation to control air quality

Both homes in the Montana example used the same ventilation system: in one house it worked perfectly, balancing indoor air quality. The other house however used the lower setting of the ventilation - and housed 4 pets - resulting in CO_2 levels above the standard. (Mukhopadhyay, 2020)
CO levels are also a concern in a small space. It is important to use a certified fire stove if you want one, and good ventilation or a hood if you plan to cook on a gas fire in a Tiny Home. (Indoor Climate course DTU, personal communication, 2020) (Raub *et al.*, 2000)

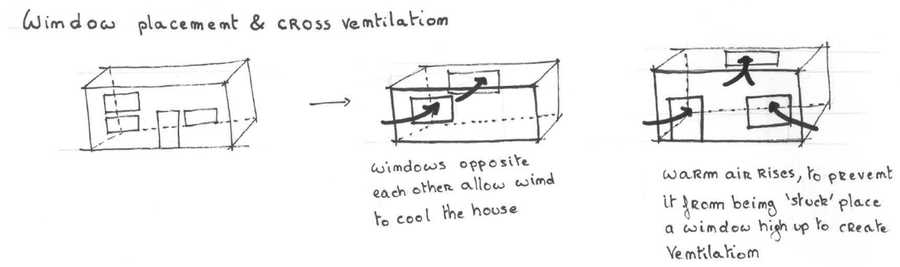


Figure 5 Sketch illustration of cross ventilation by window placement.

Thermal comfort & cooling – a challenge with an easy design solution

Stratification of the air was a problem in the small space, especially if a loft is present. The placement of mechanical ventilation can prevent this. Natural ventilation by opening windows was a strategy used very successfully in both houses to let out hot air. Careful placement of windows in the design should fully take advantage of this. The study also recommends the use of mini split heat pump systems with a variable-speed compressor and fans to help with cooling the house. (Mukhopadhyay, 2020)

Thermal comfort & heating – opportunity to use new materials and strategies

Thermal comfort was reached in both Montana homes with some minor problems. A small house is quite easy to heat. In one house the mechanical ventilation was a source of draft pointing to incorrect installation – correct construction is essential to get rid of cold bridges in the house. The radiant cooling of cold surfaces also caused disturbances in thermal comfort. (Mukhopadhyay, 2020)

An Austrian study suggests to use infrared as a heating element for Tiny Homes. This form of energy doesn't make a lot of sense for traditional housing as high energy (electricity) is transferred to low energy (thermal). But considering the volume of the building and the high requirements for thermal envelopes in Austrian building codes they found it to be a viable strategy. The infrared heating system is low cost and doesn't require much maintenance. It also has short heating and cooling phases, wich is an important element in small houses or houses that aren't used a lot. (Leindecker and Kugfarth, 2019)

- A simpler life in a mass consumption society

Tiny Homes are often portrayed as a solution to poverty. They are however a lifestyle, not a one-fits-all solution. Tiny Homes reject the mass consumerism society and strive to create freedom in life to make time for relationships and hobbies.

> *Ryan Mitchell, an author who writes books about tiny house living, captures the experiential TH essence best when he writes: "When you live intentionally, you realize you have choices—and that those choices empower you to be where you want to be, do what you want to do, and live the life you always wanted" (Mitchell 2014, p. 221).*

Tiny Home living at its core is a lifestyle - rejecting mass consumerism

The second strongest motivator for living Tiny is the search for a simpler life. Often the impact of mass consumption is referred to in regards to its effects on the planet, its contribution to climate change or its foundation in unethical labour. Tiny Homes are a reaction to the detrimental effect of mass consumption on personal wellbeing. (Boeckermann, Kaczynski and King, 2019) (Weetman, 2018)
All literature research on Tiny Homes that includes the social aspect, addresses the structural bias in our society that leads to mass consumption and a culture of celebrating overwork. This comes at the cost of personal relationships, community, time and financial stability. The essence of the Tiny Home movement is living better, with less. They are a choice for conscious consumption. (Mangold and Zschau, 2019) (Boeckermann, Kaczynski and King, 2019) (Ingram, 2020) (Kilman and College, 2016)

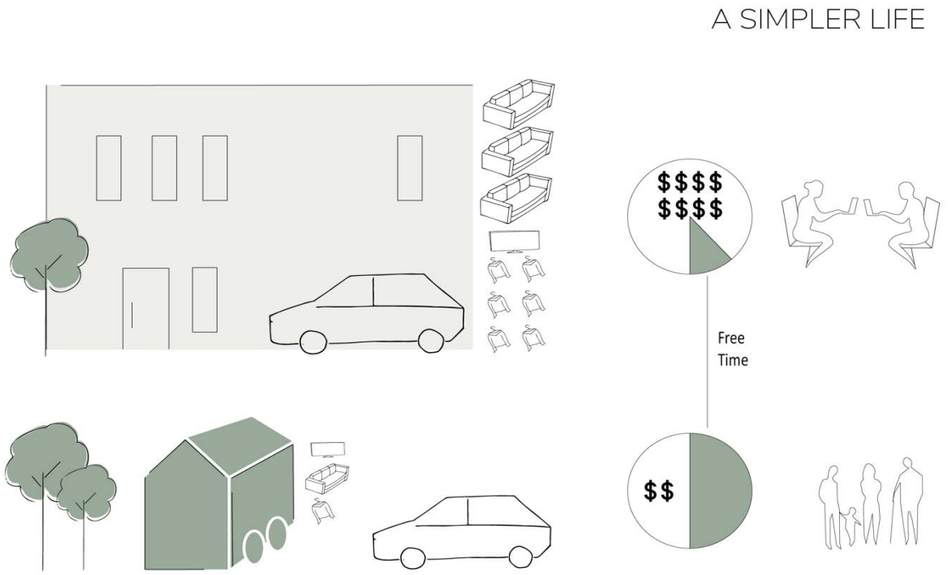


Figure 5 schematic on a simpler life

Figure 5 schematic on a simpler life

What makes Tiny Home living different from other movements?

Tiny Homes are not the first to challenge consumerism culture in the West. There is the back-to-land movement, voluntary simplicity, pragmatism, downshifting, environmentalism, as well as minimalism. (Mangold and Zschau, 2019) What sets Tiny Home living apart socially as a life style movement? For instance: while for minimalists downsizing is an ever going goal, Tiny Home owners *will* buy new items if they feel they would add to their quality of life.
Most Tiny Home owners are not moved by environmental reasons. Even if being more sustainable becomes a side effect of their lifestyle. Instead of downsizing they will be 'rightsizing'. (Kilman and College, 2016) (Mangold and Zschau, 2019) It is a much more individualistic, pragmatic and experience driven approach to find a more balanced life.
(Mangold and Zschau, 2019)

What is the value in this to you & society?

So Tiny Homes are about so much more than just their 37m^2 size limit. They are not just a housing style chased out of poverty. As studies show most Tiny Home owners are well off. It is a lifestyle looking for simplicity to create freedom in life. Of course Tiny Homes are not a golden grail. Many of the difficulties of the Tiny Home lifestyle - such as its illegal status - have been discussed.

As a lifestyle Tiny Homes can be seen as a tool to re-learn what is essential and what is a splurge in your wallet. It is critical to understand that the Tiny Home lifestyle is not necessarily limited to the Tiny Home. Tiny Homes can help people realize that a huge mansion with multiple cars might not

be the thing that makes you happy. But that doesn't mean you will be happier living Tiny: 12m² is not the perfect space for everyone. But living Tiny as an experiment can teach you what you what is truly important to you.

In society today climate change is a big concern and there is no clear guide on how to act on it. Often it is argued that to live environmentally friendly, would be to compromise your own wellbeing. The Tiny Home lifestyle seems to prove the opposite is possible. If you manage to change in a way that is optimal for you, you will automatically become a better person for the environment.
If the Tiny Home movement is accessible to more people it could help scale up environmentally conscious transformation we need to make as a society.

- Conclusion impact on you.

Tiny Homes present financial freedom in a world where housing prices are on the rise and mortgage is not a viable or wanted option for most people. While there is a clear opportunity, due to the undefined legal status of Tiny Homes, this also brings hidden costs with it.
Tiny spaces bring engineering challenges and opportunities. The small space makes indoor environmental quality a challenge, at the same time it allows to explore newer building techniques such as infrared panels.
Living in a tiny space is not a new invention. But the comparison with the slums teaches that Tiny Homes, due to their purposeful choice, have become an exercise in optimizing interior design. Research after the Corona pandemic shows that interior design is key for mental health of resident, and the solutions seem to be found in Tiny Home design. Additionally this research pointed out the importance of outdoor space, being an essential component to living tiny that is not always addressed in the designs.
However, even an optimized design finds it hard to find a solution for creating a house where one can easily host people.

The question remains: is Tiny too small for you? At its core Tiny Home lifestyle is a rejection of the mass consumption society. The Tiny Home is a tool that brings an awareness to its owners showing them what is something they need in their lives and what is extra. It is critical to understand that the Tiny Home *lifestyle* doesn't necessarily implicates living in a Tiny Home.

To fight climate change and be a more sustainable society it seems we have to transform the way we build and live. Transformation being the difficult part here. It is interesting that many movements have tried to change people's lifestyle for a better environment. The Tiny Home lifestyle never aimed for this, but in search of a better life people find themselves living sustainably. Could this be a tool we can use to teach ourselves as a society?

IMPACT ON SOCIETY

This section will look at the impact the Tiny Home movement has on society. It will investigate what the urban planning of a sustainable neighborhood looks like, zooming in on the importance of diversity in buildings. Next up is a deeper dive into the integration of Tiny Homes in the urban landscape. Research shows their wide acceptance is not reflected in current policies. The preferences of stakeholders for specific kinds of Tiny Home designs, questionnaire results, and the social impacts will be looked into.

> *The importance of the tiny house movement is not based on its quirkiness or on pictures of beautiful small homes, but instead on the application of its values to the broader public—helping them understand that smaller is better for their finances, the environment, and the community. (Kilman and College, 2016)*

– What does a sustainable neighborhood look like?

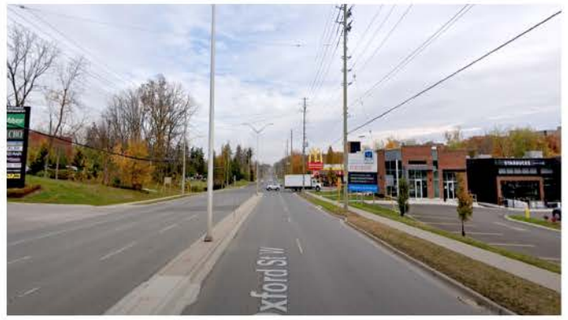
A resilient, socially and economically thriving urban landscape depends on different factors. A human centered city design has shown its importance, especially in the light of the Corona pandemic. Diversity of buildings and public space are key factors, as well as flexibility and mobility.

Laws & parking a Tiny Home

What often makes Tiny Homes expensive is finding a (legal) place to park. Zoning laws are usually local so it is a subject that is harder to tackle through literature. In Norway you can get permission to place a Tiny Home on your land and live there for 2 years. (DNB Nyheter, 2020) In most countries in Europe however Tiny Home on wheels are still undefined and usually require creative solutions in legal documents. The opposite is also true, choosing to have a house on wheels can be your way to exploit a loophole – as your structure isn't regarded as a house. Often even if Tiny Homes are legal, they still might not qualify as a residence, and thus can't provide an address. (Ford and Gomez-Lanier, 2017)

Zoning law and/or social class division laws

Zoning laws have been used in different degrees to create rich neighborhoods and affect the building landscape to this day. In America zoning has been used historically to ensure segregation between classes, and foremost, race. (Evans, 2019) While this thesis will focus on developing a design in a European context, it is important to understand politics and architectural landscape are tightly intertwined and can strongly influence the wealth of a society. One of the first things Trevor Noah mentions in his book *Born a Crime* is how architecture and laws were used after thorough research to ensure segregation in South Africa. (Trevor Noah, 2017) Zoning is a tool still used to protect property values to this day. When you create neighborhoods with plots of 5000 square feet (464.5m²), the plot itself is more expensive than a Tiny Home. This does not only make it harder for people to acquire land, but it will create a problem to get financing for a small home that isn't worth much. (Evans, 2019) In Denmark there are areas where it is illegal to have more than one family or house on a plot of land, so placing a Tiny Home in the garden is not an option. (S. B. Mackeprang, personal communication, 28.8.2019)



Top and right - Groen zuid in Hoboken, a infill project aiming towards urban and social sustainability and creating a diverse and living new neighborhood.

Left middle - a suburban street in America and Canada

Bottom - town center in America

(Not just bikes, 2021)
(Ingenieursburea CONCREET bv, no date)

Sustainable neighborhoods & 15 minute city - diversity (of buildings) is key

Sustainability can be defined as dealing with resources in such a way that it does not negatively affect the chances of the people who will live on this earth after us. Thus a sustainable neighborhood has to be one that provides for all ages, creates a strong community, and is flexible to change. A socially and functionally mixed neighborhood will create a strong identity and lively social space. (Schmedding *et al.*, 2015)

The opposite of this would be for instance the large suburban areas found in North America: highways, houses, and a mall. These become places where there is nowhere to walk and little to no chance of social interaction. Their residents are dependent on (expensive) car ownership for every action, leading to social disadvantage and pollution, threatening accessibility and livability of neighborhoods. (Not Just Bikes, 2021) (Babb, 2021)

On the opposite end of this are neighborhoods that offer a mix of price ranges and living styles. An example is Groen Zuid in Hoboken, Belgium. This was a fill in project - replacing an industrial site. The new neighbourhood had the typical Belgian rowhouses and apartments with a range of sizes, as well as loft style flats with panorama view. It also made space for a park with 3 larger towers for service flats and a kindergarten. The project successfully implemented principles to become a mixed and alive urban community. (Architectural theory 2, course VUB, personal communication, 2010) (cursus ruimtelijke planning VUB)

Of course not only diversity of buildings is an important factor here. The Groen Zuid project also focused on connecting bike paths, and quality public space. The Corona pandemic showed the vulnerability of cities. As a result it is now seen as necessary to have a walkable city with proximity based access to services for all residents. This concept of the “15 minute City” has been gaining traction. (Moreno *et al.*, 2021) Building cities for people instead of cars is key to making a sustainable landscape. (BuildDigiCraft, 2020) (Schmedding *et al.*, 2015)

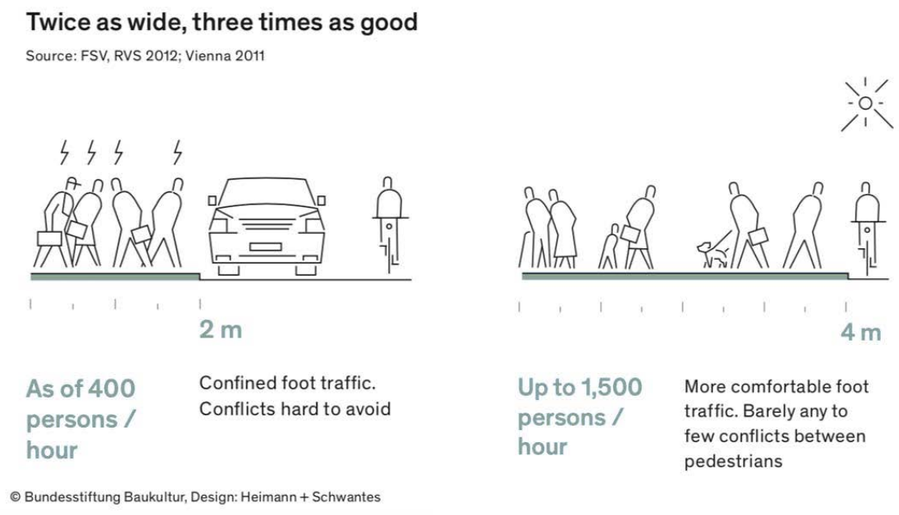


Figure 6 car based versus human based design – graphic by Baukultur (BuildDigiCraft, 2020)

Freedom, flexibility and mobility create an economically resilient country

Tiny Homes on wheels give people the freedom and option to move around and not be tied to one place. But even without wheels they too create a more diverse housing market. This flexibility might be a crucial element in reviving economies. A book published by Oxford University Press argues that the mobility of a population - their opportunities to move easily to find work - is directly related to the rate of unemployment. A striking illustration can be found in the difference between Spain and Switzerland: Spain has the highest rate of unemployment and the highest rate of homeownership. Switzerland has the lowest unemployment and homeownership rate... (Ewijk and Leuvensteijn, 2009)

Due to their limited size, Tiny Homes are a temporary space for most. Many uses of a Tiny Home are used as a holiday home, B&B, workstudio,… (Ford and Gomez-Lanier, 2017) But even when the house is used as a permanent residential space, owners often find themselves moving out sooner or later. There are many reasons, sometimes as simple as family expansion. While this is often seen as a critique, moving homes in many countries is the standard as people adapt their environment to life changes. A study showed that flexibility, mobility, modular and Tiny construction are an essential part of how the building industry is changing in Austria. Many construction and carpentry companies already offer prefab and mobile house concepts. (Leindecker and Kugfarth, 2019) As of now the undefined status of Tiny Homes makes it a harder to make them a part of the real-estate market though.

- How to integrate Tiny Homes in the urban landscape

Investing in integration of Tiny Homes and city improvement go hand in hand. Public space has to be prioritized to create a dense urban landscape and Tiny Homes provide much looked after affordable homes.

Public space is key to Tiny Home presence

When looking into the integration of Tiny Homes in urban planning it is important to realize that smaller homes require better public spaces to accommodate them. When you literally live on a small footprint, the surrounding landscape and city become a much more prominent part of your everyday life. (Hutchinson, 2009) Densifying a suburb or a city with Tiny Homes also results in an increase in the need for parking space and public transport/accessibility, for example. (Jackson et al., 2020) (Evans, 2019) Following the Corona Pandemic the importance of adequate public space has been highlighted! (Thompson, 2021) Public space is not just defined as a park or a square: it includes passageways, museums, restaurants, public spaces inside buildings,... Usually 1/3 or even half of a city is public space. Baukultur make a case for public spaces in their latest report, stating that they are a necessary prerequisite. They found that when public spaces are created and realized before the actual new neighborhood ‘s buildings, this creates increased acceptance and integration in the urban landscape. (BuildDigiCraft, 2020)

Stakeholders, property values & concerns

What are the elements holding back stakeholders to include Tiny homes in cities? A study in the southeastern United States (Evans, 2019) looked at the relationship between land use and visual preferences. They investigated two cities that have a vastly different background – one being an

Top - Tiny home villages in different styles, Canada, Oregon and Tampa

Bottom - The vernacular and wooden Tiny Home as the most preffered in a study

(Evans, 2019) (TYLER FYFE, 2015) (Difley, 2019) (Ilene Denton, 2020)

artists town and the other a holiday destination for the rich. Both have a shortage of affordable housing, especially for low wage earners.
The results showed a clear preference of stakeholders for traditional/local/vernacular aesthetics in Tiny Homes. Integrating Tiny Homes as accessory dwelling units[2] -ADU's - or in designated communities is preferred over land infill. The main concern for integrating Tiny Homes is the influence in property values. While the study found an initial lack of understanding as to what a Tiny Home is and the difference with a trailer home, it also found an amazing amount of support for Tiny Homes that is not reflected in current policies. (Evans, 2019)

2 ADU's – accessory dwelling units - are common in America and Australia, they provide a chance to build a small home in the backyard for your parents, or maybe rent out your converted garage space to earn money.

- Community, relationships & demographics

While the community aspect is not very high on the motivations list to move Tiny, the consequences are. With less financial pressure, more time is available to spend building relationships. With a Danish average household at 2.1 people, 50% of society is a potential target group for living Tiny.

Community

A common criticism on the Tiny Home movement is that people living illegally do not pay taxes and as such don't contribute to the community they live in. In a survey that investigated Tiny Houses being placed within existing neighbourhoods, the transitionary state of Tiny Homes was found as one of the resident's main concerns. (Ford and Gomez-Lanier, 2017) (Evans, 2019) Of course the legal aspect is not easy to change. But let's have a closer look at Tiny Homes and how they influence community.
The Tiny Home movement has been presented in media as an individualistic endeavor. This minimizes the aspects of community-building and social change, and facilitates the commodification of the lifestyle. Looking at motivations to move Tiny, "community" is quite low on the list. However community is and has been - and still is -a large part of the movement from the start. The main benefit people find in their move to a Tiny Home is the free time they now have to spend with family. (Boeckermann, Kaczynski and King, 2019) (Ingram, 2020) Similarly "community" was found as the main reason people *continued* living in slums in Jakarta. The kinship and bonds developed is the element that makes the lifestyle socially sustainable. (Anggraeni and Herlily, 2020)

Rich people end up in Tiny Homes, is it eluding the people it was meant for?

There is a concern that Tiny Homes will not fill the gap for low wage earners, but rather become a holiday spot for the rich. (Evans, 2019) Demographics show that most Tiny Home residents in America have middle class incomes and thus are not low wage earners. (Boeckermann, Kaczynski and King, 2019)

However an interesting counter argument was presented in a Tiny Home research. (Hutchinson, 2009) For the movement to get to the level where it can be accessible to everyone, people who can afford to take a risk should take the initiative. As such the richer people could help legalize the movement. Another critical element to legalize the movement is media presence. (Hutchinson, 2009) As seen previously many hidden costs of Tiny Homes are linked to their undefined status, so it makes sense that legalizing them could help curb costs.

While the lower cost of Tiny Homes is a critical part of the movement, it is a mistake to view them as a solution to poverty. As discussed previously the Tiny Homes movement is a lifestyle: it can't be expected that everyone will want to live like this. In that regard the critique 'this is too small' is absolutely correct. Living Tiny is not the best solution for everyone. There is a large demographic that could benefit from living Tiny, but limiting that group to "the poor" would be denying all other aspects that a Tiny Home embodies.
So who would be the target group for living Tiny? Families can live Tiny, but it is decidedly harder. But for singles and couples, a Tiny Home can offer the perfect space. Is this excluding a lot of people? Let's take a look at the numbers.

Demographics Denmark – 65% of people are living in 1-2 person households

The average household size in Denmark is 2.1 persons. Looking at the household statistics calculations show that 49% of people live in a 1-2 person household. In the Copenhagen area this number is even higher at 65%. That is a large target group for Tiny Homes. (Danmarks Statistik - population, 2021) ((Danmarks Statistik - FAM55N, 2021)

Taking a step back and looking at an 'average' person's life, we need to realize that about 50% of that time is spent in a 1-2 person household. Often people go to college when they are around 18. There is a big change in dynamic when they start a family: often in their end 20's or 30's. As people live longer, the period after kids have left the home is also becoming longer.

Thus both on a society level and on a personal level, there is a large possibility for Tiny Home integration.

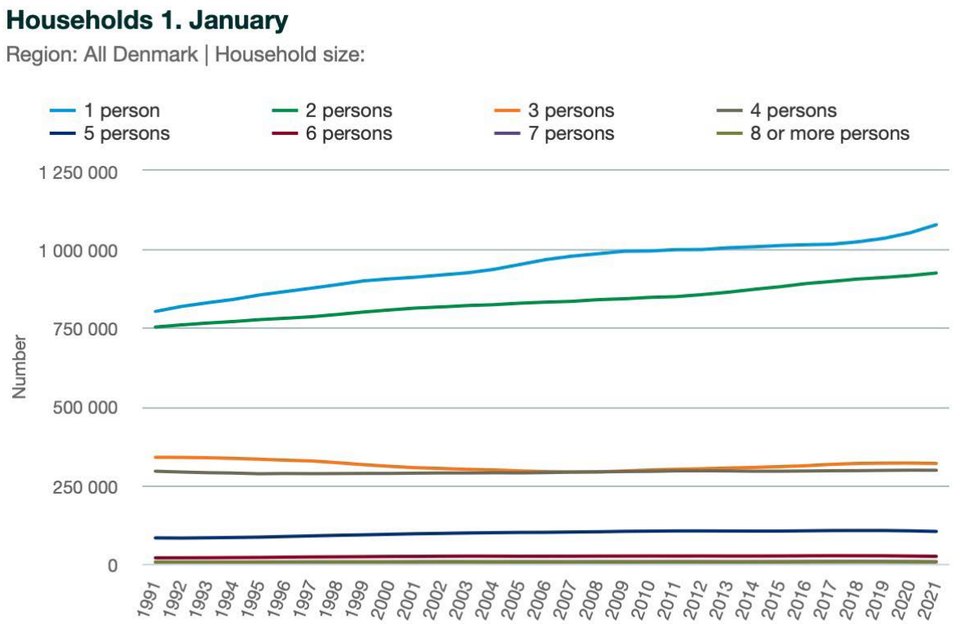


Figure 7 household division in Denmark - (Danmarks Statistik - population, 2021) ((Danmarks Statistik - FAM55N, 2021)

All Denmark:
Total: 5850189
1 person households: 1078175
2 person households: 924760

((924760 x2) : 5850189) x 100 = 31% of people live in a 2 person household

(1078175 : 5850189) x100 = 18% of people live in a 1 person household

For Copenhagen area:
Total: 1349914
1 person households: 348 772
2 person households: 270 813

(270 813 x2) : 1349914 = 40% of people live in 2 person households.

348 772 : 1349914 = 25% of people live in a 1 person household

- Conclusion impact on society.

If Tiny Homes where accessible, would they be as popular in a real-estate market as they are on TV shows? Research shows that Tiny Homes are widely accepted - see the examples of the artistic town, and the rich people's holiday town. This is however not reflected in policies. Legal hurdles continue to be a big challenge for living Tiny. There is a clear preference for vernacular Tiny Homes that suit their surroundings. ADU's or dedicated communities/parks are the preferred methods for including the homes.

There are multiple benefits to including Tiny Homes in a sustainable city development. Flexibility of housing is critical for a city's economy. They create a wider range of housing, that results in social sustainability. They also force awareness of good public infrastructure such as parks, public transport,… essentially leading to a human centric city. This coincides nicely with the "15 minute City" concept that has been much discussed in the aftermath of Corona lockdowns.

There is a big concern that Tiny Homes are becoming a popular commodity and fail to serve the people they were originally meant and built for. As Going Tiny is a lifestyle, not just a result of (limited) personal finance. Thus looking at Tiny Home living as a solution to poverty doesn't add up: a certain lifestyle cannot be forced on people. Living in a $12m^2$ space simply will not suit everyone.

An interesting argument is that to get Tiny Homes legalized, richer people have to take the lead, as it is not financially possible yet for others. Once Tiny Homes get legalized, the hidden costs tied into legislation should disappear and create a more accessible market.

The target group for Tiny Home residents is potentially huge, setting the financial aspect aside. At the moment Denmark has a 2.1 average household size. This means 49% of people live in 1-2 person households. These are an ideal group for Tiny living, as space is limited. Additionally often this corresponds with a stage in life that allows more flexibility, such as student life, or travelling after the kids have left home,…

IMPACT ON ENVIRONMENT

This chapter will look at the environmental impact a Tiny Home has, or lacks. One study showed a 70% reduction in Greenhouse Gas Emissions (GHG). But GHG is not the only factor.
Several elements in the design of a Tiny Home will have their effect on the resident's lifestyle. Off grid living is just one of them.
Prefab and modular construction are closely related to the Tiny Home industry and are becoming more prevalent. Finally this section will also take a closer look at circular economy.

- Environmental impact of a Tiny Home: the numbers

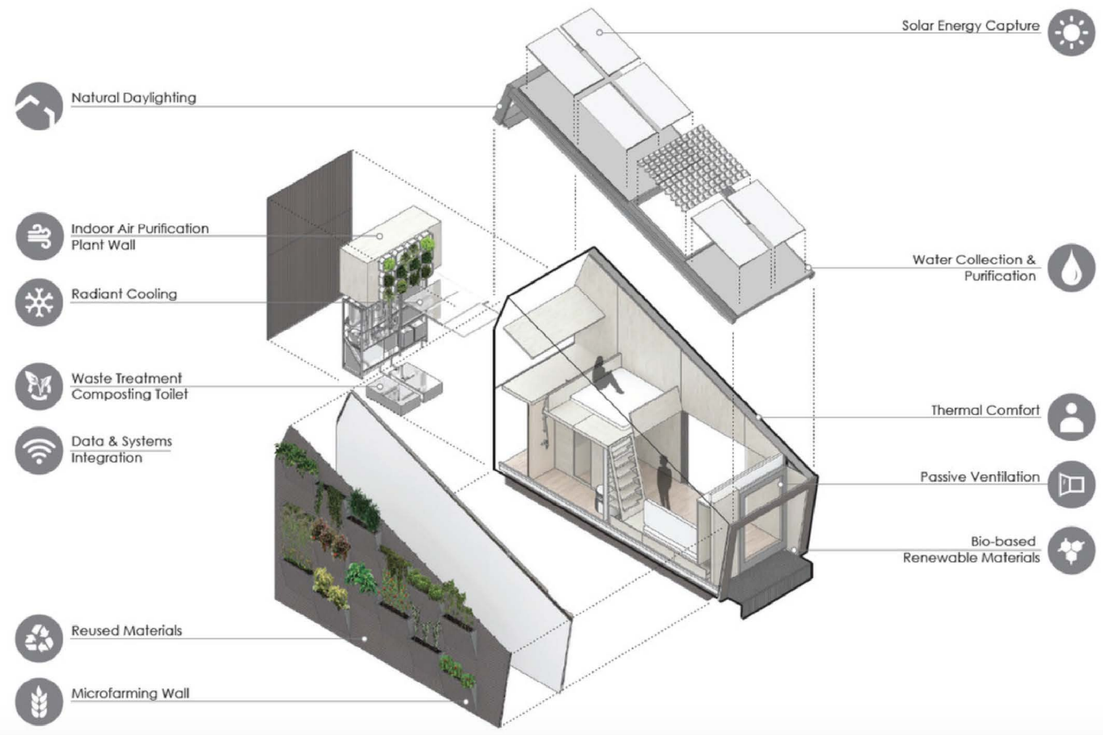
Residential buildings are responsible for 70% of global building energy demand. Multiple studies have shown that there is a direct relationship between house size and electricity use. Thus it is a reasonable conclusion that Tiny Homes will have lower environmental impact and save a lot of energy purely because of their size. (Crawford and Stephan, 2020) The effect is not as big per square meter as one would expect, since the house will still need all appliances, full thermal envelope,… They are just concentrated in and around a smaller volume.
Looking at influence on GHG directly, a study in Australia found that a Tiny Home resulted in a 70% reduction compared to traditional homes. The traditional house would have to house at least 10 people for GHG emissions to be lower than those of the Tiny House. The current average Australian household is 2.6. (Crawford and Stephan, 2020)
The study didn't include 3 important factors:
The first is the effect of personal responsibility and involvement a Tiny Home lifestyle creates. The second is the choice of materials: low carbon materials have a very big influence in GHG emissions. The last is the end of life stage: waste from buildings is a huge contributor in the world's waste stream polluting the environment. All of these elements 3 will be discussed in the sections below.

- Eco Lifestyle

As mentioned before living in a Tiny Home has the possibility to lead people towards making a conscious change in their lifestyle, towards a more sustainable and conscious consumerism (Kilman and College, 2016) A couple more tangible examples are the off grid lifestyle, minimal impact of the building on its surroundings and the close connection with the technology that regulates the home.

An opportunity to go off grid

Living off grid in most countries is more sustainable as electricity supply still mainly comes from fossil fuel sources (Martins, Felgueiras and Smitková, 2018)(Liddle and Sadorsky, 2017)
In Denmark 35% of electrical is renewable. It is often referred to as one of countries with an advanced renwable strategy.
Moreover, Denmark is heating most homes using a warm water distribution network from industrial waste energy. (T. R. Nielsen personal communication, 2.7.2021) This contrasts with many countries in Western Europe where boilers and hot water heaters are standard. In most of these countries the Danish warmwater distribution network is an example reluctantly followed by energy companies and authorities, still in experimental phases and hindered by lots of paper work….



Top - DIY technology, grey water cleaning and composting toilet

Middle - Yale Tiny Home technological overvieuw

Bottom - Tiny Homes and Solar power

(Ethan, no date) (Erica Puisis, 2020)(Living Big In A Tiny House, 2018a) (UN Environment programme, 2018)

Living off grid also creates flexibility for your house to stand anywhere. It creates independence from operational costs of the house. Solar panels are the most used solution for energy and being so small, the price of the solar installation (including batteries) is much more affordable than for a regular house. Water storage tanks and grey water recycling for the garden are also common. (Calluari and Alonso-Marroquín, 2017)

Examples of low key and high tech off grid solutions

Making an off grid ecological house can include simple low cost solutions such as a DIY rainwater cleaning system, or a basic composting toilet. (Living Big in a tiny house, 2018) (Kilman and College, 2016)
Or it can be a more high tech design such as developed by YALE and UN Environment. (UN Environment programme, 2018) The Tiny house focused on optimizing the ecological aspect of Tiny house. In it's 22m² it contains: air purification through plants, passive stack effect ventilation, solar installation, micro farming and collection and filtration of water – this last one is key to design the house for minimizing the use of natural resources. Furthermore the house is constructed from locally sourced bio-based renewable materials. (Stinson, 2018) (UN Environment programme, 2018)
More and more Tiny Home owners have smart installations. These owners get direct feedback on what they consume and use less water and energy as a result. (Faruqui, Sergici and Sharif, 2010)('A clever little home', 2021)

A new perspective on waste connected to nature

Tiny Homes force people to deal with waste. You want to use your storage space for essential needs, and waste is just not one of them. Living Tiny suddenly makes the enormous amount of packaging we use very visible.
As many Tiny Homes are on wheels, they are not connected to plumbing. This forces people to deal with something that usually disappears in a toilet like magic: human waste. A composting toilet in its many forms is the most common solution for the absence of plumbing. Composting and filtering water is a cycle between human land use and nature. This hands-on approach is an eye opener to human impact on the environment. (Kilman and College, 2016) A surprising bonus to composting toilets: they are easy to clean and they don't smell – ever! On the down side most types off composting toilets do require almost daily maintenance.

Minimal footprint and ecosystem impact

Tiny Homes, of course, do not affect the soil when being built. Most small homes are built with lightweight materials such as wood or a steel frame, instead of concrete or brick. This means the house can have a simple foundation - such as screws. This is a guarantee for preservation of property value. (Leindecker and Kugfarth, 2019) But more importantly it means that there is minimum influence to local ecosystems and biodiversity

- Modular building and prefab

Due to their size Tiny Homes are a closely related with prefab projects, they have the same construction challenges and material constrains. As well as building regulations to juggle.

Prefab as a sustainable housing market

Modular building and prefab constructions are not a new idea to architecture, however some of the limitations due to technology have fallen away and created a new high tech, high quality prefab industry. This prefab industry is often used as a way to promote sustainable housing. (Carvalho, 2019)
In Austria for example modular building and prefab is becoming more common and seen as essential for the changing building environment. (Leindecker and Kugfarth, 2019) Some of the advantages of modularity and prefab are: highly effective reduction in construction space, large-scale infrastructure for flexible use, centralized inspections and specialized workmen, assuring the building conditions for future disassembly and recycling. (Silva, 2020) (Kirsten Dirksen, 2019)

Customization to avoid the risk of monotonous architecture.

Prefab might face the same issues in housing as we find in social blocks – good intentions but a dehumanized result. (Carvalho, 2019) Car's face a similar problem. When cars are mass produced, they risk to be all the same. The car industry found a balance by offering an online catalogue with different setting/options and customization giving each owner a unique design.
We see this in action already in a small start up company in LA for example. (See picture page) (Kirsten Dirksen, 2019) (Archinect, no date) In this regard it is interesting to see Tiny Homes are known for unique aesthetics and individuality. Might this actually be one of the reasons for their success? The main examples found of prefab homes focus on strong aesthetical homes and individualization.
A concern people have with prefab construction is the need for adaptation. Different locations require different foundations, and different connections to the grid. (Carvalho, 2019) This hasn't stopped the industry from taking off in Japan. There modular and prefab building constructions have a much bigger cut than in western countries. In 2002 14% of all newly build houses in Japan where prefab. The prefab industry had a rapid growth in a declining housing economy between 1980-1983. Initially the houses where aimed at affordability. But they got a bad reputation due to their mass production and monotonous look, and where quickly rejected by the public. Nowadays the prefab industry markets itself as providing for high quality houses aimed at clients with a higher budget. Nevertheless, despite their success, most consumers still choose for a more affordable traditional house. (Noguchi, 2003)

A lower footprint

A study on modular and prefab construction found that on average green house gas emissions – GHG - of prefab building is lower than that of traditional construction. (Boafo, Kim and Kim, 2016) Modular and prefab construction is often tied to environmentally conscious construction. A thesis investigating the LCA of a prefab ADU - accessory dwelling unit - pointed out that material choice rather than construction method is the critical component to making a sustainable house. The research however did not include the end of life stage. (Moradibistouni, 2020)

Wood as the most commonly used material

Weight also plays a role in mobility of a construction. A Tiny Home on wheels is often placed on a

trailer that has a weight limit. Timber is therefore a much used material for is light weight properties. Timber is used as the most common material in prefab construction. It has a lower environmental impact than traditional materials. The material also allows a much faster construction process with claims of cross laminated timber – CLT - being up to 6 times faster than traditional construction. (Carvalho, 2019) Timber as a recycleable material (BuildDigiCraft, 2020)
Wooden Tiny Homes were also found to be preferred over other materials independent of style in a study on visual impact of Tiny Homes. (Evans, 2019)

Building codes/material constraints

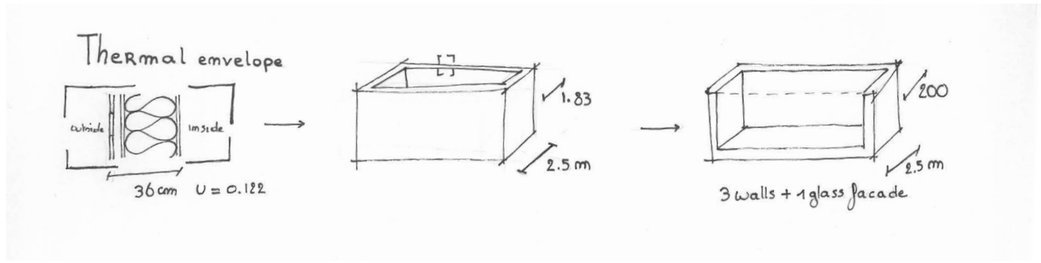


Figure 8 Sketch illustration of design adaptions to reach required U - value in a Tiny Home

Another element Tiny Homes and prefab have in common is navigating building codes for a small, moveable structure. It is an often overlooked problem, as many Tiny Homes exist in a grey area due to zoning law. So building codes are not the owner's first concern. As a result most Tiny Homes do not fit in with building regulations concerning fire safety, insulation,… (Ford and Gomez-Lanier, 2017) If you want to build a Tiny Home compliant with building codes, there are several difficulties. For instance, often sewage connection and a foundation are mandatory - which is quite pointless in the case of Tiny Homes.
Also building regulations are becoming stricter slowly moving the build industry to zero energy housing as an answer to climate change and sustainability of houses. To get U - value to 0.12 for a passive home, most construction detailing/materials will bring your wall to a thickness of around 40cm. But as in a Tiny Home the width is restricted to 2.55m, this would bring the interior width at 1.75m. That is a very limited space, even for a Tiny House. This ratio of envelope to floorspace has an influence on comfort and energy consumption. (Mukhopadhyay, 2020) So building codes often are not well suited for the case of Tiny Homes.

- Disassembly and Building for circularity

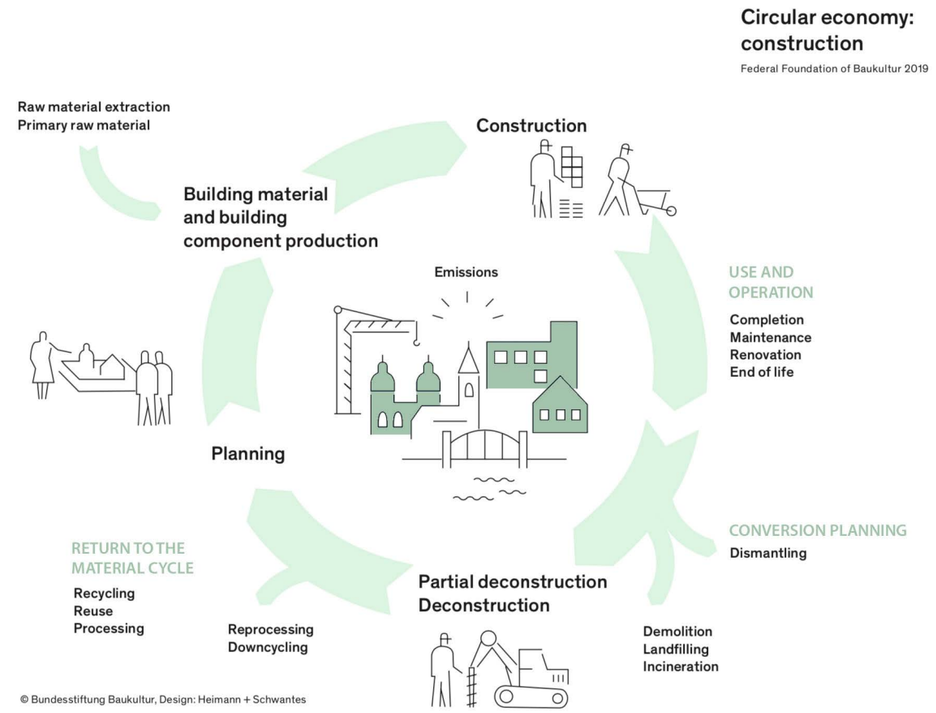


Figure 9 Circular economy of construction – from Baukultur (Schmedding *et al.*, 2015)

The influence of demolition and construction waste

Demolition of a building is an important and often overlooked aspect in architecture. Recycling and re-using is not a new concept in the building industry however. Wooden buildings have in the past been made with the purpose of being disassembled and rebuilt. When trying to save a peat shed the only solution seemed to move it. It was noticed during the deconstruction that the building had been moved before: screws and connections were found, indicating the building had changed location at least 3 times. (BuildDigiCraft, 2020) Tiny Homes fight the battle of waste mainly by reducing the size of the house, but many also actively become part of the circular building environment by reusing and upcycling materials for their homes. Using recycled materials can save over 60% of a buildings embodied energy. (Ferreira Silva *et al.*, 2020)
Circular economy is not a concept limited to architecture. Looking at plastic industry circular economy could not only save waste, they would retain 95% of the value that is lost each year from plastic packaging and generate 4.5 trillion USD in annual economic output. (UN Environment programme, 2021)
The waste created by the housing industry is significant and accounts for more than a third of waste created in Europe. (European Commission, no date) In Germany the number is estimated even higher with 51.2% of waste being contributed to construction and demolition. (BuildDigiCraft, 2020)

ReBlock – a building block wall system.

An example of a system designed for circularity are is the Reblock wall elements. They can be assembled in any design you require – following the grid of 30x32cm. Floor and roof elements are in the final stages of development and follow a grid of 1.2x1.2. (REXCON System, 2021) (J. Sørensen, personal communication, 21.6.2021)
The elements can be folded and transport on a pallet minimizing transport. After the construction is finished they can be filled with blow in insulation such as cellulose. The products have a high material utilization in manufacturing and avoid noise and saw dust pollution on site. The assembly is very simple using hand tools, and needless to say much faster than a traditional build. Additionally special care has been taken to use sustainable and healthy materials that don't contain any chemicals.
The most interesting aspect however is the elements are designed to be dismantled, repacked and used again! (REXCON System, 2021) The concept design of Tiny Step will be designed with the Rexcon grid in mind to keep construction options open.

Circularity starts at design

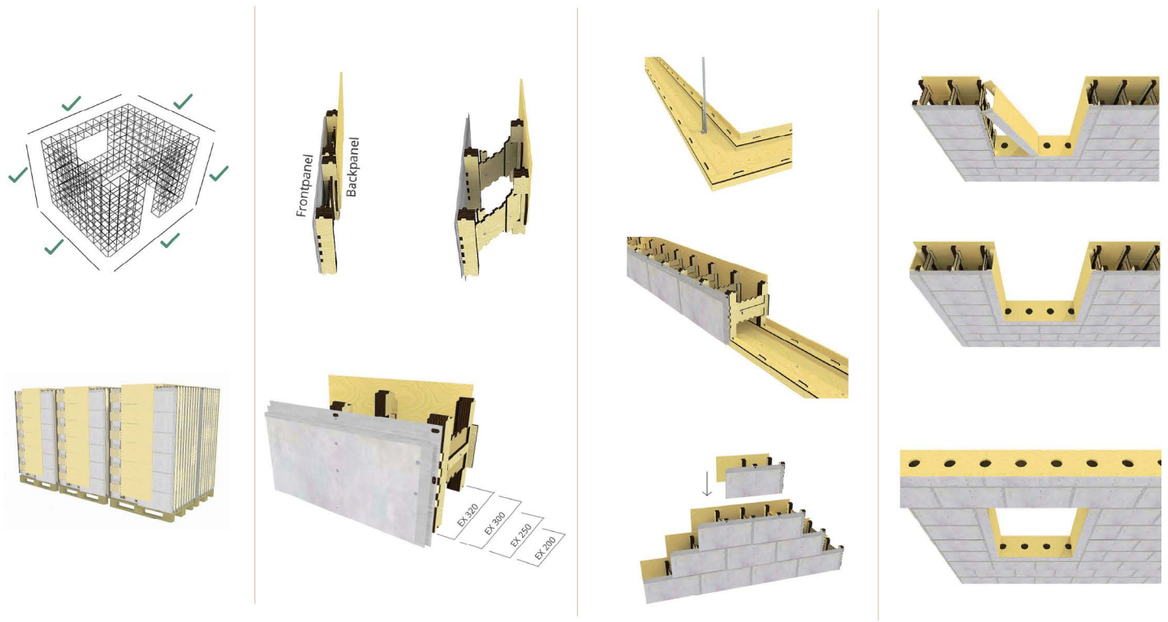
To facilitate circular design, engineering and technical detailing play a bigger role in setting up the design, thus more integrated design is necessary. (Ferreira Silva *et al.*, 2020) Baukultur however points out that integrated design should be addressed on *all* levels and sources and not only lean on technological advances. Just as the wooden building that had been created with deconstruction and re-use in mind, there are many more low tech solutions. (BuildDigiCraft, 2020)

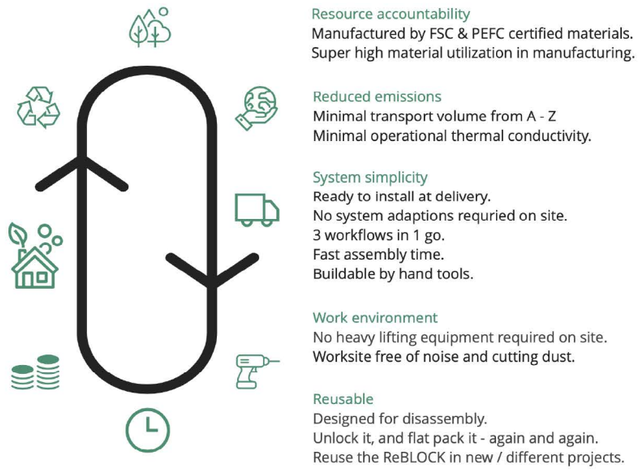
Tiny Homes have a unique combination off grid possibilities, fast construction and upcycled DIY builds that are already part of circular market . It seems on a larger scale they could be a good way to experiment fast in low carbon housing, and help change the way we built…

- Conclusion impact on environment.

Due to their small size Tiny Homes are ideally suited for prefab building and modularity. Additionally it is easier to incorporate circular design in these new and smaller projects. An example are the Reblock 'building block' elements that can be reused. Could Tiny Homes in this regard be a tool for fast experimentation in low carbon building?

It is also important to realize that sustainability in Tiny Homes doesn't only relate to their small size and optimized construction possibilities. Tiny Homes have a much smaller impact on green house gasses – GHG - and they don't disturb the local ecosystems the way traditional housing does. They have also been pioneers in off grid homes, as their smaller energy demands are easier to supply. Finally living Tiny actually causes people to adapt a sustainable lifestyle.





Top - A project being built with ReBlock elements.

Middle - From design to shipping to built project.

Bottom - Sustainability goals

(REXCON System, 2021)

TINY STEP concept design

EXTERIOR

27.6 m² footprint

Mobile house dimensions following European road law.

Special transport laws dimensions that can be used to move a prefab structure.

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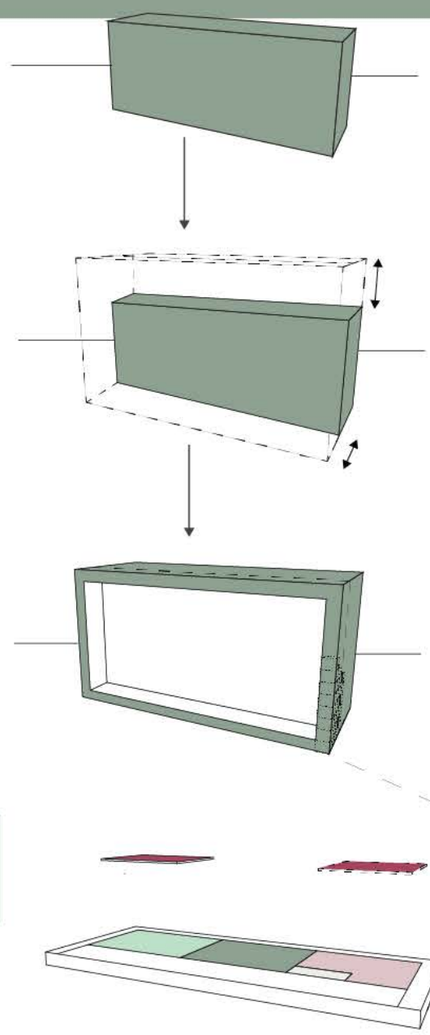
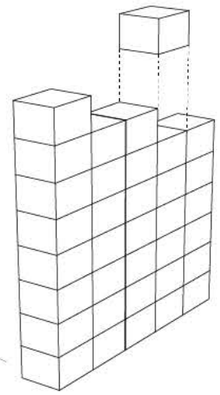
In Denmark, wind is a prominent weather feature, keeping you indoors even on the rare sunny days, this is why an outdoor space is essential to the design creating a readily available protected space.



INTEGRATING THE CHALLENGES AND POSITIVES FOUND IN LITERATURE ON TINY LIVING - THIS CREATES A FLEXIBLE HOUSE THAT CAN ACCOMODATE A STUDENT, COUPLE, ELDERLY PEOPLE,...

👤 & 👥 = 50%



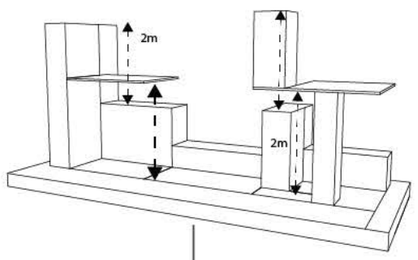
U-value envelope 0.125 W/m²K

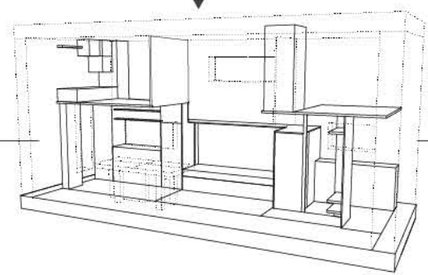
The Tiny house is designed to follow Rexcon. This startup company focuses on sustainability and circular economy. It developed a 'lego' wallsystem to be DIY friendly. Fast production can keep the price down without compromising on quality or sustainability of the building.

INTERIOR

27m² interior space

POLYVALENT SPACE
BEDROOM
KITCHEN
ENTRANCE
BATHROOM
LIVING ROOM





Fixed furniture functions as storage, walls, and floor to make 2 full height bedrooms

Transformable units add an additional level of flexibility essential in making a small space take all the functions of a big house - like hosting a dinner

2 Closed bedrooms give the Tiny Step design a level of privacey and flexibility in usage most Tiny Homes don't have.

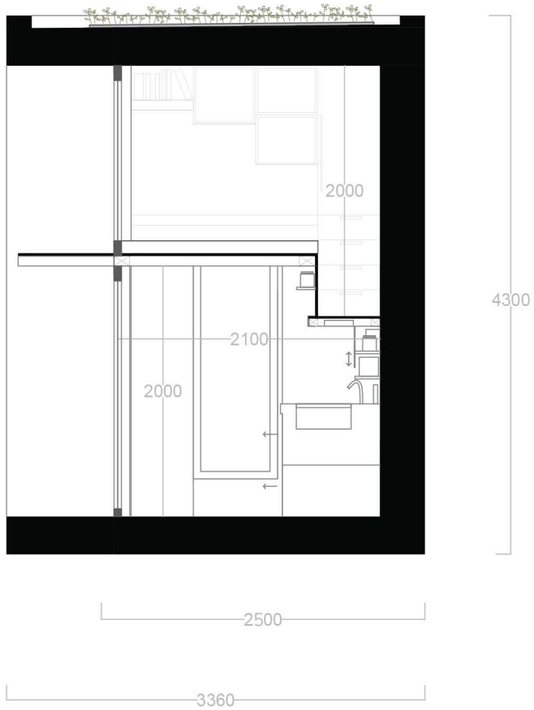
Vertical design optimizes the use of the smal space

The outdoor space becomes part of the design by opening the fold out windows.

Material choice is a main element of the design as it is key to create a buidling with low impact on environment and global warming.

TINY STEP concept design

Scale all drawings 1/50



The outdoor roof blocks the sun from entering the home in summer, keeping it cool. When needed the shading can be pulled down.

Summer evenings in Denmark can stay light untill midnight. Perfect for hosting a dinner with friends. The table can fold out to host 10 people.

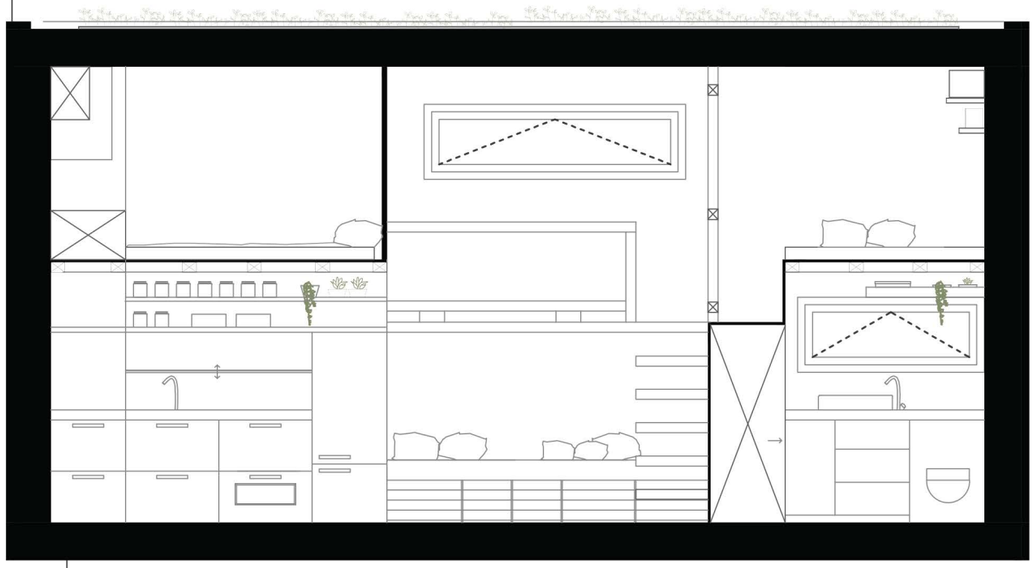
Studies show Tiny Homes are quite popular as an extra unit (ADU) in green suburbs. It is important that the Tiny Home fits in with local architecture. Wood is the preferred material.

A simple green roof combats the overheathing of cities. It cleans the air and slows down stormwater. Additionally it helps isolate and stabilize the temperatures in the house.

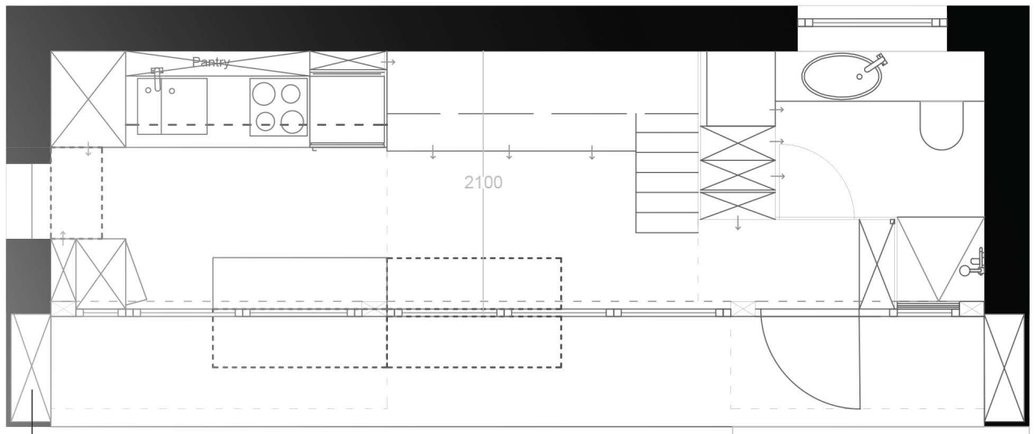
The Tiny Homes create a neighbourhood with more diverse housing. This in turn makes for a stronger community and social sustainability of a city.

SECTION CC'

SECTION BB'



SECTION AA'



The Tiny Step design incorporates a lot of easily accesible storage. Nevertheless when living in a Tiny Home you will have to figure out what is essential to you, and what is extra. Research found people Living Tiny become financially independent and environmentally friendly in a spontaneous process.

The outdoor walls don't need insulation, they serve as storage space.

STEP 2. FRAMING THE DESIGN IN A BROADER CONTEXT

The second step in this thesis will focus on widening the research to more general knowledge framed by the pillars of sustainability. The focus is not on creating a design, but improving the design concept developed in part 1. The structure is the same: first there is a research phase, connected to the design of *Tiny Step.* Then this design will be presented in 3 posters.
The communication aspect of this research will be discussed more in depth in part 3 of the thesis.

DESIGN CRITERIA & KEY PERFORMANCE INDICATORS

SPHERES OF SUSTAINABILITY

Having the first research phase concluded, it is time to look at the design from a new perspective. With climate change and sustainability in mind, the so-called “spheres of sustainability” are a holistic multidisciplinary approach to any topic.
3 Spheres of sustainability have been defined: social, economical and environmental. These 3 speres are influenced strongly by policies, and as seen in the literature study, law is a critical part in the challenges that Tiny Homes face. As such the 4 sphere framework will be used adding the political dimension and recognizing its influence. (O’Connor, 2006) (Bilimoria, Denoyelle and Nguyen, 2020)
Two design criteria, or key performance indicators, will be selected in each of the spheres to look at the design from a holistic approach. Based on this information “Tiny Step’s” design will be reworked.

4 SPHERES OF SUSTAINABILITY

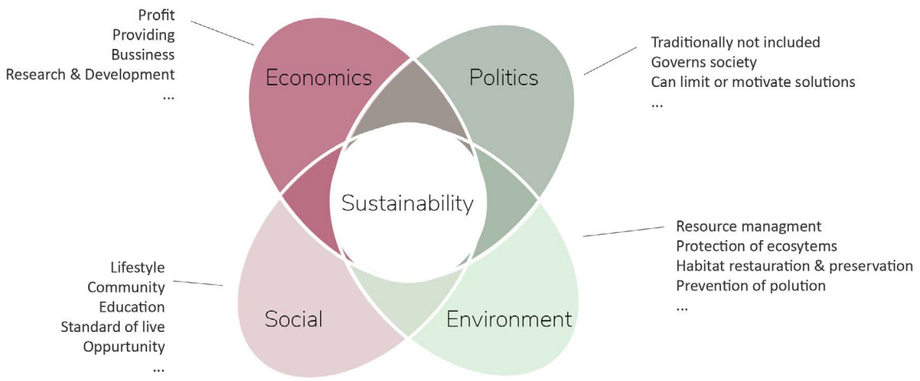
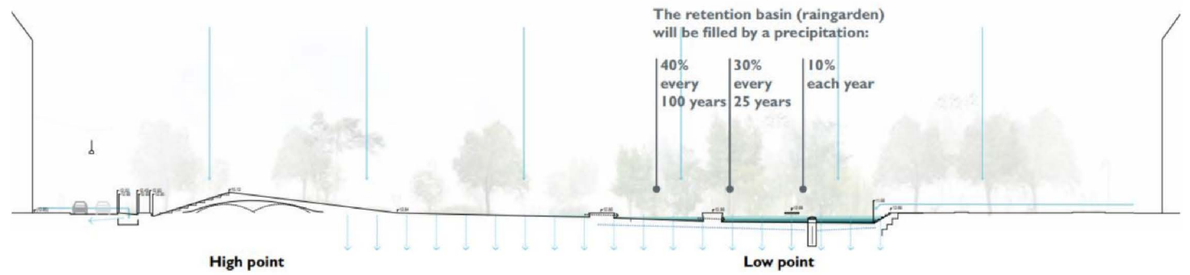


Figure 10 Spheres of sustainability – 4 spheres presentation and explanation including the political aspect as first proposed by O’Connor (O’Connor, 2006) (Bilimoria, Denoyelle and Nguyen, 2020) .



Top & right - Holmene: 9 islands to protect Copenhagen from sealevel rise and Flooding. (Freethink, 2019)

Left - Røskilde Viking Ship museum during a flood & flooding from Bodil storm (Dannemand, 2019)

Bottom - Copenhagens first Climate Change adapted square, Tåsinge Plads. . (Climate Change Adaption course DTU, personal communication, 2019)

ENVIRONMENTAL SPHERE

The environmental sphere will first discuss the effects of Climate Change in Denmark, being mainly increased storms and risk of flooding. Then we'll take a closer look at the difference between sustainability and low carbon building. Next we'll select 2 key parameters for the environmental sphere: A life cycle analysis (LCA) is made for the Tiny Step design, helping to indicate high impact materials and make changes when needed. Both waste and circular economy are discussed. One material clearly dominated both LCA and material volume: insulation.

- How does climate change affect Denmark? Are we prepared?

As mentioned in part I, in Europe buildings are the single largest consumer, responsible for one third (and worldwide even half) of greenhouse gas emissions. They are a direct contributor to climate change. (European Comission, 2019)(Abd Rashid and Yusoff, 2015)
As a coastal country Denmark has seen visible changes in weather due to climate change the last decade. Meteorological data from the beginning of measurements in 1873 to 1900 shows that the average yearly temperature then was 7˚C . The last measurements in 2020 show an average temperature of 8.5˚C: an increase of 1.5 degrees. Denmark is predicted to have more variety in weather and more extremes. Despite the short time frame we can see this reflected in heatwave data from the last 10 years. (klimatilpasning, 2020)

The biggest concern in Denmark: water

The main concern in Denmark however is not heatwaves, but water. As most of Denmark doesn't experience tides (the west coast of Jutland being the exception), the rise in storms the last 10 years has had a significant and visible impact. In 2013 two successive storms hit hard, resulting in flooding and structural damages running up to millions in repairs. As a result Denmark build its very first dike in Roskilde to protect the town. As a sidenote: a small cluster of homes that was not near enough to government property was not included in the project, so they will have to make do. But the world famous Viking Ship Museum in Roskilde was damaged so severely by the storm, that the building is beyond saving. With some waves going over the museum the salt water is slowly winning from the concrete building and ships will have to be relocated in the near future. (Climate Change Adaption course DTU, personal communication, 2019) (DHI, 2013)
As a harbor city Copenhagen is at risk from flooding and rising sea levels. Small solutions are being implemented, such as *Tåsinge Plads*, a square that mixes different flooding solutions embedded with green space for the community. A large scale project has been set up to address this. *Holmene* is about building of several islands in front of the city's coast that should manage the rising water level as well as creating space for new parts of the city. (Freethink, 2019)

Only 2 dike's ready…

While Denmark is making significant changes, at the moment only 2 towns have a dike to protect them from flooding, a phenomenon that has been increasingly happening the last 10 years. When it comes to sustainability (and other domains), Denmark is often regarded as a prime example. So if not even Denmark is ready, how bad is the situation in other countries?

The average temperature every year in Denmark from 1873-2020

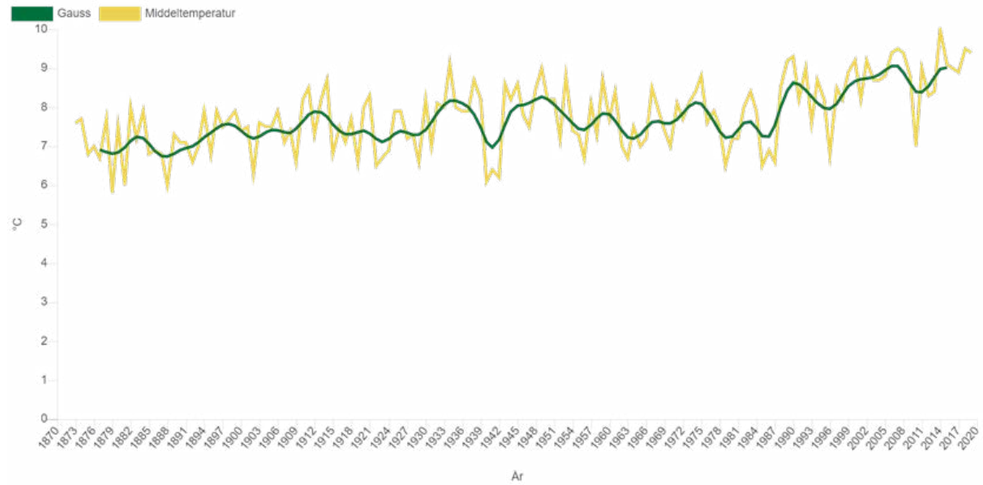


Figure 11 Average temperature Denmark 1873-2020 in degrees Celsius

(Middeltemperatur = average temperature , Gauss = median, measured in ˚Celcius)

(Rubek, Scharling and Cappelen, 2020)

TABLE?

Antal døgn med*	År								
	2011	2012	2013	2014	2015	2016	2017	2018	2019
Varmebølge**	0.9	4.3	9.4	17.5	3.4	9.6	0.0	26.0	10.0
Hedebølge***	0.0	0.2	0.0	2.9	0.2	0.0	0.0	6.1	2.3

Figure 12 Heat waves in Denmark from 2011 – 2019 ((Rubek, Scharling and Cappelen, 2020)

År = year.

* For each day, it has been calculated how large a share of Denmark's area has been affected by resp. heat or heat wave. Example: If half of Denmark is hit by a heat wave in one day, it gives 0.5 heat wave days.

** A heat wave is defined by the mean value of the highest recorded temperatures measured at the same place over three consecutive days exceeding 25 ° C.

*** A strong heat wave is defined by the mean value of the highest recorded temperatures measured in the same place over three consecutive days exceeding 28 ° C.

- Climate change versus sustainability – similar but not the same!

It is important to shortly mention the difference between *sustainability* and *climate change*. The first is defined as meeting the needs of the present without compromising the needs of the future. At a first view, climate change seems to fall under this umbrella.
Climate change is however the effect mankind created by living unsustainably during the last decades. It is an *immediate* concern affecting our weather today and more so in the future, that should have absolute priority when deciding on sustainable strategies.

To illustrate this we can look at the secondary school by Francis Kéré in Burkina Faso. Building schools for children in countries that don't have the infrastructure yet is unequivocally a sustainable practice. However you can build a school in different ways and materials – and this will impact the green house gasses – GHG – produced, and thus the environment.
The local climate in Burkina Faso is very hot, desert like. If the building had been made as a high tech building using glass, concrete, brick, roofing, mechanical ventilation,… It would be a school, but one with a very high environmental impact. Additionally this type of building would have a high cost and maintenance factor. Instead they aimed to design a school that could be built and maintained by the local community using simple building techniques and technology. The main materials used are local soil and second hand materials, which makes the impact of this building on GHG very low. The school project also aims at regrowing vernacular forest as part of its strategy to passively cool the building. This will help to reestablish local environment and create a positive carbon contribution. It shows that sustainability of a community and climate change go hand in hand, but one has to design for it! Picture page school

- Selecting key performance indicators for the Environmental Sphere

With this critical information for the design in mind, this section will look at two parameters directly affecting climate: the life cycle assessment on the one hand, and circular building & waste stream on the other. If you are familiar with the building industry you will notice the so-called Energy Frame is NOT selected. The next paragraph explains why.

Energy frame as an economical indicator rather than an *environmental* one

The Energy Frame is the total energy use of a home in a year usually expressed per m^2. A low number such as 20kwh/m^2/year would put you in an A1 class, while a large energy use like 380kwh/m^2/year will put you in an F class. You will probably recognize this as the energy label A - F that can be found on most appliances such as fridges (in the EU) these days. It is one of the main parameters considered in determining if a house is sustainable today, both in architecture and in the housing market. BUT as good as it is an indicator of general sustainability and energy use, it doesn't actually give a good indication on the houses influence on Climate Change. The latter is determined by:
1. The type of energy used (fossil fuels,..) as this directly impacts GHG
2. The materials choice. This also directly impacts the GHG, and with houses becoming more energy efficient, materials choice is becoming more and more important. This will be explained in more detail below.
So today the Energy Frame, while an important step in transforming to a more sustainable architecture, has become a mainly economical tool to save money and sell homes. As such we will discuss it in the economical section and not in relation to environmental issues.

- Key indicator: global warming potential - Life Cycle Assessment

Global warming potential (GWP) is one of the factors calculated in a life cycle assessment (LCA). It expresses the GHG emitted by production and lifespan of a product or building, and thus its influence on climate change. The LCA will isolate the large components that influence the Tiny Step design. We will also discuss the limits of the LCA and its influence in building industry.

LCA for architecture – selection GWP

Life Cycle Assessment (LCA) is a framework to determine the entire impact of a product (for this thesis we look at a building) on the environment. LCA's were developed to create data, and facilitate decision making. (Merkel, 1997) (Abd Rashid and Yusoff, 2015) (Klöpffer, 1997) There are 3 levels in LCA for architecture. First there is Product LCA: this looks at the entire process of creating for example a wooden board. Next there is Building LCA that looks at the combination of products that create a building. At the third level are certificates such as LEED and BREEAM. These aim to assess the full building framework including elements such as size, accessibility and fire safety.

Figure 13 – 3 levels of LCA for architecture based on the research off: (Abd Rashid and Yusoff, 2015)

This section is focused on level 2: Building LCA's. The reason for doing a full building LCA and not just considering the sustainability of separate materials is that a building is a complex structure where all elements work together. The choice of one material will influence many other choices in the process. The building LCA looks at the house as a whole: for example using wood will imply different foundation options as it is a lightweight structure: small screw foundations or small concrete foundations both are viable options. A concrete building would have a need for a much bigger foundation to carry the weight – thus more materials.
The LCA program will give a range of results for different factors that impact the earth. (Abd Rashid and Yusoff, 2015) For the purpose of this thesis however we will only look at one of those: **Global Warming Potential (GWP).** As most of the Tiny Home design is centered towards sustainability in general, this will be **the weighing factor in climate change impact**!

Importance of material choice – LCA as a design tool

Research shows that for traditional buildings, the energy use is on average around 80% of its impact. For low energy buildings this level is reduced, down to below 50%. Hence, the choice of materials is becoming more and more important to make a low carbon building.(Abd Rashid and Yusoff, 2015) (Moradibistouni, 2020) (Thormark, 2002)
Either way you look at it, the LCA is influenced mainly by energy use and material choice. To optimize these two elements they have to be included in the design from the start. If for example you design a wall to be 20cm wide, it will be very hard afterwards to choose a material that is sustainable and can reach the desired insulation level within that measurement.

How the building LCA is set up and influences design – not always in the right direction

The LCA tools aim at determining the full impact of a building, from material sourcing to demolition (referred to as “cradle to grave” in literature). Initially the ‘end of life’ stage was often not included in assessment, though recent research has shown its importance as recycling potential can significantly reduce the impact of a building. (Abd Rashid and Yusoff, 2015) This linear approach introduces a limit to the system: **if you design for end of life, circular economy is not considered**. This is why it will be considered in a separate section.

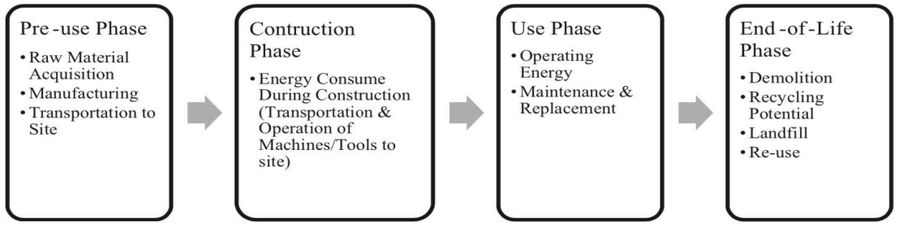


Fig. 2. Cradle-to-grave system boundary used in building's LCA research.

Figure 14 ‘Cradle to grave’ system boundaries for building LCA (Abd Rashid and Yusoff, 2015)

LCA for buildings is incredibly complex as it has to encompass an enormous field. Even more as it is quite new in the industry and therefore databases are not yet on point. If you want to add for example a wooden plate to your building LCA, you can choose one from a limited generic database, or go for a more accurate result. But the latter involves creating a specific product file – EPD – that represents the product LCA of thát specific plate from thát specific factory. One can imagine it takes a lot of effort and money to make these files, thus it is especially hard for small companies to do so. Most sustainable companies happen to be small or even start-ups. This is why we find all the classic building materials such as rockwool in existing databases, but sustainable materials such as seaweed or jute insulation are not represented at the moment.
So today the tool that is supposed to make decisions more sustainable, is actually **discouraging sustainable materials**. By making LCA a legal requirement for building development, probably the use of sustainable materials and techniques in the building industry is being discouraged. The use materials that often have a heavy impact on climate change and health is being encouraged (More on health of buildings in the social sphere chapter). And we have not even mentioned the lobbying against sustainable materials coming from big companies who don’t want to loose their market share. (R. Zwarteveen, personal communication, 5.5.2021) (D. De Vriese, personal communication, 20.5.2021)

This is not to say that LCA tools aren’t incredibly useful and important. It means that one must be aware of their limitations, and we need to rethink how to use them. For example by subsidizing small companies to create EPD’s.

Comparing 2 LCA softwares for buildings

2 LCA building software’s were considered. “One Click LCA” is an online tool that allows for Revit (3D software) input and is tied into several certificates on buildings. This LCA works with a general database and a large collection of product specific EPD files. While it has incredible potential, at the start of this thesis it served only to establish the embodied energy of a building, as ‘operation stage’ and ‘end of life’ where not available yet. This has since been updated, and even a circularity tool has been added. (One Click LCA, 2019) (OneClickLCA, 2021)

“LCA byg” is a Danish software package, and was chosen for this thesis. While free, it has an obvious limit as it is in Danish only. This was not so much a problem when using the software, but trying to sift through a database of materials in a foreign language is not something I would recommend – unless you find someone good enough to help you out! But “LCA byg” has a wider reach than “One Click LCA”: it includes transportation, end of life, operation and even energy use during construction.

As was explained before it is still very hard to do a proper LCA on a sustainable home (that would be subject for a full thesis in itself). This is why a simplified LCA was set up.This still allowed to compare different influences in material choices in the design.

Input of the LCA

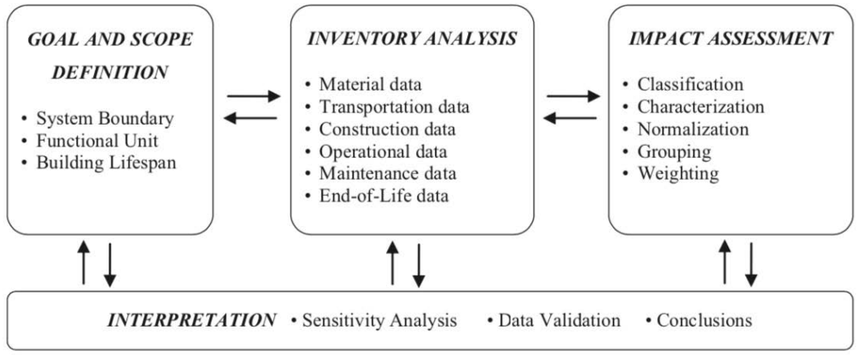


Figure 15 input and boundaries of the building LCA - Figure from (Abd Rashid and Yusoff, 2015)

For the **goal and scope definition** the following values where added: system boundary is the “cradle to grave” and the functional unit is m^2. The building lifespan was chosen at 100 years as we always have in Europe and should continue building for long timespans to be sustainable. Though we must be aware that further in the future are more unknowns that could influence accuracy.
For **the inventory analysis** the material data was taken from the general database available in LCAbyg. Transportation wasn’t included as the house is designed without a specific location in mind. Construction energy on this project will be very low: an electric drill, lights to work by, ... since no heavy machinery is used, this factor is also not considered. Operational data was taken from an IDA ICE simulation. Maintenance data is automatically considered for all elements of the house. End of life data is also part of the database and not easy to change, we will discuss this in more detail below.
For the **impact assessment** we will look at GWP data and discuss the results below.

Results – Discussion of the highest GWP contributors to the house.

The total GWP of the project for materials and electricity is 15.000 kg CO_2 eq. For comparison the standard project included in LCAbyg (adjusted to 100 years) is 184 m^2 house with 132 000 kg CO_2 eq GWP. Looking at the overall result we see that at 10kwh/m^2/yr about 10% of GWP is due to energy use/ energy frame and 90% to materials . If we set the energy use at 25kWh m^2/yr we have about 25% of GWP contribution by energy and 75% by materials. This indicates that materials and energy source have a very high impact in the design of the Tiny Home!

The design created in part 1 seems to have chosen mostly optimal materials. This is mainly as the house I currently live in has been built with sustainable materials so it was easy to find them.
I was also aware of the large impact cement and conrete have. But it was interesting to see, as an architect working with LCA's for the first time, how much impact roofing materials, foundations and bricks have.

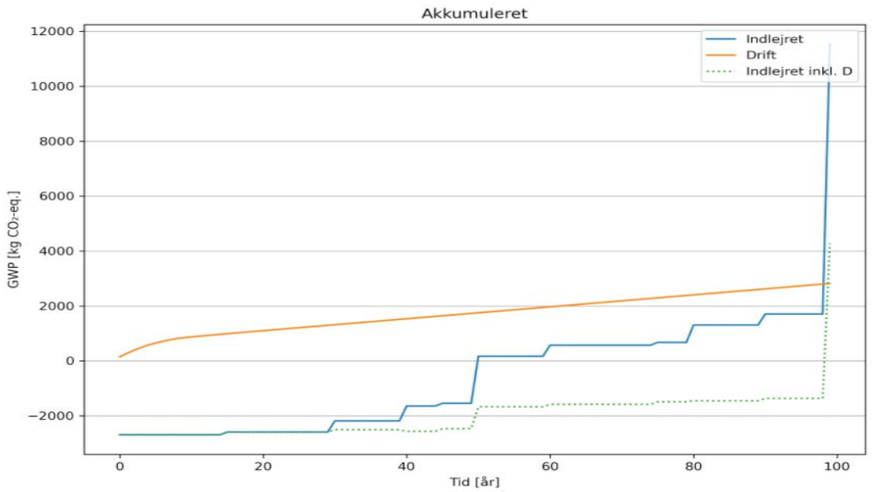


Figure 16 The accumulated GWP of the Tiny Step design, divided in embodied GHG and operational GHG expressed in [CO_2 -eq.]. Generated with LCAbyg software (LCAbyg, 2020)

Walls – floors and roof

The highest GWP contribution in the design is the outer wall. Looking at the graph below we see a major impact here is the C phase -waste treatment .
It is the single largest material volume in the design. The outer wall is built up out of several components, mainly wood insulation and screwed connections. When looking through these components it is clear the cellulose insulation has the biggest contribution (graph?).

The screw foundation

The screw foundation is built up from mostly steel - a GHG heavy material. Alternatives are concrete or brick, however these have even higher GWP when we test them in the program. Additionally the screw foundation has other benefits such as it's ability to be re-used and it causes minimum damages to the soil. It also has the benefit of raising the home making it more resistible to flooding. Ideal would be if the engineering company you work with can find them second hand.
The thought process is almost the same if the house would be on a trailer; second hand is the best option for your wallet and the environment and quite easy to find.

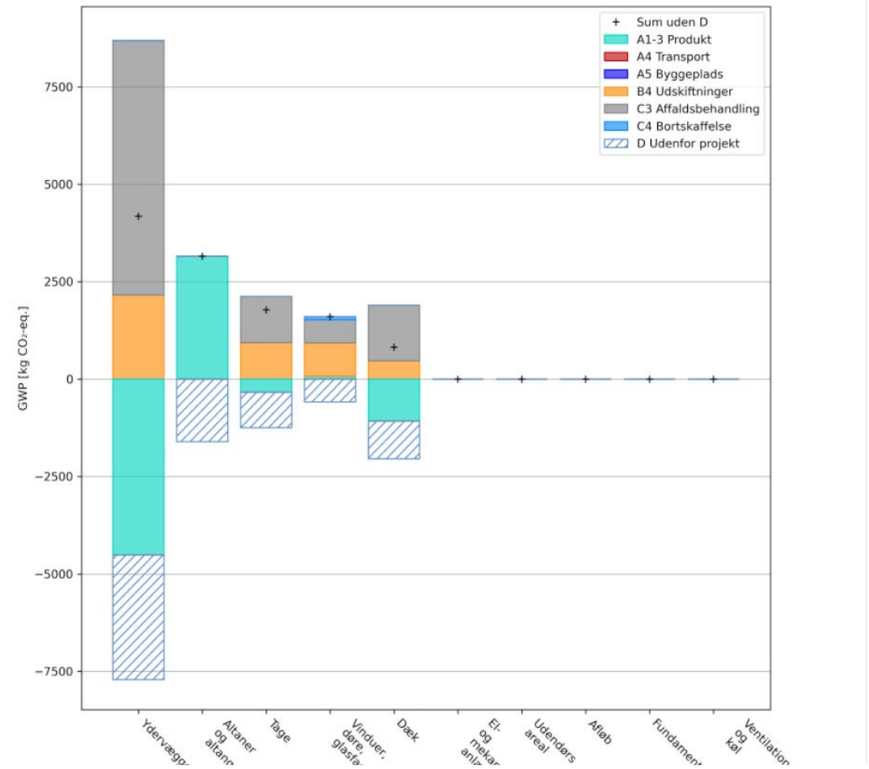


Figure 17 The accumulated GWP of the Tiny Step design Divided by product Phases, expressed in [CO_2 -eq.]. Generated with LCAbyg software (LCAbyg, 2020)

The roof

EPDM it is already the lowest GWP option on the market at 6.93 kg CO^2/sq. ft (74.6 kg CO_2 /m^2). It also has a long lifespan, easy maintenance, it is non toxic thus prevents pollution of water, it has a low impact on smog and it is recyclable. This list of advantages actually makes one wonder about the impact of traditional roofing…. (EPDMroofs, no date) (*10 Reasons Why EPDM Is The Most Eco Roof Option | Blog*, no date)
An alternative could be a sloped roof. However LCAbyg shows here we also find that roof tiles which are very common all over Europe have a very high GWP.
Thus to make the roof more sustainable we have to look at lengthening it's lifespan, and stress the importance of proper and regular maintenance. A green roof can contribute to this by protecting it from weather and UV rays.

- Key indicator: circular construction & waste

To implement circular construction it is key to address this at the design phase. An estimate of waste streams was made for the Tiny Step design, however it is difficult to put into numbers, as *potential* to re-use and recycle doesn't mean it will actually *happen*.

Some numbers on building waste

Construction and demolition waste is responsible for over 1/3th of waste generated in Europe. It consist out of numerous materials, many of which can be recycled. (European Commission, no date) Studies show that potential for recycling of houses is about 50% of the energy needed to make them. (Thormark, 2002) As these are houses that are not even build with recycling in mind, this number has potential to grow.

One should be aware there are some contradictions in play: you could build a perfect circular construction cycle, with a high GHG impact. Similarly you can make a very good LCA, that still leaves a lot of waste. If a material is burned at the end of its life this is good for the LCA, because this is waste energy that can be used for passive heating of houses instead of using energy from fossil fuels. But then this discourages re-use. Climate change is a more complicated problem than just GHG impact, waste has a huge impact on ecosystems. (Akram *et al.*, 2019) (Sarkar *et al.*, 2021)

Addressing waste streams : moving to reduce – reuse - recycle.

Due to inaccurate installation, mishandling of materials and vulnerability of products, research has suggested that during construction there is up to 5% of material waste on site. (Abd Rashid and Yusoff, 2015) The design of Tiny Step has been made as a very simple shape on purpose: to reduce complexity to build and to facilitate a prefab production or DIY build. The simple shape in combination with small size will make it easier to *reduce* construction waste. The material choice and detailing of construction details is focused on *reuse* and *recycling* potential.

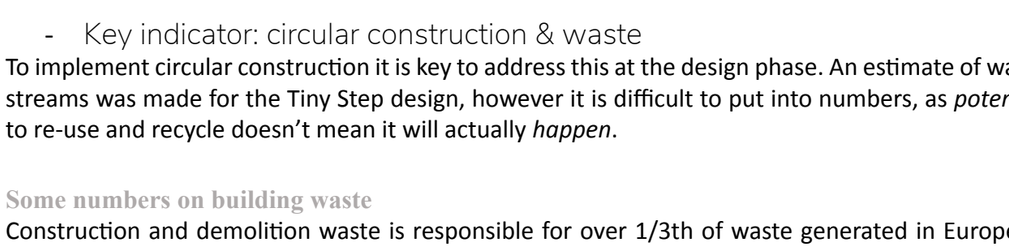


Figure 18 Sketch of the structural build up.

Demolition waste is a slightly more complicated subject. It was incredibly hard to find data in Denmark. The following information is specific to Belgium, but much of it can be applied to other countries. In Belgium there is a legal structure – Tracimat – that actually forces demolition projects to separate and recycle trash in great detail. Every material requires certification. If you do not have proper certificates it will cost you more when delivering to the waste facility. Strong legislation in this aspect is very important as Belgian culture is built on loopholes. (Only!) 3 years ago asbestos was not regulated as strictly as it is now so it would end up mixed with stone waste. The list of dangerous construction waste materials is expected to grow in the future. This especially while the demolition is being controlled but the input of *new* materials is not regulated at all. - This topic will

be studied further in the social sphere - health of design. It is also important to note that recycling is only enforced for bigger projects with over 1 ton of waste. (D. De Vriese, personal communication, 20.5.2021) (Tracimat, 2021)

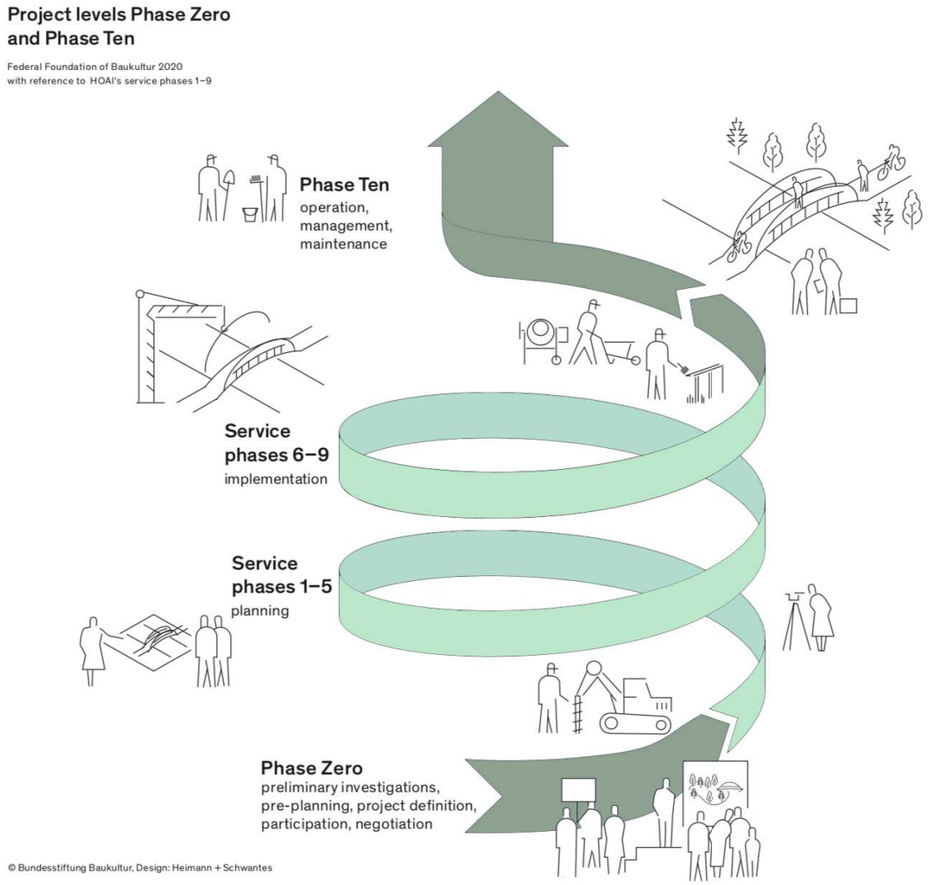


Figure 19 expanding project stages to improve communication & sustainability designs - made by: (BuildDigiCraft, 2020)

Addressing circular economy from design stage to construction, demolition & reuse.

There is still a long path to go to fully implement the concept of circular building in society. But the first steps have already been made. In Germany it is expected that only 8% more buildings will be constructed by 2030. Most of the environment is already built so they realized the importance to optimize it. For example that is why there exists a warehouse with historical building materials. (BuildDigiCraft, 2020) In Belgium a secondhand market already exists, but it is still limited. A clear indication of materials that could be reused would help. Second hand materials often only come from big demolition projects. (D. De Vriese, personal communication, 20.5.2021)

Take the wood that is used in Tiny Step. It is important to know which kinds of wood can be used. Has

it been treated chemically? It is harder to gather this information for a small project, as the budget is limited. But this detailed material information is actually right there when constructing a house, if it were documented and made part of the specifications. This would facilitate future demolition and circular economy.

Cross disciplinary design and communication a necessary factor in circular economy

For this to work there needs to be a **closer connection between architect, engineering and the building industry/contractors.** This starts at the academic level. All of these aspects are usually not included in architecture training. Architecture students have no idea what happens to building waste or how polluting it is, so they don't design with those aspects in mind. As mentioned in part one, Baukultur in Germany suggests to add a new phase before the design process that could facilitate this: **Connecting the local community** and involving them in the process of new buildings. Handing out small leaflets won't do the trick: a real forum for dialogue and active participation is needed. It should be recognized that a building is not finished with construction or maintenance! (BuildDigiCraft, 2020)

What about the influence of lifestyle on waste?

A secondary effect of a Tiny House on waste was learned in the literature study above: due to the limited space available, people in Tiny Homes inherently become more minimalistic, and more aware of trash.
While a lot of environmental damage is caused by big companies and maybe not easily influenced by a single person, a lot of problems *are*.
With the Corona pandemic came a rise in take-out delivery – the numbers on this are quite astonishing: for New York City this costs 40million USD in trash, not counting littering. The single most present material being ... napkins! (NowThis Earth, 2020)
Now, when you live in a Tiny Home, ordering take-away most likely will translate in choosing between a(n extra) trash bin or keeping your winter sweaters stored.

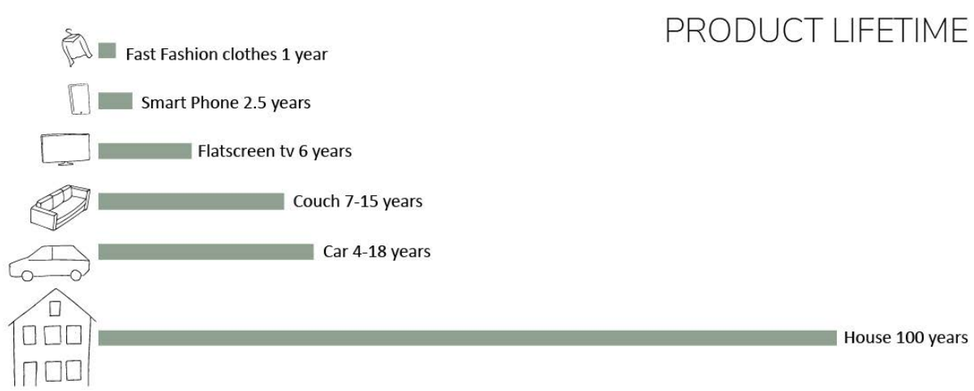


Figure 20 Product lifetime, based on general research and Baukultur (BuildDigiCraft, 2020)

A second example, more in the long run, is furniture. If you Google when to change your furniture a large number of sites will advise you to switch out your couch every 7 to15 years, pillows every 2 to 3 years,… While it is hard to find any data on whether or not these numbers are correct, it is clear there is a trend in modern society, called by numerous renovation shows, towards frequently refurbishing your home, rather than aiming for longevity. If however you have a home with custom made furniture, as you probably will need in your Tiny Home, this automatically narrows down choices and makes you more aware of the impact of frequent replacements.

The Tiny Step design - waste in numbers

There are two important factors in circular construction: what happens to the materials before you use them, and what happens after. The first one is about smart choice in product. If you need a wooden construction board, do you choose an upcycled panel made of wood chips waste or do you buy a standard one in the store? Will you do the effort to source materials secondhand? Or are you in need of time and is that not an option? The second one - what happens *after* - is more dependent on the actual design of the house. That is why we will focus on this aspect here.

An estimate on reuse – recycle – downcycle – waste.

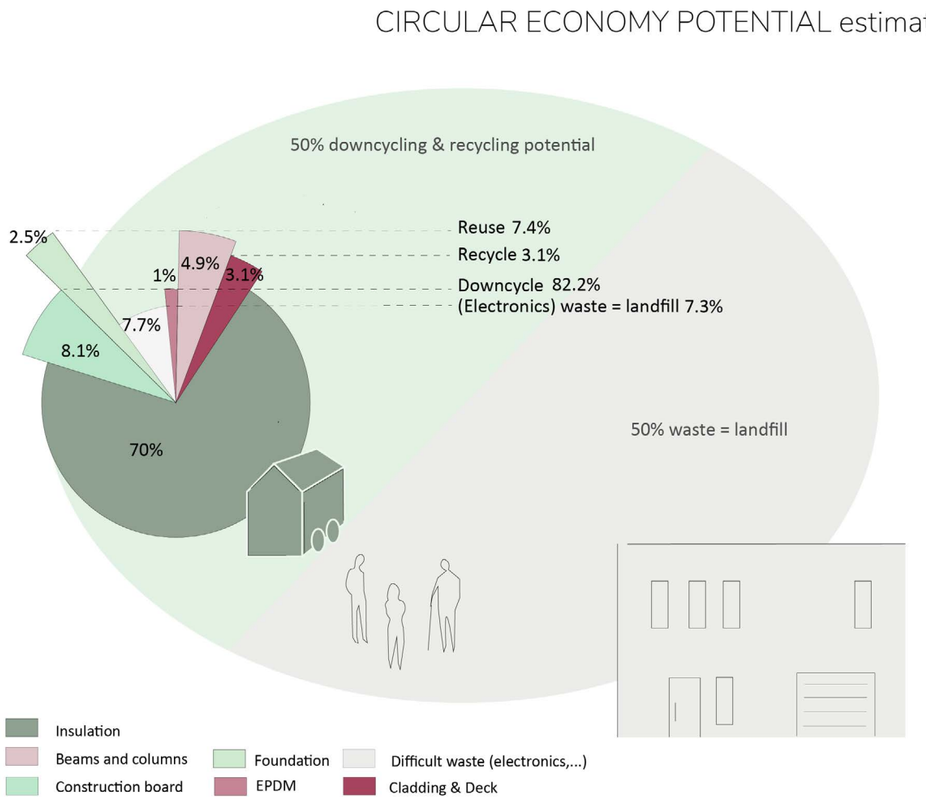
An estimate of potential for re-using, recycling, downcycling, or pure going to waste of the materials in case of traditional wood construction was made. The materials used in the LCA where divided in these four categories.

Reuse is a material that could be reused without any interference. For example the wood beam structure could be screwed apart and rebuilt again. Or if the design is built with Reblock it could be taken apart folded up and reused for other projects. (REXCON System, 2021) Similarly the foundation could be taken out of the soil and used for a new home somewhere else.
'Recycling a material' is defined as a material that can be broken down and then used for a similar purpose. For example cladding is often made out of full wood. If it has not been treated with chemicals it can be mulched to wood chips, and glued to make a construction board. Downcycling is generally referred to as recycling: wood gets mulched and used in stables, EPDM gets mulched and used as filling, etc.
The LCA does not include appliances. However electronic waste is one of the biggest challenges today. Therefore appliances and electronic waste were brought into the calulations to provide for this. (the guardian, Royce Kurmelovs, 2021) (Akram *et al.*, 2019)

This is an estimate for multiple reasons. First of all the full structural analysis was never made, thus material volumes are not exact. Secondly, the tricky part here is, that it is not because it is *possible* to re-use an element that this will actually *happen*. Glass can be recycled to mineral wool insulation, but window glass is not used for this !

A change in insulation?

From the circular ecocnomy infographic it becomes clear that the insulation choice is key for optimizing waste volume! And it was also a key factor in the LCA. Celluslose was chosen as it is an accesible and affordable greener alternative. However it is not optimal for mold control and it still contains toxins. Apart from the high impact on environment indicated in the LCA, I couldn't find any more information on how it is recycled, or disposed of. Perhaps it would be better to insulate using a sustainable material such as burlap/jutte, wool or seaweed, however these materials still cary a higher cost.



- Conclusion environment

In short, differentiating between low carbon housing prepared for climate change and sustainable housing in general is critical.
LCA as well as circular economy and waste reduction start at the design phase. To improve this a stronger collaboration between disciplines as well as input of local community is necessary. The key performance indicators we can take from this section are **GWP factor of 15 000 CO_2eq** that directly influences climate change. The biggest influence here is cellulose insulation and the wood used.
Additionally we must be aware of the limits LCA's have and carefully think how to implement them. For example by subsidizing small companies to create EPD's and a database with more sustainable materials.
The influence in lifestyle changes due to Tiny Home living is harder to put in numbers. To indicate waste and circular economy a **re-use, recycle, downcyle & waste diagram** of the construction materials is calculated. This gives an estimate of the different waste streams, and it showed that the largest volume in the *Tiny Step design* is insulation with 70%.
The largest volume doesn't mean the largest problem: electronics are the new challenge for waste!

ECONOMICAL SPHERE

The economical sphere will discuss the price of the Tiny Step design – It was estimated at 122 000 Euro's solar not included. The Energy Frame will be optimized, and we'll discuss the changes this created in the Tiny Step design.

- Key indicator: cost analysis

The Tiny Step design built with ReBlock components was estimated at 908.648kr inc. VAT (122.186,81 Euro) not including the solar installation. This is considerably less than the average house price of 2 590 000 DKK (348.165,91 Euro) in 2021. It is also possible to reuse materials up to 50% of the original price.

Cost is a term that doesn't require much explanation. One of the main motivators to move into a Tiny Home and start this thesis was the housing market in Denmark. A student dorm will easily cost 5000DKK a month (670 euro's). In Copenhagen the last 2 years housing prices went up as far as 20% in some areas. This is not a problem faced only in Denmark. All over the world new generations do not have the opportunity their parents had to buy a house and invest. (Haffner and Hulse, 2021)
Tiny Home appeal is primarily about financial independence. DIY builds are very common. (Boeckermann, Kaczynski and King, 2019) This also means the prices of Tiny Home are very dispersed: from 10.000 $ builds to 200.000 $.

Cost estimation databanks don't include sustainable materials, or small designed spaces

A cost estimation was created in SIGMA Estimate using the Danish cost databank Molio. This database has mostly traditional building components. For example the only insulation available is mineral wool. The database does not have any sustainable alternatives. To work with sustainable materials you would need to manually add them. Thus while the idea of a database for a quick cost calculation is very useful, in practice it excludes sustainable materials and businesses. Which makes it easier for a construction project to use traditional materials instead of being innovative. This is similar to the problem of building LCA. It confirms that **we need to make better use of the software tools available to stimulate sustainable and low carbon building**. Add on top of this the unusual size of a Tiny Home, and a different solution to calculate the cost was needed.

Cost estimate results for the Tiny Step design

Rexcon, a Denmark based company, made a cost estimate for the Tiny Step design. These prices could differ in the market of Zealand or in Jutland. The estimate is **726.918 DKK** ex. VAT (97.762,75 Euro) and **908.648 DKK** inc. VAT. (122.186,81 Euro). This estimate is made with high quality, healthy sustainable materials. Furniture and solar is not included.

Looking at prices online I determined a rough estimate for the solar installation. The peak demand of the home was simulated at 600 Wp. The average panel has a peak at 290-310. As this is about cost it is better to overestimate, and take 3 panels. This brings the price to 1000 euro's. The smallest battery at 3kWh costs around 3000 – 5000 euro's. (Zonnefabriek, 2021) (Solar Choice, 2021) Thus roughly 4000 – 6000 euro's.

This means at **128 000 Euro** you will have the Tiny Step home **off grid**. You might still need to buy some furniture. Though more likely moving to a Tiny Home, you will have to downsize and sell some furniture.

Based on previous projects by Rexcon it is possible to **reuse** a quantity of the products in the home, **worth 50% of the projects initial price**.

Cost estimate alternative designs on wheels

The company also made an estimate for 2 alternatives designs that where developed based on *Tiny Step*.
A student version of 2.5m x 5m on wheels comes at 515.524 DKK ex VAT (69 326.43 Euro) and 644.405 DKK inc. VAT (86 658.04 Euro). And the second design is the traveler version, on wheels and without a loft, this version features a ground floor bedroom. It measures 2.5m x 8.4m, with a cost estimate at 658 891DKK ex VAT (88 606.08 Euro) and 823 614 DKK inc. VAT (110 757.63 Euro).

A European price…

Denmark is one of the most expensive countries in Europe. Thus it is fair to say the house could be produced cheaper in other countries. It is hard to put an exact number on this. The price of a product is determined by the product factor, the market price and taxes. For example looking at the Netherlands an estimate can be made. Expat websites comparing different countries show an average of 10% difference between the Netherlands and Denmark in living cost. (numbeo, 2021)(expatistan, 2021) Thus we could say the design would be roughly about 10% cheaper when produced in the Netherlands – at 115 200 Euro.

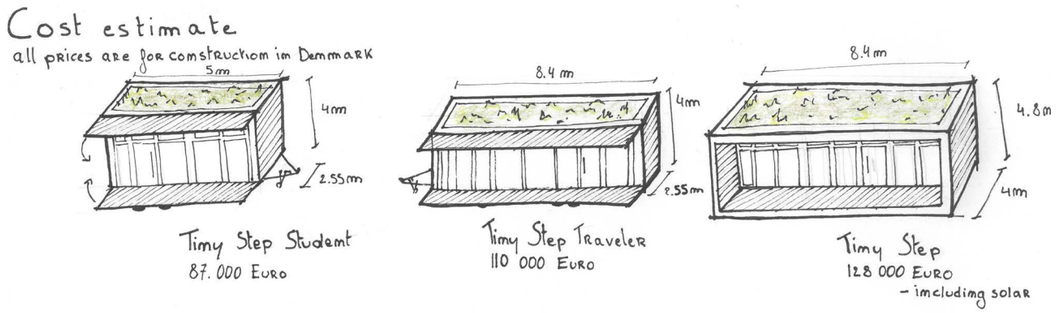


Figure 21 - 3 Design variations from the Tiny Step concept with cost estimate

- Key indicator: Energy Frame

The strategies used to reduce Energy Frame/Use in the building changed the shape of Tiny Step quite a lot, mainly to provide better passive cooling. Energy frame is not the only factor to look at in a simulation. In the section on physical health comfort parameters will be discussed in more detail.

Energy frame explained

As mentioned before the Energy Frame is the total energy use of a home in a year usually expressed per m^2. A low number such as 20 kwh/m^2/year would put you in an A1 class, while a large energy use 380 kwh/m^2/year will put you in an F class. According to Danish law the energy used for hot water, heating and cooling energy have to be included in the calculation of the Energy Frame. BE18 is the program used to fulfill this requirement. However in this thesis IDA ICE was used as it has a more detailed and transparent simulation available.This is necessary to deal with the skewed results that a Tiny sized home gives. (IDA ICE - Simulation Software | EQUA, 2021)

Results energy frame of IDA ICE simulation

As mentioned in step 1, the energy frame is calculated by m^2 and this puts the Tiny Home at a disadvantage. In the IDA ICE simulation the energy frame of Tiny Step is reduced to 37 kwh/m^2/year. The full energy use of the house is 1362 kwh/year. The yearly energy use of a 150m^2 house with the same energy frame would be 5550 kwh/year. We'll take a more in depth look at the strategies used to lower the energy frame. (IDA ICE - Simulation Software | EQUA, 2021) To qualify as a low energy home the energy frame has to be 27 kWh/m^2.
This energy frame is not exact. It doesn't take into account the influence of the users. If people leave the heating at 25˚C the energy frame will go up. If you have a very conscious user, the energy frame would fall down to reach the 27 kWh/m^2. We'll discuss this in more detail below.

1.Creating thermal envelope

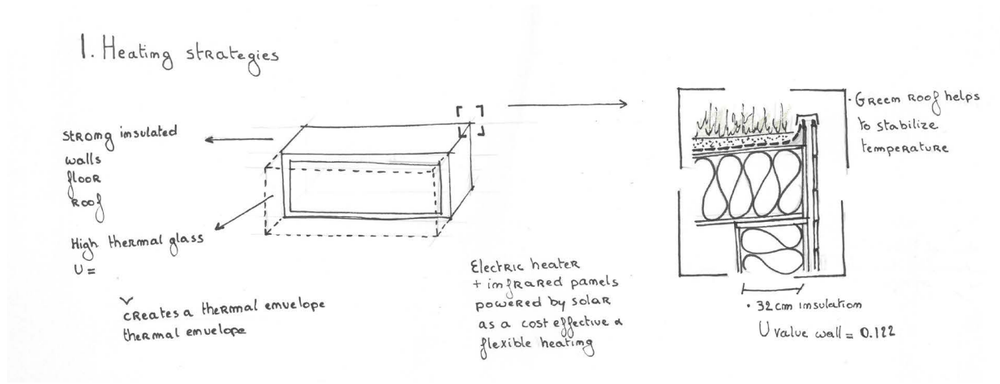


Figure 22 Sketch illustration of thermal envelope and heating strategies.

Tiny Step is created with a thermal envelope of U = 0.122 This means all walls, roof and floor have a 32cm insulation layer. Old houses will have a U value of 0.6 - 0.3. A lower U value means a stronger thermal envelope keeping temperature stable. As the house is very small and it has an easy shape it is reasonable to assume infiltration value will be low. It was taken at the passive standard of 0.6 L/s m^2. (IDA ICE - Simulation Software | EQUA, 2021)

Infrared heating

As suggested in (Leindecker and Kugfarth, 2019) a Tiny Home built with a good thermal envelope and a small interior volume can be heated using infrared panels. These come at a very low cost, easy installation, and easy repair/replacement. This type of heating needs CDF software to be simulated properly, but that is outside the scope of this thesis. Thus the IDA ICE simulation used the standard ideal heaters as a simplification.
For a house that is very flexible in usage of space, infrared panels are quite convenient as they have a short heat up phase. If you want to leave the doors open and use the full space of the house on a spring evening, you know when it gets cold you can close them and have the quick heat of the infrared panels. Though naturally it will take a bit of time for the air temperature to go up. These panels warm the person rather than the air. It's more similar to lightning a fire in the forest in that sense, the air will be colder but you are warm. This is a different type of feeling warm then we are used to, so sometimes that influences a person's level of comfort.

As they usually have a 3m radiation zone, it is easy to cover all the house in the Tiny Step design. The rule is that people prefer warm feet and a cool head. Placing these panels on the floor is not realistic, they would need to be special panels to walk on, and they would complicate the construction. Thus the next best option is to place them on the walls.

Since the space is so small, most likely the panels will not only give off heat through radiation, but the convection will interact with the air and heat it up too. Additionally as it is a small passive home the air will keep warm, thus even heat from lights, the fried, boiler,… all adds to heating the home. The main heat source however is the sun through the windows.

This kind of heating is very depended on design. If you have a radiant heat source and a badly insulated window that cools the air, you will find a great discomfort from radial asymmetry due to the cool air and a warm body. If a person is not used to this type of heating it could also be experienced as uncomfortable.
It is also very important to choose correct materials. Wood will feel cold , if you place a layer of cork on the floor that insulates, it will feel warm in contact with feet.

Thus even CDF software would not give the most accurate results as this type of heating is dependent on so many design factors and the individual comfort of the user. Ideally this type of heat source should be tested in practice in different scenarios. Maybe it would be a solution to combine it with a small electric heater to create a better air temperature.
If a good design can optimize the comfort level the energy use can be kept very low. In reality it could be that a conscious user consumes less energy as the software predicted.

2.Minimal house equals minimal lights and appliances (more detail in part…)

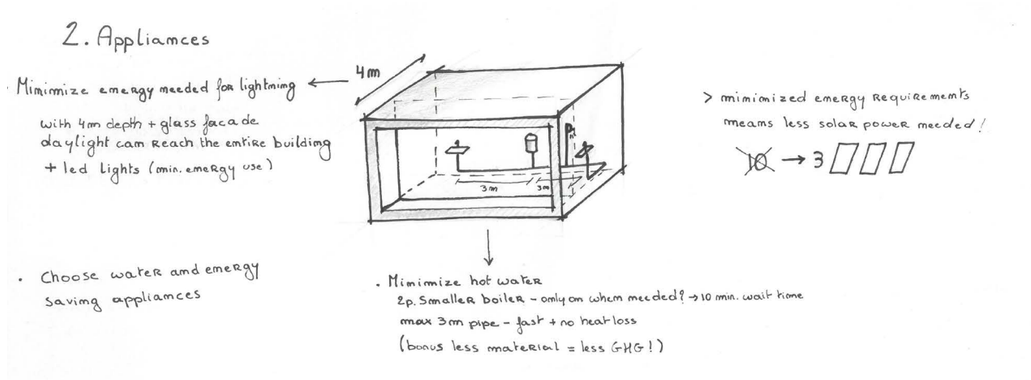


Figure 23 Sketch illustration on minimizing the impact of appliances

When not connected to the warm water distribution network there are two options for hot water provision: a boiler or a water heater. A boiler is chosen as the latter would have a peak demand that can't be obtained with solar panels. There are different ways to use a boiler: Either you have the boiler always ready with hot water. Or people often only switch on the boiler when it's actually needed. This way a smaller volume with higher temperature can easily provide enough water in a fast time. In this case the design has to ensure that the boiler's switch is within easy reach - or connected to your phone!
In IDA ICE the simulation was run adding in a standard boiler through equipment that was always on, and by using the standard value of 250 l/m^2 year. Both gave the same result at around 500 kWh/year. Thus in the case people use a boiler and their water more sparingly this could be less. Or wasting a lot of water it could be more. (IDA ICE - Simulation Software | EQUA, 2021)
How to achieve better user involvement? A Tiny Home often has a higher involvement of the owners, and they are often build for financial freedom thus there is more attention for keeping bills low. Additionally as people are often connected to someone else's electricity, they will have a meter and get a direct view on what they use. This incentive has been proven to be very efficient in lowering usage. Smart homes have a similar effect, bringing the data to your phone. (Faruqui, Sergici and Sharif, 2010)('A clever little home', 2021)

3. Designing passive cooling and thus eliminating a big energy factor

If no mechanical cooling is present in a building, this results in a significant saving on the Energy Frame. In a home that doesn't manage to mitigate heat, people will often have to supply portable ventilators, which result in a huge demand in energy that is not brought into consideration in the current Energy Frame.
Overheating is becoming an ever more pressing problem on health. On the one hand there is the increase in extreme heatwaves as discussed before. On the other hand there is the Urban Heat Island effect. In cities our buildings are mainly made with concrete and brick. These materials store heat. So instead of a surface with a grass field, there is a 3D structure that stores heat. This effect can cause cities to be up to 10˚C warmer than their surroundings. This results in a much higher health risk for

the population. (klimatilpasning, 2020) (Alskog, 2013) (Kleerekoper, van Esch and Salcedo, 2012) According to BR 18 legislation the legal weather file used for simulations is that of 2010. (Bygnings-reglementet BR18, 2021) As buildings are made to last 100 years without active ventilation, they should also make sure the cooling strategy will hold for the changing climate in 100 years. The issue is however not solely a legal one. It is quite difficult to find weather files (.epw) used in buildings, simulating the future. It doesn't seem to be a known format among the scientific community that actually makes the climate models. (Based on internet searches and my asking to multiple professors and assistants in my first semester at university.)

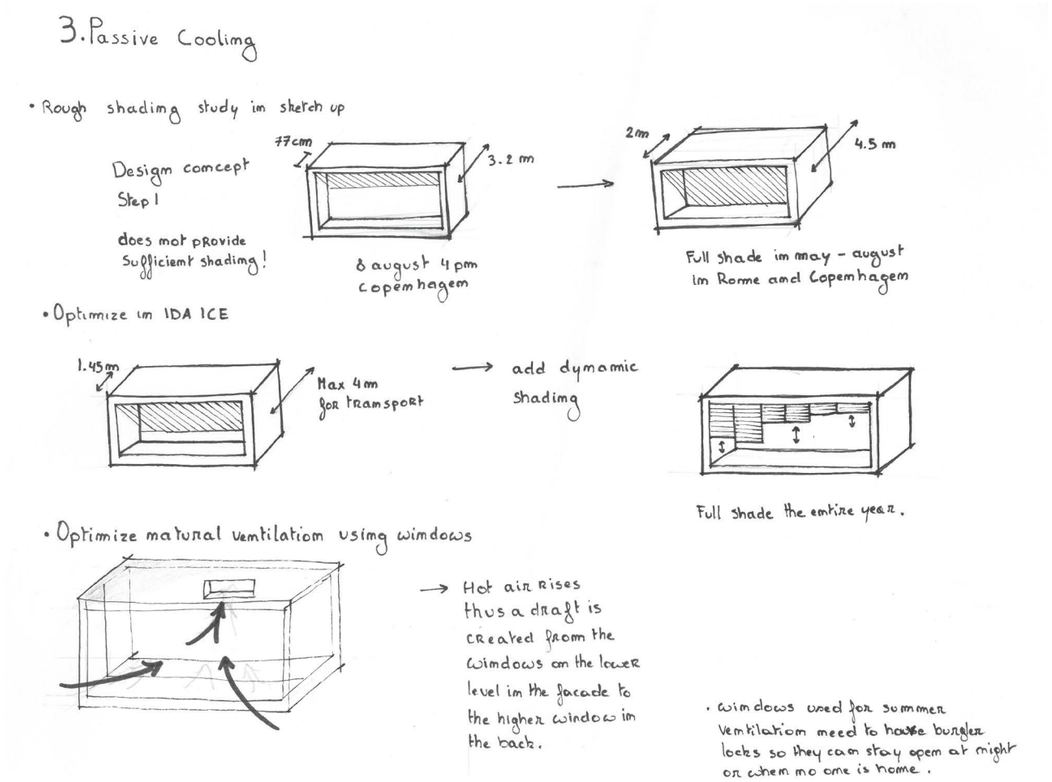


Figure 24 Sketch illustration on the design of cooling strategies

A shading study was done to regulate solar gains using the roof of the deck. At 2m all sun was blocked, this was however too big for the design. Thus the outdoor roof was set at 1.5 meters. This creates a shading zone protecting the full window façade from sun in summertime. In winter it lets in the sun in and this helps in heating the home. If no sun can reach the home heating demand went up from 500 kWh/year to 12.000 kWh/year. This means orientation of the house is critical for a low energy use.
The second element to passive shading is the window at the back of the home. It is placed high up. This way a cross ventilation can be created from anywhere in the house to the back. Additionally warm air rises, so in the central area the heat will rise up, opening the window can let that heat escape on the north side of the house. The heat that gather higher also creates an effect creating a current trough the home.

The IDA ICE simulation ended with 120 hours over 26˚C however 70 of these where in the winter time, in reality that would be quickly solved closing the blinds or opening a window.
There were very 2 peaks in summer going up to 27˚C, if a ventilator was used here to cool the home this would bring the total energy use of the home to 1464 instead of 1362. (IDA ICE - Simulation Software | EQUA, 2021)

- Conclusion economic sphere

The financial aspect is a big part of Tiny Home design . The main design of Tiny Step was estimated at 122.000 Euro including taxes and 128 000 Euro with off grid solar construction.
The smaller student version however comes at 87 000 Euro, and a one floor trailer version comes at 110 000 Euro. It can be much lower if salvaged and second and materials are used. Again here we find that cost databases are not including sustainable materials, thus motivating the companies that use them to prioritize traditional and less sustainable building methods.

Reducing the energy frame led to big changes in the design. Heating and thermal envelope was already introduced in the first concept design. Passive cooling simulations however changed the size of the overhang and outdoor area. The energy frame is 37 kwh/m^2/year, this could be less or more, depending on the user and the comfort created by the house and appliances.

SOCIAL SPHERE

The social element of architecture has been considered (unrightly so) one of the least important. The 2 key indicators will discuss social and physical health respectively and how they relate to Tiny Home design. Physical health of a building is more technological and tied to the climate you live in. Social health of architecture holds true anywhere in the world.

Already in 2003 the European Commission published an article stating asbestos, radon and benzene released inside homes are prime suspects in the increase in cancer among European citizens. A study found exposure levels at least twice as high indoors than outdoors. These are all building material related substances. (European Comission, 2003)
It is clear that the Corona pandemic is finally changing this perspective. Research papers from all over the world - from Canada over Egypt to Korea - come to similar conclusions: the health of a home has not been considered adequately. The building industry should renew their focus on the residents of a home, and their health. (Peters and Halleran, 2020) (Spennemann, 2021) (Chung, 2021) (Zaher, 2020) (Bereitschaft and Scheller, 2020) (Rassia, 2020) As such the interior design is being scrutinized and guidelines for a more flexible, contemporary (interior) design are being laid out. A design with a positive influence on mental health of its inhabitants. The Indoor Environmental Quality (IEQ), and specifically the influence of materials on a home is being investigated and put under a magnifying glass.

- Key indicator: Social health of design

Social health of a design has been underestimated, looking into post corona research some clear design rules are identified to help residents create a good environment that considers their mental and social health.

A research study on architectural certificates such as BREEAM and LEED shows that social and mental health is not addressed, or barely touched upon in the evaluation of homes. (Rice and Drane, 2020) The thesis will go more into depth on architecture certificates in Step 3.
Two papers put up specific design rules for post Corona epidemic and social health of a residential building. While elaborating or focusing on different elements, they have several points in common. (Peters and Halleran, 2020) (Zaher, 2020)

A Tiny Home breaks with traditional design, and it is very interesting to see what this reveals. Essentially it takes away the element of space in a home. So to create a liveable home, design has to be optimized. For example: cooking is a needed function in a home, but with limited space this function has been rethought. A kitchen is used only a couple of hours a day, so why not make it transformable into a desk area for work ? This **interior design** focus has become very relevant in a post Corona pandemic setting.

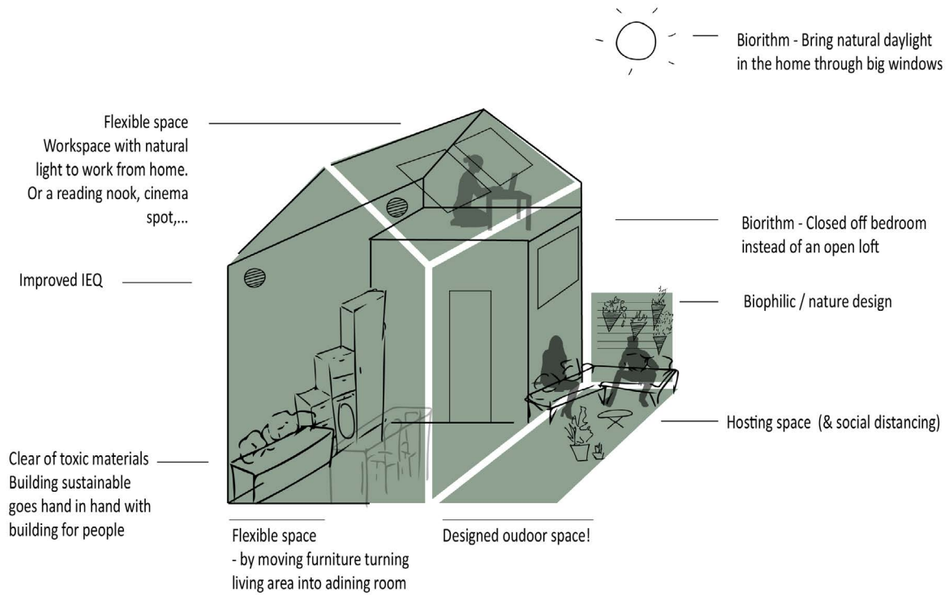


Figure 25 Design principles for social health of a building. (Peters and Halleran, 2020) (Spennemann, 2021) (Zaher, 2020)

The modern open concept with the entrance, kitchen and living room in one space is not feasible in a post Corona pandemic area where you might have to work from home and host meetings. Going back to a Victorian house setting - a house divided in a lot of small rooms - might not be the ideal solution either. The focus is on **flexible** spaces, spaces that can take on multiple functions, that can merge or separate from one another. There is one exception - having a separate bedroom is important for mental health and bio rhythm. (Spennemann, 2021) (Zaher, 2020) (Peters and Halleran, 2020)

Another specific element in architecture that has gained importance with the Corona pandemic is **biophilic design**. It is the influence nature has on our mental health. Even merely visual engagement with nature can reduce stress and anxiety. (Bereitschaft and Scheller, 2020) (Peters and Halleran, 2020) (VELUX, no date) A Tiny Home often is placed in nature - a forest or someone's backyard - and takes the biophilic benefit from there. There are many more opportunities however, a **green roof**, green walls or **vegetable garden walls**.
Restorative environmental design closely relates to this, it is a theory that the built environment can help recover from stress, by using nature. Current city design, especially apartments don't offer these opportunities. (Peters and Halleran, 2020)

Figure 26 Sketch illustration of biophilic/nature in the design. And a sketch on the design of the outdoor space

Daylight is **essential to bio rhythm** of people and their comfort. (Peters and Halleran, 2020) The Tiny Home also has to serve as a potential workspace. So where 300lux is the residential home standard, 500lux is the work environment standard. As a rule of thumb daylight will enter 4m deep in a house, which happens to be the depth of the Tiny Home considering the outdoor space. The IDA ICE simulation showed the illuminance level was at 600 lux. Sometimes it went higher, which can cause glare but in this case the outdoor shading can be closed.
The daylight factor has to be min 2%, 5% is very good. In the *Tiny Step* design a minimum of 4% was found and an average of 7%. (Bygningsreglementet BR18, 2021)

A Tiny Home of course has **spatial limits,** and it has been discussed in the literature study (Step1) that the urban network and public social space is relatively more important for Tiny Home owners. Considering the Corona pandemic a house with a separate entrance space is easier to disinfect. This was brought into the *Tiny Step* design as best as possible. The bathroom is placed next to the entrance, so it can be used for disinfection if needed. (Spennemann, 2021) The entrance space also serves as a wet room for shoes, and it also allows for riding the baby's stroller into the house without interrupting the baby's nap. It these small details that make a small home a workable space.
There is no double bathroom for quarantining, but the one available is very quickly cleaned and aired out should you be forced to do quarantine at home with more than 1 person. (Zaher, 2020) (Spennemann, 2021)
Hosting meetings or parties is the hardest issue to solve when living Tiny. This is where the outdoor space, harmonica doors and **flexible furniture** are key to transform the house. The Tiny Step even has space for social distancing! I actually found that creating the 1.5m circles open space for a wheelchair or as social distancing measure really helped open up the design.

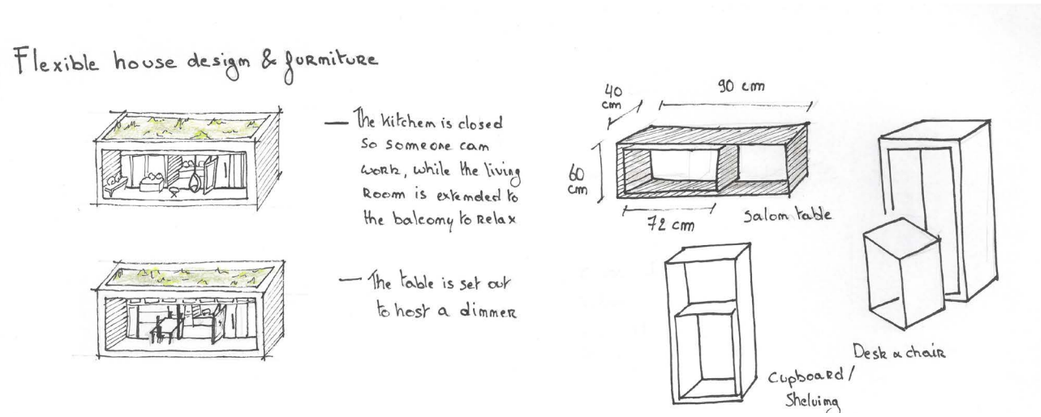


Figure 27 Sketch illustration of different scenarios for the house, and different configurations for some of the furniture.

- Key indicator: Physical health of design - IEQ

Classically the Indoor Environment Quality - IEQ - considers active and passive strategies to create air quality, temperature (heating and cooling) and hot water provision. Thermal comfort and hot water provisions have been discussed elaborately in the Energy Frame section. So the focus here is on ventilation.

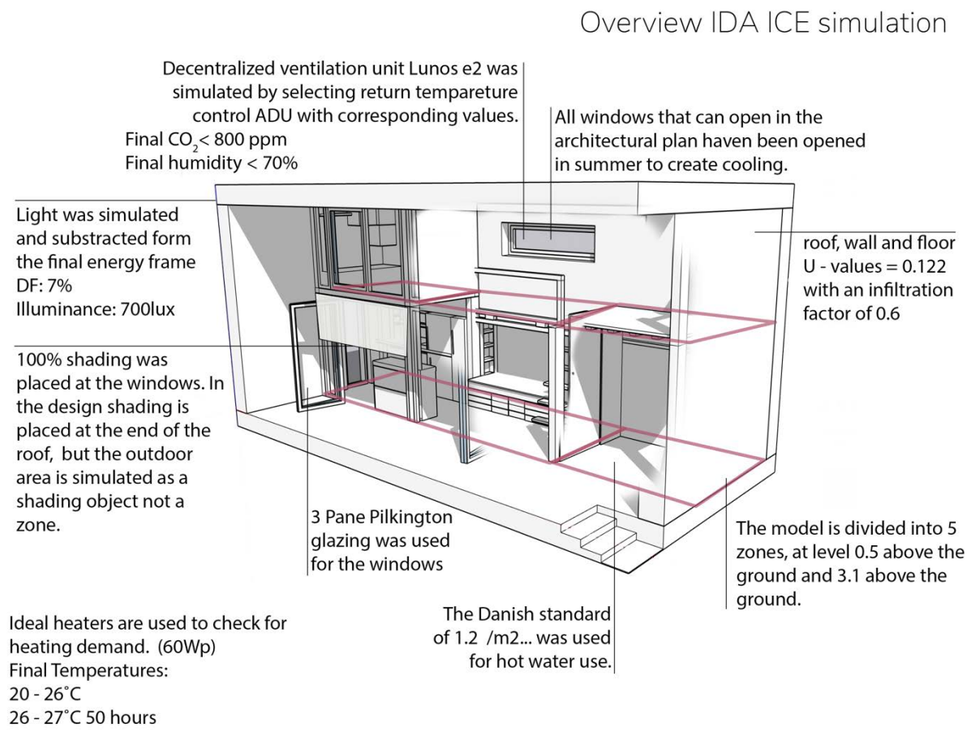


Figure 28 Schematic presenting an overview of values used and achieved in IDA ICE simulation.

Why should a house be ventilated? What are pollution sources?

A Tiny Home has a much smaller indoor volume than a general house, inherent in this size difference is a need for a closer attention to the indoor air quality.
In industrialized countries people spend about 90% of their time indoors and indoor air pollution is a higher health risk than previously thought. 84 million Europeans today live in damp/moldy homes. These houses are a threat to physical health, mental health and increase the risk of asthma by 40%. To prevent mold keeping humidity levels under 70-80% is key. This means a proper ventilation of the indoor climate. (European comission, 2003) (Zaher, 2020) (Grün, Urlaub and Foldbjerg, 2016) (Mukhopadhyay, 2020)

These are not the only pollution sources affection physical health in a home. When a house is build it should be aired out 7 weeks before being lived in. (Indoor Climate course DTU, personal communication, 2020). This illustrates how toxicity of materials is an ever-growing problem in the building industry. Asbestos is perhaps the best known material for its carcinogenic qualities, but benzene, radon and tobacco are also found in homes. (European comission, 2003) A big factor here is that new materials on the building market are not screened for these factors. (D. De Vriese, personal communication, 20.5.2021) Similarly furniture and appliances in the home have the same effect of releasing toxics long after they have been placed. (Ford and Gomez-Lanier, 2017)

What is the solution? On the one hand being a conscious buyer, and purchasing building materials from small sustainable companies. This is not affordable for everyone though. But having a small house will help with the financial aspect. A second option is to buy secondhand. This is by far the cheapest and has the least impact on the climate. – Often a combination of the 2 will get you a long way.
On the other hand, good ventilation is essential to make sure that the air stays clean.

Natural ventilation or mechanical?

Why not use natural ventilation? Usually what people mean by this is opening a window in the morning. This only works well in some older houses. This is because these have many small cracks where the wind can come through, so there is always a small exchange of air throughout the day. As you can imagine the downside here is that this natural ventilation will bring in cold air even in winter, and you heating bill will go up a lot. This is not good - not for your personal finances, nor for the environment.
This is why newer homes are built more airtight, but it also means we have to provide fresh air in the house at all times. Even if the home is built from toxic free materials, and good furniture – there will be still be the pollution factor of people! And ventilation is key for humidity control.
The Tiny Step design has open windows in the summer for cooling purposes. Thus in the summer time the ventilation system is off. But fall, winter and spring are supported by mechanical ventilation.

Decentralized ventilation

For *Tiny Step* decentralized ventilation was investigated – this means that it is not a traditional system with pipes running through the home and a central air handling unit (AHU). Instead small units are placed in the wall, that work together. These have the advantage of being small, so they are easy to replace, maintain and install. Less material also means a lower carbon footprint in general
Decentralized ventilation also avoids the problems of bad air quality and mold due to lack of maintenance. This can be observed quite often in traditional installations. As these small units contain a lot less material they will be easier to recycle. And they most likely contain less embodied GHG, though I could not find specific numbers.
Another complaint to ventilation is usually sound. The first and quickest decision ever made back when I moved into an apartment some years ago, was to shut down the ventilation system. While deciding on a cleaning schedule took weeks…. This is why the proposed unit for Tiny Step has a sound limit of 29 – 40 DB. (LUNOS, 2021) This is within the acceptable levels according to EN 15251.
Another element that helps here is control. If the Tiny Home owner is informed about how the home works, there is a higher tolerance towards discomfort.

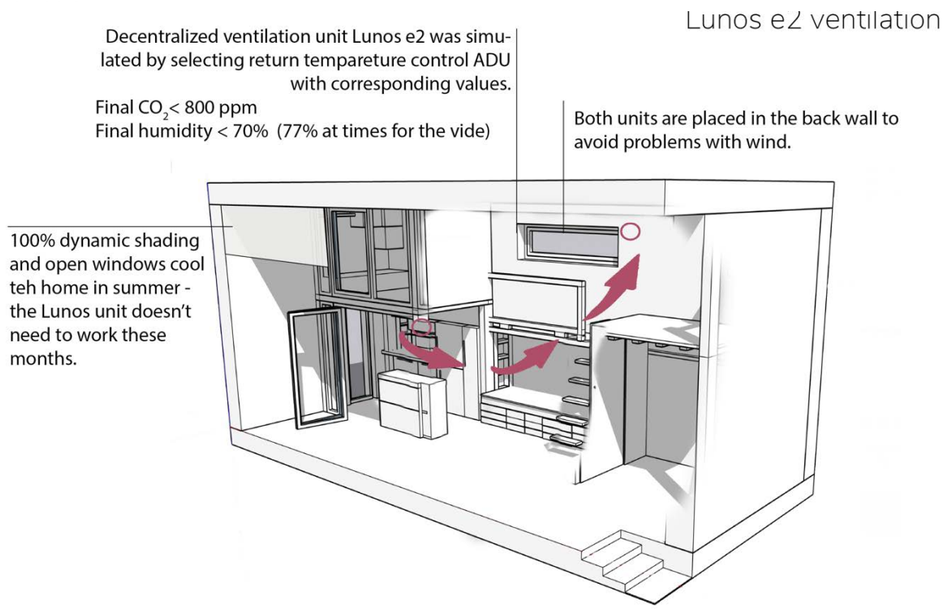


Figure 29 Schematic of the placing of the decentralized Lunos e2 units.

The most common ventilation unit used is the Lunos e2 – it has been widely used in Tiny Homes and was investigated in 2 different homes for a research paper. (LUNOS, 2021)

An important difference to note is that this type of decentralized ventilation with a ceramic core doesn't create humidity control as a central ventilation unit does. One core will be bringing in supply air, and a second core will exhaust the air. These 2 cores will switch direction every 70s. In a normal ventilation system warm and cool air cross, and because there is an impermeable plate in between, the water will condense and be taken out. Now, as there is no interaction between supply and exhaust air in the Lunos e2, the humidity control becomes more complicated. The Lunos has a humidity control built in, thus it would be best for users to choose this stand. The humidity control could be done by slowing the cycle speed, or actually speeding it up as (warm) air has the capacity to hold a larger amount of water.

Another element to consider is if the ventilation unit can handle the extraction of humidity from shower and kitchen. Adding a separate extractor vent in the bathroom seems like the logical choice. But it is tricky as it will create a pressure difference in a house. It needs to be checked if the Lunos system can increase the supply air to manage the pressure difference.
Right now a simplified version of the Lunos e2 has been simulated in the IDA ICE model. All the values are the same, but it is an ideal situation. A more detailed simulation should be done to check what is more optimal: one Lunos e2, two Lunos e2 units or one Lunos e2 + extractor unit.
These type of ventilation units are more prone to being affected by wind, so in Denmark this is a serious concern. The wind creates a pressure difference influencing the fans. However, if the fans are all on the same wall, this effect will be cancelled out. So in *Tiny Step* all units will be placed on the back wall.

- Conclusion social sphere

Health of a design has often been ignored, while toxicity of buildings contributes to asthma and even cancer. The use of good materials, both for construction and furniture, are key in avoiding chemical build up in a home. Additionally a good ventilation is necessary when we build with more insulation or passive standards, in order to ensure fresh air at all times. Humans do pollute the air, and this is especially true in a tiny space.
The Corona pandemic pushed research on mental health of (building) design. Biophilic design, interior design and the importance of outdoor space all are essential elements.
Natural daylight and a separate bedroom to have a proper place to rest are essential for a person's biorhythm. Especially in a home that has to serve multiple purposes. As people are working more from home, it is time we start to make the changes to optimize our homes a priority.

POLITICAL SPHERE

The literature study showed that “law and regulations” is one of the main challenges for Tiny Homes. This section will take a closer look at Policy and Law. It will investigate different stakeholders’ interest in Tiny Home development, what the regulations are now, and what solutions have been researched.

- Key indicator: Policy

There are many stakeholders that could benefit from Tiny Homes. We’ll take a look at the different problems Tiny Homes could address on a business, and a political level.

Cities & climate change

As seen right now the law is preventing Tiny Homes to become mainstream in most countries. This comes at a cost for industry and society. Policy however does not have the same limitations building regulations have.

Under the United Nations the Cancun agreements where set up in 2010 to help developing countries combat climate change. It is one off the largest global efforts that has been made in a way that holds countries accountable. An element in this was the development of National Adaption Plans (NAP). (*National Adaptation Plans | UNFCCC*, 2021) The Danish NAP includes an overview on policies regarding climate change. It states the importance of government, companies, and even individuals to contribute and work together to face the climate crisis. It specifically opens the possibility for government to adapt new laws and regulations for climate appropriate projects. (Climate adapt - Denmark, 2021) (klimatilpasning, 2021)

This thesis is focused mostly on residential Tiny Homes. Laws to allow and include Tiny Homes might be written purely based on climate change policy. However, while climate change should be the most urgent concern, it is not the only one. Other stakeholders, like industries and private persons are missing out due to constrictions in regulations.

Jobs and opportunities for a sustainable circular industry

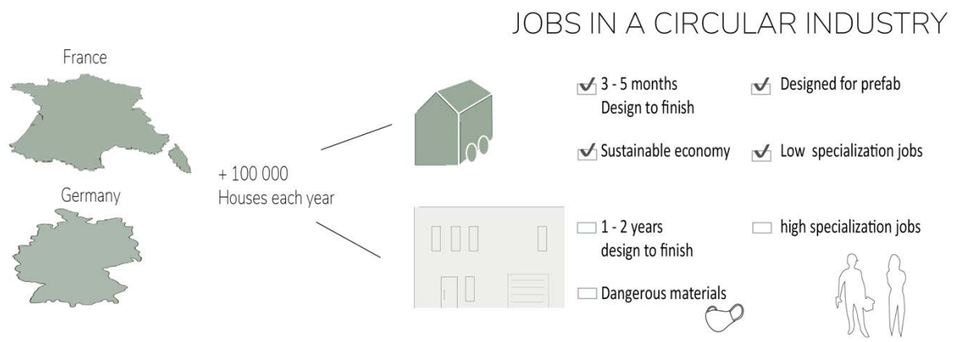


Figure 30 Jobs in a sustainable construction industry with Tiny Homes

Job security is a big issue tied in with sustainability. The ‘unsustainable’ jobs include specialized factory workers that would have to change career, and often don’t have an educational background to fall back on. The Tiny Home was designed with simple construction methods in mind to facilitate DIY and prefab production. This will allow a new sustainable housing market that creates jobs that can

be performed by people with a low level of training, as opposed to the complicated and technical construction system that is required for traditional house building.

Housing shortage is a problem in different European countries such as England and the Netherlands. Countries like France and Germany build annually over 100.000 houses. (EU Buildings Database, 2016) (D. Wiese, personal communication, 17.8.2021). Tiny Homes are designed for modularity and prefab, in combination with their small size production can be very fast. As discussed in the literature study - research shows Tiny Homes have a wide and growing market and are highly accepted by communities. (Evans, 2019)

Both of these topics require **Innovation in the building industry**. Investing in traditional homes is a long term affair and usually expensive. This makes it risky to try out new strategies. Tiny Homes however come with a lower price tag, a faster construction and a history of pioneering. They facilitate experimentation and rapid growth of sustainable techniques. (Moradibistouni, 2020) (Carvalho, 2019) (BuildDigiCraft, 2020)

Demographics – what type of housing do we actually need to build new?

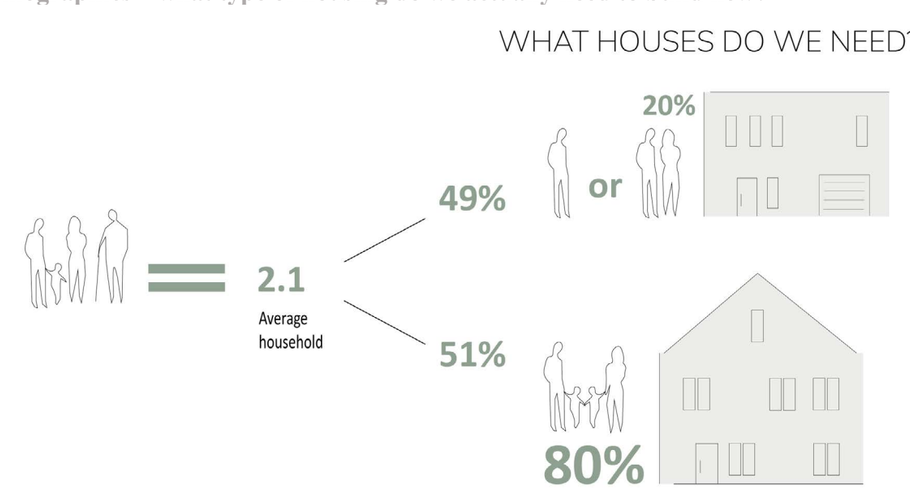


Figure 31 Demographics show 50% of people live alone or with 2, while according to Belgian number 80% of new buildings are for bigger households (2/3 bedrooms). (D. De Vriese, personal communication, 20.5.2021) (*Statistics | Eurostat*, 2021) ((Danmarks Statistik - FAM55N, 2021)

Additionally the current housing typology does not fit the needs of today’s society, with demographics in Denmark at 2.1 and in Europe at 2.3 average household sizes (*Statistics | Eurostat*, 2021) (Hutchinson, 2009) This means about 50% of our society is one and two person households. Traditional housing however has been built for families. In Belgium around 80% building projects by Matexi will be 2-3 bedroom houses. (D. De Vriese, personal communication, 20.5.2021) Thus there is a need for affordable housing catering to the growing group of one and two person households. This includes for example students, young adults, retired people,…

Education

On a society level more Tiny Homes for students would have the benefit of teaching an entire generation how to value their time, be financially independent, live on a minimal footprint and invest in quality. Looking at the category of students and young adults, these are the people who struggle financially to afford housing. Especially student housing can be a quite tricky in Denmark. If a student can loan or buy a Tiny home, this is an investment they can use to save money until they start a family and are in need of a bigger place. As this period spans often from 18 – mid thirties, it will considerably improve the economic stability and purchasing power of this generation.

Talking to Danish citizens, specifically young families, a need for Tiny Homes as transition houses was established. (S. Mackeprang, personal communication, 6.2021) It is a market already being explored by the Danish firm Tiny House Living that has Tiny Homes for rent. (TinyHouseLiving, 2021) Once children start to grow beyond toddler stage more space is needed in the house. Often this results in the move from an apartment to a house, or in a renovation. In case of a renovation temporary housing can be needed for up to half a year, so being able to place a Tiny Home in the backyard could be an easy way to accomplish this.
When moving homes, depending on your finances and current housing arrangement, some families find themselves in the situation where they have to sell their house before being able to buy a new one, so an undetermined time frame of 'in between housing' could possibly be solved with Tiny Homes.

Change in weather and environment… , building for extremes has already started.

Floods are just one of the extreme weather events that will continue to increase in the next years. Denmark already had their fair share, and recently Belgium and Germany experienced a disaster flood not seen in decades. Entire villages and railways have been swept away. (D. Wiese, personal communication, 17.8.2021).
There are two sides to this: on one hand the people who survived need a new place to live, which means a rapid production of housing is needed. And this is something Tiny Homes are uniquely placed to provide.
On the other hand we need homes that are capable of withstanding these new weather schemes. Low flooding can be stopped by raising a house. There is no house however that will be able to manage 10m of soil being swept away from under it, though a house that can easily be moved away before the storm, like a Tiny Home, could prove to be a solution.

France has experienced **ground instability** the last years. This leads to cracking of the foundation and tears in the house that undermine structural stability. As a result the market is looking for a solution to replace traditional foundations. Tiny Homes, whether on wheels or screw foundations, are an instant solution to this.

Environment and lifestyle

As discussed previously **Tiny Homes can make a contribution to mitigation and preparedness** in climate change. There is a **direct effect** when we look at data, when living in a small home you will reduce your footprint. A secondary, harder to measure, impact is the **change in lifestyle**. 2/3 of GHG come from Households lifestyle. 50% of these are from the 10% richest people. Who are they though? To be part of the 10% you need to earn 158,002 $ (~1million DKK) a year, almost 1/5th of people in Denmark reach this number! Looking at the Danish statistics on wages we see this is almost the salary of someone working in a managing position (974 157 DKK) Given that in most families both parents work we need to realize the 10% is actually quite a big group in most western countries. (Stuart Capstick, Radhika Khosla, and Susie Wang, 2021) (Kagan, 2021) (Danmarks Statistik - INDKP104, 2021) (Investopedia, 2021)
How do you change your lifestyle? It is a question attempted by some through the 'zero waste movement'. While this is an incredible effort, it is not a simple thing to achieve and requires dedication, time and resources to do. As seen research showed that living in a Tiny Home however seems to trigger that transformation spontaneously and due to their popularity the knowledge is spread through society. (Kilman and College, 2016) (Weetman, 2018)

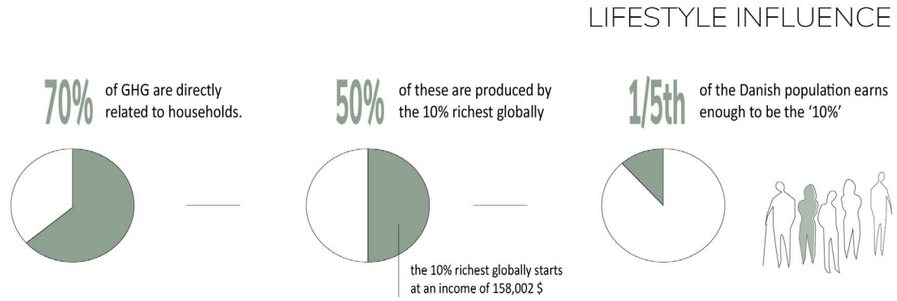


Figure 32 Lifestyle influence (Danmarks Statistik - INDKP104, 2021) (Investopedia, 2021) . (Stuart Capstick, Radhika Khosla, and Susie Wang, 2021)

- Key indicator: Building Regulations

On a European level separate building regulations for Tiny Homes are allowed, so what should be prioritized when developing regulations on a national level?

European law allows for Tiny Homes!

On the European level there is the Energy Performance of Buildings Directive (EPBD) and Energy Efficiency Directive. Both have been established to promote legal frameworks that will help create an energy efficient and decarbonized building stock and a stable economic environment. (European Comission, 2019) In this regulation an allowance is made for any country to make specific laws for houses under 50m². Looking at Denmark specifically The BR18 gives the framework for building codes on a national level.
The last level is separate regulations for every village that will go into detail on plot size, amount of buildings allowed,… This is one that can either give you a lot of trouble - or help!

Schematic laws

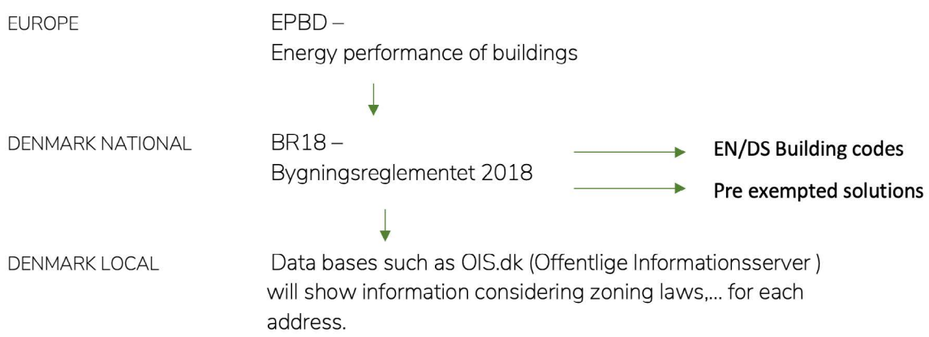


Figure 33 schematic of law structure and building codes relations

Some examples of building regulations and zoning laws that prevent legal Tiny Homes

BR18 – any temporary structure you live in for more than 6 weeks has to adhere to building regulations.

Energy frame work calculation – in Denmark use BE18 program. For thesis IDA ICE software was used as it is more detailed. The energy frame is defined in energy used per m², so to have a Tiny Home get a low number is quite a challenge and the most accurate software is necessary. If the energy requirements would be redefined for Tiny Homes as the total per year, this would create a representation much closer to the truth.

BR 18 - The door has to be 0.77m wide. And a hallway 1.2m.

If plumbing is present the house should be connected. This would make it difficult to place a Tiny Home in your backyard, it would require new plumbing. An expensive job, and one that would make the Tiny Home a permanent set up, while their power lies in flexibility.

Zoning laws will not allow multiple families to live on one plot in many communes.

Building regulations: priorities in implementing policy

When the EPBD law – allowing for different regulations under 50m² – would be applied, how can this be applied nationally or locally to Tiny Homes? Standard homes are subject to minimum doorsizes, a rule that could be dropped for Tiny Homes. Similarly, as explained before, it is quite hard to live up to standard energy regulations in a Tiny Home. That does not mean that the general regulations should all be thrown overboard. Tiny Homes should also follow the rules about structural and fire safety.

As discussed earlier Tiny Homes present a unique opportunity. With small size, fast building time and low investment Tiny Homes are ideal to experiment fast. (M. Lane, personal communication, 18.5.2021). What should be the priorities of new regulations to implement a policy aimed at Tiny Homes to help fight climate change? Four points are discussed below based on the research done in the thesis.

1. **Low carbon development instead of energy frame focus**

If Tiny Home law would prioritize a low climate impact (a low GWP) instead of the general sustainability, this could be the push needed to reinvent the building industry.
How to implement this properly? GWP is directly tied to LCA, but as discussed in the environmental sphere LCA on its own is not sufficient right now - it even limits efforts to go low carbon. As such the implementation of GWP based rules needs to be done in combination with circular economy concerns and support to help small companies to create EPD files.

2. **Regulations on health of materials**

As discussed in the Social sphere, an overseen part of building legislation is the health of homes. Currently building related health problems cost the European union 82 billion. (Grün, Urlaub and Foldbjerg, 2016) Laws regulating materials on the market should be set up, laws preventing toxics from being brought into homes. This applies to all materials, including furniture industry.

3. **Adjusting zoning laws**

The localization of Tiny Homes is a problem that need to be fixed. Several laws prevent Tiny Homes from being installed in most places. As mentioned in the literature study, Norway created a solution where 2 year permissions can be obtained. Another example is the construct of accessory dwelling units -ADU - in America and Australia.
Additionally it is important to see how to implement the homes best. A preference for wood and local architecture was found in a study. (Evans, 2019)

4. **Freedom to experiment with new techniques**

There are quite some building regulations limiting Tiny Home design as shown above. Eg. door size, or heating.
Tiny Homes often will not be able to connect to the grid. The Danish law requires new buildings to connect to the warm water distribution net. In the case of Tiny Homes this might not always be the ideal solution. Additionally their small size makes them ideally suited for solar provision, which can provide green energy to power heating equipment.

- Conclusion political sphere

On a European level the law already has a provision for Tiny Homes, so it is up to countries to create that opportunity on a national level. To optimize policy this means prioritizing low carbon and circular economy regulations for Tiny Homes. 4 Elements that are critical to new laws where isolated:

1. Think low climate impact development (GWP) instead of energy frame
2. Regulations on health of materials
3. Adjusting the zoning laws
4. Freedom from small regulations to experiment with new techniques

Many stakeholders can benefit from the introduction of Tiny Homes: from single students over families in need for affordable or intermediate housing, to providing new sustainable jobs for a changing construction industry. A policy supporting Tiny Homes could open up a new sustainable market, create jobs and help fast track low carbon building.

CONCLUSION RESEARCH STEP 2

Differentiating between low carbon housing prepared for climate change and sustainable housing in general is critical.

Tiny Step has a carbon footprint of 15.000 kg CO_2. An estimate using traditional wood construction showed **re-use 7.4%, recycle 3.1%, downcyle 82.2 % and waste 7.3 %** The largest impact for Carbon and Circular is the insulation with a volume of 70%. Seaweed could be used as a more sustainable and qualtitative insulation, but it comes with a higher pricetag. The Tiny Step design was estimated at **128.000 Euro.** This could be cheaper of course when using salvaged materials in the build.
While LCA is an incredibly powerful tool, right now it is encouraging unsustainable building. Thus we need to rethink how to use them purposefully. For example by subsidizing small companies to create EPD's for sustainable materials.
LCA as well as circular economy and waste reduction start at the design phase. To improve this a stronger collaboration between disciplines as well as input of local community is necessary.

Reducing the energy frame led to big changes in the design. Heating and thermal envelope was already introduced in the first concept design. Passive cooling however changed the size of the overhang and outdoor area.
This matches the health research. Post Corona re–emphasized the need for biophilic and outdoor design of a home. Health of a house as often been ignored, while it ranks up 82 billion every year to the European union.
The use of good materials, both for construction and furniture, are key in avoiding chemical build up in a home. Additionally a good ventilation is necessary when building with more insulation or passive standards, in order to ensure fresh air at all times.
Daylight as a measure of time and a separate bedroom to have a proper place to rest are essential to a home that has to serve multiple purposes. As people are working more from home, it is time we start to make the changes to optimize our homes a priority.

A policy and supporting Tiny Homes could open up a new sustainable market, create jobs and help fast track low carbon building.
On a European level the law already has a provision for Tiny Homes, so it is up to countries to create that opportunity on a national level. Four elements to implement low carbon policy in laws where isolated:

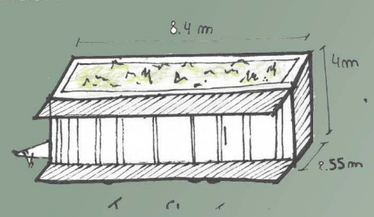
1. Low climate impact development (GWP) instead of energy frame
2. Regulations on health of materials
3. Adjusting the zoning laws
4. Freedom from small regulations to experiment with new techniques

TINY STEP
an integrated Tiny Home design

Cost estimate provided by REXCON

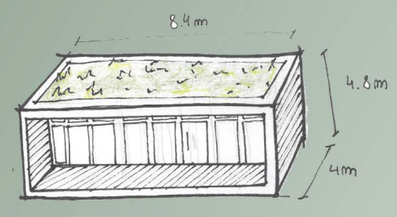
TINY STEP Student
87 000 Euro.

The student version is the smallest, it had to compromise on insulation to fit in road limits. But it is still within legal guide-lines.



TINY STEP Traveler
110 000 Euro.

The Traveler has the same dimensions to Tiny Step but is a groundfloor design on wheels.



TINY STEP
128000 Euro. (including solar)

This version of the design is the most flexible. It can be taken on the road as special transport only.

GREEN ROOF

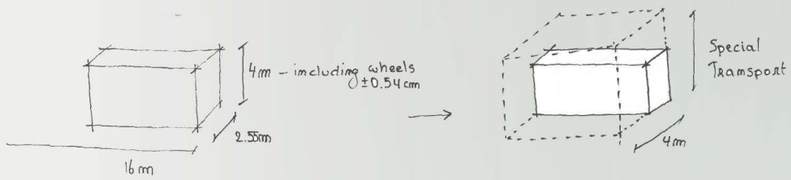
A green roof has several advantages. It will help stabilize the indoor environment, protects against wind, hail,... it helps slow rainwater, and it cleans the air. It also gives the house a lower albedo, fighting overheating, especially if the house is placed in a city environment. It also protects the EPDM layer underneath increasing the lifespan of the home.

Vertical food garden

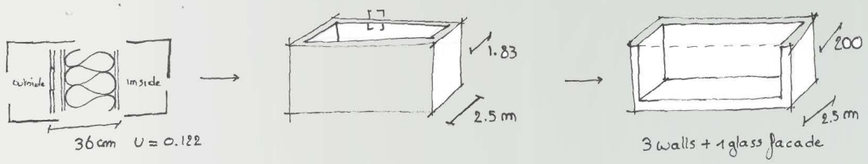
Structural cladding allows to hang a vertical garden werever you want it. The ladder makes everything accesible.

The goal for the design shape was to simplify. This means easier prefab production, a simpler construction & DIY, easy repairs, possibility of component building,... It gives the design a flexibility in construction.

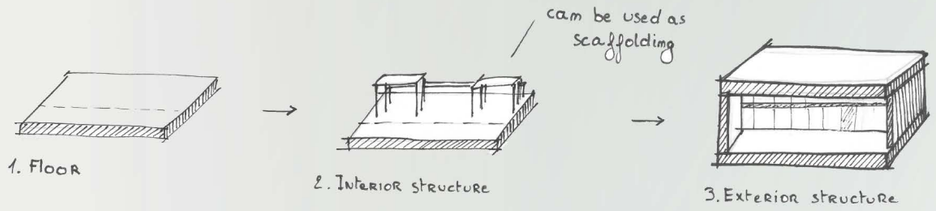
Transport limits on dimensions



Thermal envelope & design



Build up structure

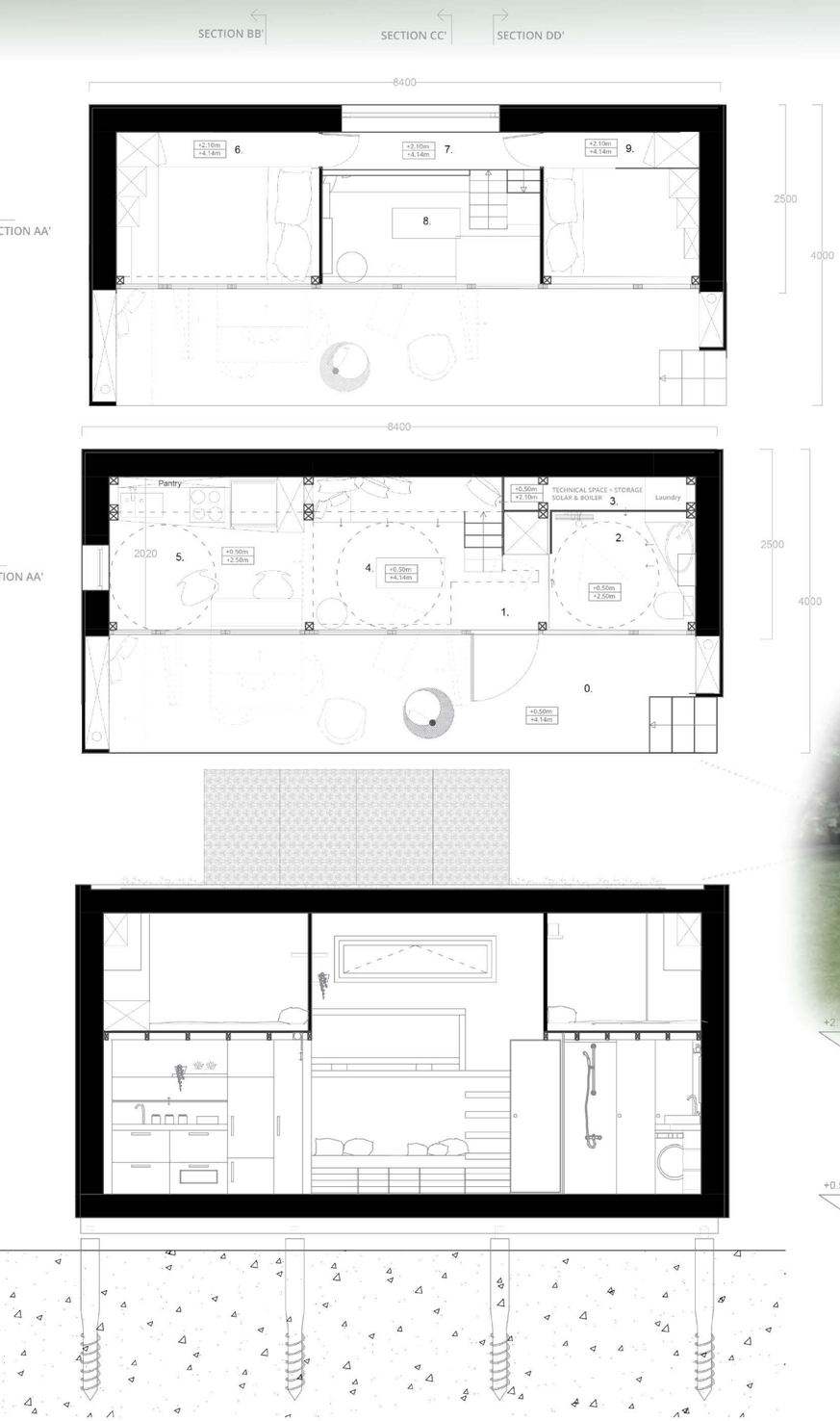


Foundation

The foundation is steel screws, they have a lower climate impact than concrete foundation. Even better they can be reused easily, and have minimum impact on the soil. Ideally you can find them secondhand!

Having a raised foundation helps prevent radon to enter the home. It also makes sure the house is adapted for raised water table or floods following extreme weather events from climate change.

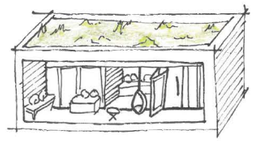
TINY STEP
an integrated Tiny Home design



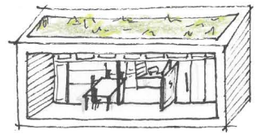
Designed outdoor space

A functionally designed outdoor space facilitates a change in lifestyle.
Adding biophilic design(nature), a regenerative space, it encourages people outside instead of staying stagnant at one place in the home.
The balcony has space to grow herbs and following corona the outdoor space gives the ability to host safely.
Sun shutters will keep the scape cool in summer and make the space comfortable even in fall and spring.
The walls and overhang protect against wind.

Flexible house design



— The kitchem is closed so someone cam work, while the living Room is extended to the balcony to Relax



— The table is set out to host a dimmer

Flexibility in rooms

With 2 full bedrooms the house is moreflexible than the average Tiny build. It allows for changes in lifestyle such as living with a roomate, to a partener joining the house. It could serve as a work space or sewing studio.

Both bedrooms are designed as full bedrooms, not open lofts. This allows for people

Vertical space

The high ceiling in the living room gives a feeling of space even without the m^2. Ilt also makes space for a desk on top of the entrance space. It is faced towards the window, granting a great view.

Wooden Cladding

Wood is the most popular and accepted material for Tiny Homes & a sustainable choice.
Sioo-x is a natural wood treatment that lasts 10 years so maintenance is minimalized. It would color the house silver over time.

TINY STEP

an integrated Tiny Home design

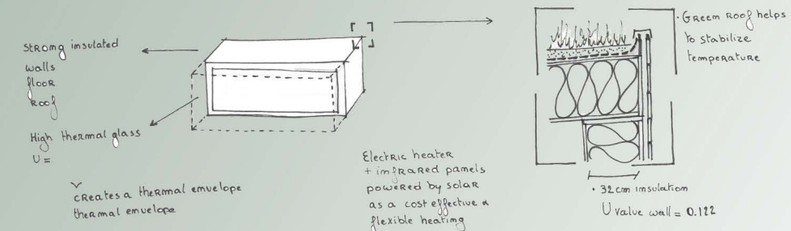
Energy Frame & comfort.

The energy frame was reduced to 37 kWh/year/m² or 2000 kWh/year. A 150m² home would use 74 000 kWh/year. This was achieved while keeping comfort standards. Final Temperatures in teh home are between 20-26 degrees.

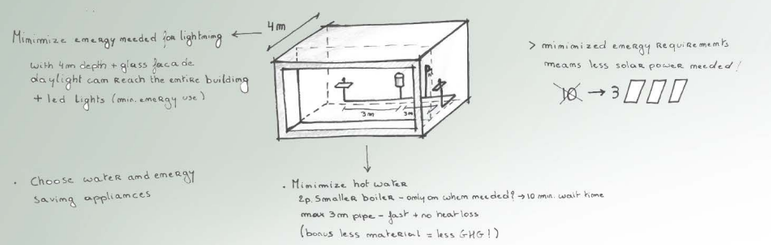
SOLAR

Solar panels allow the house to be off grid & fully on green energy. Due to the houses small energy demands not a lot of panels are needed, and with a battery the house can be fully independent.
If the house is placed in a snowy area it is recommended to place the solar system on the ground, this will help prevent structural damage. The solar panels should also be free of edges, this will allow the snow to glide off easily instead of piling up.

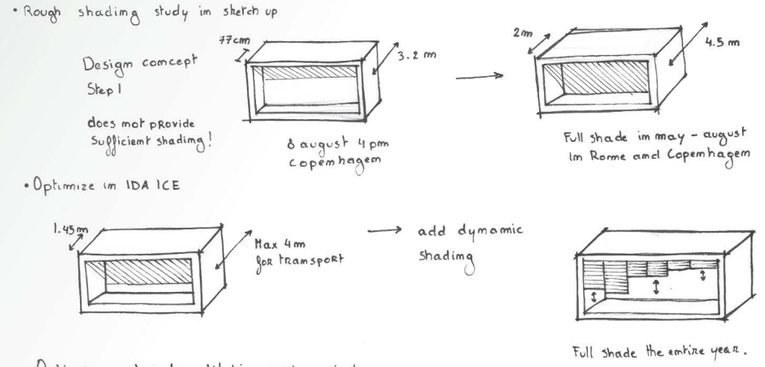
1. Heating strategies

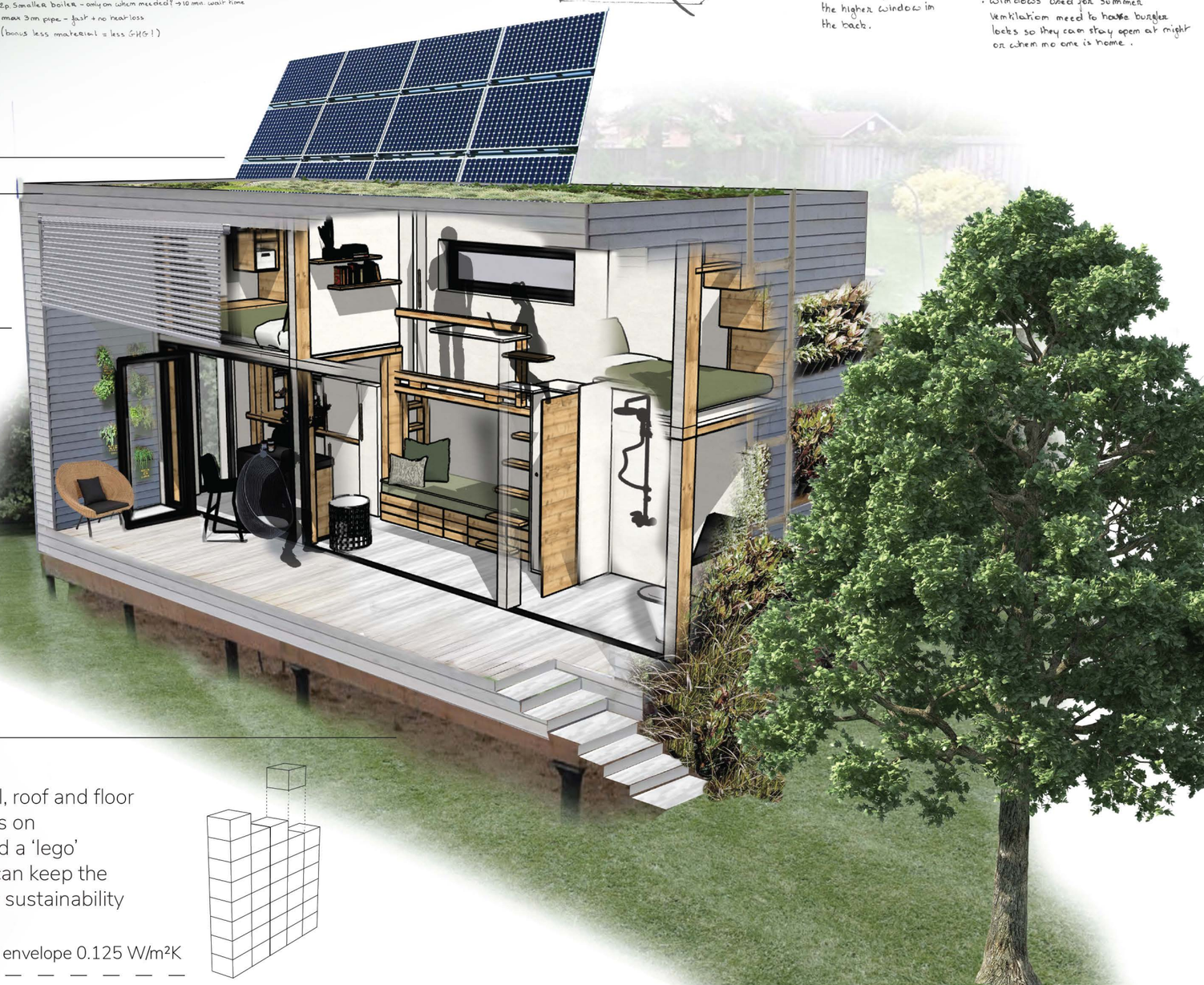


2. Appliances



3. Cooling strategies

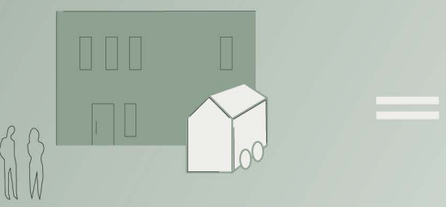




The roof is essential as a passive strategy to keep the house cool. The roof and walls also protect the outdoor space making it a comfortable space.

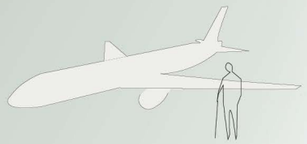
Life Cycle Analysis

The total GHG emissions of the house for a hundred years is 15 000 kg CO2 eq. A newly build house would be 130 000 kg CO2 eq.



90.000 CO_2eq

is saved by building a Tiny home instead of a traditional brick and concrete house .



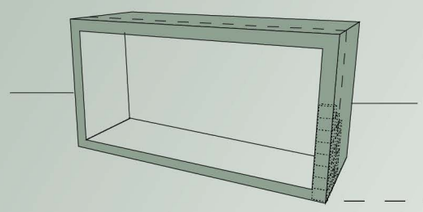
100 years of flying

for the average Danish citizen

ReBlock system

The Tiny Home is compatible with Reblock wall, roof and floor elements. This Danish startup company focuses on sustainability and circular economy. It developed a 'lego' wallsystem to be DIY friendly. Fast production can keep the price down without compromising on quality or sustainability of the building.

U-value envelope 0.125 W/m²K



STEP 3. CLIMATE CHANGE COMMUNICATION & A TINY HOME

The last part of the thesis will focus on communication of the design in the light of climate change. Again a research phase is followed by a conclusion and then the results are applied in *Tiny Step*'s design.
The research will first look into climate change communication and how it can be improved. Then it will focus on two main strategies to apply this to the *Tiny Step* design: the introduction of labels and a comparison with different houses.

OPTIMIZING COMMUNICATION FOR THE DESIGN

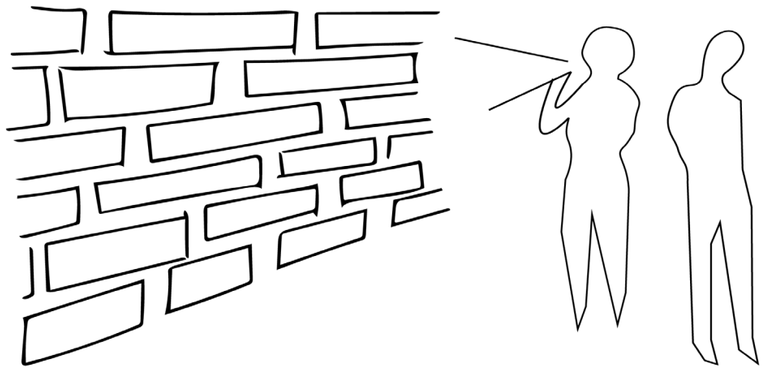


Figure 34 talking to a wall...

Today climate change seems to be 99.9% talk and 0.1% action. What use can Tiny Homes be in this context? Can we use a climate action – such as a low carbon building - as a communication platform? Tiny Homes already have a wide platform in media. They are very visible and attractive. I can personally testify to that: spontaneous visitors show op at my door even in Corona times! Thus Step 3 of this thesis will investigate how to present the *Tiny Step* design as a climate friendly solution and use it for climate change communication. Different communication strategies will be researched and it will be investigated how they can be applied to *Tiny Step* – and architecture in general.

IMPORTANCE OF COMMUNICATION IN TACKLING CLIMATE CHANGE

Climate change is an incredibly complex topic to address. The lack in action is largely due to the lack of good communication. A collective awareness of the change needed and responsibility on a personal, business and governmental level is missing.
There are several factors at play, but the gap starts at the level of the scientific community. Many scientific findings don't find their way to the broader public, businesses and governments, because they are not written with them as readers in mind. Communication research shows solutions can be found in: the correct use of graphics, the need to acknowledge politization of a scientific topic, the need for narratives instead of numbers, personalization of the problem and many more.

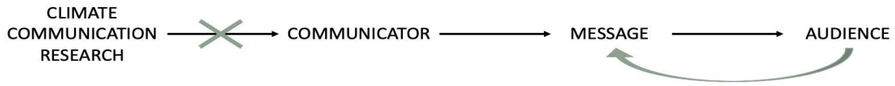


Figure 35: The information gaps a climate change communicator faces are filled by insights from their audience. Graphic by (Yanaika Denoyelle, 2021)

- Where is the action people are demanding?

Climate change is bad news, and here are some examples … - do we care?

People *do* care about climate change. This has been confirmed by research and multiple questionnaires. In fact it is a trend that has been growing stronger the last years! Despite this growing awareness and the support for climate action, actual change on a personal level or business level is still scarce. (Howarth, Parsons and Thew, 2020)
Extinct a theathre play in London, gave a striking image of the inaction our world faces. One of the data thrown at the audience stated that on a global level 60% of banks have invested 3.8 trillion pound in fossil fuels. It makes one wonder how that is affecting the market on sustainable materials, sustainable investments, alternative resources? (OfficialLondonTheatre, 2021) The play dramatized the possibility of floods: a couple of days later entire villages, roads and trains disappeared in Belgium and Germany after heavy rains and flooding. Climate change is on our doorstep.

> *"In this somewhat cynical world, people can't imagine that you do something that you aren't doing to further your own gain . . . So then I use that as something that they can understand: "I do this for myself, for my kids"." – Nic Balthazar (Yanaika Denoyelle, 2021)*

Often climate communicators will defend their actions before being asked. Caring for other people's wellbeing and ethical reasons are still waved away as dreamy and immature attitudes. This dismisses the fact that a lot of people are genuinely worried about how climate change will affect less fortunate communities. Climate anxiety and climate depression is a growing phenomenon affecting more and more people. Many youth feel guilty for being part of the countries with highest GHG contributions. (Howarth, Parsons and Thew, 2020) (Clayton, 2020) (Yanaika Denoyelle, 2021)

At the same time people feel overwhelmed facing a problem that will turn their life upside down. A problem you are not only unable to fix but contribute to every time you even eat an apple. Unless you decide to grow all your own food… Providing people with information and action is one avenue to change this.

It needs to be noted that other issues are at play. Like misinformation and lobbying from the oil industry for one. But these are beyond the scope of this thesis, we will focus on communication.

The problem starts at the source of information: the failure in clear communication between the scientific community that has solutions, the politicians that can implement them, companies that can realize them, and the general public that has to live by them. A communication in an effective way that inspires change, is essential to reach a wider audience. *(Howarth, Parsons and Thew, 2020)* (Harold *et al.*, 2016) (Climate Outreach, 2021)
Accelerated action is required to respond to climate change. This is not possible without acknowledging and placing people at the heart of this issue. There is a need for technological advances, regulations, laws and policies. All of these only work with long term and active engagement of citizens. (Climate Outreach, 2021)
It also can't be ignored that climate change has become politicized in the public narrative in many countries. Science has as a priority being unbiased and getting the most exact results. Policy making is often time bound and it is dependent on social climate and context. Thus it works with the best evidence available, while often science wants to be 99.99% sure.
In this regard it could be essential to provide multifaceted solutions. If a proposal is good for economy and happens to be excellent for environment it is easier to have it accepted. It seems to be similar to Tiny Home motivations. Environmental concern is not the main reason for their success, so in addressing financial benefits and a simpler life style a bigger impact can be made.

- What communication strategies can be used to change this?

7 strategies to improve communication – and how they are used in this thesis

Six strategies where proposed in a paper exploring effective climate change communication. (Howarth, Parsons and Thew, 2020). While translating them into an infographic, we found 7 strategies. The strategy around "clear language, eliminating graphs and numbers - instead having a trusted messenger and two-way communication" has been split, as there are 2 important elements here: the importance of two-way communication and the reduction of scientific jargon and increased readability. The last one applies to many different communication fields, so it makes sense to give it its own space.

In the next paragraphs, the way these strategies were applied in this dissertation are summarized.

1. Use Clear Language - Scientific jargon has been reduced in this thesis to make it more accessible. Additionally, most of the graphs and numbers have been put into infographics for the support by visual communication.

2. Make things Interactive – Since this thesis is a document, interaction is harder to achieve. Opportunities for dialogue could be created by a blog. This thesis' defense presentation will be structured as a Ted talk and could be publicized on YouTube, a platform that allows discussion.

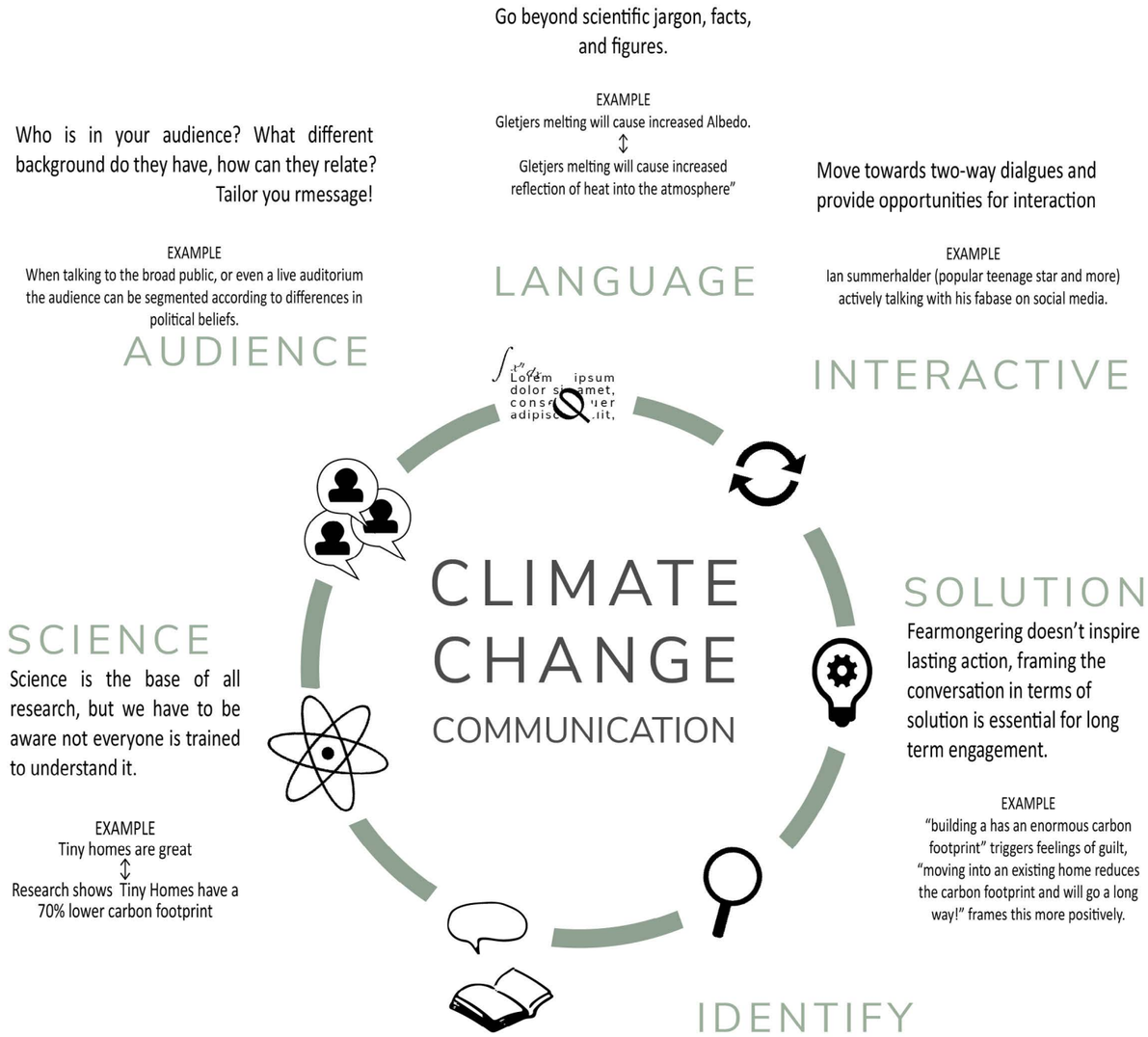
3.Science as a base for everything – this is why all findings in this thesis are preceded by extensive research.

4.Tailored to the Audience – A thesis is primarily an academic document, but as it concerns a popular topic and specifically addresses communication, the thesis was written to be accessible to people without a basic knowledge of architecture or engineering.

5.Solution Oriented Communication – Due to the integrated design strategy all research is immediately linked to a practical solution: the design of *Tiny Step*.

6. Narratives are essential to engage people – Part of the popularity of Tiny Homes lies in their 'cuteness factor'. They inspire people to dream. The thesis uses integrated design to explore sustainability and climate change through the design of the Tiny Step. Designing not only a low carbon home, but a low carbon lifestyle that can be applied to more than just a Tiny space. This is also where the personal touch (and tone) comes in. As I wrote this thesis living in a Tiny Home, the story becomes even more appealing to the wider audience. The idea of the Tiny Home lifestyle is one people can connect with, even if it wouldn't be their personal choice.

7.Identify barriers and use them as opportunities to instigate change. – A good example here is how Tiny Homes create quite some engineering challenges. So they actually push technology to improve. Of course their illegal status is a second barrier. But campaigning for Tiny Homes could add to their media presence and thus spread the message they bring: an example how to live sustainably for yourself, society and the environment.

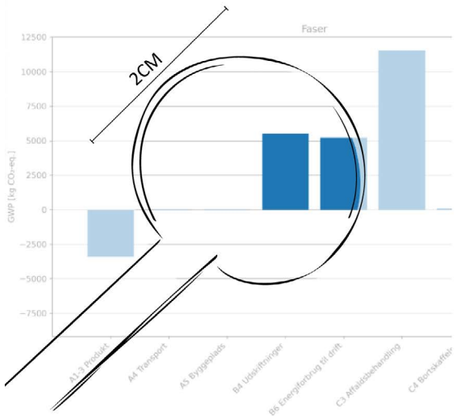


Infographic based on the findings of the following paper:
Effectively Communicating Climate Science beyond Academia:
Harnessing the Heterogeneity of Climate Knowledge
(Howarth, Parsons and Thew, 2020)

The start of information and miscommunication: IPCC and communication

The above communication strategies need to be supported by clear graphic materials.
People who have read the IPCC will agree, there is a lot of work and information in these reports, but it takes a specialist to decipher them. Visualizing scientific data in an effective way is critical to communicate climate change findings to non-experts as well as experts. (Howarth, Parsons and Thew, 2020) (Harold *et al.*, 2016)
To create effective visuals one needs to understand the scientific information very thoroughly. You need to understand what your expertise is - what do you know exactly that others are not trained in? Then you need to 'translate' this so a wide variety of people on different levels come to understand the topic. On top of this, transferring this knowledge into effective visuals is a skill in its own right. Cognitive and psychological science clarify some of the underlying proven insights on how to make the switch from general numbers to an effective communication tool. (Harold *et al.*, 2016)

Research based graphic design



GRAPHIC COMMUNICATION

1. **Size**
2. **Motion** = arrows
3. **Orientation**

4. **Color** - contrasts makes something pop up -
It is important to remember the meaning of colors. As an example: Red is perceived as "a bold statement", as on a chemical level it is the first color that reaches the eye.
Or the reader can be color blind. A rule of tumb is to see if the graph still works in monochromatic colouring.

5. **Text and language** can be used to draw attention, support and explain info to non experts. Don't forget language is bound to culture and expertise.

6. **Title** - Stating the purpose of the graph can help direct attention.

7. **Knowledge,** experience with the chosen type of graphic (a table, line graph,...)

8. When objects are in close **proximity**, they will be interpreted as connected, while if they are far apart the brain will have to separately search them out and the connection will be harder to make.

Figure 36 How our brain processes graphics, and how to help direct attention. (Harold *et al.*, 2016)

Intuitive design can go wrong easily. Improving readability of a graph does not mean a loss of scientific rigor! When looking at a graph we remember separate pieces of it and build it together in our heads from memory. Research shows the central vision for details: at 60cm distance with a 2 degrees angle there is 2cm focus! Where you look, what info you see first is important and can be directed by good graphics. Important details have to be highlighted or they will not be processed.
Graphics are not only used to communicate, but also as a process of sense making, summarizing and decision making. Specifically further research is needed to optimize communication of uncertainties. (Harold *et al.*, 2016)

Computer models today are able to indicate visual clutter. Eye tracking software has been used to identify guidelines that help highlight important elements: (Harold *et al.*, 2016)

- How to apply these communication strategies to the thesis?

Thesis from communication perspective

As the reader (hopefully) has experienced by now, most of the above mentioned recommendations have been included in this thesis.
The saying goes “practice what you preach”. This is why I made graphics a big part of this thesis. I hope this will show others the importance of the communicative value of their work.

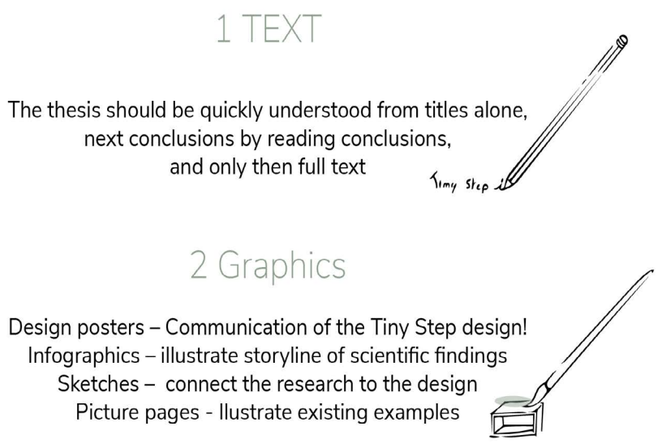


Figure 37 Text and graphics the thesis used to support research and communication.

As Tiny Homes are such as popular subject, it was deemed very important that the thesis is accessible to people without prior engineering or architectural knowledge. It was then decided to keep three stakeholders in mind: “you”, “society” and “the environment”

How can we use Tiny Step as a tool to help climate action and communication?

Until now we have made posters to explain the design of Tiny Step. What if we turn this around, and use Tiny Step to explain the climate change principles addressed in architecture? In this poster we should clearly state the difference between climate change preparedness and mitigation. In scientific publications these are mostly treated separately, with confusing communication and double work as a result. (Howarth, Parsons and Thew, 2020)

To optimize the circular and low carbon housing discussion, we need information to be available to everyone. We cannot expect everyone to read a thesis like this or to educate themselves on housing. Instant communication is all around us. On every piece of fruit a label can be found stating price, originating country, nutritional value,… Could we improve a buildings’ communication with labels? Energy labels have been implemented successfully in Denmark in the real-estate market. The next chapter will investigate this in depth.

It is hard to see the influence of Tiny Homes when you look only at Tiny Homes. That is why the last chapter will make a comparison to get a perspective and make clear communication possible with practical examples.

- Conclusion

Communication is a field in its own that has often been underestimated. It requires interdisciplinary work to be optimized. Much can be done to improve the transfer of information from the scientific field to the wide pubic.
Linking action to communication is a good strategy. Architecture might actually be a good field to experiment with this practical communication as there already is a link between science (engineering) and a tangible solution – a house. To test this the Tiny Step architecture posters will be rethought to address climate change communication
The thesis has tried to use different strategies outlined in research to make it a more readable, and a useful, accessible document.
Addressing stakeholders is important to have a targeted message. It is also important to recognize that Tiny Homes are an environmental solution second to financial and social benefits. This is key to avoid the reaction that this is just another environmental push, and to show a lifestyle that is sustainable for people, society and the planet.

LABELS

Lets take a step back and see how we can integrate what we learned about homes so far in a way that is transparent information for all. – through labels. Today only m^2 and price are considered when buying a home, but these are not necessarily indicators of quality. Labels have shown to influence behavior even for people who actively avoid environmental issues. They provide instant accessible information for people to make better informed choices.

- Labels as a transparent & instant communication

Labels can alter behavior, making people go for products that are 12% - 32% less impactful for climate change. Additionally they provide the most direct way to communicate and give people the option to make an informed choice. Instead of spending years getting a science degree and reading research papers.

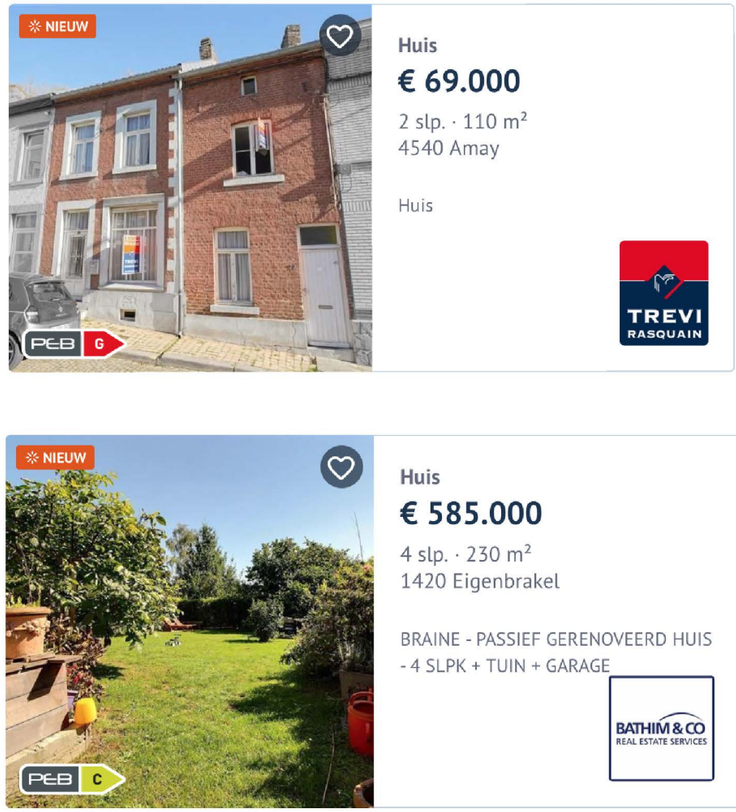
Society is still set up to motivate unsustainable decisions

To initiate change in society it is necessary to create social situations that allow or motivate people to take environmentally friendly actions. It is necessary to make sure that the 'unecological decision' doesn't come up, or clearly is not the best option. This way even people who do not care about the environment will contribute to a sustainable future. (Kilman and College, 2016)
As people become more aware of climate change, they also notice every situation they find themselves in, choosing for climate friendly actions is often impossible. Because they don't have the necessary data to make a correct decision. People are looking for information, but it is hidden in specialized research. How can we make information transparent?
Today people choose a home based on m^2 and price. The price of a Tiny Home is a strong motivator, but the m^2 will scare away a lot of people. Taking a step back though, it is important to question 'is this the best way to judge a home?'. The key indicators discussed in step 2 included much more than these 2 elements.

Transparency is being included in laws and policies

European law is forcing companies to show what steps they are taking to reduce their environmental impact. (Peters and Halleran, 2020) This seems to be following a general trend toward transparency that is for example being practiced by small companies who genuinely try to be sustainable in every part of their production chain. Out of 7 goals for climate change put forward by UNFCC transparency is the second. (UNFCC, 2021)

> *Transparency of actions*
> *Ensure international transparency of the actions which are taken by countries, and ensure that global progress towards the 2˚C goal is reviewed in a timely way. – source UNFCC Cancun agreements. (UNFCC, 2021)*



Top - Hous listings in Denmark, all homes have an energy label.

Bottom - Hous listings in Belgium, these examples have an energy label. I had to scroll 10 min to find them! Even new construction doesn't give an energy label.

(REXCON System, 2021)

Labels alter behavior to be 12% - 32% less impactful for climate change

A recent study in Sweden showed the importance a label has on consumption habits of people. According to the findings the presence of a label indicating the carbon footprint of groceries results on average in 25% lower emissions from food shopping. The study differentiated between people who actively avoid this information, about 1/3, and people who actively look for it. “Avoiders” still altered their behavior and reduced their impact by 12%. People actively looking for information reduced their behavior with 32%. (Edenbrandt, Lagerkvist and Nordström, 2021)
We should note that this study is located in Scandinavia, where there is a more ‘ecological’ mindset. Both from political side and construction industry in Belgium the feedback is that the individual will not make decisions based on sustainability – thus results would not be as impactful. (D. De Vriese, personal communication, 20.5.2021) (D. Wiese, personal communication, 17.8.2021).

This is similar however to the Tiny Home motivations: people move Tiny for their own benefit. So if we can create labels/communication that show people the benefit for their own life, it would create a stronger resonance and action.

- Existing labels

Energy labels are very effective, but not necessarily good for the climate. Architecture certificates are not well known, and not transparent. They do not communicate a clear message to their users.

The energy label: effective but imperfect

Looking at Danish and Belgian real estate websites there are 2 main indicators considered when buying a house, one is the price and the other is size (m^2 and number of rooms). Additionally at the bottom an energy label is present. In Denmark the label is present for most homes, and is currently a deciding factor when choosing a house. In Belgium you don’t see the label often, but when it is there it is accompanied by a detailed section containing also CO_2 count.
Looking at this detailed information for energy, there is quite a lot of data available, albeit not very clear. We would have to assume CO_2 numbers are from energy usage.
Price, location and size of house are the only filters on the website, so you cannot select a house based on energy class or any other sustainable element. And as a sidenote: the units are not correct: CO_2 eq. should be used otherwise not all GHG are accounted for!

This energy label based on the energy frame discussed in part 2 is used for everything from food to technology. It has become very common and successful. But as discussed in the economic section, you can easily build a home with a low energy frame and a very high environmental impact! So this label is not watertight.

Architecture Certificates

Another label existing for buildings are architecture certificates. These are not as well known by the general public and used more for bigger projects. The main certificates used worldwide are BREEAM, LEED, CASBEE, SB Tool and Green Star. In Denmark DNGB is used.
These certificates have been developed as a holistic architectural tool to evaluate and measure the sustainability of buildings. As such they also require the LCA of building as seen in step 2, environmental sphere.

Research into architectural health indicators however shows a need to update these certificates. Usually five subject areas are measured: air quality, lighting levels, acoustics, thermal comfort and safety. However the definition of health according to the WHO requires a state of complete physical, mental and social well-being. Not just the absence of disease. Thus a wider range of factors as was addressed in the social sphere in Step 2, should be included. (Rice and Drane, 2020)
Additionally there is no real connection between these certificates, and they all are rated differently. A suggestion made in a research paper is to use the familiar A-F system for all certificates to create clearer communication. (Rice and Drane, 2020)
There also seems to be a gap between the architectural engineering and practice. From the contractors point of view these certificates don’t pertain any useful input. They require quite some effort to put together, so mostly a consultant is hired to do it. But there is no connection to decisions in design or construction. The construction companies want to have more direct data on materials as this is what influences their work and environment the most. (Moradibistouni, 2020) (Abd Rashid and Yusoff, 2015) (D. De Vriese, personal communication, 20.5.2021)

These criticisms seem to point in the same direction: an update is needed if we want these certificates to be useful. This will require a focus more on social and mental health and on materials – as they are the strongest indicator usually of GHG. (Rice and Drane, 2020) (D. De Vriese, personal communication, 20.5.2021)

DNGB – the architecture certificate used in Denmark

In Denmark the DNGB label is used. It has more detailed specifications for indoor environment than most. It mentions outdoor space and the importance of a user manual for a home. In general you will get points for good aspects, and you need a minimum in the end to get the certificate. For example you will get points if the ceiling is minimum 2.5 meters. A lot of these rules simply don’t work in a Tiny Home design though. (DGNB – German Sustainable Building Council, 2021)
The label also emphasizes wheelchair accessibility. This was implemented in *Tiny Step’s* design. It was quite a puzzle, but in the end it actually improved the space making it feel more open. Including wheelchair accessibility in the home is not because I expect many people in a wheelchair to move tiny – and if they do they will probably design their Tiny home differently, as they know their needs better. But in the past most buildings where designed without these considerations in mind. So if we build something new, we should do it with care for these aspects as well.

Thus….

The 3 main factors of price, energy frame and size are definitely not adequate to describe the quality of a home. But even with the added architectural certificates, the importance of design when looking at health, material choice and carbon footprint, is information that is not available on the market.

- Label design

What are the communication priorities for Tiny Step?

Key indicators where already chosen in Step 2. But if this full analysis were to be published in every add for a house that is for sale, it would be too much information. The average potential buyer would not even know what it all is about. Labels require a clear instant communication: there is no space to explain every detail. It is important to choose a message and stick to it.
We'll start with the focus of this thesis: environmental impact. Climate change should be the absolute first indicator, a **carbon footprint** (GWP) should be the main focus in combination with **Circular economy.**

As mentioned earlier, personal benefits to the buyer of a house should be highlighted. Concern for the environment is not high on everyone's list. **Financial benefit** is at the top of the list, but it's usually not necessary to remind people of this, so this label can be at the bottom of the list.

The second most common motivator to move Tiny is the search for a better simpler life. Key indicators of **social and physical health** of a home should get their spot.

We should not forget the political key indicators. But a label indicating if you're house is legal(ly placed) will seem dodgy. If a house is on the market, potential buyers will assume it's legal, so there is no need for a separate label.

The Energy Label is a tricky factor : although very well known by the public, we have shown it is not a good indicator of how low carbon a home is. This is why we will place this label together with the price in the bottom (left) corner.

Important elements;

The labels suggested have been placed in a specific order as we need to know what information is more critical to properly visualize. Similarly to the graphic design principles based in cognitive science, research shows that visibility, placing, A-F marking and avoiding vague terms are important. (Edenbrandt, Lagerkvist and Nordström, 2021)(Rice and Drane, 2020).
A paper specifically on carbon labels found that the placement of labels plays a big role in people's perceived importance of the information. The top right corner is perceived as the most important, while the bottom left is the worst placing. The buyer behavior is influenced accordingly, though to what degree it is influenced, is dependent on the need of structure a person has. (Zhou *et al.*, 2019)
Going back to the house listings, remember the price was on top right followed by m^2 while energy label was in bottom left, hidden on top of the picture of the house.
People have a different degree of need for structure. This influences their behavior looking at labels. Aka it moderates the connection between location of label and purchase intention.

- The carbon label

Existing carbon labels

Carbon labels have been around for a while. They also seem to be on their way to become as mainstream as energy labels. So what hurdles are there to take? Looking into some of the most common carbon labels there are two issues:

1. They do not always give correct scientific information. This is understandable, as the matter of Climate Change and Climate Communication is quite complex. But we should definitely start from the basics:

> *Green House Gasses – GHG - is a collection of all gasses that are heating up the climate. They are expressed in "CO_2 equivalent" since carbon is the most common GHG we know. The units are kg CO_2 eq. Sometimes instead of using the term GHG, 'carbon'or 'carbon emissions' is used, which doesn't help with clarity.*

For example the Carbon Trust label always talks about CO_2 instead of kg CO_2 eq. In the age of misinformation wars these details matter. As a minimum a small eq will not confuse people, but it will indicate scientific validity. (the carbon trust, 2021)

Figure 38 – Carbon labels used by the carbon trust (the carbon trust, 2021)

2. Perspective is needed. If I tell you buying a shoe will create 200 kgCO_2eq, then what does that mean? Less GHG is better, but how much is "a lot", let alone "too much"? We need a baseline to compare. This is why the energy label for example works with A- F, so your shoe might be a F class compared to another shoe, or it could be a A+.
Another way to do this is to compare with the offset: I have to grow 3 trees in my garden to balance out buying these shoes. Or 2000 trees for a house. – this is trickier as it will always be an estimate. Trees store carbon at different levels over time Different trees also store different amounts of carbon, and their environment will influence these factors too.
Nevertheless it has become a familiar way to visualize data. So while not exact, it holds value.

For this thesis we suggest the usage of a Carbon label, including an A-F scale, and the total count of GHG in "tree count". We do not mean to say that this is the perfect choice for a label, but we hope to point this discussion in the right direction.

GHG alone doesn't give the full picture on climate impact, even if it is the strongest indicator. Circular economy is another aspect that ideally would be addressed. However doing this would defeat the purpose of the labels to be clear direct indicators. Thus we will leave the recycling factor out.

- Health Label

This one is more complicated as it encompasses the complexity of indoor environmental quality, and it encompasses social health of a design – interior design principles.

A possibility for the label could be a list that gets points, these points then place the label on the F-A scale.

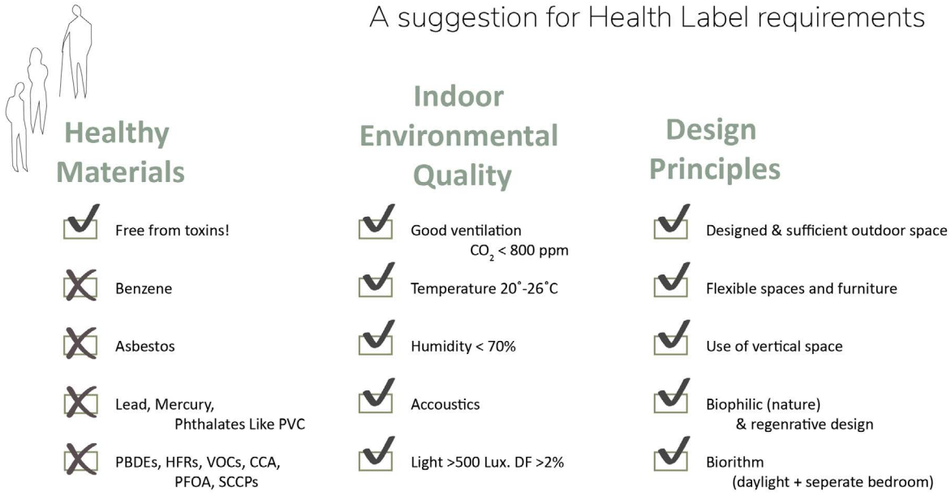


Figure 39 A suggestion list for Health Label requirements.

- Conclusion

Today information on housing is focused on two parameters: m^2 and price. These are not indicative of quality or environmental impact. Existing measures such as energy label and certificates are not transparent or clear. Information about health of materials, health of design and environmental influence is not present.
Labels are a very effective tool to add this information and to inform a broader audience. Thus a first suggestion has been made here. Based upon research done in the thesis GHG emissions was prioritized, and a second label describing the health of a building was suggested.

A COMPARISON BETWEEN TINY STEP AND 'STANDARD' HOMES

We can place the labels on the Tiny Home. But how do we assess their value? We need something to compare with to have a sense of scale. Here we will look at what the typical Danish newly built home's carbon footprint is. It shows that - for 2 person households - the Tiny Home is the clear winner, even over renovated homes. Building Tiny instead of a 'normal' home would save as much GHG as not flying your entire life.

- What house would a Tiny Home replace?

Often a comparison is made between Tiny Homes and average houses based on people/m^2. But that is not necessarily the best reflection. As stated before Tiny Homes still are quite expensive and a lot of people investing in them have a stronger financial background. (Boeckermann, Kaczynski and King, 2019) Thus we will take a closer look at the statistics and choose a suitable comparison.

100m^2 or 200m^2? Investigating house size statistics

The main target for the Tiny Home so far as has been 1-2 person household. As mentioned in step 1, this is 65% of people living in and around Copenhagen.
When we want to compare to other homes a choice has to be made, and we fix the targeted household size at 2 people. A common way to compare the Tiny Home to a normal home is to look at m^2 per person. Looking at statistics in Denmark we see that on average sqm pp is 45 - 60 m^2 depending on the housing type. This is not necessarily the most correct comparison – lets take zoom in on a 2 person households in Denmark.
Looking at a more detailed table showing 2 person households and housing size there are 2 main groups: apartments and detached houses (row houses are not very common in Denmark; but they are in other countries). Apartments have the largest group at 50-100m2, while detached housing is from 100 m^2 and up.

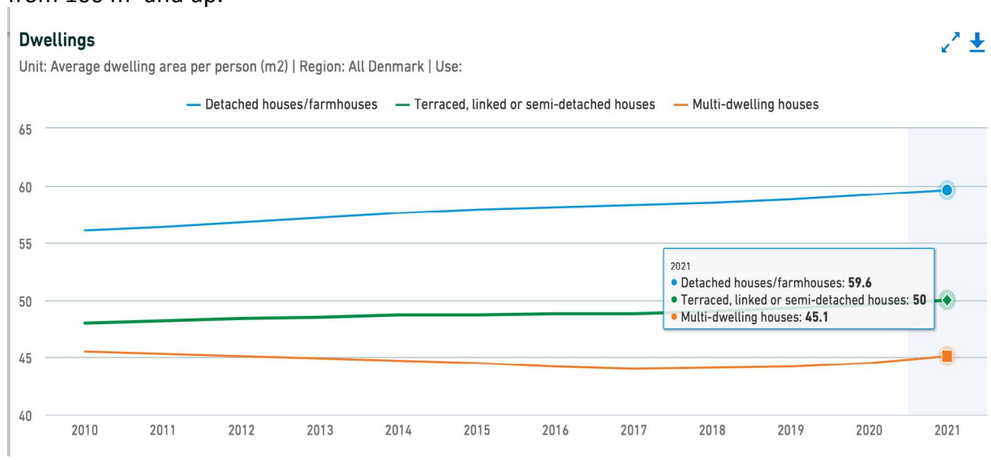


Figure 40 Dwellings by use and m^2 per person (Danmarks Statistik - BOL 106)

The house of a demographic who would potentially 'go Tiny'

This last group will be used for the comparison. This is for several reasons. Most people living in apartments are located in cities. This seems to be a lifestyle choice, one for city living. (Danmarks Statistik - BOL101, 2021) While people in detached houses are choosing for a garden space, rather than proximity to the city. Some prime locations for Tiny Homes are available in city property, but they will be rare. However it is perfectly possible to live at a 20 minute travel distance from Copenhagen in a green villa neighborhood.

Thus the choice was made in this thesis to compare the Tiny Home with a 184m² home, instead of average m² per person.

Dwellings by household size, type of resident, county, time, size of dwelling in square metre and use

	Detached houses/farmhouses	Terraced, linked or semi-detached houses	Multi-dwelling houses	Student hostels	Residential buildings for communities	Cottages	Other
2 persons							
Dwellings with registered population							
All Denmark							
2021							
- 50 sq m	252	1 187	16 067	2 908	27	464	265
50-74 sq m	5 386	11 041	104 846	1 744	52	2 484	211
75-99 sq m	34 957	53 416	118 696	134	32	3 999	274
100-124 sq. m	92 332	42 250	43 987	5	5	2 963	301
125-149 sq. m	127 049	14 279	12 981	5	4	1 130	213
150-174 sq. m	99 136	3 348	4 902	0	1	394	189
175 sq m and over	111 696	1 818	3 974	16	60	232	301
Unknown	0	0	0	0	0	14	446

Figure 41 Dwellings by household size, type of resident, county, time, size of dwelling and use. (Danmarks Statistik – BOL 103)

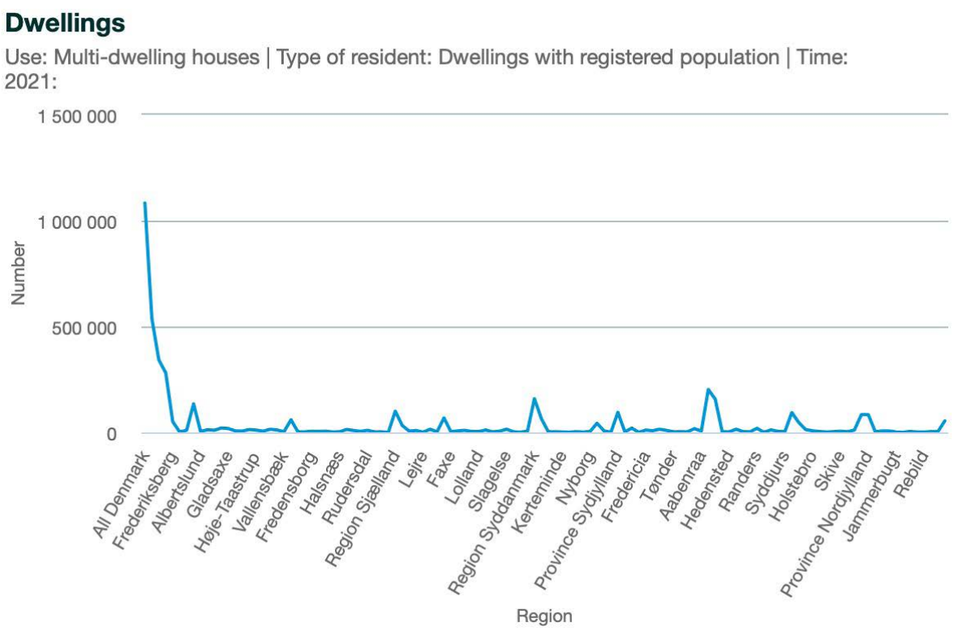


Figure 42 Apartments in Denmark by region (Danmarks Statistik – BOL 101)

- One on one comparison

Comparing to a renovated home or a newly build one?

While the size of the house has been decided, one question remains: there is an important distinction in buying an older home, or a newly build one. While older homes might require repairs and have a higher energy frame, they are part of the built framework and thus a lot of energy and carbon is stored in them – so less to be created newly.

Newer buildings due to regulations and market demand usually come with a better energy frame. This doesn't necessarily translate in a lower carbon footprint. A house made out of concrete or a wooden prefab home have a very different footprint.

Comparison to new build – concrete and brick

Tiny Homes are not widely available yet, so if you want to live in one most likely you will need to build it. For this reason it seemed logical to compare the Tiny Home with a newly built construction. This way an insight is gained of the GHG that would be saved based on the house you decide to build.

The house is 184m² with an energy frame of 17.3 kWh/year. The settings have been adapted to match those of the Tiny Home (100 year standard comparison). The materials used are mainly concrete for foundation, floors, walls, roof, general roofing, EPS insulation and mineral wool insulation. All of these are heavy contributors, in combination with size this results in a GWP value. The GWP of electric and materials is at 132 000 kg CO_2 eq. There is a clear difference, where materials are the dominant influence.

These results will be used in a poster page to compare a Tiny Home listing with labels, to a 'normal' home listing.

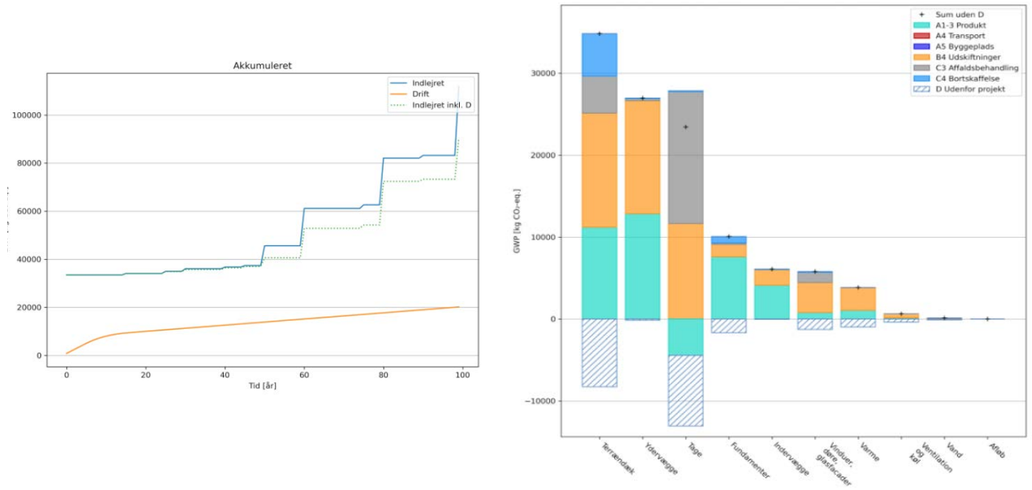


Figure 43 Concrete example home from LCAbyg results Generated with LCAbyg software (LCAbyg, 2020)

Discussion comparison to renovation.

According to European commission 75% of older buildings are inefficient and renovations could reduce GHG emissions by 5% (European Comission, 2019) (BuildDigiCraft, 2020)

For a renovated building, the embodied carbon of a building, operational (energy use) and demolition “carbon” is respectively 24%, 75% and 1%. Current research says it is not possible yet to determine if building new or renovation is the best decision. In general renovated buildings have a lower GWP. (Schwartz, Raslan and Mumovic, 2018) Of course these data are looking purely at GWP of 1 building. From a city perspective, throwing down a city and building it new entirely intuitively does not seem like the most climate friendly option.

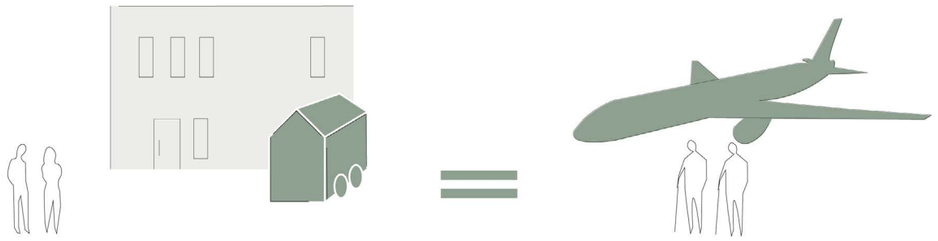
Looking at the concrete home from LCAbyg we see that 20% of its influence is from energy use (electricity). This while the energy frame is very low at 17.3 kWh/year. At 20.000 kg CO_2eq the energy use alone of a large, well constructed, home is already bigger than the entire Tiny Home GWP.

This means that living in a big home, even when its renovated, doesn’t seem to be the best solution from a climate point of view - not when occupied by a 1-2 person household!

117 000 CO_2 eq saved by building a Tiny Home – is this relevant?

Tiny Homes are still rare, so it is safe to assume most of them will be built new. Thus comparing the Tiny Home to the most commonly build new home we see you would save 117 000 kg CO_2eq.

CARBON FOOTPRINT SAVED
BY BUILDING A TINY HOME



What do these numbers mean? Building a Tiny Home instead of a concrete and brick house saves 117 tons of CO_2 eq. Based on the average Danish persons GHG output from flying, this means that is you need to live for a 100 years and never fly to save the same amount of GHG. (Our world in data, 2020) Of course building a Tiny Home doesn’t mean you should suddenly fly out on trips every month! Buying a Tiny Home second hand will be even better: you will still have the small energy use and energy bill, plus you avoid the carbon footprint of a new construction.

- Scale up – Copenhagen area

What if we scale up this data ? What would a policy supporting Tiny Homes in the greater Copenhagen area mean in terms of carbon reduction? Would it be of help reaching the 2030 goals?

Statistics on demographics and housing in surroundings Copenhagen

We can make an estimate based on data provided by Danmarks statistik. There are 798 976 people living in Copenhagen, and 550 938 in the areas around Copenhagen. (Danmarks Statistik - FOLK1A, 2021) Copenhagen city is quite densely built, and the chances of finding a spot for a Tiny Home are quite small. The surroundings of Copenhagen are the result of superb urban planning. Low density, green neighborhoods and fast connections to the City with either car or public transport. This is why we will look at the surroundings of Copenhagen for the potential capacity of Tiny Homes.

For simplification reasons we will first look at people living in 1-2 person households, as they are the main candidates for Tiny Homes. Demographics in Copenhagen area show that this is 40 % of households. (Danmarks Statistik - FOLK1A, 2021) ((Danmarks Statistik - FAM55N, 2021)

Every year 2014 homes are built in the surroundings of Copenhagen. Well over half of these are apartment buildings. (The full year data from 2019 was used to exclude Corona pandemic irregularities) (Danmarks Statistik - BYGV22, 2021)

We don’t have any info on *who* is buying these new homes or building them. It could be only families are investing in home ownership, and our target group isn’t part of the equation. On the other hand Tiny Homes are lower in price and thus would result in more people willing and able to buy them, effectively changing those numbers.
Families who would move out of the city to live in a Tiny Home are also disregarded. This could be a considerable amount. The 1-2 person households in Copenhagen city are approximately 890 000 people! Especially taking into account housing prices in the city, the good transport connections in Denmark and the increased ability to work from home since the pandemic.

Results

Of people living in the suburbs 40% will be 1-2 person households. Let’s assume half of them would decide to build a Tiny Home. That means 20% of 2014 homes being build would be Tiny Homes. Thus in total around 400 homes would be built. This would save 46.800.000 kg CO_2eq in 1 year time. Which equals 2373 football fields filled with trees...

We’ll make a simplified tree estimate – all trees store different amounts of carbon and they will not store as much the first years while growing, so this is assuming a grown forest. (Anna, 2015)

1 tree = 21 kg CO2eq. every year.
46.800 000 kg CO2eq. : 21 kg CO2eq. = 2 228 571
7000 trees can be placed per acre
2 200 000 : 7000 = 318,36 acres
318,36 acres to kilometer = 1.29 Sq. kilometer
1.29 km^2 = 241 football fields.

If all the people 1-2 person households would go Tiny, this would mean 800 new homes would be Tiny Homes, and thus **93.600 tons CO_2eq.** saved.

To put this number in perspective:

> This would be equal to planting **482 football fields**, or a forest about **2 times DTU campus.**
>
> This number will also be saved if every person in Copenhagen area - 1.3million people - would eat 3 steaks less every year. (Ritchie and Roser, 2020)

Thus a big impact can be made converting our new buildings to Tiny Homes. On the other hand, it seems convincing people to stop eating steak would have a bigger impact… Honestly it's probably easier to sell the Tiny Home idea!

- Conclusion

Looking at comparable homes that potential Tiny Home owners would live in, there is a clear difference in impact on the environment. Even compared to a renovation the Tiny Home will still score better, as its full GHG count use doesn't even match the GHG produced by the energy use of a big home. This is looking at 1-2 person households of course. The amount of GHG saved by building a Tiny Home instead of a traditional building is equal to not flying your whole life. Looking at the scale of a city this means planting an area the size of Copenhagen center full of trees, 4 times over.

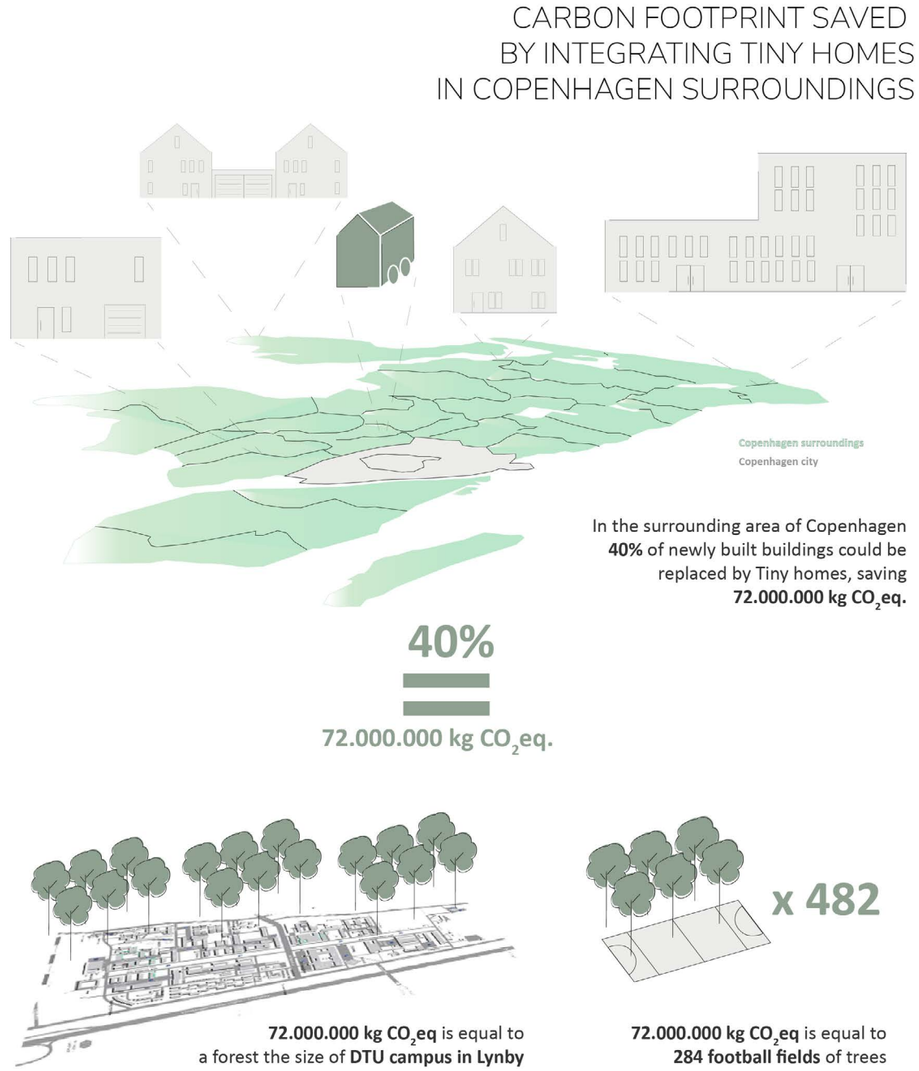


Figure 44 If the target group of 1-2 person households would build Tiny instead of a traditional building, a forest the size of DTU would be saved in GHG/carbon footprint or 482 football fields with trees.

-

-

CONCLUSION ON STEP 3 COMMUNICATION

Much can be done to improve communication of climate change. It is a field in its own that requires interdisciplinary work to be optimized. The thesis applied several techniques research suggested, from narratives to graphics to support the written research. Additionally the thesis identified its stakeholders to bring a targeted message: you, society and environment. This is why language has been kept accessible for all.
2 additional measures where identified to improve communication:

1. Labels

Transparency and information are key to creating a society that can change track. Real estate today is judged by m^2 and price. Existing measures such as energy label and certificates are not transparent or clear. Information about health of materials, health of design and environmental influence is not present.

A carbon label, and a health label are proposed as quality parameters to accompany the price of a home.

2. Comparison

Looking at comparable homes that potential Tiny Home owners would live in, there is a clear difference in impact on the environment. . Even compared to a renovation the Tiny Home will still score better, as its full GHG count use doesn't even match the GHG produced by the energy use of a big home The amount of GHG saved by building a Tiny Home instead of a traditional building is equal to not flying your whole life. Looking at the scale of a city this means planting an area the size of Copenhagen center full of trees, 4 times over.

The results will be translated into the new *Tiny Step* posters:
Poster 1 will be tiny step design, but used to explain climate change principles.
Poster 2 will be a listings page of homes with the suggested labels introduced.

Climate Change & a Tiny Home

A low carbon life style

MITIGATION OF CLIMATE CHANGE

To avoid severe levels of global warming, we need to reduce greenhouse gas emissions and look after the ecosystems of our planet. Thus our homes need to play their part by supporting a low carbon and environmentally conscious lifestyle.

PREPAREDNESS FOR CLIMATE CHANGES

Local climate is changing already, we need to prepare our cities and envionment to these changes. For example, your home needs to be able to handle more extreme temperatures.

Green energy

Renewables are cheaper for you and better for the environment! A small well designed home does not have a high power demand. Tiny Step can be supplied by 2-4 solar panels.

Houses are responsible for 1/3th of GHG* in Europe

Green roof

A city can be up to 10 degrees warmer than its surroundings. This is due to a combination of several effects. In short a city changes a green field that reflect sun/heat into a 3D surfaces of concrete. This concrete absorbs a lot of heat while the nature mostly reflects it.

To combat this it's essential to reduce dark surfaces & thermal mass. This is why the house is colored in a silver color and has a green roof.

Vertical food garden

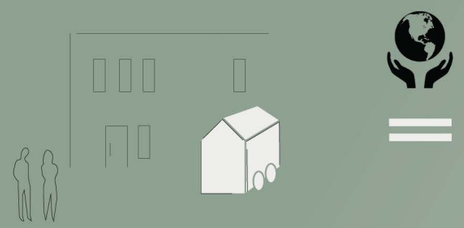
Food has a high impact on the environment, it is responsible for 26% of GHG* globally. Thus starting to grow some at home will lower your carbon footprint. and reduces pressure on agriculture worldwide.

Cooling the home

It is important to install dynamic cooling on the outside of the home. This will prevent the sun from reaching the windows in summer and overheating the house.

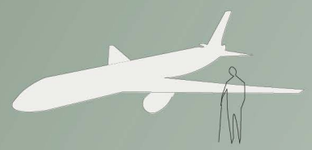
Carbon Footprint

CO_2 is the GHG* of who we affect the cycle the most. Thus it is important to limit its impact in building a home. Additionally Tiny Homes have also been shown to create a low carbon lifestyle for the owners. 2/3th of all GHG can be directly related to households.



90.000 CO_2eq

is saved by building a Tiny home instead of a traditional brick and concrete house .



100 years of flying

for the average Danish citizen

Disaster preparedness (floods and storms)

Increased storms and erratic weather, including flood risks, demand a shift in building. A raised foundation protects from flooding. On wheels a Tiny home can even be removed from danger zones.

The home is easier to replace as it costs less and it can be manufactured fast in prefab. Tiny homes can be used as shelter homes after a disaster.

*GHG – GREENHOUSE GASSES [CO2e.] are the collection of gasses responsible for heating the earth's surface and atmosphere. These gases are also referred to as "carbon" and "carbon emissions". Units are expressed as carbon dioxide equivalents- the greenhouse gas that humanity is impacting most.

Comparing house listings - with labels

CARBON FOOTPRINT A ---------- F

100 000 kg CO_2 eq.

4761

Health score A ---------- F

Energy A ---------- F

Price 200 000 Euro

100 m² - 2 bedrooms

CARBON FOOTPRINT A ---------- F

50 000 kg CO_2 eq.

2380

Health score A ---------- F

Energy A ---------- F

Price 150 000 euro's

50 m² - 2 bedrooms

CARBON FOOTPRINT A ---------- F

130 000 kg CO_2 eq.

6190

Health score A ---------- F

Energy A ---------- F

Price 420 000 Euro

184 m² - 3 bedrooms

CARBON FOOTPRINT A ---------- F

13 000 kg CO_2 eq.

620

Health score A ---------- F

Energy A ---------- F

Price 128 000 Euro

30 m² - 2 bedrooms

The 2 projects on the right are based on the thesis research.

On the left general examples are shown.

1. Bias thesis & taking a step back

Taking a step back – bias of research questions.

This thesis found Tiny homes to be a very effective way to communicate a sustainable life style. It also seems on a larger scale Tiny Home construction could help the architecture industry move more rapidly to a low carbon housing typology. When I started this thesis I was looking for a way to get tiny homes out of the fringe and legalized, so they would be accessible to all those who would want them. I thought about general sustainability but I didn't realize the further social or sustainable consequences, nor had I thought about it from a business perspective.

Taking a step back. The thesis showed Tiny homes are very climate friendly solution, but is there better? I would have to say, renovation – if done with sustainable and low carbon materials. Numbers show the Tiny Home is better than renovating, the fact remains that not everyone will want to live Tiny, or should live Tiny. Thus a double strategy seems pertinent: use the development of Tiny Homes, to experiment and develop good low carbon building solutions that can be applied in the renovation industry.
Surprisingly conscious food choice might have a bigger influence than building Tiny. Of course this is considering you can convince all of Copenhagen area to eat less meat. It might be easier to convince a smaller amount of people to move Tiny.

The bias of the methodology

Research by design is itself a method that creates aspirational results. (Gaver, 2012) Often the solutions are temporary and change with time. This is logical as the setup of the methodology recognizes that the world is changing, now more than ever due to climate change.
(Gaver, 2012) (Roggema, 2016)

2. There is a 4th stakeholder in the thesis – building professionals

The thesis started by identifying 3 main stakeholders: *you, society and the environment.* Drawing up the conclusions it seems there is a 4th one: the building professionals. The research and Tiny Step design brought up several points on architectural design, engineering and construction.

Architecturally it was surprising to see how interior design came up very detailed, both through the Tiny Home research and post Corona Pandemic findings. Additionally the influence of user behavior on the energy use of a home is much higher than expected. This means a closer connection between architecture – material choice, design of a room, windows,… - with the engineering side is needed to create an environment that can foresee comfort and have a low energy use.
Engineering environmental quality in a small space is a quite a challenge, and the small size skews

results in simulations. Additionally much of the technology that could be applied in Tiny Homes does not yet have a standard setting in simulation software such as IDA ICE.

The construction industry is where I have the least experience, so it is harder to make accurate statements. It is clear however that there is a disconnection with the more academic side of engineering and architecture. The construction time of a Tiny Home on average is 3 months, a 'normal' house can be easily a year. Thus it is fair to say that Tiny Homes could serve as a rapid experimentation in green buildings. Intuitively it seems a larger Tiny Home industry would create new sustainable jobs that don't require too much specialization. For example installing decentralized ventilation units, or a composting toilet can be done easily and doesn't require the knowledge of a plumber or technician. This addresses one of the bigger concerns in switching to a sustainable economy: the factory workers whose specialized skills would be worthless on the new job market would be able to find jobs in a Tiny Home industry.

For Tiny Homes to work all building professions have to be integrated better. BIM software is making the first steps in this direction. But it is important to adjust these softwares for the design phases of a project. Both the final engineering and construction require specific data – this is where modelling and simulation such as IDA ICE usually come in.
However the concept design of a home has the biggest influence. This decides the size of a home, the orientation, the materials and construction methods,…10 hour simulations and correct numbers are not practical when making these decisions. A tool that instantly shows the impact of the decisions that are made is much more useful.
This why Sketch up was used as a first step to determine the size of the outdoor roof for shading. Then it was followed up by a more detailed simulation in IDA ICE. Sefaira is a sketch up plugin that does simple simulations while you are shaping a design. LCAbyg and One Click LCA to fit very well into the design category. It is not focused on the most accurate numbers. It gives the impact of material choice and size of the design, directly linking it to climate change.
Optimally these the programs should be accessible for all architects. This means in English, easy to use and affordable. A lot of architects in Europe work in small studios, they cannot afford to buy too many programs. But a software such as LCAbyg could help them make more informed design decisions.

3. Climate change communication & architecture

It surprised me to see research showed renovation can have the same impact on environment as a newly build home. This is relative to each case, but purely energy use of a bigger home at a low energy frame is 20.000 – while the *total* influence of a Tiny Home is 13.000. But based on these findings it seems living Tiny and rebuilding is better for the environment than renovation and preservation of big buildings. Living in a Tiny Home is not ideal for everyone. Thus it would be interesting to see more comparisons looking at renovations that create smaller homes in a structure.
More research is needed on this topic to make any final conclusions, it would be interesting to see a detailed comparison on LCA versus circular building and the impact of waste.

The importance of graphics and interdisciplinary work was part of the thesis from the start. It was improved with the research on climate change communication. Labels however where originally not included. Labels as a communication tool could change the building market. They are already introduced on food and are quickly becoming a standard in fashion. So carbon labels are a known factor, and applying it to houses is a logical step.
A health label goes one step further, a step that should have been taken years ago based on toxicity of buildings.
These labels will change consumers behavior and force the market to evolve to a more sustainable economy.

Explaining Climate change through architecture can be a powerful tool. Architecture is people's home, it is close to peoples' heart. And it as a very big influence on lifestyle, as Tiny Home research showed. Additionally architects are a discipline already trained in communication.
Small solutions to adapt a home for climate change are already suggested on danish climate plan website! (klimatilpasning, 2020) But they are a bit outdated and not specific enough at the moment. This is not just on the scale of a home. The first climate change adapted square in Copenhagen - *Tåsinge Plads* - is be a tool for communication of climate change on the scale of a neighborhood or city, explaining flooding due to extreme rainfall. But is it fully used? I personally don't know if they take any action, but an idea would be school tours, or local signs.

4. Still to look into

As the thesis took a holistic approach some elements couldn't be discussed in depth. It would be interesting to see a full in depth LCA of a Tiny home with dedicated EPD files for the materials used. Even more interesting would be to have the comparison with dedicated LCA of a wooden prefab home, a renovation ánd a concrete home. Ideally this would be accompanied by a recycling potential or in depth research in circular economy.
It would be interesting to see research go in depth on the relationship between circular economy, LCA and law. It is necessary to rethink how to optimally use these tools so that they can support a low carbon development in the construction industry. Subsidies for EPD files from small start ups seem like a must.

The development of a carbon label and health label where just a suggestion. More research needs to be done to optimize transparency and connection between community – real estate – construction and design.

The technology in the home could be simulated in more detail. But for this to be a true representation practical testing would have to be done, looking at how infrared heating reacts to a space, and certain materials. And mostly the influence it has on user behavior. Will the different type of heat source be uncomfortable? Or merely a matter of getting used to a new situation?

Of course the suggestions for law adjustments will probably not be complete as my perspective is mainly an architectural and engineering one.

Finally it should be accessible and standard to check for future scenarios, or more extreme weather events. To create climate prepared homes.

Environment
Social
Economic
Political

SUSTAINABLE DEVELOPMENT GOALS

SDG 7 Affordable, sustainable energy
Tiny Homes are pioneering off grid homes due to their small energy demands - which facilitate the use of renewables. Thus they create a lower environmental impact. This also results in a smaller price, thus better accessibility.

SDG 8 Sustainable work
Tiny Homes are a fast growing market that requires low specialization workers. These are jobs that help lower environmental impact.

SDG 6 Water and sanitation
While not exclusive to Ttny Homes, composting toilets and local water recycling are popular practice, providing social and environmental benefits.

SDG 10 Reduce inequality
Tiny Homes create an accessible housing market. This allows people to buy a house earlier in life and save to become financially stable.

SDG 12 Consumption
A Tiny Home automatically reduces consumption.
The Tiny House itself is already part of circular market with many secondhand builds. Additionally, the Tiny Step proposed is designed for circular economy.

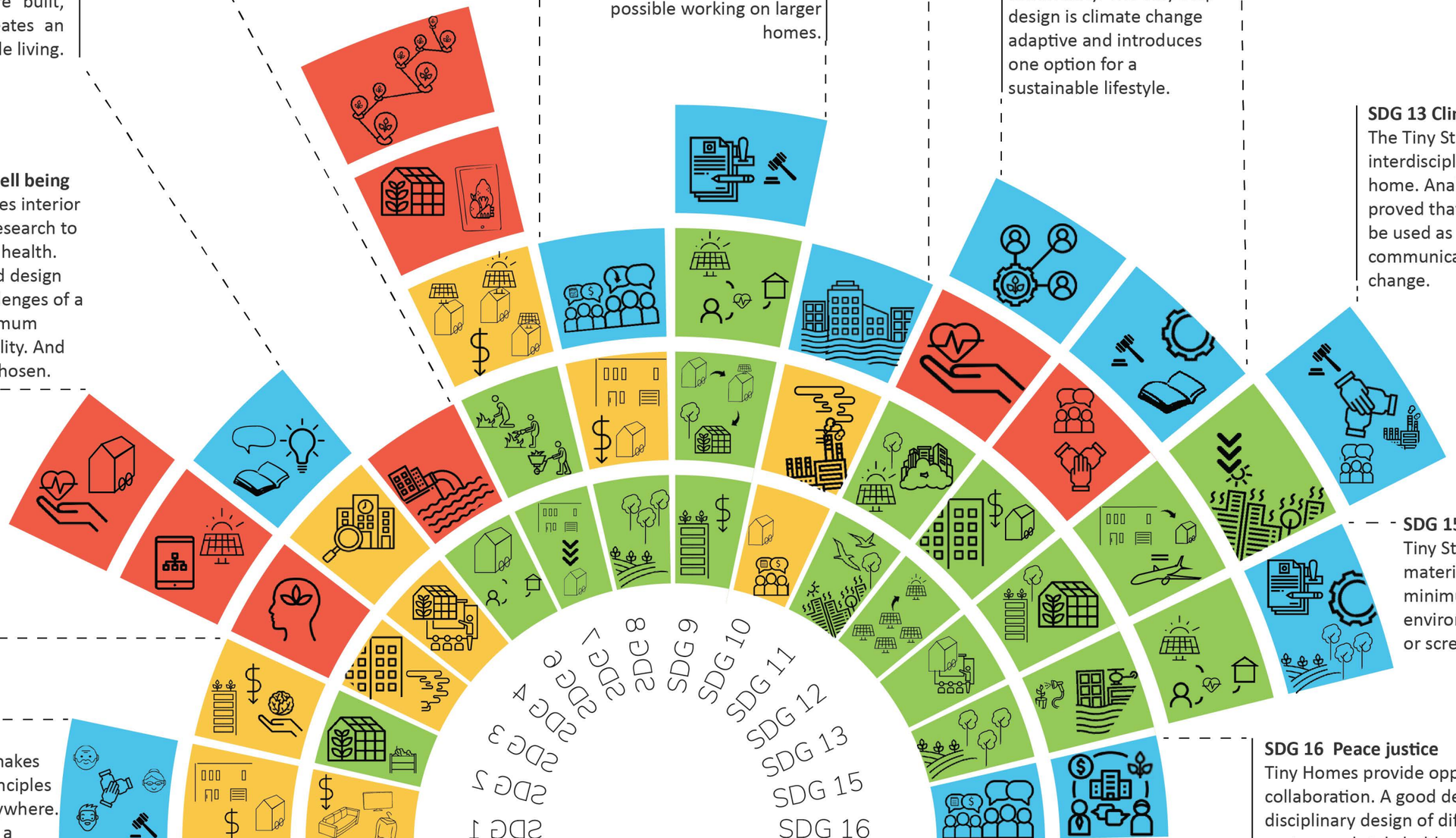
SDG 4 Quality education
Tiny Homes are very popular. They receive wide media coverage. Thus creating a design that is specifically low carbon and sustainable can use this popularity to further educate that small is not the only sustainable factor a Tiny Home has. Additionally, as more homes are built, their visibility in the streets creates an interest in sustainable living.

SDG 9 Innovation
Tiny Homes are closely tied to prefab, modular building and circular economy. Their small size allows a more rapid experimentation that is not possible working on larger homes.

SDG 11 Sustainable cities
Tiny homes create a more diverse housing. This creates a stronger community. The Tiny Step design is climate change adaptive and introduces one option for a sustainable lifestyle.

SDG 13 Climate action
The Tiny Step design is an interdisciplinary low carbon home. Analysing this design proved that Tiny Homes can be used as a tool to effectively communicate about climate change.

SDG 3 Good health and well being
The Tiny Step design applies interior design parameters from research to provide social and mental health. Additionally the integrated design adresses engineering challenges of a small space to create optimum indoor environmental quality. And healthy materials where chosen.



SDG 2 Zero hunger
The Tiny Step design has outdoor cladding that supports growing a vertical food garden. Thus stimulating people to grow food at home, lowering their financial needs and carbon footprint.

SDG 15 Protect ecosystems
Tiny Step minimizes material use and has a minimum impact on its environment through wheel or screw foundation.

SDG 1 No poverty
The lower price of a Tiny Home makes housing more accessible. The principles of Tiny Homes can be applied anywhere. Living in a Tiny Home also means a quality home, preventing the financial burden that diseases such asthma bring.

SDG 16 Peace justice
Tiny Homes provide oppurtunities for collaboration. A good design follows inter-disciplinary design of different building sectors and stakeholders. Tiny Housing for the homeless is a common example.

Infographic SDG's modeled after the graph by Navaz Bilimoria (Bilimoria, Denoyelle and Nguyen, 2020)

CONCLUSION

An integrated overview of literature studies on Tiny Homes didn't exist when starting this thesis. The largest part of the literature written has been published only the last couple of years. At the same time the thesis made the link between this research and practical implications.

The thesis identified 3 main stakeholders at the start: you, society and environment. Drawing up the conclusions it seems there is a 4th one, **building professionals.**

Throughout research and development of the design it became clear that there is a big challenge in engineering to these small spaces. They are ideal for more experimental appliances such as infrared panels and decentralized ventilation. These technologies have existed for a long time, but they are not yet standard in simulation and modeling.
It also showed that there is a disconnect between the newer tools and design discipline. Simulation tools are often complex and used by an expert, while this information should be used in the earliest design. Similarly LCA building tools, while much easier to use, are still not accessible enough. At the moment building LCA can discourage sustainable building due to the lack of a sustainable material database. They also miss a link to circular economy.

You

The findings in the literature study showed very clearly the personal benefits tiny homes bring to an individual, due to change in free time and financial health. It also stated that Tiny Home living is a lifestyle, not a one-fits-all solution or a fixed-for-life situation. People live as a single or in a 2 person household 50% of their lives, which means everyone can try out the Tiny lifestyle to see if it fits.
The thesis showed how interior design is a critical factor in Tiny homes. Emphasized by post Corona research, the lessons learned from Tiny Home design can be applied in all homes. Specifically the relationship to outdoor space and design is critical for smaller living spaces.
This thesis also showed how people can make a more informed decision on choice of not only Tiny Homes, but houses in general - if we start to use transparent labels. Specifically the benefit of information on Health that has never been included.
The thesis also found that it is essential to work with the knowledge that most people are not going to change their life style for the sake of the environment, but when they move Tiny, they adopt a more environment friendly lifestyle automatically! Thus finance and a simpler life are key factors to communicate the benefits of moving Tiny.

Society

Many studies have shown the way we build is not good for people. Anything from varnish to furnishing contains carcinogenic materials. The thesis found that laws have to be set up to regulate materials entering the building market and furniture industry.
Tiny homes could be an opportunity to create fast market change in the building industry. Their fast build time, small cost and engineering challenges create a perfect environment for experimentation in low carbon housing.
Demographics show that the average household size in Denmark is 2.1 people. This means more than half of the people live in 1 or 2 people households. This is the ideal market for tiny homes! If the 1-2 people households that are living in the suburbs would build Tiny when building their home, it would result in carbon saving equal to a forest the size to 4 times downtown Copenhagen. Or 2800 football fields…

Environment.

Looking at one home, if you build Tiny instead of a concrete home, you will save as much as you would never flying your entire life.
Harder to put in numbers is the educational purpose of Tiny Homes that the thesis found. Due to their popularity Tiny Homes already have a wide audience. Adding sustainable building as a requirement for Tiny Home builders – specifically low carbon building - would show a wide audience what a low carbon and sustainable lifestyle can look like. The price at 128 000 Euro shows that it is accessible now.
Labels would be an excellent way to educate and involve the general public in the building industry. It would allow people to make informed decisions and create an incentive for building companies to prioritize and invest in low carbon solutions.

Last but not least.

Thus overall the thesis concludes that Tiny Homes are a holy grail solution, as they do not apply to all people. In Europe the biggest asset and challenge is existing housing. Tiny Homes can however fill in the gap here. Renovation is slow and costly, and not everything is build yet. Tiny Homes cater to a market containing 50% of the population, that hasn't been addressed properly. On a large scale they can create a fast experimental industry in development of low carbon building techniques. A combined focus on renovation and Tiny Home development would help the build industry move at a fast pace towards a low carbon and sustainable society.

When I moved to Denmark two years ago, I moved into a Tiny Home for financial reasons mainly. But the care for climate and environment was - and is - a big part of who I am. Living in a Tiny Home was not the fairy Tale experience one might hope for. But I was inspired to write this thesis because of it. While writing, some of my assumptions were confirmed. Tiny Homes *are* good for the environment in more ways than I imagined. One adopts a climate friendly way of life. Some findings were real eye-openers. Tiny Homes can give building professionals a healthy push. Communication is a big deal, and labels are a great tool. Health is much more closely related to materials used than I figured.
This thesis about *Tiny Step*, is a Tiny Step. But hopefully others will be inspired to add more and more steps !

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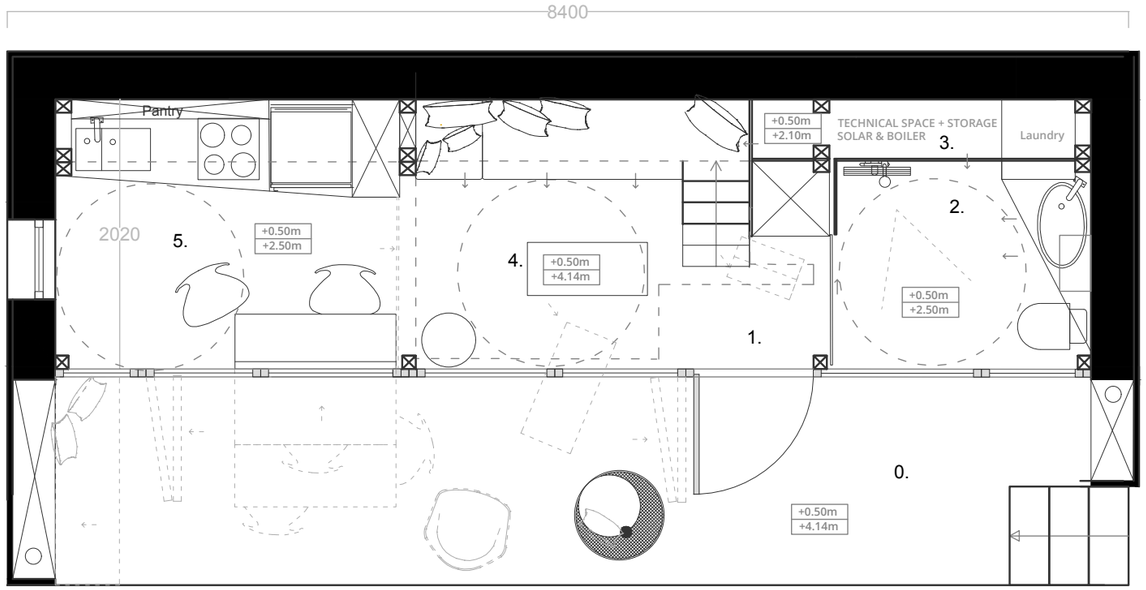
ANNEX

SECTION BB'

SECTION CC'

SECTION DD'

SECTION AA'



Groundfloor plan - Tiny
Scale 1/50

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by Laura Denoyelle
17/9/2021

LEGEND

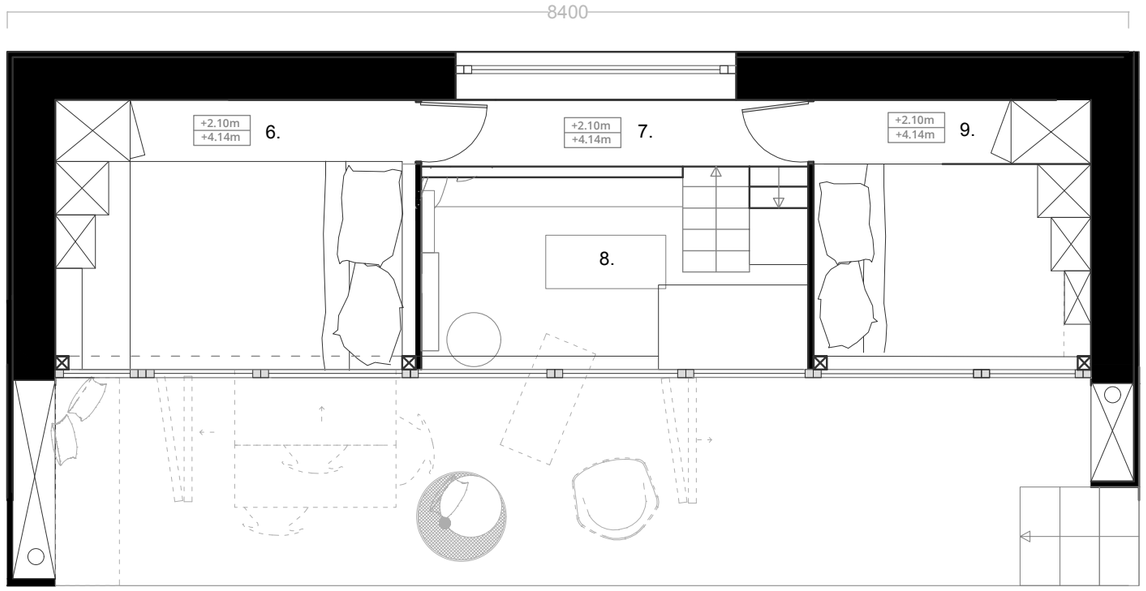
0. Balcony
1. Entrance
2. Bathroom
3. Technical space
4. Living room
5. Kitchen
6. Bedroom 1
7. Open hallway
8. Vide
9. Bedroom 2

SECTION BB'

SECTION CC'

SECTION DD'

SECTION AA'



First floor plan - Tiny S
Scale 1/50

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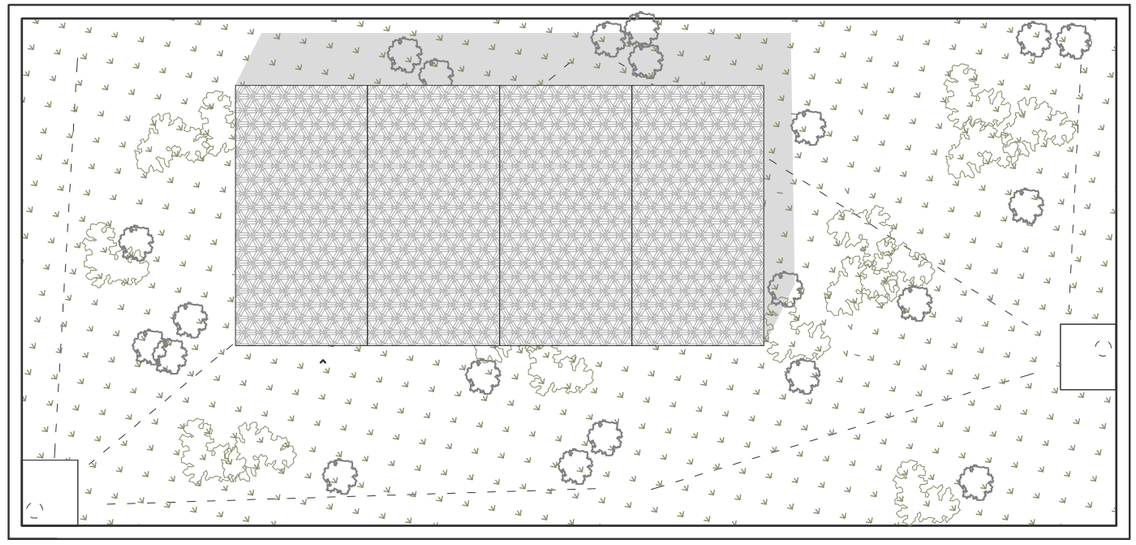
17/9/2021

SECTION BB'

SECTION CC'

SECTION DD'

SECTION AA'



Roof plan - Tiny Step
Scale 1/50

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Section AA' - Tiny Step
Scale 1/50

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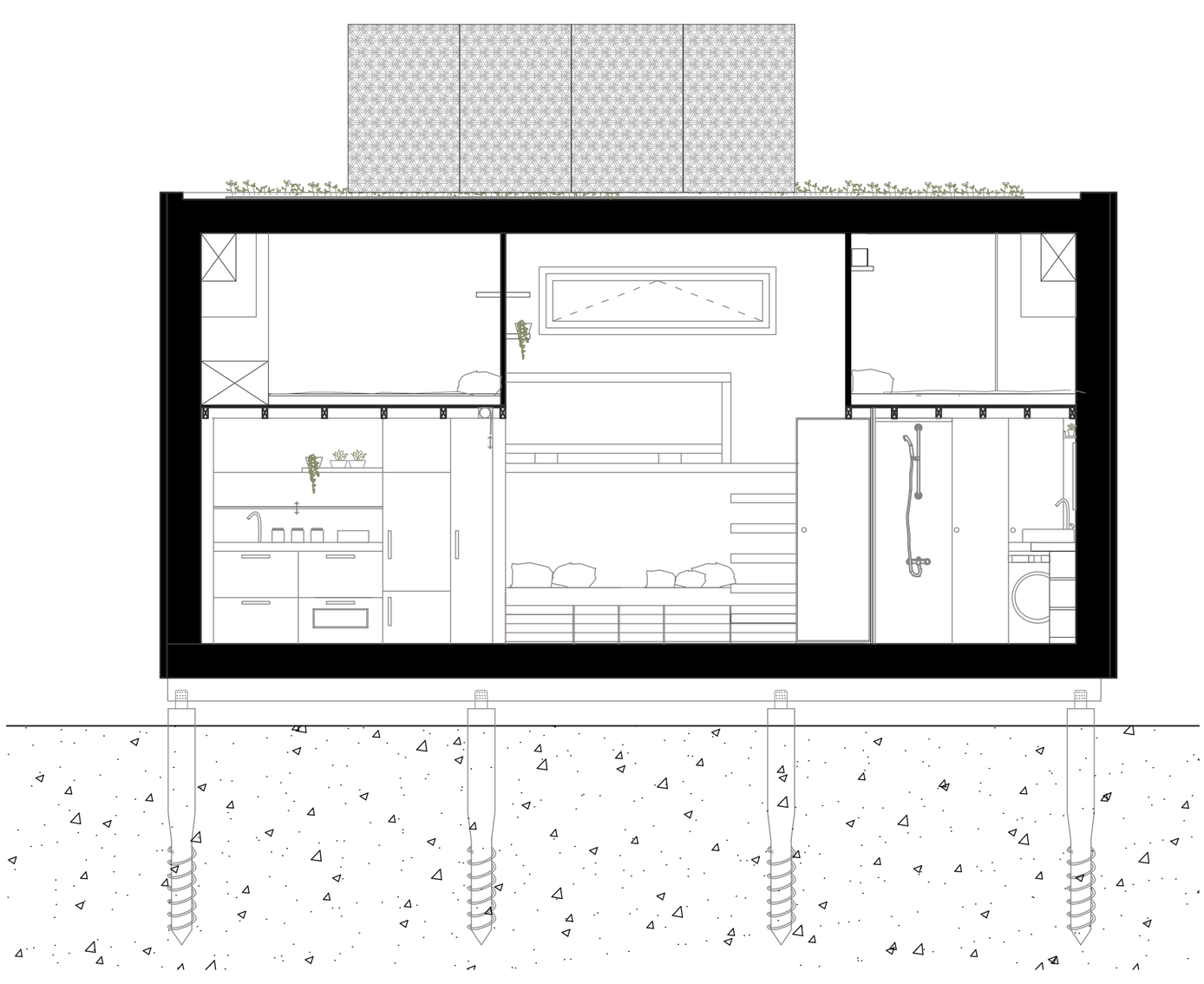

Section BB' - Tiny Step
Scale 1/50

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Section CC' - Tiny Step
Scale 1/50

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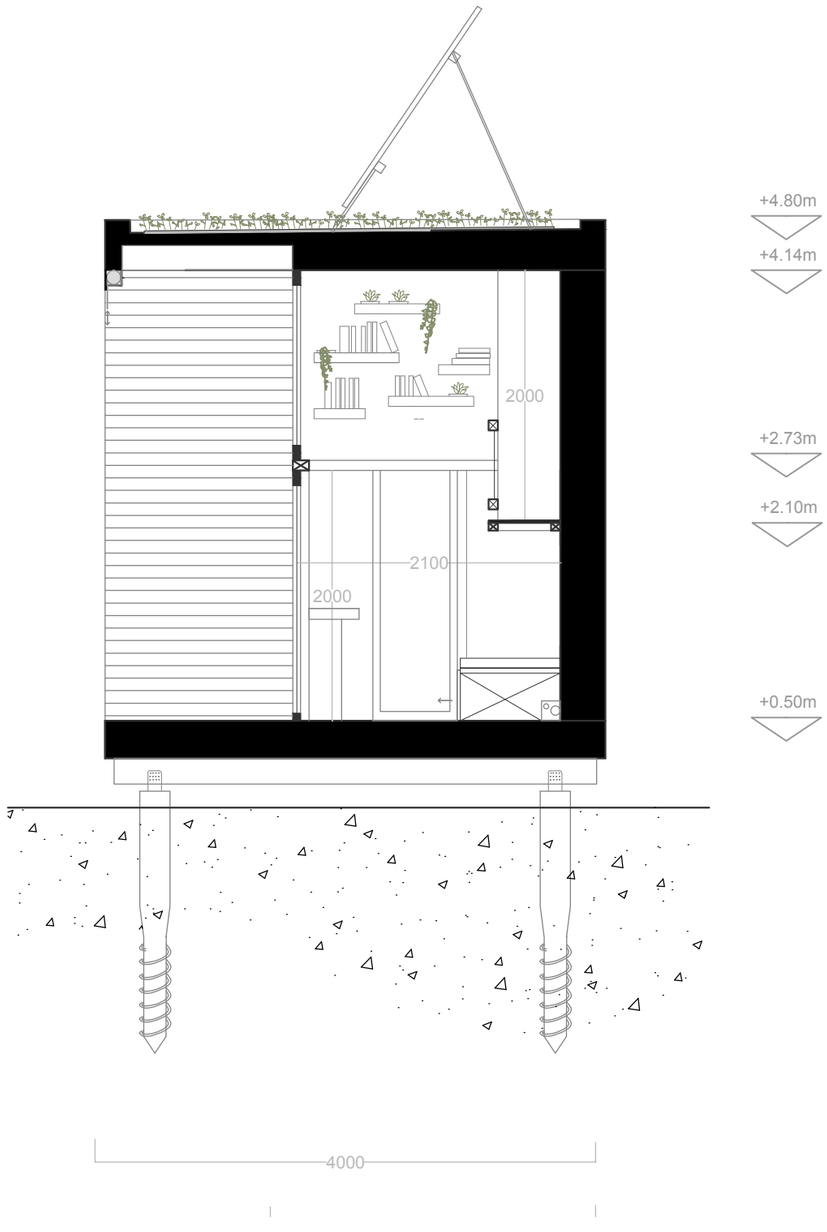

Section DD' - Tiny Step
Scale 1/50

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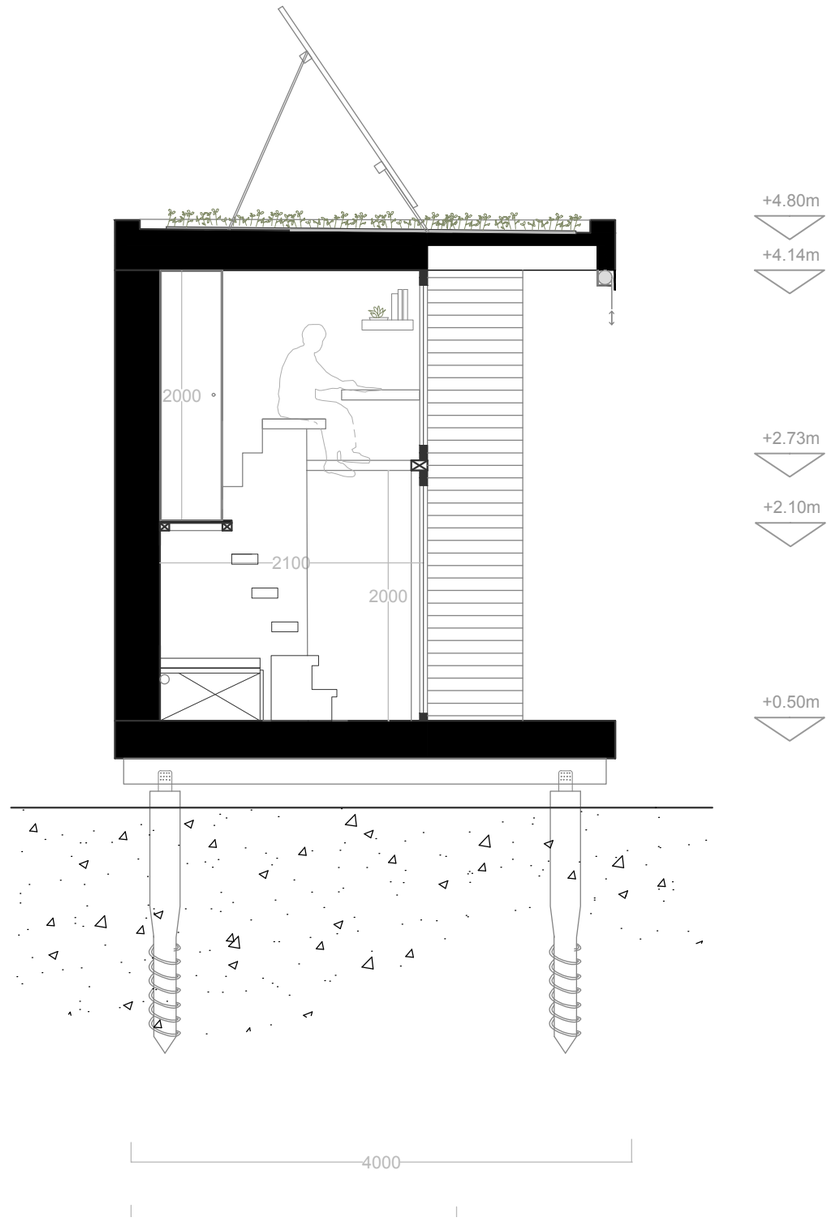
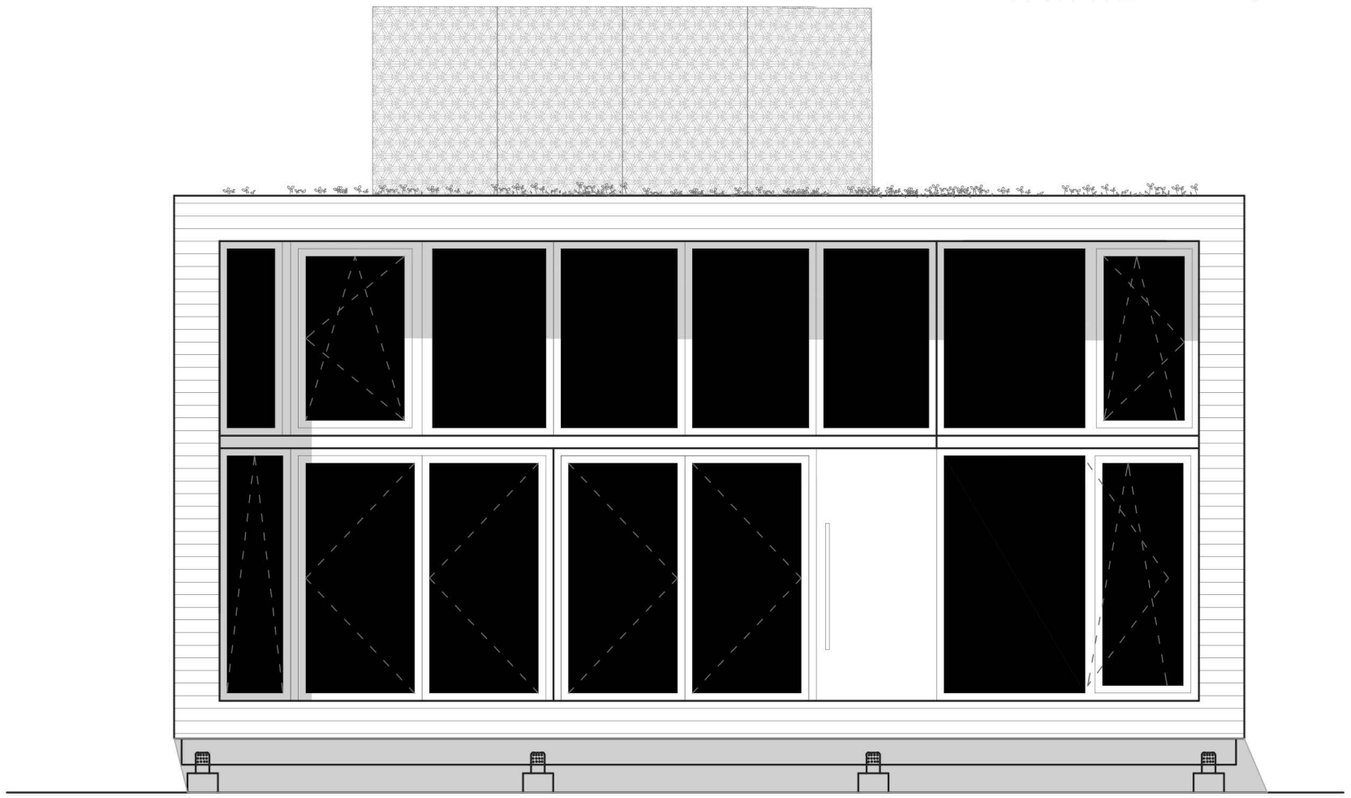
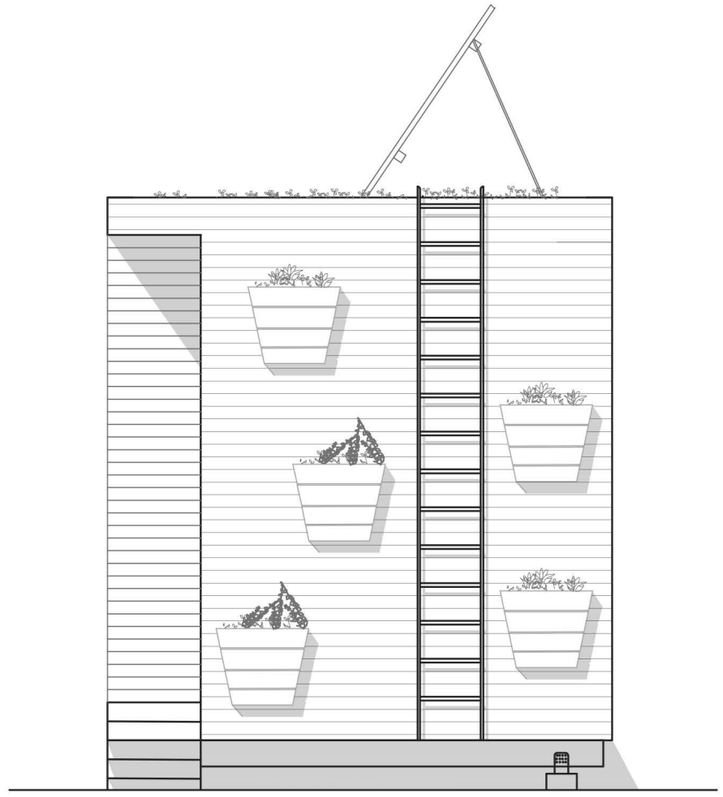
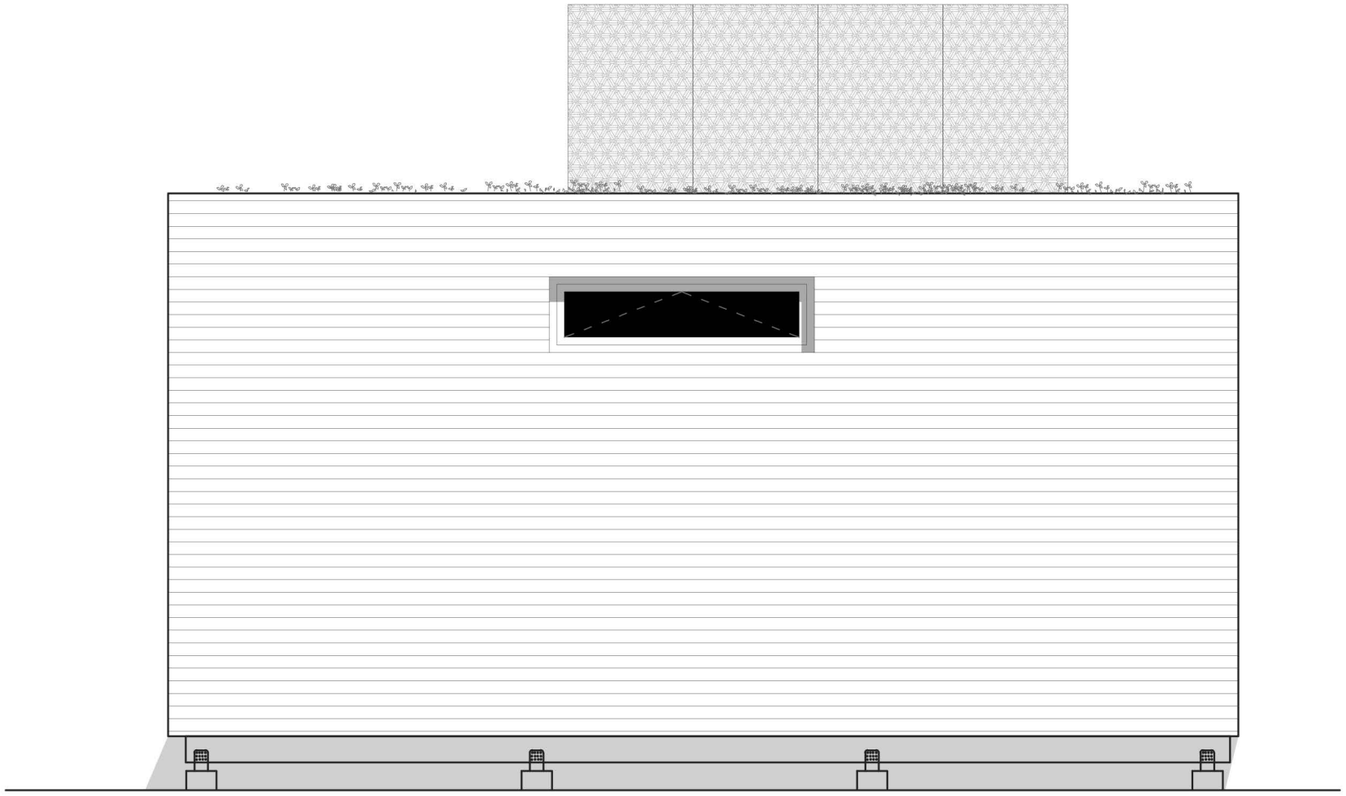


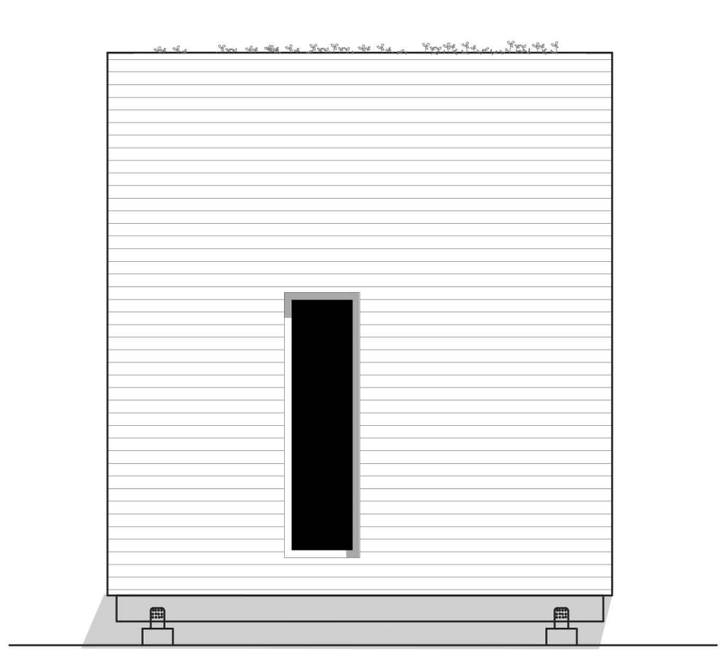




Facades South
Scale 1/50

Mastherthesis p
by Laura Denoy
17/9/2021





Facades North
Scale 1/50

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by Laura Deno
17/9/2021

Different configurations - Tiny
Scale 1/50

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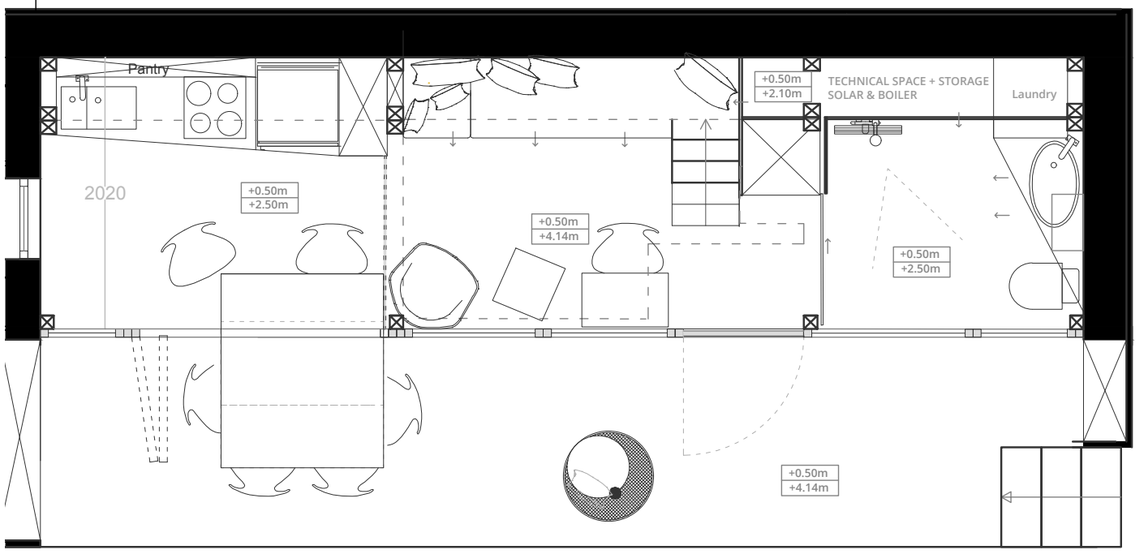
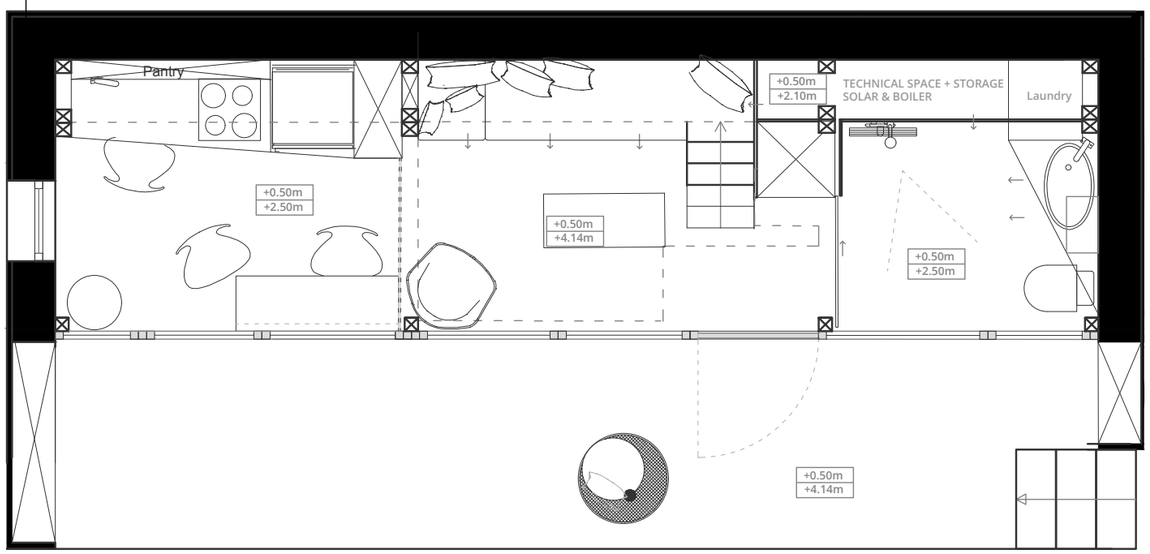
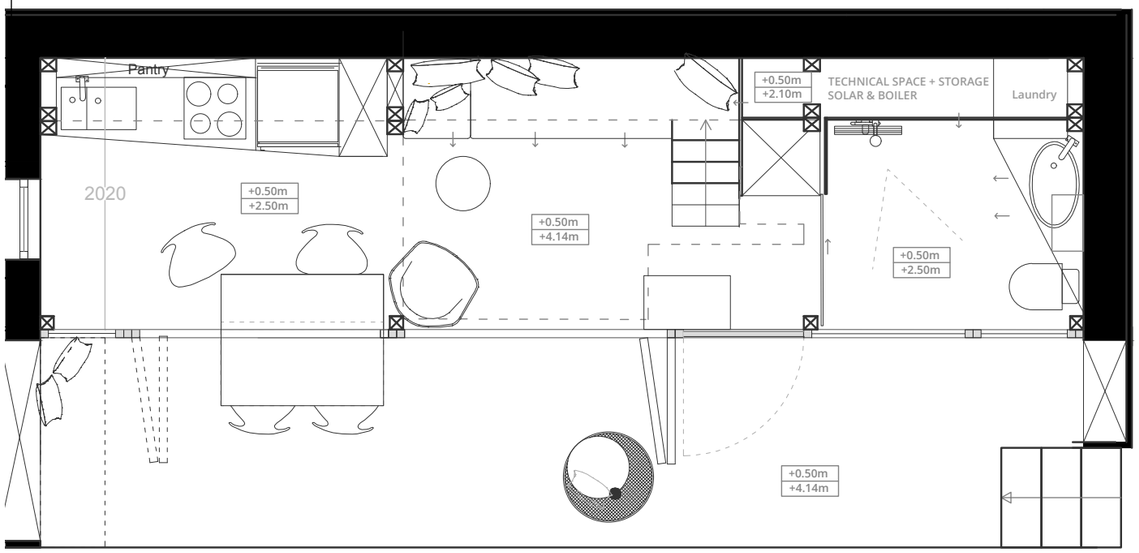
At the kitchen the big table is set and there is a hosting opportunity
The living room is separated, for work or studying.



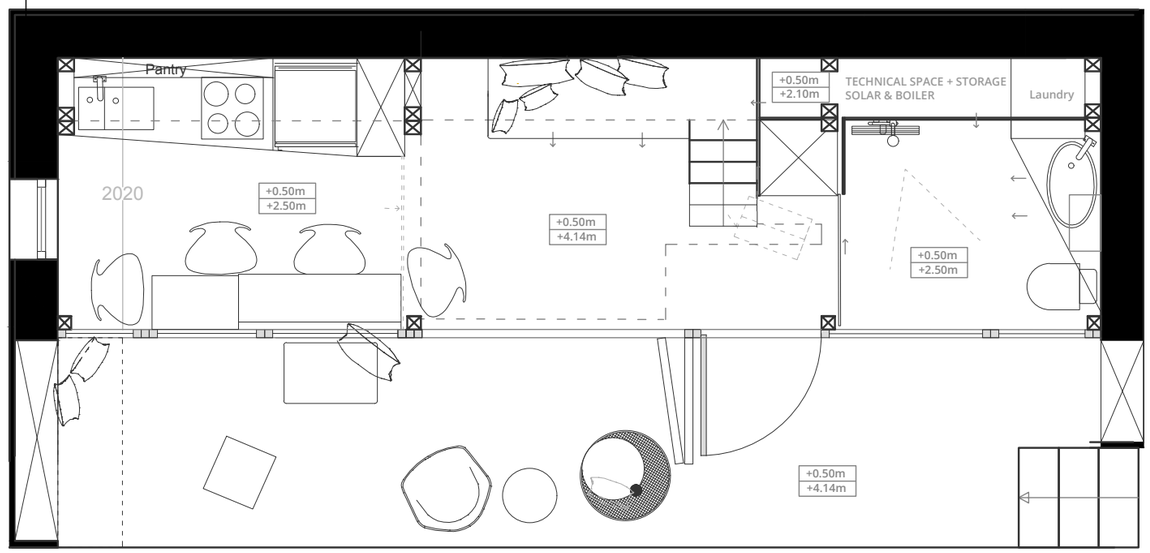
In winter the outdoors is not used. In this drawing the sink is covered by the cutting board, making it a nice large space to work at, do online meetings,...
The living room is closed off for reading a book or watching a movie.



The house is open and the kitchen the table is folded out for 4 people.



All seating spaces - including the moveable part of the couch - have been brought outdoors.
Inside the counter table is set for 4.



INNER STRUCTURE

Columns

Primary Beams

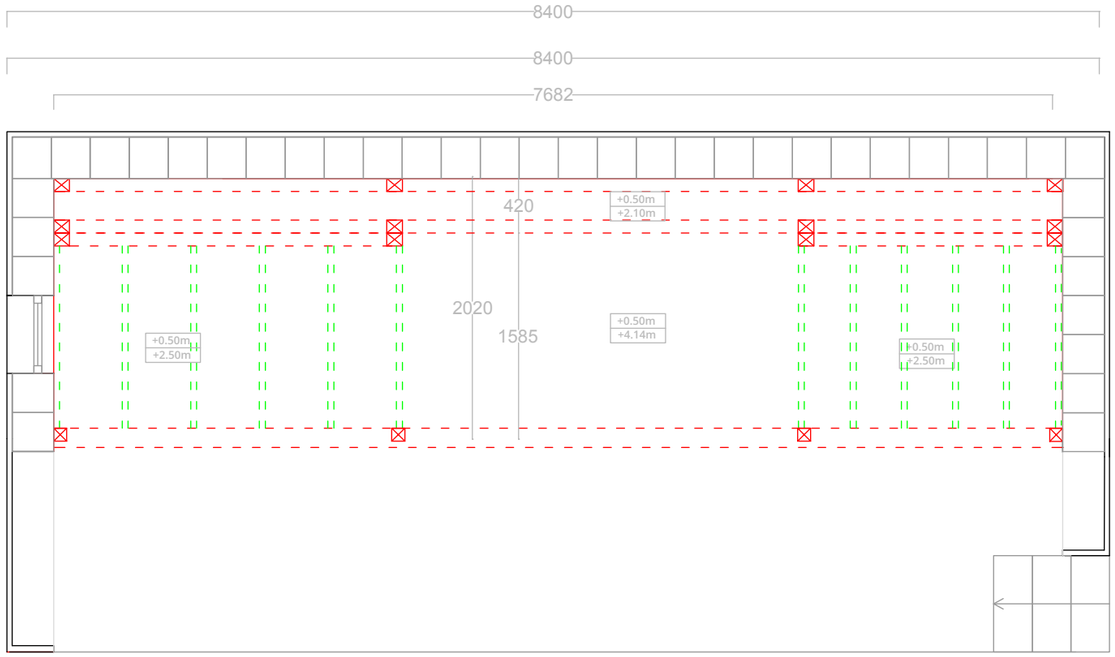
Secondary Beams

OUTER STRUCTURE
- using Reblock, loadbearing outer wall that will support the roof in combination with the beam at the glass bearing facade.

Reblcok structural wall element. (a Lego block system)

Exterior cladding - can bear weight of flower pots, self sufficiency in food is essential to being sustainable

OUTER STRUCTURE
Alternatively a traditional wood framing structure could be used.



Carrying walls - Length standard 3 axis trailer

Length with outer cladding included

Structural plan - Tiny Step
Scale 1/50

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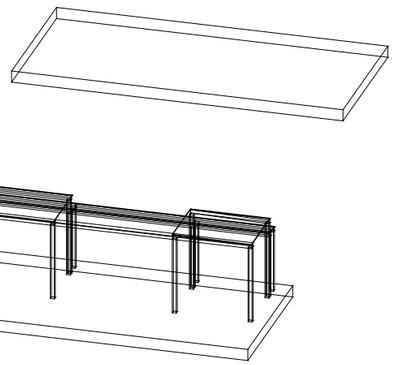
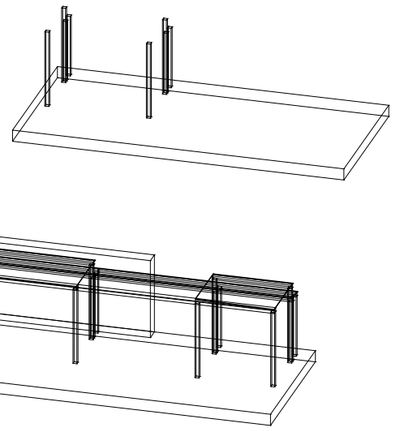
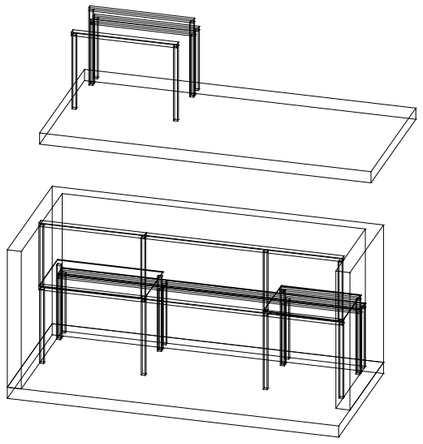
1. Build up the floor



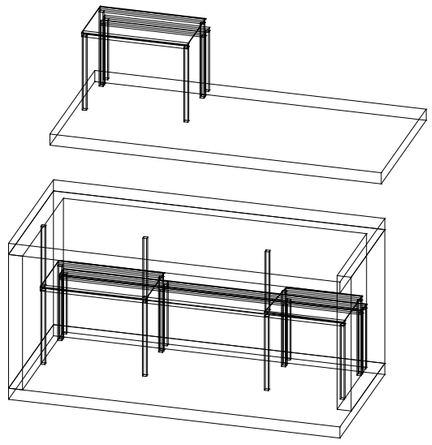
2. Build up the columns



3. Add beams



4. Add platforms



5. Finish interior structure

6. Start building exterior wall

7. Finish exterior wall using interior structure as scaffolding

8. Place roof, using interior structure as scaffolding

Build up structure - Tiny Step

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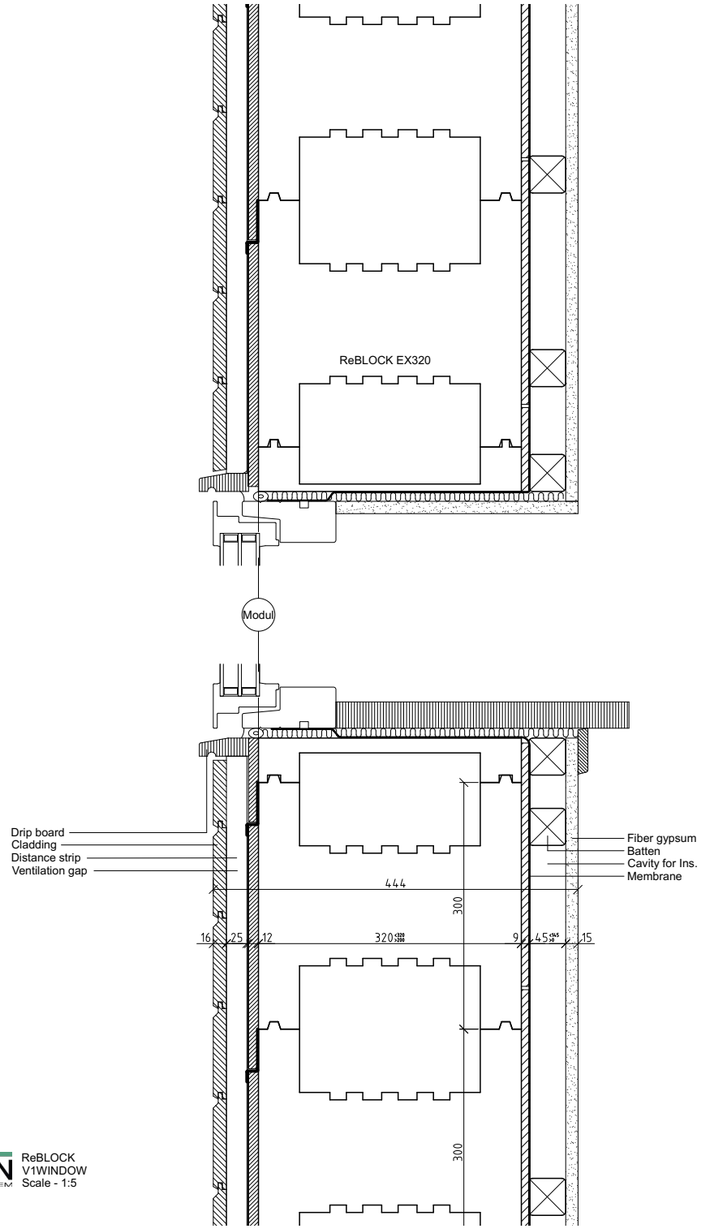
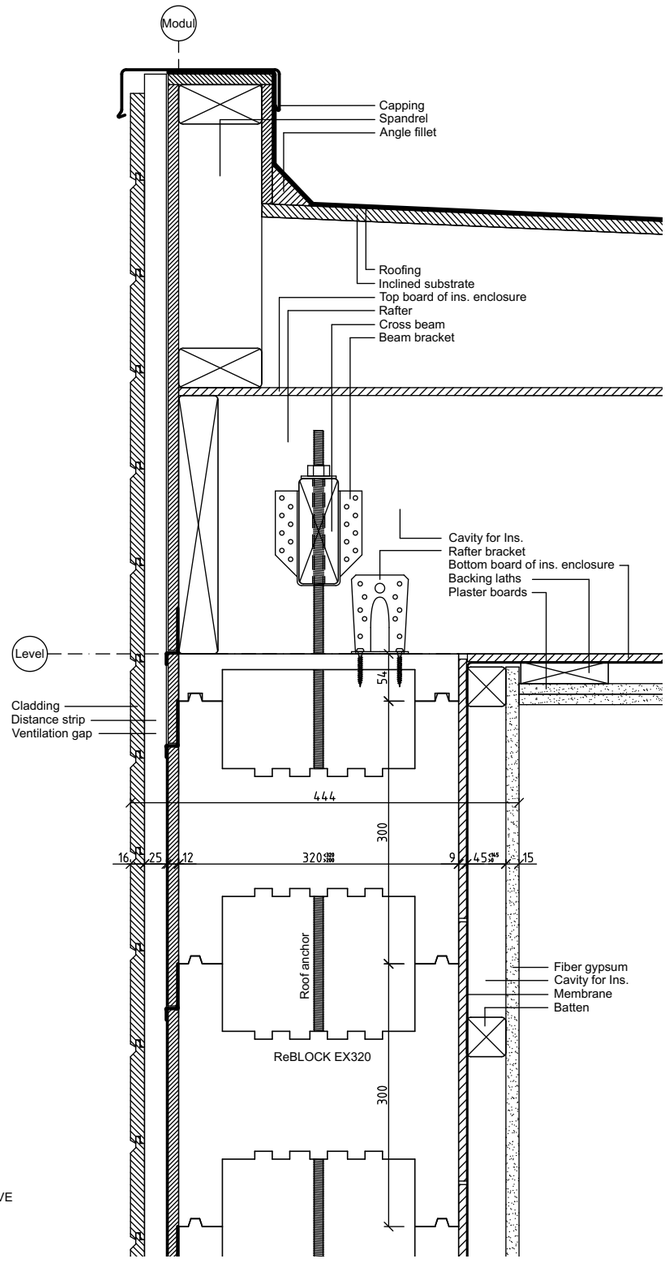
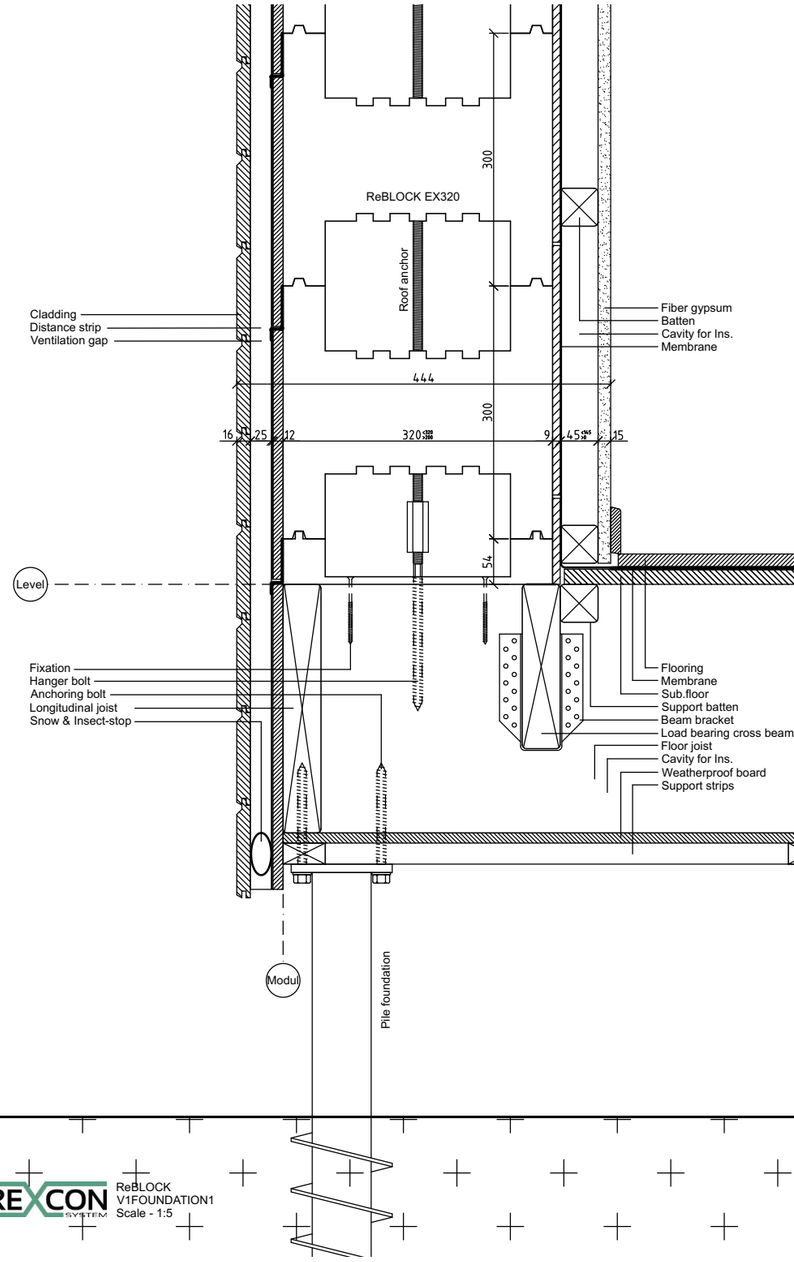


REXCON SYSTEM ReBLOCK V1WINDOW Scale - 1:5



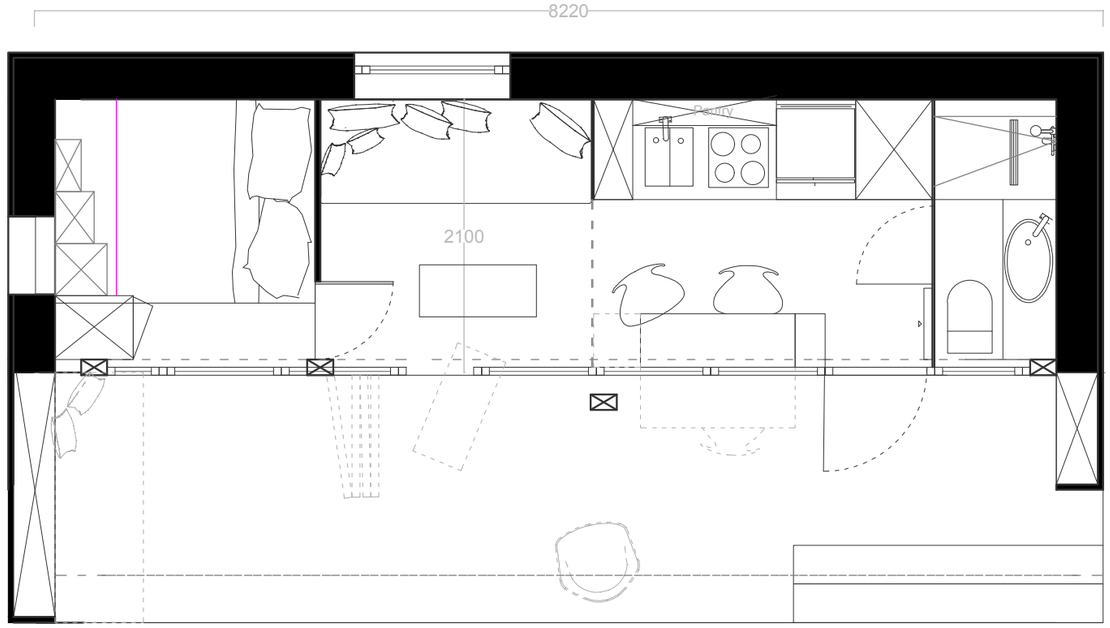
REXCON SYSTEM ReBLOCK V1CROWNEAVE Scale - 1:5

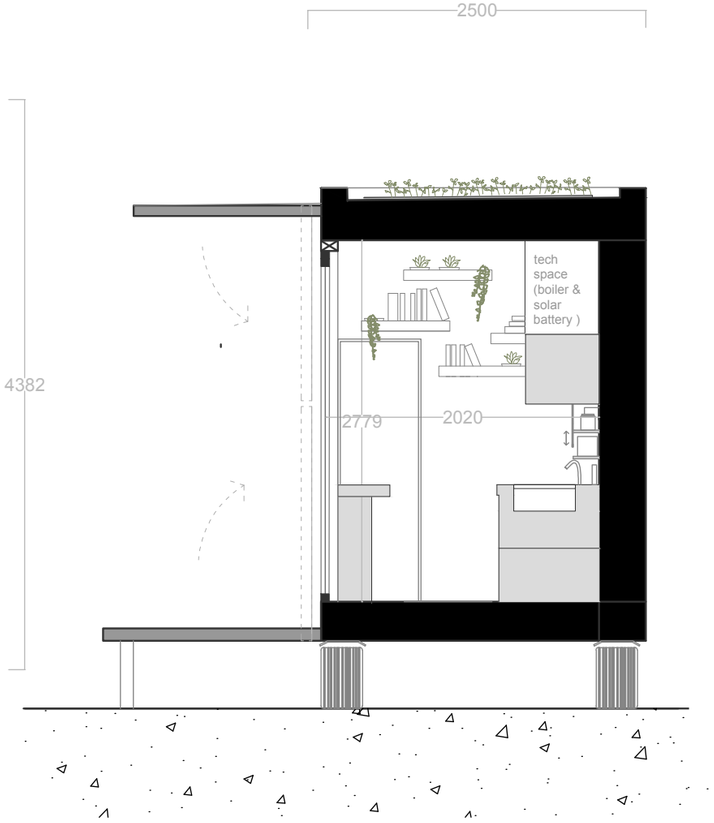


REXCON SYSTEM ReBLOCK V1FOUNDATION1 Scale - 1:5

Construction detailling by REXCON (REXCON, 2021)

SECTION





+4.00m

Tiny Step student &
Tiny Step Traveler

Scale 1/50

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