‘Tiny Impact’

Using tiny houses as a springboard to reduce our reliance on critical raw materials and fossil fuels in the human building interaction

A TU-Delft MSc Graduation thesis by Judith Meijer, May 2023

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Abstract

For the European nation-states to reach the objectives of the Paris Agreement using existing green technology would require unrealistic amounts of space and critical raw materials(CRMs). The solution posed is twofold: Develop new energy solutions that are less dependent on critical raw materials, and reduce our energy usage.

Tiny House communities are leading the way by being mindful of resources and focusing on what is necessary. I researched the resources and fundamental human needs of tiny house communities to design a podcast that helps us reduce energy needs and CRM dependence, and fight climate change.

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Preface

This research was done for my master's thesis for the Design for Interaction track at the faculty of Industrial Design Engineering at the Delft University of Technology.

I have been interested in sustainable design since I had one very lacklustre course on sustainability in my Bachelor's program in 2015. I have had the dream to design my own house for many years and when I heard about the Tiny House movement a few years ago I was hooked immediately. During the master course ID5356 Sustainable Design Strategies for Product Development, a rather overshadowed problem with sustainable energy was pointed out: Solar Photo Voltaic (Solar PV) panels and wind turbines require a lot of Critical Raw Materials (CRM) to produce (Metabolic, 2021). To meet the energy transition goals set out by our government regarding solar and wind energy, in 2040-2050 the Netherlands would need a minimum of 10% of the global production of Iridium, Lithium, Neodymium, and Dysprosium (See Figure 0.1, Metabolic, 2021). The Netherlands only accounts for 0.5% of global energy usage (Metabolic. 2021). Considering most other developed countries have similar ambitions and plans as the Netherlands, and are betting on similar technologies, it is unlikely that these technologies can solve the energy transition for all of them since there just won't be enough materials for that many solar panels and wind turbines.

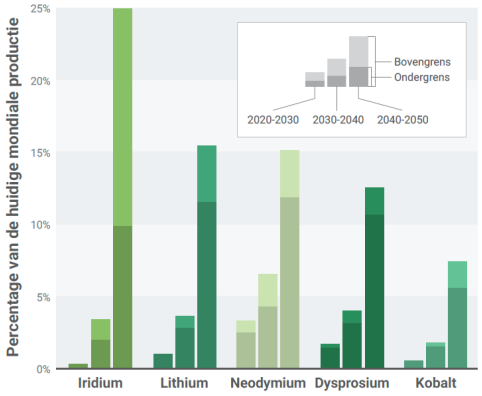

Figure 0.1. Projected increase in mineral demand of 5 CRMs for the netherlands: percentage of current global production (Metabolic, 2021)

It is unrealistic that the Netherlands would be able to get this large of a share of the produced CRMs. That means that our climate goals cannot be reached. The same will probably apply to most other countries that are part of the Paris Climate Accords. If our climate goals cannot be reached, that means stopping global warming and limiting it to 1.5 or even 2 degrees above pre-industrial levels will not be possible. A 3 or even more degrees increase will prove catastrophic for large parts of the world (IPCC, 2022a). The challenge of fighting climate change before us is immense, and small gains are just not going to cut it. We need many small improvements and several radical ones. So I want to focus on high-impact areas for this research. The built environment is a large contributor to greenhouse gas (GHG) emissions (IPCC, 2022b) ánd a large consumer of CRMs (Meyer, 2018) so this makes it a prime candidate for my thesis. Tiny houses communities are living with minimal resources and as a result, use much less energy and CRMs. I believe that tiny houses can teach us a lot about how we can live comfortably without needing much space, energy and materials. All the while reducing our impact on the climate and the world without ignoring our personal and collective needs.

Acknowledgements

I'd like to thank my chair David Keyson for his help, tips and guidance and my mentor David

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List of Acronyms

CRM - Critical raw material

TH - Tiny House

CC - Climate change

GHG - Greenhouse gas

BE - Built environment

COP - Conference of the Parties

CCS - Carbon capture storage

EC - European Commission

EU - European Union

EV - Electric Vehicle

PV - Photovoltaic

REE - Rare Earth Element; H= Heavy; L= Light

HBI - Human Building Interaction

IPCC - Intergovernmental Panel on Climate Change

Glossary

Built Environment

Any human-made condition that provides a setting for human activity, such as buildings, infrastructure and landscaping.

Carbon Capture Storage

Technologies that aim to re-capture carbon from the atmosphere (CO_2) and store them in a non-harmful way.

Conference of the Parties

Also known as the United Nations Climate Change Conference. COP21 held in Paris in 2015 was the conference where the well-known Paris Agreement was signed, where nations

pledged to keep global warming to well below 2 degrees this century. COP27 held in Egypt in 2022 is the most recent conference as of writing this report

Critical raw materials

This term is often interchangeably used with variants such as critical materials, critical metals or critical minerals. I stick to the term critical raw materials because it's the term the European Commission uses and this thesis is based on their assessment and methodology of critical raw materials.

Energy transition

The energy transition is also sometimes called the green energy transition. It is the necessary transition away from fossil fuels as our main source of energy towards more sustainable sources of energy such as wind, solar, hydro, tidal and nuclear.

Green technology

To say something is "green" is about the same as saying someone is "nice". It is a term often used and misused in daily life. When this thesis calls something green it means it is different from its "grey" counterpart. For example, green energy is energy like solar photovoltaic, wind, hydro or nuclear; as opposed to grey energy like coal, gas and oil. Even though during the production of solar panels or wind turbines still some greenhouse gasses are emitted and thus its production might not be green, the technology itself is considered green as long as it significantly contributes to a better climate.

High-fidelity prototype

A prototype of high quality that is in many aspects representable to the final product. Suitable for late-stage testing and presentation purposes.

Human Building Interaction

Anything or place where people can interact with the built environment.

IPCC report

The reports released by the Intergovernmental Panel on Climate Change. This panel consists of 3 working groups and releases a report every 7 years. In this thesis, I will only reference the 6th assessment reports released in 2021 and 2022.

Low-fidelity prototype

A prototype of lower quality; used to test an interaction or proof of concept. Suitable for cheap, adaptive and early testing.

Photovoltaic

The technology most solar panels rely on to convert light into electrical energy.

Sustainable

Sustainable is a term that is often used rather loosely and is frequently used for greenwashing. Occasionally I adopt wording from sources I cite in this thesis. Still, in general, when I say something is sustainable I follow the definition of the World Commission On Environment and Development's Our Common Future (1987, p. 16):

"Meeting the needs of current generations without compromising the ability for future generations to do so"

Tiny House

Other variants of a tiny house include tiny home, tiny living and small home. There is no consensus about a single official term (Shearer & Burton, 2018). In the Netherlands, the term "Tiny House" is the most used variant by people who live in tiny house communities, so that is the term I will use in this report. Occasionally I will use the term tiny living to refer to the lifestyle of living in a tiny house. According to Tiny House Nederland (2020) and Shearer and Burton (2018) a tiny house is not just any house with a floorplan of less than 50m2. It's a type of home closely tied to the personal philosophy of the owner. There are two types of tiny houses: Moveable houses and permanent houses. A tiny house must be a home for permanent living, so no recreational or temporary housing like a trailer, campervan, or vacation bungalow. Tiny houses in the Netherlands are usually placed together on a large plot of land in groups of 5 - 20 houses. The inhabitants share much and divide community tasks such as composting waste, growing food and organising activities. They also share products like power tools and ladders. Inhabitants of tiny houses are closely involved in the making of their houses. Either by designing, constructing, or doing both themselves. Reasons to choose to live in a tiny house include wanting to be more sustainable, becoming more self-sufficient, reducing monthly expenses or the desire for a closer community (Pionierskwartier, n.d.)

Phase 0: Project Setup

0.0 Chapter introduction

The first chapter 0.1 introduces the problem for this graduation project. Chapter 0.2 lays out the initial problem definition. 0.3 and 0.4 describe the objective and the scope of the project. In chapter 0.5 the research questions are formulated and in chapter 0.6 the methodology for answering these questions is briefly described. The final chapter 0.7 shows the overall design process and project setup for the rest of this thesis.

0.1 A short introduction to the problem

David Attenborough called climate change the biggest problem humanity has ever faced(BBC, 2020). The world is connected and for the first time in the world's history, we can collectively fight this coming catastrophe. The industrial revolution was powered by burning fossil fuels which releases a lot of greenhouse gasses(GHG) into the atmosphere. These GHG are causing the world's climate to change for the worse(IPCC, 2022a). The era of burning fossil fuels has to end (MacKay, 2009). It has to end very soon, or large parts of the world will become unhospitable for humans to live in, many ecosystems will collapse, and natural disasters will become more frequent and severe around the world (IPCC 2022a). Ultimately climate change will cost a lot of money and lives. This rapid technological advance has gotten us into this climate crisis, but not all technological advances are bad. We have also developed ways to get energy from renewable sources: water, wind, solar and biomass power. Solar panels and wind turbines especially seem to be good candidates to replace fossil fuels but these technical solutions have their own problems. Our current consumption patterns and lifestyles demand a lot of energy (Jancovici, 2005) and these renewable energy sources are diffuse. This means that the total energy in these sources might be high, but it's spread over a large area. Unlike fossil fuels, solar and wind energy are not located in a single place, cannot be transported to another place and cannot be used whenever the need arises. This results in high requirements of space and equipment to harvest a useful amount of this energy, and it needs accompanying storage and transport facilities to be able to use the energy when and where we need it.

The manufacturing of these renewable energy harvesters and batteries is highly complicated and requires a lot of different materials, including many materials labelled by the European Commission (EC) (2020) as "critical raw materials" (CRMs). These are materials that have high economic importance for the European Union (EU) and that have a high supply risk, usually because only a single country supplies the vast majority of the material. Scaling up the production of these materials is complicated and setting up new mines is a process that takes decades (International Energy Agency, 2022a)

The IPCC report (2022) warns that we need to limit climate change if we want to avoid catastrophe. The European Council (2022) has set out goals to do this by replacing fossil fuels with solar PV panels and wind turbines. But in order to reach the goals and limit climate change we need to build a lot of them. David MacKay (2009) made a calculation that showed how much space is needed to cover the energy use of all UK citizens. The UK itself does not have enough land area and renewable energy sources to cover its energy use, even if it managed to utilize nearly all of it. As can be seen in Figure 0.2. The CRMs needed for the manufacturing of all this equipment vastly outweigh the current possible supply of these CRMs. Since these materials already have a high supply risk, and the demand will increase manyfold (Metabolic, 2021) We cannot reach the agreed-upon climate goals by building turbines and solar panels. That means other solutions are needed. My research shows that tiny living is a viable solution

So we have a problem: for the European plans for the energy transition to succeed and to limit climate change we need more critical materials than we can produce and supply in the short available timeframe.

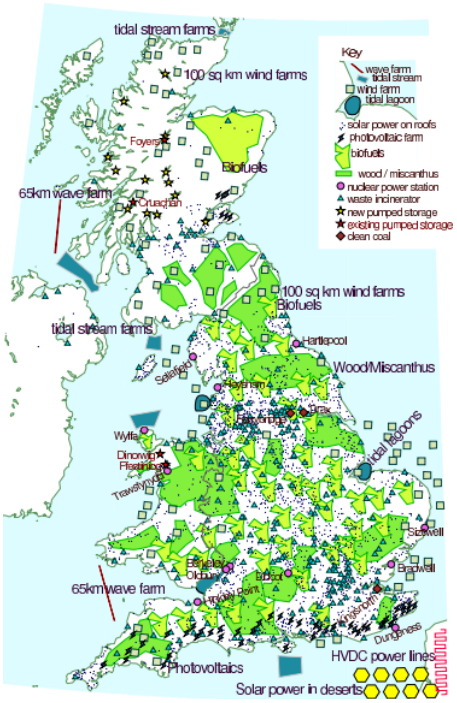

Figure 0.2. Visualisation of green technology needed to meet the UK energy demand (MacKay, 2009)

0.2 The design problem

The research in phase 1 has established a few things that are summarised here:

1. We are facing a climate crisis: The rising levels of greenhouse gasses emitted by humans are causing the climate to change (IPCC, 2021).

2. We need to limit global warming to 1.5 degrees Celsius, or many more ecosystems and human lives will be lost (IPCC, 2022a).

3. To limit global warming our main objective is to have net zero greenhouse gas emissions by 2050 (IPCC, 2022b; European Commission, 2021; International Energy Agency, 2021).

4. Most of our GHG emissions (75%) come from burning fossil fuels to provide energy (European Council, 2022).

5. The climate crisis is in essence an energy crisis. We need to use no- or low-carbon-emitting energy sources (green energy technology) to replace our fossil fuels (Mackay, 2009).

6. To meet EU climate goals and supply enough green energy, many more of these green energy technologies will need to be produced (European Council, 2022).

7. Our green energy solutions are dependent on CRMs (European Commission, 2020). These materials have a high supply risk and the demand for these CRMs is projected to grow massively (Metabolic, 2021).

9. The production or supply of CRMs cannot easily be increased on short notice (International Energy Agency, 2022a).

10. Our energy transition currently depends on materials that already have a high supply risk and of which production cannot easily and quickly be increased.

To conclude: To limit global warming, we need to reduce our dependency on CRMs.

The **Design Problem** is this: European climate goals to limit global warming to 1.5 degrees Celcius are unachievable in their current form because current green energy technologies needed for the energy transition rely heavily on CRMs, and the demand for CRMs will massively overtake the supply in the coming years.

0.3 Initial design goal

What makes critical raw materials critical, is their high economic importance and high supply risk (European Commission, 2020). Securing and increasing supply is a difficult and time-consuming process. The currently available best alternatives for CRM-heavy solutions are fossil fuels, but of course, this is exactly what they are trying to replace. Direct material substitution of CRMs in products has been a topic of research for years but it has varying results (Pavel et al., 2016). Increasing CRM supply will inevitably happen, but it will not be able to match the demand needed to build the number of turbines and solar panels necessary for those involved in the Paris Accord to reach the climate goals at the set time (Metabolic, 2021). So interventions are needed that reduce our CRM demand. This can be tackled in 2 ways:

a) Changing our energy technology.

b) Reducing our energy use.

To limit global warming to 1.5 degrees Celcius we need radical change and big improvements. The built environment is a massive consumer of critical raw materials (Meyer, 2018) and is responsible for about 21% of our total greenhouse gas emissions in 2019 (Lwasa et al., 2022). So by focusing this thesis on buildings I can have a significant impact. Due to the time constraints of this project and the rapidly closing timeframe to slow down climate change, the best way for me to quickly develop and test solutions is in a built environment which is already living with less energy and technology: Tiny houses. People living in tiny houses usually live minimalistic lives and have limited resources, space and energy available for their living needs. Because of these limitations, they are very mindful of their use of material, space and energy. All of this makes tiny houses a great source of inspiration on how to live consciously yet comfortably with minimal resources and a tiny impact.

As humans, we have certain basic needs like food and shelter. We will always need some energy to fulfil these needs. However, our current way of living is unsustainable (it's the reason we are facing a climate crisis), and technology alone will not be able to solve the energy problem (due to its CRM dependency). So we need rapid radical change, and we need to make concessions and changes.

I propose to focus on reducing both CRM and energy demand, giving me the following **Design Goal**: "Design something that reduces the negative impact living has on the climate while making living less reliant on critical raw materials."

0.4 Project scope

I'd love to design something that makes áll buildings completely GHG and CRM-free. However, the time and resources available to me make this an unrealistic goal. So the scope has to be narrowed down while maintaining an as high as possible impact. I decided to focus on tiny houses as opposed to more common buildings because tiny houses already have fewer products and a lower energy demand than most other buildings. This gives me a good starting point with fewer variables, to understand which products and how much energy is actually needed to live comfortably.

This thesis will focus on designing a solution for users between 18-50 years old, who own and live in a house in the Randstad of the Netherlands. It will take a European perspective of climate change and CRMs and be limited by the building regulations and infrastructure of Dutch municipalities and governments while considering a European collaboration. For the user research and testing of the design, I will focus on tiny house inhabitants in the Netherlands.

Non-critical materials are often processed in a factory and transported using machines that themselves use a lot of CRMs, so even if a product contains no CRMs, they are still dependent on them. Making a product or service that is completely independent of CRMs is an extremely complex task. So for the scope of this project, I will mainly focus on the CRMs within the product itself, not on all related systems. CRMs are also sometimes used in materials such as Textiles or Alloys (European Commission, 2020a), for the sake of time this project will focus primarily on electronic products.

0.5 Research questions

In order to achieve my design goal: "Design something that reduces the negative impact living has on the climate while making living less reliable on critical raw materials." I need to first answer a few Research Questions:

RQ1: What are high-impact areas in the built environment to reduce GHG emissions?

RQ2: Which energy-consuming technologies do we use in tiny houses that rely heavily on CRMs?

RQ3: How do these technologies contribute to meeting human needs?

RQ4: Which design directions are suitable to reduce energy and CRM use in the built environment based on human needs?

RQ5: What new or existing sustainable solutions can fit these design directions?

0.6 Methodology for answering the research questions

RQ1: What are *high-impact* areas in the built environment to reduce GHG emissions?

How to answer RQ1: Desk research.

To stop climate change we need big reductions to our GHG emissions. So this thesis starts with a deeper analysis of our global - and in particular European - GHG emission trends related to buildings and CRMs to identify prime areas to have a big impact. This can be found in chapters 1.0 to 1.7.

RQ2: Which energy-consuming technologies do we use in tiny houses that rely heavily on CRMs?

How to answer RQ2: Desk research and field research.

As a first step, I will look around and write down all the products and services I encounter in tiny houses that I suspect contain CRMs. Often CRMs are not visible on the outside of a product, but if a product contains electronics it most likely will contain at least some CRMs. A full list is hard to find but a report about CRM resilience from the European Commission (2020b) lists a couple of example uses for each CRM. That list shows that even in non-electronics such as Textiles, Steel, or Aluminum Alloys CRMs play a role these days. This project limits its scope to mainly electronic products. A combination of field and desk research should provide me with a non-exhaustive list of common products and services. This list can be found in chapter 1.9.

RQ3: How do these technologies contribute to meeting human needs?

How to answer RQ3: User research.

To uncover which needs these products contribute to, I have to ask users of those products why they used them. For this, I will design and conduct a user workshop based on the theory from Design for emotion by Pieter Desmet (2022), the Human Experience Catalog (Desmet & Fokkinga, 2021), and creative facilitation techniques from Sanders and Stappers (2012). This methodology is further described in chapters 1.10 to 1.13 and the results can be found in chapter 1.15

RQ4: Which design directions are suitable to reduce energy and CRM use in the built environment based on human needs?

How to answer RQ4: Analysis methods.

Several analyses will be done on the selected impact areas and the needs expressed by the participants. Design directions will be formulated based on these analyses. For each of these directions, suitable design criteria will be formulated. These can be found in chapters 2.5 and 2.6.

RQ5: What new or existing sustainable solutions can fit these design directions?

How to answer RQ5: Design methods.

The design criteria will be the starting point for designing solutions to the design problem. To find solutions I will use a combination of brainstorms, prototyping, user tests and other suitable design methods to design and validate alternative solutions. The best ideas will be chosen based on design wishes and verified and improved through user tests.

0.7 Design project setup

This thesis mostly follows the traditional double-diamond design approach with some minor adaptations, as seen in Figure 0.3. It starts with a diverging exploratory research phase called Discover. It mostly consists of desk research such as reading literature and books, exploring the contexts and doing exploratory user research. The second phase is a converging analysis phase called Define where the aim is to take all the gathered information, draw conclusions, find insights and eventually boil the problem down to a few suitable design directions with well-defined design goals with design criteria. With the design criteria in mind, the next phase is a diverging ideation phase called Develop. During this phase, ideas are generated for the design directions and are quickly prototyped, tested, evaluated and adapted. This cycle is often repeated several times to go from ideas to concepts. At the end of this phase, the process converges again and the concepts are evaluated by the design wishes and user test results and the best concept is chosen. During the last finalizing Deliver phase this final concept is further detailed, and a final high-fidelity showcase prototype is made. Since there is no more time to iterate any final results and evaluations will be incorporated into recommendations. Part of the final deliverable for this thesis is a report, a presentation, a showcase, and any other relevant material. While there are 4 neatly defined phases in theory and in this report, in practice one often goes back and forth between activities from different phases when needed.

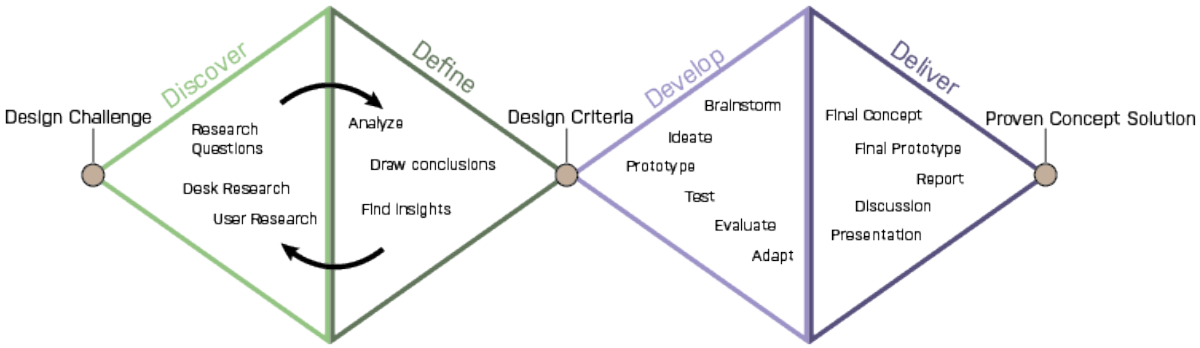

Figure 0.3. Double Diamond approach used in this thesis

However, even though my design process is fairly traditional, my design approach is a bit more unorthodox. Many designs start with a discovery of a materialistic property. This then translates to a useful function. This function is then incorporated into a technology or design that can be sold to customers. Visualised in Figure 0.4.

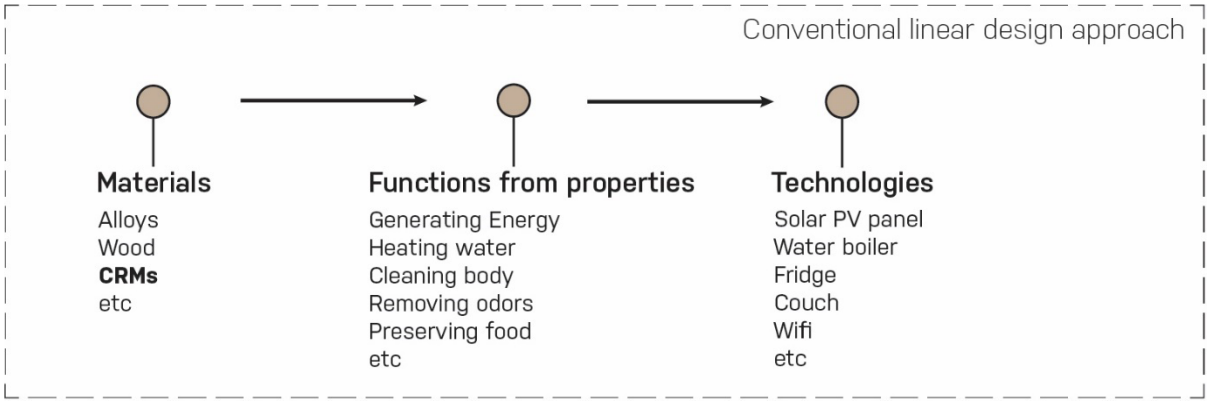

Figure 0.4. Visualisation of linear, material based design approach

I want to do it the other way around. My design approach takes user needs as the starting point. These needs are then translated into designable functions. These needs-based functions are then compared to sustainable, local and available materials (so no CRMs). Technologies that intersect both of these lists are then chosen as these are based on human needs, desirability and sustainable material sourcing. Visualised in Figure 0.5.

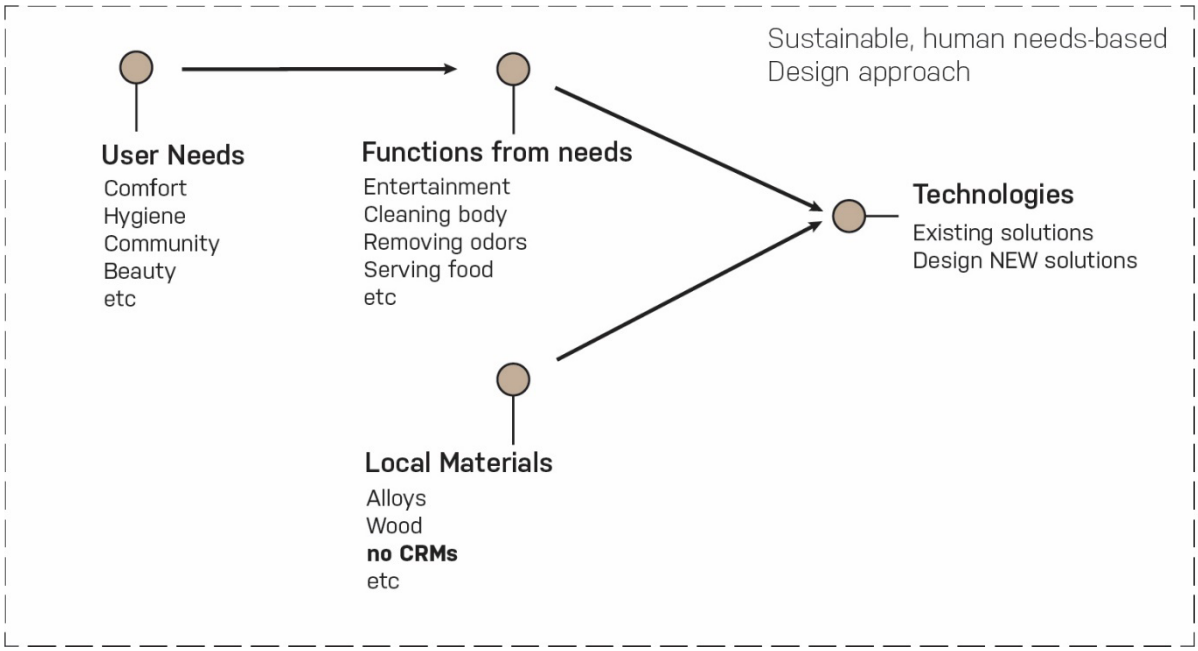

Figure 0.5 Visualisation of my proposed sustainable human needs-based design approach

Phase 1: Discover, research

1.0 Chapter introduction

Phase one is the research phase, in the double diamond design method called Discover. In this phase, I will do research into the topic, both literature and user research. Chapters 1.1 to 1.3 discuss the climate crisis and how it is in essence an energy problem. Chapters 1.4 and 1.5 discuss why the green energy transition will result in a CRM problem. Chapters 1.6 and 1.7 explains why focusing on temperature control in buildings is a good area to have an impact on the climate crisis. Chapters 1.8 and 1.9 explain how Tiny Houses fit into this design problem and solution. Chapter 1.10 discusses why a human-needs-centred approach is needed and chapters 1.11 to 1.13 explain the setup and methodology this thesis uses to incorporate a human-needs-centred approach into the design solution. Chapter 1.14 discusses the pilot test findings and chapter 1.15 shows a quick overview of the type of results gained from this research.

1.1 Why the climate is in crisis

David Attenborough called climate change “the biggest problem mankind has ever faced.” (BBC, 2020) But what exactly does climate change mean and why do we call it a crisis?

During the industrial revolution, mankind discovered that burning fossil fuels like coal, oil and natural gas gave us a lot of fast and cheap energy. This sudden availability of energy catapulted societies into a world of new inventions, development, and changes. It has made countries like Saudi Arabia and Qatar very wealthy due to their large natural deposits of these fossil fuels. Countries in Europe and North America used this fast and cheap energy to quickly develop their own economies and this has given privileged people like me a comfortable life. The burning of these fossil fuels releases a lot of carbon, mainly in the form of CO2 into the air. Carbon dioxide is a greenhouse gas. That means that CO2 is better than normal air at trapping heat from the sun inside the atmosphere. This is not a new phenomenon as it has been demonstrated as early as 1856 by Eunice Foote. This trapped heat makes the world as a whole warmer, similar to how a glass greenhouse traps heat inside. Because the world’s climate is a complex system not every part of the world will get equally warmer. The exact effects of this are also extremely difficult to predict. However, according to the recent IPCC report of 2021, we can say with very high certainty that climate change is a massive threat to people and the planet and action is required now. Even if we limit global warming to 1.5 degrees above pre-industrial levels, as the goals of the Paris Agreement in 2015 state, global extreme weather events will become much more frequent and the sea levels will rise.

Ecosystems will be damaged beyond repair, many species will go extinct and human lives will be lost (IPCC, 2022a). If global warming increases more than 1.5 degrees these events will be even more frequent and severe, and we might reach tipping points for a positive feedback loop where there is nothing we can do to stop global warming anymore (McKay et al., 2022). The current levels of CO2 are higher than they have ever been in the past 800.000 years of the history of the earth as seen in Figure 1.1. This Figure also shows that the increase of CO2 in the atmosphere is no longer part of earth's natural cycle but something else is massively increasing this. Even though humans only emit a very small amount of CO2 and CH4(another potent greenhouse gas) compared to other global systems: only a few gigatons compared to dozens of tons emitted and absorbed by plants and ocean surface waters as visualised in Figure 1.2 (Department of Energy Genomic Science program by Biological and Environmental Research Information System (BERIS), 2011). However, the problem is that before humans started emitting GHG from fossil fuels, the world's carbon cycle was in inbalance for 800.000 years. Roughly the same amount of CO2 was emitted as was being absorbed. Our relatively small contribution disrupted this equilibrium, and over time this small increase has accumulated to have a big impact.

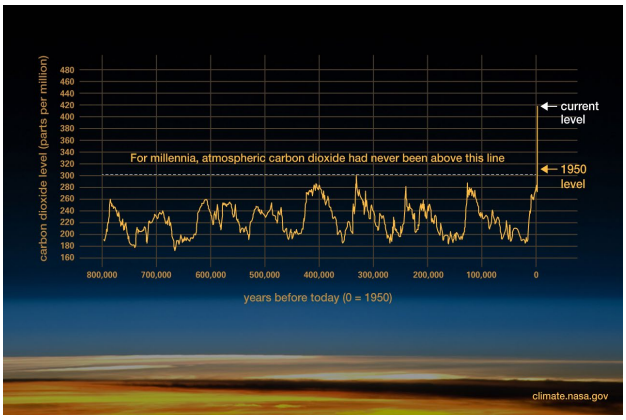

Figure 1.1. Fluctuations of atmospheric CO2 on earth over the past 800.000 years (climate.nasa.gov, 2008)

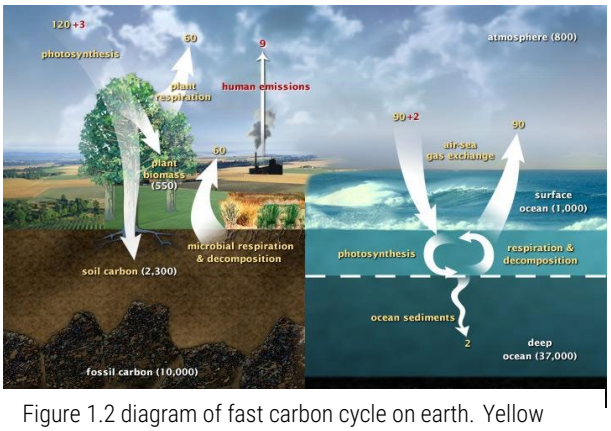

Figure 1.2 diagram of fast carbon cycle on earth. Yellow numbers are natural fluxes, and red are human contributions in gigatons of carbon per year. White numbers indicate stored carbon (BERIS, 2011)

1.2 Why the climate crisis needs to be stopped

We've established that because of the added greenhouse gas emissions of humans, the earth's climate is changing significantly. But why is this a problem?

This increase of GHGs in the atmosphere allows the atmosphere to trap and hold heat from the sun better, thus warming our climate. This warmer temperature melts ice which increases the sea levels, eventually flooding large inhabited areas and forcing the displacement of over a billion people by 2050 (Yeung, 2020). In addition to higher sea levels it will also change normal weather patterns creating longer periods of drought followed by extreme rainfall periods; creating a host of problems for people and the planet (IPCC, 2022a)

The ocean's surface waters absorb part of this atmospheric CO2 quite quickly which causes the "acidification of the oceans". Making the surface waters of our oceans more acidic, which will likely result in the loss of all coral and much other life in the sea that is not adapted to live in more acidic waters (National Oceanic and Atmospheric Administration (NOAA), 2020). To sum it up in the words of the IPCC report:

> ‘The cumulative scientific evidence is unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all. (very high confidence)’ (IPCC, 2022a, p. 33)

1.3 Why the climate crisis is in essence an energy crisis

The current climate change is primarily caused by humans' excessive emissions of GHG, as discussed in the previous paragraphs. The solution then to climate change seems rather straightforward:

Stop emitting greenhouse gasses. Primarily CO2 and CH4. Most of this comes from burning fossil fuels.

But while seemingly straightforward, it is at the same time very complex, because countless lives are built and reliant on the availability of cheap and instant energy. Just think about it; if we suddenly stop burning all fossil fuels in an instant, most of the developed world would collapse: We would no longer have enough energy in the grid to power most of our buildings, devices, vehicles, networks and security systems. But leaving our energy supply as it is is also not an option: The climate is changing for the worse, large parts of the world already struggle with power outages and according to experts the number of energy-related crises is only expected to increase over time (NOAA Climate.gov, 2016). So regardless of whether we continue business as usual, or we stop emitting GHGs, we will inevitably face energy crises.

We’ve collectively known for decades that we need to stop emitting GHGs, as illustrated by Shell’s own ‘Climate of Concern’ video of 1991. (Mommers, 2017) The main question is this: How do we emit less GHG?

If we want to discover how we can stop emitting GHGs, we need to first establish why we burn fossil fuels in the first place. Figure 1.3 (Ritchie, 2020) shows the sources of global GHG emissions in 2016. As you can see, most of it comes from energy production. Especially for industry, transport and energy use in buildings. MacKay has made an overview of an average British person’s energy use in

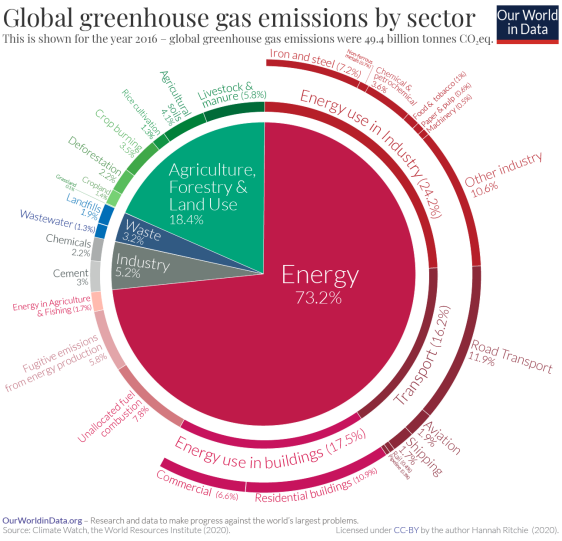

Figure 1.3 Pie chart of Global GHG emissions in 2016 by sector (Ritchie, 2020)

2009, expressed in a single metric: kWh. Figure 1.4 shows that our main personal energy use goes to transport, 'stuff' and heating and cooling. But do we really need that much energy? Let's start by taking a look back in time: How did people live before the industrial revolution? People's lifestyles were much less energy intensive than they are today.

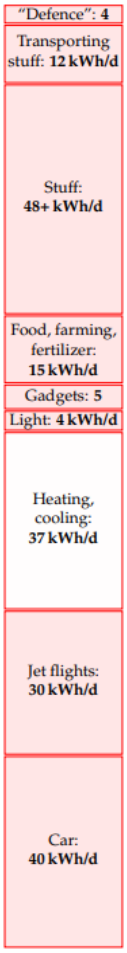

Figure 18.1. The st added up all the t renewables.

Figure 1.4 Stack chart showing energy demands in kWh/d of a British citizen in 2009 (MacKay, 2009)

Over 400 years ago Europe lived completely on sustainable sources, mainly wood. They lit a fireplace in their homes that gave them light, heat and a way to cook food. The global population back then was small enough to sustain this use (MacKay, 2009). Our current population density is too high to sustain us the way we did in the middle ages. And let's not forget: while not technically a fossil fuel, burning wood still emits a lot of CO2, so with our current global population it would still significantly contribute to climate change.

Today, is it possible to travel from one end of the world to another within a day. In the middle ages, a full day's travel would take you only about 30 miles (~50km, about the distance between Utrecht and Rotterdam) and this would require significant effort, energy, preparation and risk (Boyer, 1951). The amount of energy required to travel half the world in a single day is immense. Transport accounts for approximately 16.2% of our total energy consumption as seen in Figure 1.3 (Ritchie et al., 2020). We simply live by different standards than we used to. These high standards require more energy, and thus more GHGs.

Energy used for heating and cooling our homes has also vastly changed. Modern houses usually have a thermostat connected to central heating with which a person can easily set a fixed temperature for their homes. In ancient times orientation of the building, windows, and rooms was a much more important aspect since heating and cooling a home was not quite so simple(Hansen, 2022). There are lessons to be learned by re-integrating ancient knowledge into our heating and cooling practices. The passive house movement for example takes some of these into account in their building practices(Passive House Institute, n.d.), as do initiatives like Prêt-à-Loger (2014), but for most new buildings in the Netherlands there is still a lot of room for improvement.

Modern lighting probably doesn't require significantly more energy than burning wood. Even though we often light up more space than needed, LEDs have pretty good efficiency and lighting only accounts for around 2% of our total energy consumption (MacKay, 2009).

We humans love comfort and much prefer others to do the necessary work. We thus surround ourselves with "mechanical slaves" (Illich, 1974). To illustrate how much energy our mechanical devices use daily, Jean-Marc Jancovici (2013) calculated that for the lifestyle of one average privileged person in France in the year 2000 to continue without machines, the labour of at least 400 people was needed. Having 400 people serving your every beck and call is something only a king might be able to afford back then. So we can in a way say that today most urbanites live as luxuriously as kings of old. The world can easily support a few dozen or even hundreds of people living luxuriously. But billions? The food and land needed to sustain this much human labour are immense. Having our mechanical devices perform this labour

does not diminish the energy demands. It only asks for a different energy demand. So to burn fewer fossil fuels we either need new energy sources to power our mechanical labour. Or change our way of life to require less energy.

So in essence the climate crisis is an energy crisis. Our high-standard, fast-paced, global modern lives require too much energy for the earth to provide sustainably.

1.4 Green energy is part of the solution

So what is the way forward?

I mentioned earlier that the way to reduce our GHG emissions is to use green sources of energy to power our lives and change our lifestyles to require less energy. So what is the best way forward? I'll start by breaking the illusion that technology alone can solve the climate crisis. It cannot. Increases in technological efficiency will likely be overshadowed by the increasing world population and increased energy demand as the developing world continues to get more access to electricity and gain higher standards of living (International Energy Agency, 2022b). The answer will be a combination of both green energy production ánd energy use reduction.

First of all, we need green and new technology to power our lives. We cannot go back to our time of burning wood, and we cannot continue to burn fossil fuels. Yet, living will always require energy of some sort. So green energy is necessary. Luckily, green energy is not only possible, but it's also sustainable and affordable (IPCC, 2022b). It currently is lacking in only one key aspect: Stability (van Geuns, 2022). Our current primary options for non-GHG emitting energy sources are wind, solar, hydro and nuclear. The wind is variable and unpredictable, sunshine is intermittent and only available half the day at best, hydro requires height to produce a significant amount of power and not every place has mountains or hills. Only Nuclear can provide a stable and reliable baseload of energy. However, nuclear has the obvious problem of producing nuclear waste. But even if we combine all 4 sources of power, and include some biomass burning, tidal power, wave power, "clean" coal ánd solar farms in Africa, it's simply too diffuse, too intermittent and we have too high a population to provide enough energy to power our current European lifestyle for every European. (MacKay, 2009) We would need an unrealistic amount of land area and equipment to break even with consumption, as seen in Figure 1.5.

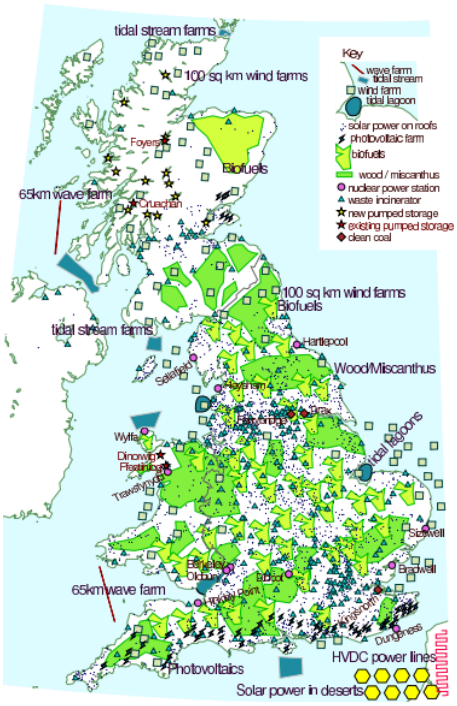

Figure 1.5 Visualisation of how much space is needed for green energy to meet the UK's energy demand (MacKay, 2009)

New green technology is needed to supplement or replace the sources we have. But we don't have new technology yet and we don't know when we will. And so a reliable way to reduce our dependence on fossil fuels is to reduce the current energy demand.

1.5 Why the green energy transition will cause a Critical Raw Material problem

As mentioned in the previous chapter, to provide enough green energy for our current lifestyle we need an enormous amount of equipment like windmills and solar PV panels. These products are widely available, but if we want to roll them out on a scale where they will make a significant impact on limiting climate change we need a lot of them. And to manufacture them we need a lot of raw materials. While there is probably enough lithium on earth to produce enough batteries to replace all combustion engine cars with EVs (MacKay, 2009), the rate at which we currently mine lithium is far, far too slow. According to the International Energy Agency report 'The Role of Critical Minerals in Clean Energy Transitions' (2022a), if we want to uphold our Paris agreement of keeping global warming well below 2 degrees pre-industrial era, our demand for minerals will be 4 times higher in 2040 than it was in 2020. Not every material demand will increase by the same amount. Lithium will likely increase the most due to its use in EVs and batteries for energy storage. Lithium demand could rise 42 times, and increasing mining production 40-fold in only 20 years is an extremely difficult task. Firstly because setting up new mining projects usually takes up to 10-20 years from exploration to production (International Energy Agency, 2022b). Secondly, critical raw materials are frequently acquired as a byproduct of another main ore (McKinsey & Company, 2022). So if the demand for the main ore does not increase to the same extent it makes scaling up CRM production rather awkward and difficult. Thirdly, critical raw materials often come nearly exclusively from one country, due to geopolitical tensions that country might not be willing or able to export that much material to Europe, thus disrupting the supply. (European Commission, 2020a)

The European Union has set the goal to be the first climate-neutral continent by 2050, but to become that we need more materials than we can currently get. Especially the elements labelled "critical" will likely be a big issue in the near future, since these materials already have a high supply risk. The European Commission President von der Leyen acknowledged this problem herself: 'Without secure and sustainable access to the necessary raw materials, our ambition to become the first climate-neutral continent is at risk' (European Commission, 2022). The Critical Raw Materials Act (European Commission, 2023) is one step towards securing these materials, but it is not enough by itself.

1.6 How do we solve the energy and critical raw material problem together?

How to tackle this CRM problem?

There is a multitude of strategies that we need to employ parallel to each other to secure a supply of the materials needed for our green energy transition (TU Delft, n.d.) (European Commission, 2023).

- Localize our supply. We have plenty of unused resources in the EU that we could mine and manufacture here, reducing our reliance on unreliable suppliers, while gaining the possibility to increase the labour conditions and quality controls for these materials and products (European Commission, 2020c).

- Invest in green technology. The amount of global investment in green technology is not nearly enough to keep us on track for a net zero emissions scenario in 2050 (International Energy Agency, 2022b).

- Strong guiding policies to accelerate investment, innovation and implementation. And to help give companies and customers more certainty and keep green options accessible for all (TU Delft, n.d.).

- Make our energy consumption more efficient. For example by better insulating our homes.

- Utilize the Urban Mine. Over the coming decades, a lot of CRMs will be embodied in products that are located in Europe. Designing these in such a way that they can be recovered at the end of life would greatly reduce our dependence on non-EU countries for our CRM supply over the coming decades. This solution is however not quite as simple as it sounds and especially because most critical materials are very difficult to recycle (Bakker et al. 2019).

Even though all of these strategies are necessary and a good step towards solving the CRM problem. With these strategies, we can build a more green, sustainable, efficient, local and circular economy. However, I argue that they are missing one key strategy:

- Reducing our energy demand.

The energy crisis can be simplified into a twofold solution: replace fossil fuels with green energy and reduce our energy demand. Our over-reliance on CRMs has a multitude of problems. Since increasing supply will happen regardless, but at a too slow pace to keep within our climate goals of 1.5 degrees warming, our best option is once again to focus on reducing our demand. There seems to be a massive research, innovation and design gap: ***Green energy solutions that do not contain CRMs.***

1.7 The built environment is a large part of the problem

So we need more green energy solutions that do not contain CRMs. Let's zoom in further on this current-day energy use to see which focus areas can have the biggest impact in reducing energy and CRM use.

Figure 1.3 (Ritchie et al., 2020) in chapter 1.5 showed that 73.2% of our GHG in 2016 came from Energy use. Of that, the biggest chunk is from energy use in industry (24.2%), and after that energy use in buildings (17.5%) and Transport (16.2%). Looking even closer we can see that the biggest single areas accountable for GHG emissions are road transport (11.9%), Residential buildings (10.9%) and the Iron and Steel industry (7.2%).

According to David MacKay's analysis of the energy use of a British person in 2009 the biggest energy consumption areas a single person has is through "stuff" (~25%) car use (~20%), Heating and Cooling in living and office spaces (~19%) and jet flights (~15%) as can be seen in Figure 1.4.

These analyses show that the production of "stuff", transport and living are the three biggest impact areas regarding our energy usage.

This graduation thesis is about designing an intervention in the built environment to help mitigate climate change, and this research shows that the built environment is a massive contributor to climate change. So an intervention here could have a big impact.

But 'living' is still a broad area, and within the context of living a person needs energy for 5 key aspects:

1 Heating

2 Cooling

3 Cooking

4 Light

5 Media

So which of these aspects requires the most energy, and thus is accountable for the most GHG emissions?

According to the IPCC report of 2022 buildings contributed around 21% of all global GHG emissions in 2019. the majority of which, 57%, were indirect emissions from the generation of electricity and heat. I.e. electricity and heat used inside the home but generated elsewhere. 24% were from direct GHG emissions in and around the buildings themselves, and 18% were embodied emissions inside the buildings, mainly from cement and steel. Residential buildings accounted for 70% of the final energy demand of buildings (IPCC, 2022b). According to the report most of the energy required by housing in Europe goes to heating and cooling. And in the Netherlands heating will require more energy than cooling due to its climate and culture.

So the biggest chunk of GHG emissions is from the use of electricity and heat used in residential buildings, totalling around 50% of all GHG emissions in the built environment. So reducing the energy and heat requirement of a building could massively reduce GHG emissions.

As we've established, heating and cooling require the most energy for buildings in Europe. In other areas of the world, cooking contributes to the majority share (IPCC, 2022b). MacKay's calculations for a British citizen in 2009 will give a pretty good approximation to use for Dutch energy use in 2022 considering Britain and the Netherlands' similar climates and cultures. Most of the assumptions and conditions he used in his calculations still hold up today. Heating accounts for about 18% of energy consumption. Cooling only around 1%. Cooking is roughly 2%. And light and media both contribute only a small share of our energy use (about 2 and 3% respectively) according to MacKay's 2009 calculations.

Looking at these numbers it seems obvious to focus on heating homes, however, cooling will in a warming climate increase in demand. For this purpose, it seems logical to focus on solutions that can both warm ánd cool homes, but if only a single application has to be chosen heating will be preferred.

Buildings have a relatively high contribution to global GHG emissions and they are also a massive consumer of CRMs. For example, the 'greenest building in the world' (Bloomberg) in

2015, “The Edge” uses 28.000 sensors (2018 Charley Meyer), each of which contains many CRMs. So the built environment is a logical area to focus on for my graduation project.

1.8 How do tiny houses fit in?

A tiny house is a term that gained popularity around 2013 and since 2016 has seen relatively stable search numbers(Google Trends, n.d.). According to Heather Shearer et al.(2019) defining what a tiny house is exactly is a difficult task, and there seems to be no single consensus. However, tiny houses usually are based on a few of the following principles:

- Small floor area, often restricted to fit on a trailer. (less than 50m2)

- DIY, either designed, constructed or both by the inhabitant themselves.

- Used as the primary residence. So it is not a holiday bungalow, but a permanent living space of the owner.

- (semi) Mobile home. Often tiny houses are movable in some form. Some are built directly on a trailer, some are bigger than that but with special transport vehicles can still be transported. On top of that in the Netherlands, it is customary for municipalities to give tiny house owners a 5 or 10-year lease to a plot of land that they have to care for during this period but will have to leave at the end of the leasing period.

- Has some emphasis on sustainability. This differs vastly from person to person, highlighted by just reading the introduction page to the tiny house community Pionierskwartier in Delft, the Netherlands(Pionierskwartier, n.d.). and also shown by a survey from 2016 by Shearer et al (2019). Some people built their houses to be energy neutral, some build their homes completely from waste and reused materials. Some people go tiny to own and consume fewer products. Some people choose to live tiny for the community and sharing aspect.

I will focus in this project on tiny houses, not because that is where I can have the biggest impact (there are far fewer tiny houses in the Netherlands compared to apartment blocks for example) but because people who live in a tiny house usually have a strong focus on sustainability. People living in tiny houses live with very few items and generally have limited available energy and water. This means these people have already adopted a large part of the solution by lowering their consumption of stuff and energy. There are however many CRMs present in tiny houses because each house has its own power generation, storage and management system. Most tiny houses do this using solar PV panels and Lithium batteries. The physical limitation of space and the off-grid nature of tiny houses makes them adopt many clever, efficient and original solutions to make living inside the house possible and even pleasant. Since living in a tiny house requires some ‘out of the box’ thinking, it makes this a prime area to look for inspiration and find and test some more radical and untraditional ideas. And radical is needed because our current, conservative and technological ways are just not going to cut it. We need to widely adopt a mindset of scarcity and balance, and tiny house residents do this much better than most other Dutch residents. By looking at Tiny house inhabitants as my primary target group I will have far fewer unnecessary CRM and Energy products to sift through and it makes it easier for me to identify what technologies are not

necessary, and which technologies need to stay but can perhaps be redesigned.

Tiny houses do have one big drawback: They are tiny and unique. This means that economies of scale don't necessarily apply. A successful design fit for one tiny house cannot be directly scaled up to mass production. Tiny houses also have very little thermal mass making passive heating and cooling a lot more difficult. Tiny houses do have something most neighbourhoods in the Netherlands don't have: A close-knit, open-minded community. Tiny house communities often operate on partly shared ownership. They have shared stewardship over the land they own as a community, but they also sometimes have small shared food gardens, organize events together and share many large products like ladders and power tools. This sharing community aspect could provide an alternative to utilising economies of scale.

Every tiny house is different, both in looks and in construction methods or ideology. But overall the flexibility, community aspect, out-of-the-box thinking, and minimalist lifestyle of tiny house inhabitants make it a great place to look for inspiration and provide proof of concept for energy-reducing and non-CRM green solutions.

1.9 What could be improved in tiny houses?

Most tiny houses have some emphasis on sustainability. However, I have not yet encountered one which had considered a low CRM usage in their design. For example, all the tiny houses I have seen so far get their energy by using solar PV panels on their roof, and a battery system to generate and control their home's energy use. Solar panels and batteries both require a lot of CRMs to build and currently are very difficult to recycle if it's even possible at all. Also, small home appliances found in tiny houses are full of CRMs. This makes sense since the recent development of CRMs into technology has made it possible to make many products much smaller, which is ideal for tiny houses.

A full list of all products inside tiny houses that contain CRMs is difficult to come by. But by combining information from the European Commission's study on the EU's list of critical raw materials (2020) on CRMs, and websites on building and the costs of tiny houses (Lamboo, 2022)(Mitchell, 2020) and by walking and looking around in actual tiny houses I ended up with the following list of products and services that are commonly found in tiny houses that contain CRMs. This list is limited to products that require energy to use or are directly related to energy use and contain critical raw materials in the product itself.

Gas boiler (hot water)
Water pump (toilet, shower, sink)
TV
Smartphone
Laptop
Light
Power socket
Electricity cables
Dishwasher

Washing machine
Dryer
Microwave
Oven
Induction/gas/electric cooking stove
Gas burner
Wood oven
Wood/hot air/central heating
Sound installation/speakers
Batteries
Solar Panel
Wind turbine
Fridge
Freezer
Sensors
Ventilation
Electricity Transformer
Internet (router) / cables
Power tools
Hair dryer
Kettle
Coffeemaker
Camera

This is a long, but a not exhaustive list. But this shows that in any given tiny house there will be many products that consume energy and contain CRMs. So there are many things to look into and improve upon.

1.10 Why a human needs-centred approach is needed

Even though a tiny house is small and cannot have too many unnecessary items, there are quite a lot of products still to be found containing CRMs. This project aims to provide inhabitants with comfortable living while providing them with non-CRM green energy or to reduce their energy and CRM use in some other way. The most obvious way is to just remove all energy-consuming products or energy-generation products that contain CRMs. But people own these items for a reason. People have needs that a lot of these products help fulfil such as preparing food and giving warmth. People won't give up all their products without a clear reason to do so. So to be successful in redesigning green energy to be CRM-free, and for it to be widely adopted, I will take a human-centred approach. Keep the human needs as a basis, and redesign products or services around these needs. But this time in a green, sustainable, and non-CRM way. As stated previously, people need energy for 5 key aspects of living: Heating, cooling, cooking, light and media. But these are not the same as human needs. Desmet and Fokkinga's (2020) theory of 13 fundamental needs will provide a much more useful, human focussed list of needs, as seen in Figure 1.6. Not all 13 needs will be equally important in the context of a residential home, but which needs are more important and which

are less is difficult to know and no research or literature regarding this specific question could be found. So to discover the answer I designed a workshop to conduct with tiny house inhabitants to understand why they used their CRM-containing products and what their underlying needs were. This is further detailed and explained in chapter 1.13.

1.11 Short explanation of the theory of 13 fundamental human needs

In the Human Experience Catalog Desmet and Fokkinga (2021) state that there are 13 fundamental human needs. They range from needs such as the need for fitness to the need for relatedness. Essentially everything we do is driven by these 13 needs. However, the link between everyday actions and fundamental needs is often not immediately clear. For example, taking a hot shower could contribute to the fundamental need for competence. There are some steps between the everyday action and the underlying fundamental need(s), I'll call these intermediate steps 'middle needs'. In the example of taking a shower, one might take a shower in the morning to feel fresher and more awake. This feeling helps them prioritize and accomplish more in their day. And accomplishing what is important to them helps them feel competent. Designing a product or service for competence is too broad to effectively design. But designing something to give the user a "fresh feeling to start the day with" is already a lot easier to work with. Design for emotion (2022) calls these 'middle needs' impulses. Forces that drive human behaviour. These impulses can be internal or external. Internal impulses are often needs-driven. External impulses are driven by our environment. I prefer to call these external impulses 'triggers': Something that triggers a certain behaviour. Triggers are a practical starting point for a redesign. For example, a trigger could be: "I feel cold". The action could be that someone takes a hot shower. But they might just as well fill up a hot water bottle. Or put on a sweater. Or turn on the heater. Or hug their partner. The need is that someone wants to feel warm and comfortable, the trigger is that they feel cold. The trigger is what pushes them to take action. So a designer can design something to fulfil the users' middle needs, using a trigger to push them to action.

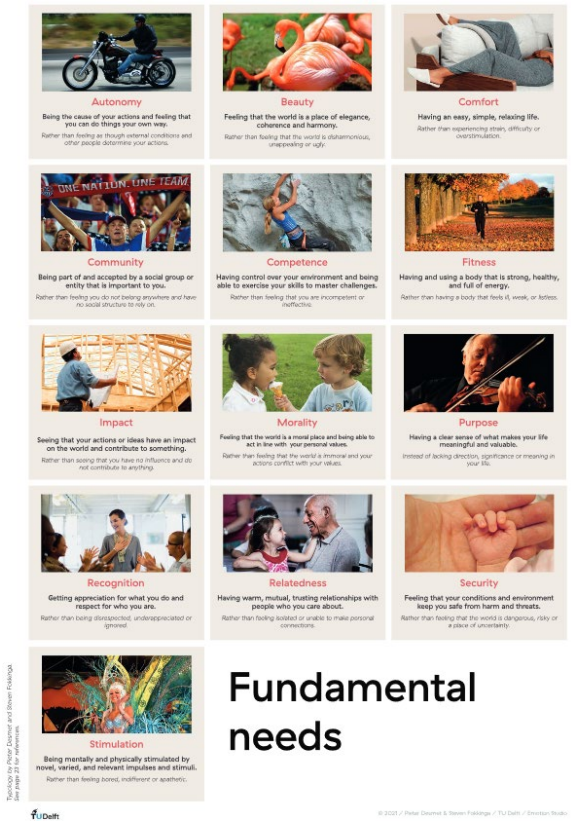

Figure 1.6 visual of all 13 fundamental needs according to Desmet and Fokkinga (2021)

1.12 A combination of the theory of 13 fundamental human needs with creative facilitation techniques could help to better understand the problem on a human needs scale

The goal of the workshop is to discover some of these 'middle needs' and 'triggers' to

better understand the human motivation behind our usage of CRMs and energy-consuming products and services.

According to Design for Emotion (Desmet, 2022) the best tactic to discover the fundamental, and middle needs behind a simple action is to ask participants "why is that important to you?". So in the example of taking a shower, the action would be: "I took a hot shower in the morning." To which I could ask: "Why is it important to you to take that hot shower this morning?" If their answer is: "Well, to wake up." I can again ask: "Why is it important for you to wake up in the morning?". To which their answer might be: "Well if I feel awake in the morning I get more stuff done". This sequence of questions and answers is an effective way to get to the underlying middle needs as to why they use certain products. Somewhere in the middle is the sweet spot to design for, but where exactly is hard to know beforehand.

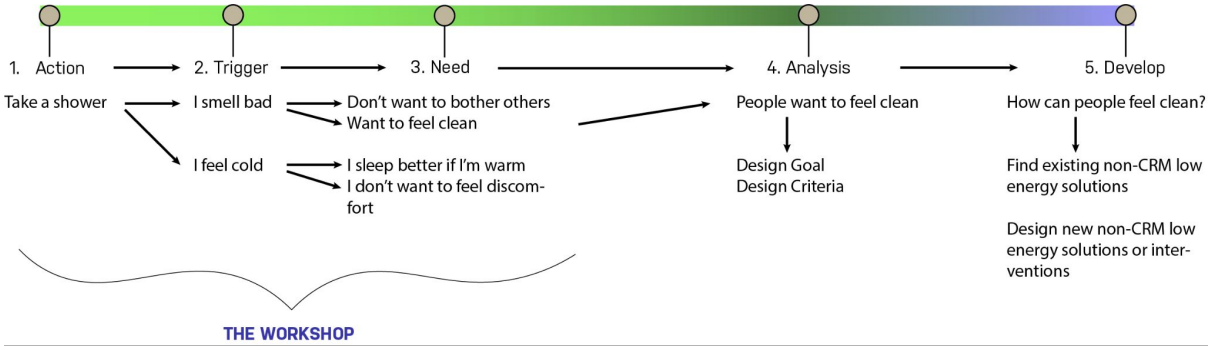

Figure 1.7 visualisation showing which questions the workshop covers in the planned user research

I can know or ask which actions my participants did, and I can take that as a starting point for the workshop. From this action, I can ask what the trigger was that pushed them to do this action, and then go down the sequence of "Why is that important to you?" questions to discover the middle and ultimately the fundamental needs. So for the workshop, I will start with a product and an action, ask what the trigger was for this action, and then work my way down to the users' fundamental needs. During analysis, I can then review the answers, compare, draw conclusions and see what fundamental needs these current products fulfil, and thus which needs need to be considered for a redesign or intervention. The triggers could perhaps be used to push people to use my design or as a basis to redesign certain technologies or other solutions, and the middle needs are valuable as insights into what good focus areas for a design direction could be. Figure 1.7 shows which parts of the user research the workshop covers.

To set up this workshop to discover triggers and needs related to products and actions I will use general advice on creative facilitation and co-creation sessions from the Convivial Toolbox (Sanders & Stappers, 2012). For example, I'll ask the participants to take the two days leading up to the workshop date to carefully consider their product use, how often and why they use the products they use. This will serve as a miniature sensitizing activity to get the participant thinking about the topic beforehand. And I'll use extra physical props as a toolkit that the participants can look at and manipulate to give the participant more ways of expressing themselves.

1.13 Research methodology and setup to discover the human needs of tiny house

inhabitants

Pieter Desmet's research on fundamental human needs came up with a list of 13 basic human fundamental needs that apply to all humans regardless of their nationality, culture or affluence. It is difficult to say which need a certain product fulfils, since one product can fulfil multiple needs, and different people might use the same product to fulfil a different need. More research is needed, so I conducted a workshop with tiny house inhabitants living in a tiny house community in Delft, the Netherlands, to see if the list of products in their homes can be translated into a list of needs. Chapters 1.11 and 1.12 explain the general design theory behind this workshop. This chapter details the exact setup and method of the workshop.

Workshop Goal:

The workshop aims to discover middle needs, triggers, and common fundamental human needs(explained in chapter 1.12). The triggers and middle needs will most likely be the most useful result to design for, while the other data will possibly provide new insights for additional context and design criteria.

Workshop theory:

The workshop is based on a combination of theories from Pieter Desmet's Design for Emotion (2022), and Desmet and Fokkinga's (2021) Human experience catalog. This theory, combined with interspersed creative facilitation theory and methodology input from Convivial Toolbox: Generative Research for the Front End of Design (Sanders & Stappers, 2012), and common interviewing techniques. As explained in chapter 1.12.

Workshop details:

The workshop contains 2 parts, preceded by a preparation assignment: First the participant is asked 2 days in advance of the workshop to take the coming two days to consider their product use and why they use it. I asked them to consider for example what triggered them to take a shower.

The first part of the workshop is a mini masterclass from me to the participants about CRMs. I will explain in about 15 minutes what critical raw materials are, why they are so commonly found in our current lives, and why we are currently over-reliant on them. With this masterclass, I hope to inform my participants but also to get them invested in the problem. It helps them to understand why I do this workshop and why it is important. For this mini masterclass, I used A3 printouts of relevant graphs and Figures. In addition to informing and involving the participants in the topic, giving them this masterclass is also my way of giving them something in return for their participation.

The second part is a creative variation of an interview. Here, I present them with small printed-out icons of CRM containing products that are energy-related. The participant picks out one of the icons of a product that they recently used. I then ask them what triggered them to use this product. After that initial question, I adopt the design for emotion approach by continuously asking the participant "Why is that important to you?" And continue asking this question till we

arrive at one of their fundamental needs. I placed these icons on a large A3 paper printout with 3 rows. The first is for the product icons. The middle row is for writing down their answers to the questions. The bottom row places the fundamental need(s). Figure 1.8 shows how these materials looked before the workshop.

Workshop materials:

For the preparation, only a small text message or email text containing the assignment was needed.

For the first part of the workshop, I used A3 paper printouts to use as visual guides for my story

For the second part of the workshop, I printed out A3 papers with 3 rows on them. And icons of CRM products and small pictures of the 13 fundamental needs. A picture of how these materials looked can be seen in Figure 1.8.

I'll also need tea and cookies for during the workshop.

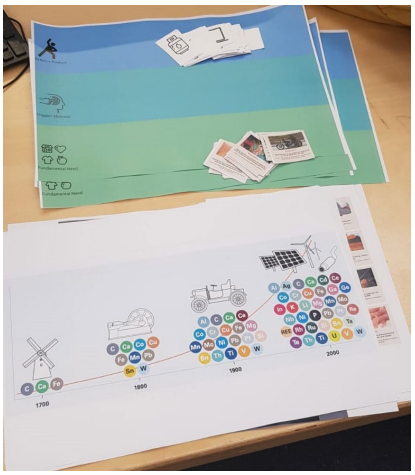

Figure 1.8, picture of workshop materials before the workshop

Workshop participants:

To find and recruit participants I first tried to contact tiny house communities via their public email addresses and asked for participants that way. After no response, I decided to create a flyer to distribute on social media and via email to different tiny house communities. The flyer is shown in Figure 1.9.

I conducted 5 workshops in total. 4 of which were with tiny house inhabitants in pionierskwartier in Delft. 1 was done online with a participant who had recently begun construction of their tiny house in Twente. All participants were aged between 25 and 55 years old.

Considering the small number of tiny house participants in the Netherlands, and the fact that a common response was that the inhabitants already participate in too many initiatives I decided that 5 users were enough since it is generally assumed that 5 participants are enough to find the majority of trends (Faulkner, 2003). Considering the timeframe of this thesis, it is likely that the time lost searching for more participants will not be worth the added benefit of research accuracy

Figure 1.9 flyer that was distributed to find participants for the workshop

Workshop data collection:

For every workshop, I collected data using written notes. These were stored on paper and digitally. Pictures will be taken and stored of the workshop materials with notes and printed icons placed on top. For the first workshop, I will use a voice recording app on my phone, so that I can listen back after the workshop to find improvements in my interviewing techniques

and the workshop flow if needed. I will delete this voice recording after review and adaptation. The full details of the user research were approved by the Human Research Ethics Committee of the TUDelft.

1.14 Pilot test description and adaptations

1 day in advance I sent the participant an email and WhatsApp message asking them to take note of the products they used in the past two days, and what triggered them to use them.

In the first workshop I conducted, I recorded the audio for the full workshop to listen back if it didn't go as planned to discover where I could improve.

I prepared the paper materials, brought tea and cookies and met with participant 1, I'll call them A. It was a beautiful sunny morning. After a short tour around A's house and the full terrain of the tiny house community, we started with the workshop itself. A had considered the homework assignment and that gave them a starting point for the workshop.

Results Pilot test and changes:

The workshop went surprisingly well for a pilot test, and I ended up making minimal changes. Primarily in the first part of the workshop, I changed my story and presentation materials slightly. The results from the pilot workshop do not significantly differ from the rest of the workshop participants so the pilot results are included as equally valid results with the rest of the workshop results.

1.15 Research results

The research produced consists of filled-in worksheets. These are photographed and one is shown in 1.10. For each of the 5 participants, we discussed the use of and needs behind roughly 4 different products. This gave me a total of 22 qualitative datasets of middle needs related to products. Each product contributed to an average of 2 fundamental human needs, for a total of 43 fundamental needs. And since there were multiple middle needs for each fundamental need, the number of middle needs exceeded well over 100 unique needs. I will not show all the results here in detail for privacy reasons since most of the middle needs are too specific and personal. Appendix B shows a digital version of the results that have been

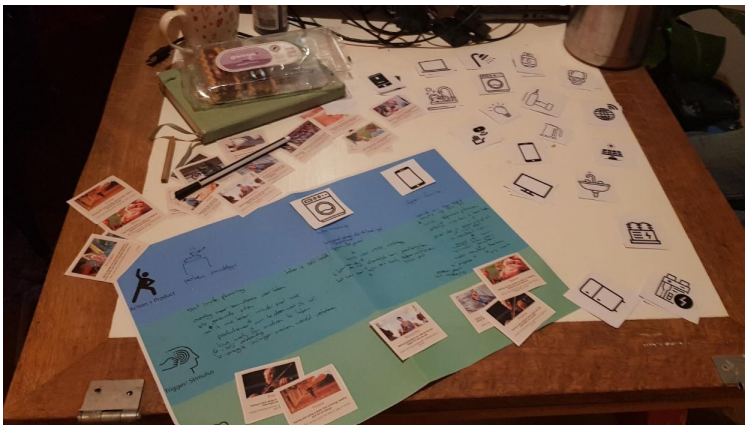

Figure 1.10, picture of workshop materials at the end of the workshop

stripped of the personal data One of these images can be seen in Figure 1.11. Most participants choose different products to talk about so for one single product, no more than 3 datasets are gathered. This makes drawing product-specific conclusions difficult, but overall the 22 datasets do give valuable insights into why these participants used certain products and showed many different triggers and middle needs.

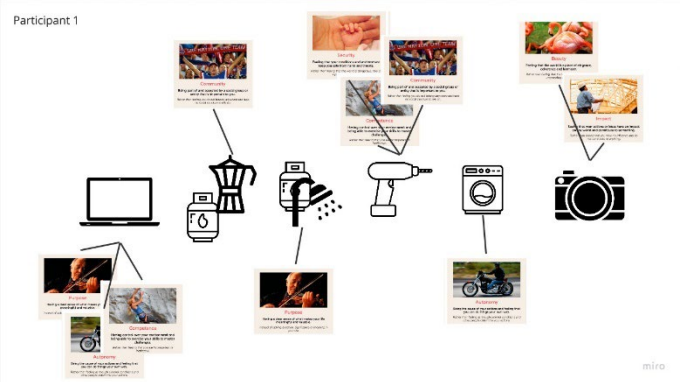

Figure 1.11 simplification of the results from one participant of the workshop.

Phase 2: Define, Analysis

2.0 Chapter introduction

Phase 2 is the analysis phase, also called Define in the double diamond design method. In this Phase, I will analyse all of the research from phase 1 and draw relevant design conclusions that can help solve the design problem. In chapter 2.1 I will explain how the results were different from my expectations. Chapter 2.2 shows a broad analysis using word webs and details two interesting insights gained from the user research specifically. Chapter 2.3 talks about findings from other sources than my user research. Chapter 2.4 summarizes all insights gained into a few paragraphs. Chapters 2.5 and 2.6 explain how these insights led to 4 possible design directions. Finally chapters 2.7 and 2.8 detail the design criteria and design wishes for any potential redesign.

2.1 The results were more diverse and complex than I had anticipated

I designed my research in a way to end up with a list of middle needs to design for. This list turned out to be too long to be useful for my design approach with well over 100 unique middle needs. I found that one product can contribute to multiple fundamental human needs, which is in line with the theory behind the 13 fundamental needs. However, since I conducted this research on a larger number of products and people, I expected to find overlap, repetition and similarity. And while there were some similarities, it was not enough to come up with a list of functions that can each of them be redesigned. One product can contribute to the same, but also to different needs between two people, and two different products could contribute to the same need for one person. Figure 2.1 shows an example of this complexity, overlap and differences.

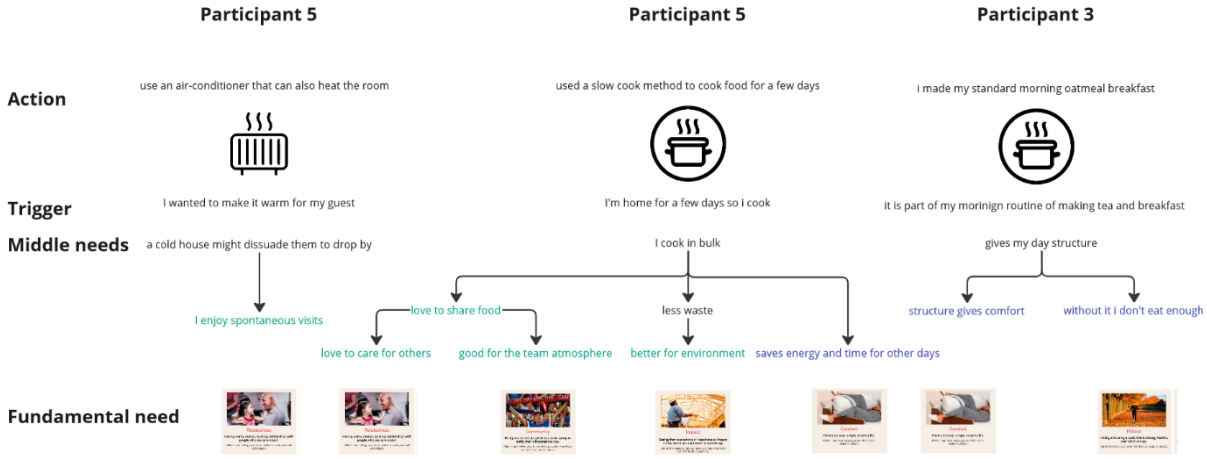

Figure 2.1. Path analisys showing the complexity of answers between products and participants and their needs

While I would argue that preparing food is an essential function for any home, the triggers, middle and fundamental needs for cooking are so different that I cannot translate the middle needs into a short list of essential functions. This meant that the results of my research are not suitable for my intended design approach explained in chapter 0.7. The research was still very interesting, however, and so I attempted to find other insights using the data I had.

2.2 Analysing the user research outcomes

I attempted to make sense of all the data I found by writing it all down on massive whiteboards and paper. I made multiple variations and iterations of this. One of these iterations was a word web (as seen in Figure 2.2) with answers for middle needs related to heating, Starting with heating in the centre, and ending with their final fundamental needs. I did this because I discovered that most energy and CRM products we discussed in the workshops were somehow related to heating. This might have something to do with the fact that I conducted this workshop in October, a somewhat cold part of the year. But it is in line with the earlier findings in chapter 1.7.

The first, and most important insight I found was that the biggest difference in answers was due to a divide in motivation: Some actions people do for themselves, and some they do for others. For example, one person might take a shower to feel productive, another might take one so they smell nice for others around them. This split turned out to be roughly 50/50. To highlight this I marked all answers in Figure 2.2 related to 'other' with green, and all answers related to 'self' with blue.

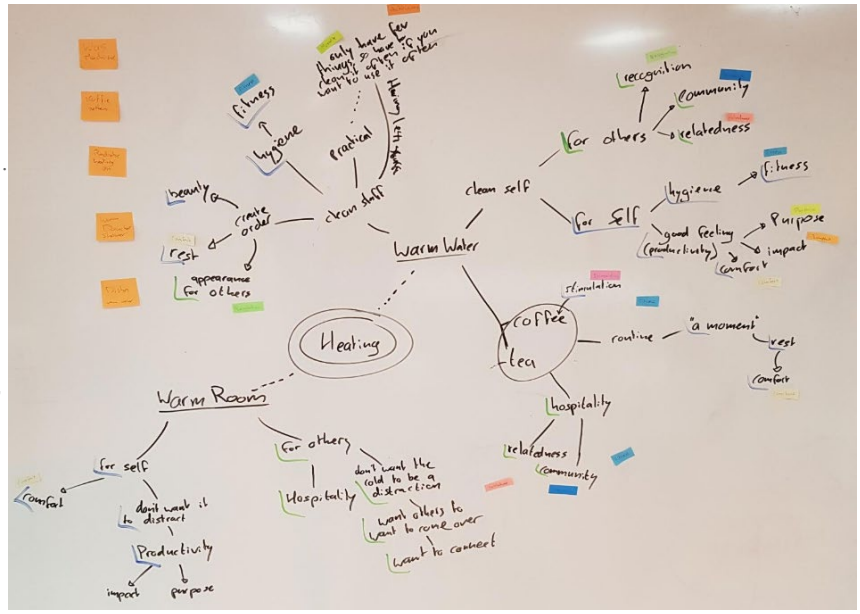

Figure 2.2 A wordweb with needs related to heating. Blue lines indicate a need related to 'self'. Green lines indicate a need related to 'other'.

2 other interesting insights I found by analysing the workshops are that a) The motivations and needs of each participant are wildly different. Even though the activities are mostly the same, the timing, effort and reasoning behind why people do these activities are very personal. And b) The timing of when people do certain things is often guided by when there is power for it. It makes more sense to shower in the evening since the solar boiler has had the entire day to warm up the water.

2.3 Additional research analysis and symposium findings

I also attended a symposium for geosciences about critical raw materials and energy. The most interesting insights from this were that a) there is enough money and technology to

keep global warming to 1.5 degrees. Political barriers, too low investments, and slow adoption of the necessary measures prevent us from achieving these goals (van Geuns, 2022). b) We need the majority of society on board, but there is a financial threshold. We need to make sure that those will less money are also included in the scope (van Geuns, 2022). c) For many people and companies doing the right thing has no benefits. We need incentives to support sustainable choices (Dijkhuis and Oterdoom, 2022). d) "Us" matters more than "them", For most people an issue needs to affect them personally before they are willing to make changes to solve it (Kleijn, 2022).

2.4 Research conclusions and insights

The goal of this thesis is to redesign living in such a way that it consumes less energy and becomes less reliant on CRMs to keep global warming below 1.5 degrees. Combining all insights gained from my research leads to the following conclusion:

People and companies don't take (enough) action to stop climate change because:

To reach our climate goal of 1.5 degrees Celsius there need to be more incentives for people and companies to take action. The threshold is often too high to easily make a change. Most people are not personally invested enough to care enough to take action. Social stigmas, prestige and peer pressure are slow forces that could work in favour or against taking action. Going local in our production would make things more personal, and would reduce our reliance on outside sources. Media and other forms of exposure are often conflicting, echo chambers, or too difficult to understand, resulting in people not having a clear idea of what the problem is and what they can do to help. Many people are willing to take action and to make changes, however, the problem and solutions are often perceived as 'too big' or 'too complex', demotivating people to take action. Choices like going vegan, or getting solar panels are something often only available to privileged people with time or money to spare. People who are struggling to get by also need to be included in the scope in order to curb climate change.

CRMs are embedded in most electronic products nowadays, and there are several reasons why people use these products and keep using them.

People use CRMs because:

CRMs make their lives more comfortable (remote control, sensors, automated work etc).

It is available (Cheap, polluting and poorly made products are pushed in advertisements making it easy for people to purchase the 'bad' thing).

It is cheap (If something is made using child or unpaid labour, or done with little regard to environmental concerns, the price can be much lower, which makes it out-compete the more ethically and sustainably made products).

People are unaware of the presence of CRMs (CRMs might as well be invisible and magical for most people. Knowing how your phone works is way too complicated for most, and these CRMs are used in trace amounts and hidden behind a nice phone casing).

People are unaware of the CRM crisis (Most people know about the climate crisis(Center For Climate Change Communication, 2021), but the CRM crisis gets very little coverage in popular media).

It is fast (the newest phones are much faster, but contain a lot more CRMs than old ones).

It is cool (the newest gadget or trend is often not good for the environment per se, but people want to fit in).

It is necessary (try to get a job without access to a computer, phone and internet).

It is familiar (we are used to sending each other a text and having sensors that switch on the light for us, once we are used to it it is difficult to go back, or change to something new without enough incentive).

People choose the road of least resistance (Most people don't stop to reflect on their behaviour because they are unaware of any problems or do not wish to be confronted by their mistakes).

People feel entitled. (Once you have gotten a (perceived) right, people don't want to give it up. People have gotten used to their "right" of going on holiday twice a year, eating meat every day, and taking a hot shower. Telling them they can no longer do this makes people angry).

There is a sense of 'plenty' (If you turn on the tap, water comes out. If you turn on the heater, your house warms up. The costs come later. In a tiny house, you have to first look if you have enough energy or water left to take a shower. It creates a sense of scarcity and thus makes people use resources more sparingly and thoughtfully).

People want to be inviting to others (sitting in your own house at 18 degrees Celsius is one thing, but if you have guests over you want them to feel comfortable so you turn up the thermostat).

2.5 Choosing 4 design directions for a possible (re)design

To redesign something that will help people make better decisions regarding climate change and CRM usage it is important to keep all of these factors in mind. And play into their hand rather than against them. To stop climate change we already established that we need green solutions that don't rely on CRMs, and we need to reduce our energy demand. Our GHG emissions come from many different fields, and CRMs are incorporated into nearly every product, so there is no single thing that will solve the crisis. The scope of this project settled on focussing on the heating and cooling inside buildings, but within this scope, there are still many different routes to take. The most obvious design direction is to design something that cools or heats a home without the use of energy and containing 0 CRMs. But that is only one design direction. Figure 2.3 shows a word web which combined the insights of the research into a couple of potential design directions. From these design directions the ones I think are

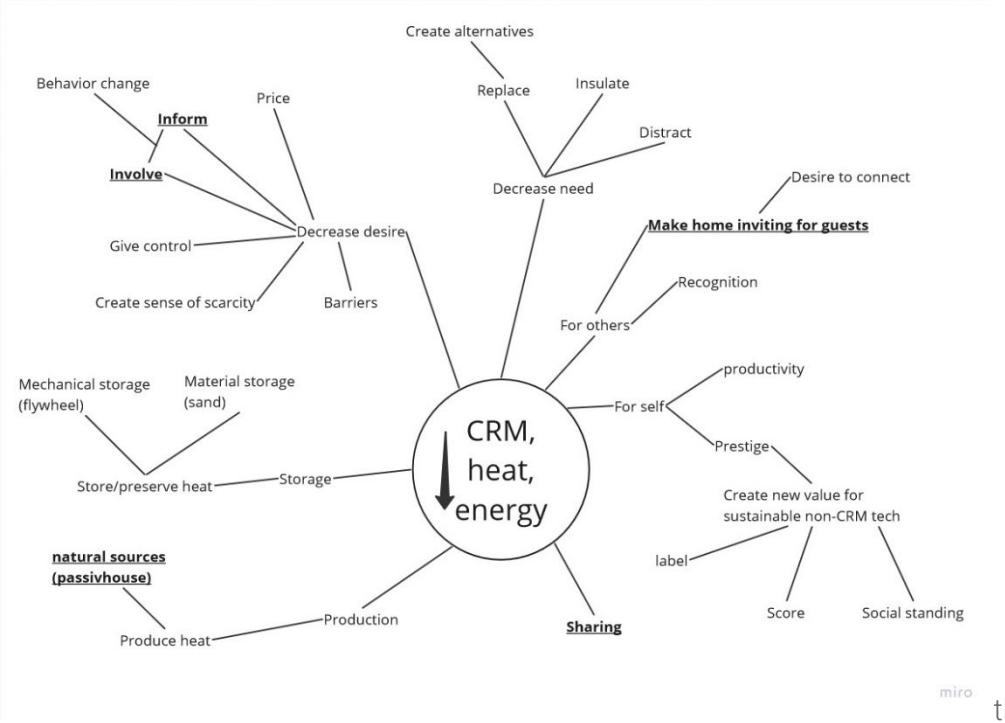

Figure 2.3 word web of potential design directions related to reducing CRM, Heat and Energy use

the most promising are highlighted in bold. These were selected based on a combination of what the research showed to hold the most potential and what sparks my personal inspiration. So I will primarily focus on the following 4 design directions:

1. People need to be informed and involved in the climate crisis. People need to care about the crisis personally and they need to know what's going on and what they can do to help. People need to become more literate in the climate crisis and be given incentives to do the right things.
2. People want their homes to be inviting to guests and they want to connect to people. Making their home inviting to others should be made possible, attractive, easy and affordable using low-energy and low-CRM alternatives that can replace current solutions.
3. People are living highly individualised and materialistic lives. By sharing products, and having more services and experiences instead of products we can greatly reduce our collective reliance on CRMs and energy consumption.
4. A home needs to be cooled and heated for people to be able to live in them. Heating and cooling should be redesigned to be achieved without the use of fossil energy and CRMs.

Each design direction does not necessarily rule the others out, and it might be possible to come up with a single solution or a combination of solutions that play into all 4 spaces. However, each design direction warrants its own ideation. I will ideate ideas for each of the

different design directions while keeping an eye out for opportunities to combine all 4. The first design direction has 2 distinct aspects, that I believe go hand in hand. Ideating for both aspects at the same time makes the design process too complicated, so for the sake of simplicity, I will narrow that design direction to 'informing' only. Only after ideation will I consider whether incorporating the involvement of people into the same idea is possible.

2.6 Defining 4 Design Directions

Each of these design directions can be written as a design goal that can serve as a starting point for ideating solutions. However, there is one single over-arching design goal that applies to them all:

"Design something that reduces the negative impact living has on the climate while making living less reliable on critical raw materials."

Each of the design directions also warrants its own design goal for ideating specific ideas:

DG 1. Design something that informs people about their personal influence in the climate crisis and enables them to take direct action.

DG 2. Design something that provides low-energy and low-CRM alternative solutions that make a home inviting for guests.

DG 3. Design something that utilizes communities to create a shared economy between them.

DG4: Design something that contains 0 CRMs and has 0 carbon emissions in use that sufficiently heats and/or cools a home in the Netherlands.

2.7 Defining the Design Criteria

There are 2 over-arching design criteria, that if not met will instantly reject any design idea.

1. Does the design contribute to combating climate change?

2. Does the design create a lower direct reliance on critical raw materials?

Design goal 1 has to additionally meet the following criteria:

- Does the design inform the user about their own influence in the climate crisis?

- Does the design enable the user to take action without delay?

Design goal 2 must meet the following criteria:

- Does the design require less energy to operate than its alternative?

- Does the design reduce the overall energy and CRM use of the user?

Design goal 3 has to meet the following specific criteria:

- Does the design make use of the existing community of the user?

- Does the design help reduce the overall per-person use of energy and CRMs?

Design goal 4 has to meet the following specific criteria:

- Does the design contain 0 CRMs in its design?

- Does the design have 0 carbon emissions in use?

- Does the design allow the inhabitant to comfortably reside in winter and/or summer temperatures in their home in the Netherlands?

These criteria have to be met, otherwise, an idea will be rejected in its current form.

N.B. These criteria will only take into account energy use and CRMs that are part of the design itself, not the indirect CRMs and energy necessary unless these indirect sources provide a significant and clear increase in overall Energy and CRM requirements.

2.8 Optional Design Wishes

There are also some more flexible criteria, called wishes. If a design idea does not (partly) fulfil these wishes it makes one idea less desirable over another but does not automatically reject an idea. Since each idea might be better in some regards than another idea and worse in other regards, having design wishes to rank the ideas helps to choose which idea is the best overall.

Using these wishes and the Harris profile evaluation method from the Delft Design Guide (Van Boeijen et al., 2020), the best potential ideas can be chosen when there is no clear favourite. These wishes are ranked from most important first, to least important last. Some wishes are not related to the design potential but to personal constraints and the master's graduation thesis project format.

The design ideally should ...

- Be achievable for me (given my personal abilities, available facilities and time)

- Have a high impact (on reducing climate change and reducing reliance on CRMs)

- Have a short timeframe (be able to have this impact as soon as possible)

- Be accessible (for the large majority of society, not just for the privileged)

- Have some human-product interaction (considering this thesis is for the master's track 'Design for Interaction')

- Be appealing (people should want this product or idea)

- Help create or deepen connection to nature (this helps to make people care more and makes them more willing to take action and more likely to make more sustainable choices)

Phase 3: Develop, Ideation

3.0 Chapter introduction

The previous phase ended with 4 design goals and their respective design criteria and wishes. For readability in this chapter, these are shortened to ‘inform’, ‘invite’, ‘community’, and ‘temperature’. These 4 design goals are the starting point of the ideation process. Ideation is a highly iterative process with many [(re)design, test, evaluation] cycles, called iterations. Chapter 3.1 describes how the first iteration sessions led to 4 concept directions, one for each of the design goals. Chapter 3.2 details how and why the podcast idea was selected as the best concept direction. Chapter 3.3 explains how the SCAMPER method generated many variations for the podcast concept and chapter 3.4 explains the process of quickly narrowing these down to 3 concepts using ultra-rapid prototyping. Chapter 3.5 discusses the user tests of the 3 concepts and which feedback and insights were gained. The final chapter 3.6 lists the conclusions and details how the final concept will take shape.

3.1 The first ideation sessions led to a concept direction for each of the 4 design goals.

The first iteration cycle started with a general brainstorm(Van Boeijen et al., 2020) to get any initial ideas written down on paper. After that, an ideation session was held to generate ideas for each of the possible design goals. These ideation sessions used different methods. For the inform and community design goals, I only used the standard brainstorming technique, since this provided me with good potential concept directions for those two design goals; for the inform design goal a podcast, and for the community design goal a central neighbourhood energy hub. The podcast is a way to educate people about the climate crisis and CRMs in the comfort of their homes. The neighbourhood energy hub is an idea based around creating a single large-scale structure that contains several energy generation methods, such as solar and

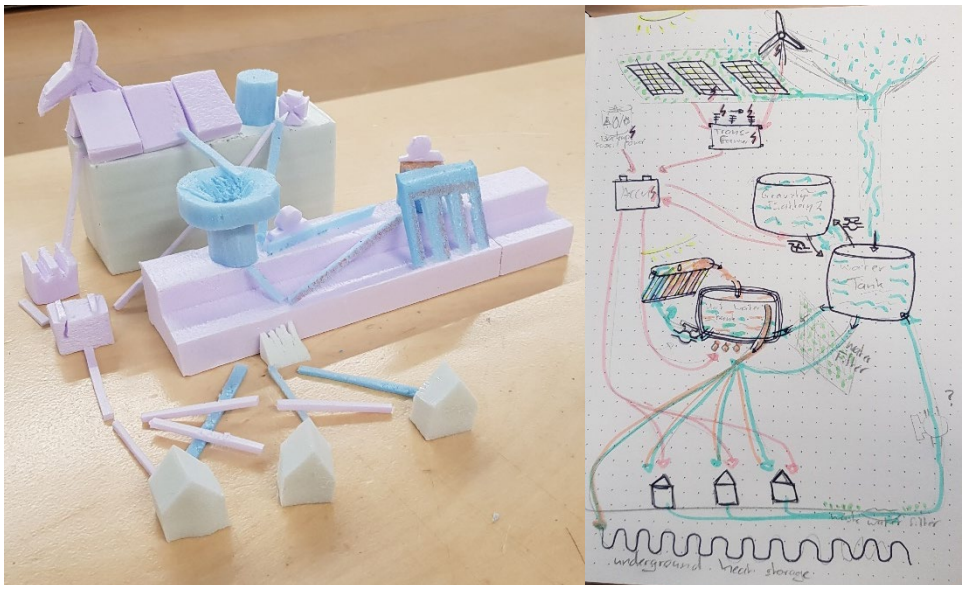

Figure 3.1 Drawing and model of the central neighbourhood energy hub idea

wind, and water collecting, filtration and solar heating systems. From this central energy hub, multiple homes can draw power and hot and cold water. Combining these systems into one reduces the amount of materials needed per home since not every home needs its own system, battery, and transformer systems. And it can be designed in such a way as to make optimal use of the available energy and water sources. Figure 3.1 shows some basic visualisations of how such a system could take shape.

For the invite and temperature design goals, a standard brainstorm did not prove to be enough to generate potential good ideas. So for the invite design goal, I followed it up with a "How To" (Van Boeijen et al., 2020) ideation session with 3 fellow students (Hendrik, Mirte and Lucas). I did this because 'making a home feel inviting' is a rather subjective goal and coming up with ideas on my own for this goal would risk me incorporating only my own perspectives and upbringing into the idea, potentially missing out on different perspectives and ideas that could work for other people.

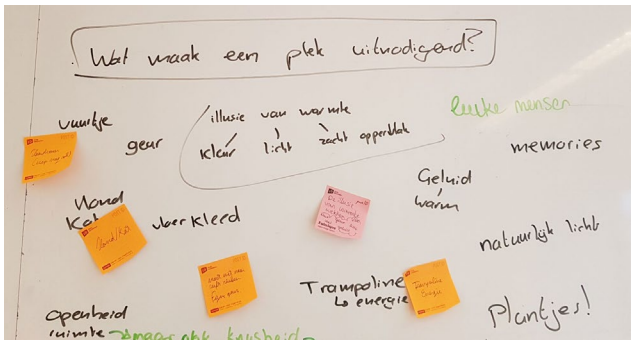

Figure 3.2 Brainstorm on the "How to make space inviting?"

In this session, I first asked my brainstorming participants to make a word web of all of their associations around the invite design goal: Design something that provides low energy and low-CRM alternative solutions that make a home inviting for guests. From this word web, we settled on a How-To for the brainstorming formulated as: "What makes a space inviting?" From this, we found that an illusion of warmth is enough to make a space feel inviting as seen in figure 3.2. So we did another round of brainstorming around the How-To of: "How can you give a space (the illusion of) warmth?" This eventually gave me 8 different avenues to pursue to achieve the illusion of warmth, as seen in Figure 3.3.

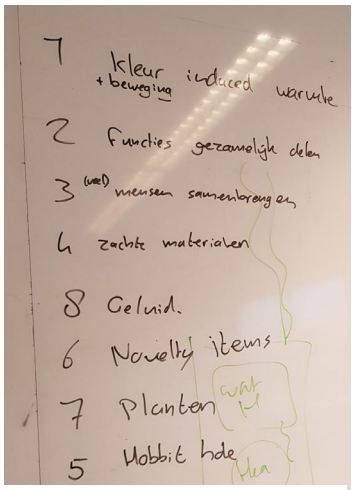

Figure 3.3, 8 potential design ideas for designing for illustionary warmth

For the temperature design goal I looked towards a biomimicry approach(Biomimicry Institute, 2023) for finding good ideas since this design goal - keeping cool or warm in different climates - is something nature already achieves in plenty of different ways and I think we can take inspiration from this. I used the website AskNature.org (The Biomimicry Institute, n.d.) to look for nature-inspired existing solutions that I could adapt or that could spark my inspiration for new ideas. I eventually found the concept direction of a camel-fur-inspired outer shell to cool a home. Figure 3.4 (Schumacher & The Biomimicry Institute, n.d.) shows the theory behind the cooling fur-inspired shell.

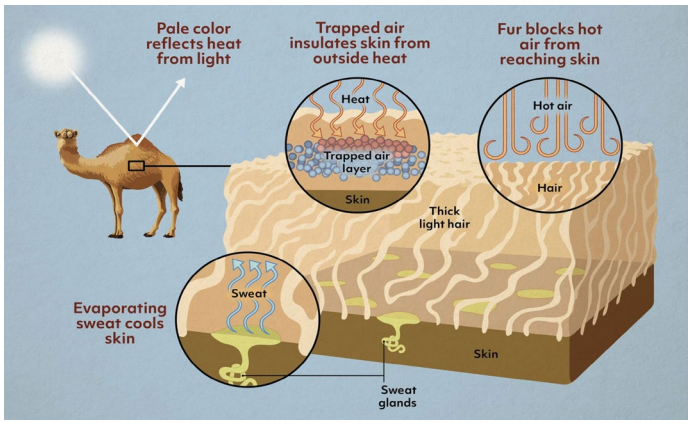

Figure 3.4. Visualisation of how a camel fur employs multiple tactics to keep cool in a hot climate (Schumacher & The Biomimicry Institute, n.d.)

These ideation sessions resulted in the following 4 concept directions, as shown in Figure 3.5:

				
Design Goal	1. Design something that informs people about their own influence in the climate crisis and enables them to take direct action.	2. Design something that provides low energy and low-CRM alternative solutions that make a home inviting for guests.	3. Design something that utilizes the community of tiny house inhabitants to create a shared economy between them.	4. Design something that contains NO ciritical raw materials for its heating and cooling (and is not fossil fuel)
Design Criteria	- Does the design inform the user about their own influence in the climate crisis? - Does the design enable the user to take action without delay?	- Does the design require fewer energy to operate than it's alternative? - Does the design reduce the overall energy and CRM use of the user?	- Does the design make use of the existing community of the user? - Does the design help reduce the overall per-person use of energy and CRMs?	- Does the design allow the user to reside comfortably in their home both during hot summer days and cold winter days? - Does the design contain 0 CRMs?
Ideas:	**Audio advice CRM-fighters** Low threshold, multi-faceted solution	**Illusionary warmth** Interactive, non-CRM solution.	**Neighbourhood energy tower** Technical, multi-faceted scale-able solution.	**A water-fur based outer layer.** Technical, multi-faceted, non-CRM solution
Short description	An audio guide (podcast) that people can listen to in their own home. Asking them to go to a certain area (cooking, living) in their home and look around what products they have. The audio guide will give them background information and tips on what the best thing for them to do now is to improve in regards to the energy transition (Energy and CRMs)	A collection of tricks and ideas that utilize auditory, visual, haptic, scent and taste perception to create the illusion of warmth in a room. For example by the use of red lights and soft surfaces. So that no energy or CRMs are needed to create the illusion of warmth.	A large tower structure is placed in each neighbourhood within it solar and wind power generator, water collection systems. Along with solar boiler and gravity water storage, water filtration and green roofs/walls. It is all linked to seasonal underground temperature buffer.	A design that can keep the inside temperature of the home a comfortable level without the use of CRMs by utilizing the concepts of trapping air, sweating and reflective colours. Might require manual labour to operate depending on the outside temperature.

Figure 3.4. Table briefly explaining all 4 design directions, along with their design goal and criteria.

3.2 The podcast idea was selected as the best concept direction based on the design wishes

After generating one potential concept direction for each of the design goals, the next step is to evaluate the 4 concepts by the design wishes formulated in phase 2. This evaluation was done using the Harris Profile technique (Van Boeijen et al., 2020). A Harris profile is an assessment tool that visualises the performance of a product based on predetermined criteria. In this case, the criteria are my design wishes. The wishes are listed from most important on top to least important on the bottom. By putting an imaginary “pole” in the middle you can roughly estimate which way a concept direction is ‘leaning’. With the top wishes adding the most ‘weight’ to the tilt. Each wish is then ranked on a scale of -2 to +2. If it does not achieve the wish at all 2 blocks are filled on the left side (adding ‘weight’ to the left side of the pole). If it achieves it somewhat poorly 1 block is filled to the left. If it scores mediocre 1 block on both left and right is filled. If it achieves the wish quite well 1 block is filled in on the right. And if the wish is fulfilled excellently 2 blocks are filled in on the right. The heavier a concept is leaning towards the right (towards +2) the more favourable it is. This is a subtle and subjective way to evaluate ideas, but it gives some more clarity to quickly see which ideas are less and more favourable. Figure 3.5 shows the Harris profiles of all 4 concepts. The dark grey column in the middle of each profile is this imaginary pole visualised to make it easier to see which way a concept is leaning. From this image, it is clear that the neighbourhood energy hub concept (3rd profile) is the least favourable since it is more left than right-leaning. The illusionary warmth and camel-fur temperature control concept profiles (2nd and 4th profile) are not strongly leaning any way and are difficult to choose between based on this profile. However, the podcast concept (first profile) is leaning heavily to the right

and is thus the most favourable concept based on my design wishes.

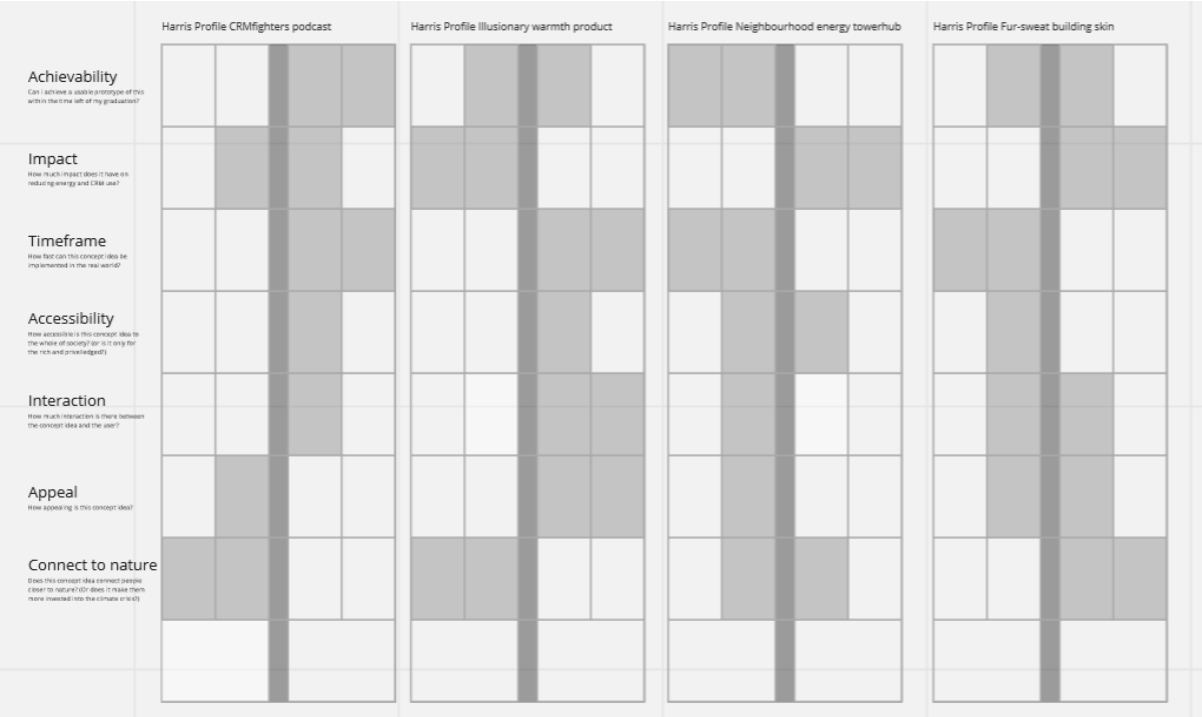

Figure 3.5, Harris Profiles for all 4 design directions based on the design wishes. The more the profile seems to 'lean' to the right, the more preferable the design direction is

3.3 Different podcast formats were generated using the SCAMPER method

With the podcast selected as the final concept direction, the second iteration cycle could begin. The first step was another ideation workshop with fellow students. This time using the SCAMPER method(Van Boeijen et al., 2020). SCAMPER is a method where you look at 7 different variation areas (Substitute, Combine, Adapt, Modify, Put to other use, Eliminate, Reverse) to come up with original changes and alternatives to the existing idea. This is a method more suitable when an idea is already relatively well-defined. After generating ideas on sticky notes these were clustered into topics. Figure 3.6 on the side gives an impression of the brainstorming session. The result of this ideation session was many different options for certain design areas of the podcast. For example differences in the tone of voice, different target audiences, accompanying the podcast with physical materials like stickers, and different topics for the podcast.

Figure 3.6 Picture from after the brainstorm of the SCAMPER method, where all ideas are clustered

3.4 Ultra Rapid Prototyping led to 3 concept variations of the podcast

The SCAMPER method gave me many different ideas on how to design the podcast. In order to quickly test many of these ideas without having to make countless podcast prototypes I used the Ultra Rapid Prototyping (UPR) method (Schermer, 2020). This is an extremely fast and fluid method of prototyping an idea with an emphasis on the interaction between the user and the product. In URP the designer and a few participants engage in a type of roleplaying: Multiple minute-long sketches are played out where one person 'plays' the product, one person plays the user, and other people could fill observing or context-related roles. There are three rounds of sketches and the participants swap roles between rounds so that the designer can experience their idea from the perspective of a user, of the product itself, and from an outside perspective. Within each round, there are several sketches. Each round starts with a different scenario, but within each round, the same scenario will be played at least three times, and variations can be made between each sketch based on the feedback.

For this method, I won't need any elaborate props or large participant groups to quickly test different versions of the idea and adapt instantaneously according to the outcomes of each sketch. The chosen scenario is as follows:

The user has just had dinner and wants to do the dishes before going to bed. So they walk to the sink and start doing the dishes while listening to the podcast. The podcast informs them about their energy and CRM use and gives them tips on what to do in their own life.

All I need are some foam blocks and a sink, with this the user can simulate doing the dishes without actually having to do the dishes. This way no water or soap will be wasted, and the foam blocks give the dishes-doer something to hold and distract them, just as doing the actual dishes would. These foam blocks are taken from a bin with waste foam in the workshop of my University.

I will conduct two separate URP sessions each with 2 student participants. I need 2 participants because one podcast variation is an interview and thus I need one person to do the dishes, and two people to improvise a podcast interview. Usually, one URP session is enough to get desired results, but by doing two sessions I could see if certain outcomes were specific to the participants. If outcomes were consistent between the two sessions I could be a little more certain that the findings were not outliers.

Overall, the results from both URP sessions showed that all four participants preferred the interview format to listen to for longer periods of time. The storytelling from the point of view (POV) of a product or material was also liked by multiple participants. Lastly, there was some debate because listening to a podcast about doing the dishes, while doing the dishes yourself was liked as a format because it feels like you have a partner to do the task alongside with. But the podcast will unlikely take exactly the same amount as the household task.

Eventually, I settled on 3 potential formats for the podcast to test further: Storytelling from a product POV, an Interview with an expert, and the podcast-along.

3.5 Testing the 3 concepts with users led to the final concept direction

Methodology and setup

After the URP sessions, I ended up with 3 different formats for my podcast. For each of these formats, I made a low-fidelity prototype that I then tested with 3 of my initial target users. Unfortunately, I could not do this test with all 5 of my initial users since some of my participants no longer had the time to help with my thesis or were out of the country. Considering how long finding tiny house participants took at the start of this thesis I decided to not look for more participants. Instead, I will accept that I only tested these designs with 3 people. According to Faulkner (2003), 5 participants, will find a minimum of 55% of the usability problems and an average of around 80%. With only 3 participants I will thus likely not find all and possibly not even the majority of all usability problems. But finding all usability problems is not the aim of this thesis, nor of this user test. This thesis aims to gain proof of concept and this test is here to quickly narrow down my possible design options. Thus, considering my tight schedule, I deemed 3 user tests to be enough for me to get useful and actionable feedback for the last round of iterations.

Each of the prototypes was presented in a slightly different way. The interview with an expert was an audio recording of somewhat poor quality of two people improvising an interview with one person acting as the 'expert'. The Storytelling POV was me reading a pre-written script to the participant in person. The Podcalong was an audio recording of me doing the dishes at home while giving some tips and advice on sustainability related to doing the dishes.

The difference in delivery will make it harder to conclusively tell which format is preferred since not only the format but also the method of delivery was different. However, I clearly pointed out to the participants at the start that each prototype had different delivery and quality. I asked them to keep in mind that this is a low-fidelity prototype and many options are open at this point. And I specifically asked the participants if they could also tell me if the delivery and the quality affected their opinion of the prototype. In a way, the fact that all prototypes were different and of somewhat low quality can also play in my favour because a too-detailed and high-quality prototype can often make the user feel like a prototype is already fixed and prevent them from freely giving feedback and thinking outside the box.

User test 3 concepts results

Prototype	Interview expert	Storytelling product POV	Podcalong
Description of prototype	A short recording of an improvised interview between an expert on sustainability (played by a fellow student) and an interviewer who will ask the questions from an 'average Jane' perspective, trying to understand the science and trying to learn what	A short verbal story, narrated by me from a pre-written script. The story follows the lifecycle of two different dish brushes, one made from bamboo and one made from plastic. It personifies the material and gives them human-like perceptions and emotions.	A short audio recording of me doing the dishes. Sounds of running or splashing water and the clinking of the dishes can be heard in the background while I give commentary on how I do the dishes, my actions, and my thought process and I give advice on actions the listener can

	the best practices are		take when doing their own dishes.
Notes and questions told to the participants	The expert in this prototype was not an actual expert, and the facts and stories told were improvised on the spot. So the content of the podcast is not to be believed, but feedback on the content, format and listenability of the format is appreciated.	The lifecycle of the products was lightly researched but should not be taken as hard truth. Any feedback on the storytelling, tone of voice and listenability of the podcast is appreciated.	The facts in this podcast are not researched and should be taken with a grain of salt. The audio quality, opinion on background noises and the listenability of the format is appreciated.
Summary of the feedback given by the participants	The quality of the recording was poor and the volume was very low, making it difficult to hear over the sounds of doing the dishes. Listening to these two people talk was a pleasant experience as it felt 'gezellig', lively, and was good entertainment. I would listen to this type of podcast easily and for a long time.	The tone of voice was a bit childish. However, I was really intrigued by the first story, because I wasn't sure what was coming next and the storytelling was very visual. But after the first story, the second felt not so interesting because the novelty had worn off. It felt like there was a strong judgement value given to one of the stories over the other. I'd listen to this podcast maybe once, but If I want to listen to storytelling I'd pick more interesting stories. This podcast stands or falls by the quality of the story writing and storytelling	This was fun to listen to. But I'm not sure if I'd pick this myself to listen to. The tips were very useful and directly related to the task of doing the dishes, but I now have wet hands I cannot execute most of the tips you give me. So I feel a bit frustrated. It did make me actively think about how I actually do things. The background noises of doing the dishes can easily get too loud, but overall it was fun to do the task 'together'.

Feedback conclusions

The 3 user tests gave me largely consistent results and feedback; Listening to a conversation is a lot easier than listening to a single person. Giving direct tips is nice and makes the listener think. But by giving tips during household activities, the listener is not always in a position to execute the advice directly. The storytelling was fun as a gimmick, but will unlikely hold for a long podcast with many episodes unless the quality is extremely good. The impact and usefulness of the story were also rated the least out of the three formats. Doing the activity while listening to a podcast about that same activity was perceived as fun. But was not very practical, because people usually pick the podcast they want to listen to based on what they feel like listening to. It's unlikely to perfectly align with the activity and their desire to listen to that specific episode. Plus the duration of the podcast and activity will unlikely align. Interviewing an expert while they are doing the dishes might also be a fun format (though more difficult from a production point of view). The activity of doing the dishes might be a little bit too loud for the listener to hear the podcast, perhaps cooking or cleaning might be a

more suitable activity to choose.

3.6 Conclusions from the ideation and testing iterations

To conclude: I will drop the idea to make a podcast about an activity perfectly align with doing that same activity. Storytelling might still be used but the tone of voice should be more informative and less childish. It should also be a small, and separate part of the podcast. This will allow me to learn and get better at storytelling but at the same time, it is easy to skip if people don't want to listen to this. The main bulk of the podcast will be an interview with an expert, where I as the interviewer have the responsibility to ask the right questions and make sure that what the experts tell is clear to the listener and that the topics are not only informative but also actionable. To help with making the podcast more actionable I will end the podcast with a final part where I give conclusions about the interview and list the relevant actions that the listeners can do.

As a final showcase prototype, I will produce a pilot episode for the podcast that has elements of all three tested formats, with the main portion being an interview format. The topic for the episode will be cooking since I think it is more suitable for a pilot episode. This is because cooking usually takes a bit longer than doing the dishes, and cooking is considered - by the people I know - to be a more fun and interesting topic to talk about, making it more likely people will listen to this pilot episode. I made a high-fidelity prototype of this final design that I presented to my participants. The details of the final design are described in phase 4.

Phase 4: deliver, finalize

4.0 Chapter introduction

Phase 4 is the fourth and final phase of the double diamond design method. In this phase, I will finalise the chosen concept details in chapter 4.1 I explain why the podcast medium is a good fit for my design goals. Chapter 4.2 describes the final design details. Chapter 4.3 contains the script of the podcast episode. Chapter 4.4 contains a link to the showcase podcast episode and chapter 4.5 evaluates the final prototype based on the 4 design criteria. This phase ends with final recommendations to optimize the podcast further in chapter 4.6.

4.1 Why the podcast medium is a good fit

Podcasts are a relatively new media form, the term popped up in 2004 (Kalsey, 2022) and it has steadily increased in popularity since then (Google Trends, n.d.-a). A podcast is a pre-recorded audio media form that is very suitable for our modern lifestyles due to its on-demand, diverse and combinable nature. Podcasts are most often listened to while doing a household activity(Tobin, 2022), making them very suitable for my thesis. Stephani (2021) pointed out 4 different factors of how podcasts can cater to different needs of an audience: The edutainment factor to educate and entertain people; Storytelling to make time fly; A social factor to make listeners feel connected; and finally a multi-tasking factor for during monotonous and routine tasks. My podcast proposal is primarily focused on the edutainment factor, but it also tries to include storytelling and multi-tasking factors. Podcast listeners are usually more curious and open-minded, and have a higher need for information according to Tobin (2022), making podcasts an excellent medium to fit my design goal, and will not likely fall on deaf ears. However, I have learned from experience that after listening to a long interview it can sometimes be difficult to pinpoint what the most important things were. For this reason, I will make sure to add a final, short, easy-to-remember conclusion to the end of the episode.

My research found that reducing energy and CRM use is a complex task since every person has different products and habits for different needs. Even in a tiny house, there are many different products present that use energy and CRMs, but in tiny houses, there are at least fewer of these products. If you live in a smaller house, you'll generally need less energy and fewer materials. So going tiny is a great step towards reducing your energy and CRM use. However, this will not get your use down to 0. Achieving a close-to-0 impact requires a person-by-person, a need-by-need, and a product-by-product approach. A podcast can have many different episodes that each address one specific topic. One need, one product, one technology, or one behaviour. By making a different episode for each of these topics there is more time to dive in-depth and discuss nuances, caveats and tips about each of these. This

allows for a case-by-case approach, eventually, all these steps add up to a large impact. A visualisation of this hypothetical reduction through multiple interventions, each from one podcast episode is seen in Figure 4.1.

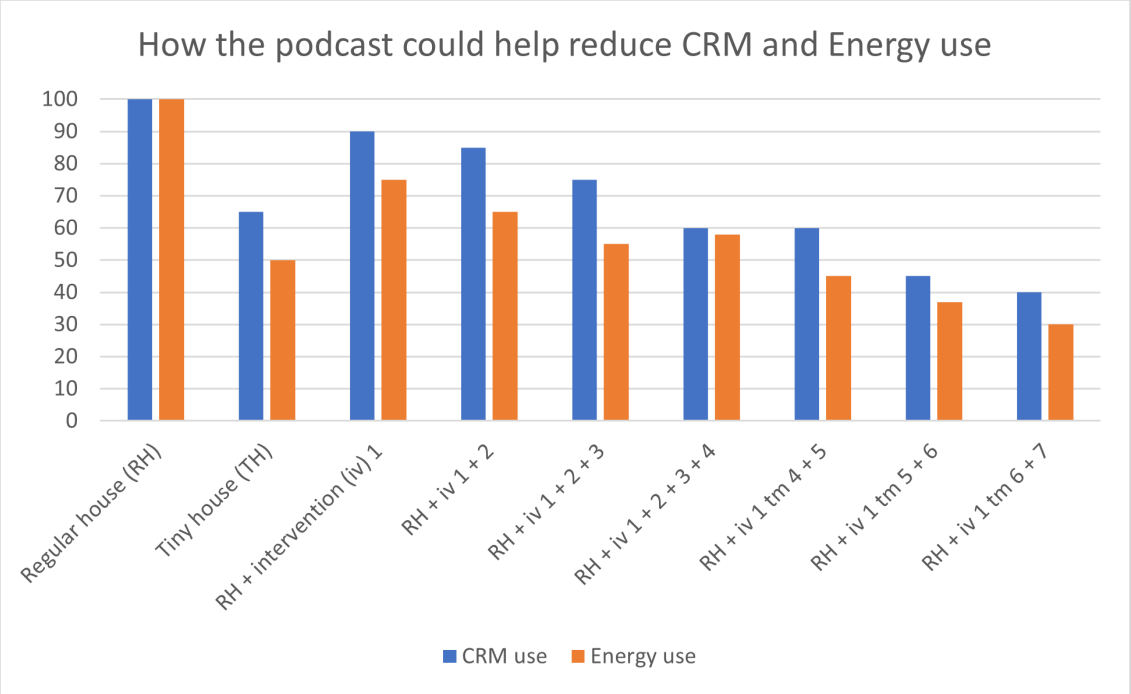

Figure 4.1, visualisation of the hypothetical effect of the podcast on CRM and Energy use in a regular house compared to that of a Tiny house.

4.2 Final concept design details: Podcast: Climate critical

Climate critical, the podcast

"Climate critical" is my final concept design. Climate critical is a podcast that informs people on what actions they can take to help fight climate change and reduce their CRM dependency.

Each episode is cut into 3 parts. Of roughly 10 - 20 - 5 minutes. Each episode will be centred around a simple task the listener can do in their home, such as doing the dishes, cooking, taking a shower, etc. The showcase episode will be about cooking and food.

The first part is 10 minutes of me introducing the topic. I'll give the listener some basic facts. This is the space where there is room for storytelling experimentation.

The second part is about 20 minutes of me interviewing a relevant expert. I'll play the part of the average Jane and ask the expert to explain things as uncomplicated and useful as possible.

The third part is about 5 minutes of me giving a conclusion of the interview and practical tips on what the listener can do to help fight climate change.

4.3 Podcast script

TRAILER :

Hello and welcome! I'm Judith Meijer, the host of climate critical! A podcast about sustainability, energy, critical raw materials and the wicked complex problem of the climate crisis. It's easy to get lost in the whirlpool of conflicting information, greenwashing and false promises surrounding sustainability. Through this podcast, I hope to teach you to be more critical towards governments, companies, and yourself and arm you with a better understanding of the complex problems and what actions you can take right now. Episodes start with a short introduction to the topic, followed by an interview with an expert, and at the end, I'll summarize and end with practical, actionable advice and conclusions. I'll provide links to sources in the description. I hope you enjoy it, and let's get climate critical together!

Part A: Introduction

Hi and welcome to climate critical! I'm Judith, your host for the show. This is my first podcast episode, and this episode is a showcase for my master's graduation project for Design for Interaction at the Technical University in Delft, the Netherlands.

Why this podcast? We as humans emit way too much greenhouse gasses for the earth to balance out, and that's why the climate is changing. This is due to many different factors, but can in essence all be boiled down to energy use and agriculture. The amount of stuff and food we produce and consume is huge. It is simply not sustainable anymore. There are many things we need to change, if we want to keep the climate livable for us humans.

Through this podcast, I hope to teach you about the climate crisis, and how it's a very complex problem. And hopefully make you more critical towards the plethora of greenwashing, good intentions and able to filter out the actual sustainable actions. Each episode will discuss a different topic. After this introduction part I have a discussion with an expert to look at the data and the science behind it and have them answer some questions. I end the episode with practical tips and conclusions that you can actually use in your everyday lives.

One of the biggest impact areas is cooking and food, today's episode!

We all need to eat, so even if you never cook, you are still dependent on cooking. Cooking accounts for about 3.7% of our global GHG emissions. That's not even considering the impact of the food itself, which contributed around 18.4% of global GHG emissions in 2016. So it is a good topic to dissect for this first episode.

Cooking has a significant impact in terms of GHG emissions, but why? Do we cook too much? Or just inefficient? Or is it just a necessity we can't get around? Is induction cooking superior to electric or gas stoves? Does the kind of food matter? Or the materials of the stove and pans?

The answers to this are different for different areas around the world. We'll be discussing a relatively wealthy, western European cooking perspective. But for now, let's dive into the second part and let's ask an expert.

Part B. Interview.

0. What are your name and your pronouns?
1. What do you do, and what is your area of expertise?
2. What is the impact of cooking on the climate?
3. Which part is responsible for the most GHG emissions? Is it the energy use, the manufacturing and materials, recycling, transport, our behaviour, or the food itself?
4. Which is better: Induction or gas stoves?
5. How much of this is the responsibility of the consumer, and how much of governments and companies?
6. What are the best habits we can teach ourselves to improve our cooking?

Part C: Conclusions.

That was a lovely interview, and I learned a lot. But I know from experience it's hard to filter and remember the most important things after listening to a long interview. So I'll summarize the key points for clarity.

We've established that the biggest impact is in what you eat, not in the cooking.

Single best thing: Less meat, the smaller animal is better.
Next best things: Less dairy, and less waste.
In the supermarket, be aware of what you buy, and think about it. Sometimes you might not know for sure which s the best choice, but be aware of the tradeoffs. In general, products that are in season, are locally grown, and are not processed are the best foods to buy.

For cooking, green energy production is needed, if our energy grid is fully sustainable, induction will be by far the better option over gas.
Be creative in how you cook. Plan ahead, use leftovers, freeze food before it goes bad, and be more efficient in your energy use.

Governments should have a guiding role: support good production, and set rules to prevent bad production. Companies have the means actually to change the systems for the better. And consumers can use the power of choice to change the demand, which again can stimulate the companies to change for the better and you can use your power to vote for leadership that will make those sustainable rules for companies are in place.

So, think about what you eat, eat less meat, less dairy, and create less waste. Be creative in how you cook and use the power of your choices. And don't forget to have fun.

That was all for this episode. I hope you learned something new, and have a better understanding of what you can do. Links to all the sources can be found in the description, and if you have any feedback, tips, or requests, let me know via the link in the description. Thank you for listening to this episode of climate critical!

4.4 Final prototype

The showcase episode can be listened to on Spotify by searching in the podcast section for: “Climate Critical; Cooking and Food with Yvette Sweringa.” or via the following link:

https://open.spotify.com/episode/6XH2jzug1PaBHyEUIhbcPQ

The audio file of the podcast is also added to the repository of the TU Delft along with this thesis.

4.5 Evaluation of final prototype podcast

Phase 3 delivered 4 design criteria for my design. Here I’ll list them again and answer briefly if my design is successful in achieving them.

1. Does the design contribute to combating climate change?

Yes. It discusses clear contributors of GHG emissions and educates people about the crisis, their personal impact and gives them actionable tips to reduce their impact.

2. Does the design create a lower direct reliance on critical raw materials?

No. Direct CRM needs are not reduced. By adding a podcast to a podcast platform, which people listen to using their technological streaming and audio devices, I and the listeners used a lot of CRM-containing materials. I did however not create a new product or source of CRMs. This episode did not discuss CRM use, since the expert I interviewed had no expertise in this field. Another episode could interview another expert that would be able to discuss the topic, but this showcase episode did not succeed in giving the listener actionable advice on reducing CRM reliance.

3. Does the design inform the user about their own influence in the climate crisis?

Yes. The prototype podcast gives a wealth of information, backed up by papers, statistics and critical discussion. But since influence differs per person the information is still somewhat generalized rather than discussing exact personal influence.

4. Does the design enable the user to take action without delay?

Yes. The final part of the podcast summarizes the in-depth discussion and gives the listener actionable tips.

This showcase did not manage to fulfil the second criteria. This is not a problem since this showcase is only one episode of the podcast. With more episodes, I can interview more experts, and address all aspects, including the second design criteria.

4.6 Recommendations and suggested adaptations for the podcast

I want my podcast to achieve a few specific goals: Give easy-to-understand information, explain the complexity of the climate crisis problems, set clear priorities, and give actionable advice to the listener.
I tried to achieve this around a certain household activity per episode and finding an expert to talk about that activity. Finding a person who is an expert in energy, materials and sustainability is a hard task to begin with, but one that is also specialized in a certain household activity is nearly impossible to find. The people I found that might be suitable experts for the podcast didn't have the exact expertise I was looking for.

To achieve all of these goals, more episodes for the podcast are needed. One episode could be for discussing energy use, one for material use, and perhaps another for behavioural change. This way I can find a relevant exert for each topic, and it will prevent me from having to skip important aspects.
Since I am looking for specific information, another way to achieve these goals is to search for this information myself. Looking at papers, books, videos, and talking to experts off-podcast. Then, invite a friend over with whom I can discuss these topics in a friendly, yet critical way. This will make it easier for me to discuss more topics combined in a single episode and still gives the listeners a conversation between two people to listen to instead of a monologue. This will however probably increase the amount of work needed for each episode, but make it easier to share sources with the listener, and a good dynamic between myself and my friend could make the podcast more enjoyable to listen to.

PHASE 5

5.1 Reflection on the project and the field

At the start of this project, I hoped to lay out a theoretical design of a house that contained no CRMs and needed a tiny amount of energy for household tasks and temperature control. Whilst this goal should continue to be sought, the scope was much too large for a 100-day Master's graduation project. I do still believe a home can be designed in such a way, but it would require a lot more research and work. First of all, such a research project needs work in redesigning many different technologies, such as energy generation and storage, heating water, heating and cooling spaces, cleaning, preserving and preparing food, lighting, and re-thinking the use of sensors and 'smart' systems. These need to be based on our human needs and available local resources. To complement this it needs to be paired with work in human behaviour - changing the mindset and lifestyle of people, governments and businesses to get them to buy fewer products, become less digital, share more and have a mindset that is centred around scarcity and balance rather than abundance and desires. The podcast from this thesis represents the 'design' output which aims to achieve some parts of both of these aspects. Via this podcast, new (or old), low CRM technologies with more informed design approaches, can get a platform and through the discussion and interview, I hope to make a small step towards changing the mindset and lifestyle of the listener.

We have an enormous task ahead of us to stop climate change and achieve net-zero emissions in 2050. We need universal systems, benchmarks, targets, certifications, rules and regulations, and open-source resources and research so that all systems can together form a new circular economy. But there is hope. The EU's Green Deal, Net Zero Industry Act, and Critical Raw Materials Act show that serious effort is being put towards regulations that enforce and ensure a sustainable future. With these EU-wide policies now taking shape member states will have to follow and eventually, businesses will need to adapt or move out of the EU. Companies that best adapt towards a net-zero future are the ones that will eventually outlast their competition. Our educational systems should also follow along with these transitions. And while Industrial Design Engineering's (IDE) slogan is: "Design for our future", most of what I've learned here is how to design new things that require new energy and materials to produce and operate. Some thought is given to the end of life but a truly circular design is not enforced and rarely even mentioned. We need to move completely away from this linear design thinking. IDE needs to change fundamentally towards a more circular design thinking. We should stop designing new smart things, and start smartly re-distributing what we already have. If we train our designers of the future to design linearly, we are hindering the move towards a circular economy. We should invest in teaching the designers of the future to design for circularity.

To aid with this objective I propose that IDE adopts 4 new master tracks to replace the current ones:

Track 1: Strategic Circular Business Design. SCBD will look at changing the industry: how to transform businesses to make them circular and sustainable, both from a business, customer and environmental perspective.
Track 2: Closed Loop Product Design. CLPD will specialise in the practical elements of circular production. How to close the loop? Which materials are sustainable, how to make products long-lasting and repairable(design for disassembly), and how to upcycle the end-of-life and waste products?
Track 3: Design for Inclusivity and Accessibility. DfIA will specialise in the human point of view. How to make a circular economy accessible for all people. How to make it inclusive for people, climate and nature. How do we get everybody on board to adapt to this changed way of life?
Track 4: Design for Upcycling of Existing Products. DUEP will focus on finding new opportunities for products that are already created. And how to get current waste streams back into the production cycle.

5.1 Discussion

The green energy transition is unachievable due to our high energy demand and current green energy technology's over-reliance on CRMs. I sought to find opportunities in the built environment to reduce our energy and CRM use. I conducted research intending to compile a list of needs-based functions that a home needs to have. These functions can then each be redesigned to be less energy and CRM-reliant. The list my research produced was too long to be useful for effective redesigns. This is in line with the theory of 13 fundamental human needs (Desmet and Fokkinga, 2020), which states that although fundamental, human needs differ from person to person and one product can fulfil multiple needs. I had expected that since my approach looked at a larger number of products in a single context, that the needs would be repeating and similar, leaving a small number of essential needs that a home should fulfil. This turned out to not be the case. Considering with only 5 participants I found over 100 different needs, conducting this research with more participants will not likely come up with a shorter list of needs. However, a large-scale execution of my research could uncover new insights and patterns. That would however require a lot of time and produce a very large dataset. So I propose using a different research approach to arrive at a list of essential home functions. Perhaps a bottom-up approach could be more effective: Participants are asked to live for a short time in a house with no functions. Adding one function at a time until a satisfactory living standard is reached. But this would be a topic for further research.
The long list my research produced still proved to be valuable, but it required a case-by-case approach. This was attempted by creating a podcast that could allow for many different episodes which could each address a single topic. This is somewhat of a band-aid solution,

and not addressing the problem by its roots. In addition to that, the impacts of the podcast are difficult to estimate since its effectiveness depends on the quality of the podcast and its reach. If only a few people listen to the podcast the impact will likely be limited. The podcast however is a design output that can have immediate effects, as it considers what is already there and suggests better alternatives that are currently available. So it is a suitable solution to bridge the gap while new research and technologies are being researched and developed. When these technologies are brought to the market, this podcast can give them a platform to help with faster adoption of the new technologies.

5.2 Conclusions

European climate goals to limit global warming to 1.5 degrees Celcius are unachievable in their current form because current green energy technologies needed for the energy transition rely too much on critical raw materials (CRMs). This thesis sought to design something that reduces the negative impact living has on the climate while making living less reliant on critical raw materials. Literature research showed that in the context of buildings, space heating and water heating are the biggest uses of energy in Europe. CRMs are found in many different products in homes, but primarily in electronics. This includes energy generation technologies such as solar panels, energy storage technologies such as batteries, entertainment technologies such as computers, but also other technologies such as boilers, pumps, ventilators and sensors. My research found that the link between human needs and current technologies in homes is a diverse and complicated one. Further research is needed to compile a more suitable list of essential functions for homes in the Netherlands. To reduce our energy and CRM use in the built environment, a shift in the consumer's mindset and a redesign of our technologies are needed. Tiny houses are a great inspiration and show that we can live comfortably with less energy and materials. This thesis looked at tiny houses as a springboard and example of how we can live more consciously and from a mindset of scarcity and balance instead of abundance. As a result, I designed and recorded a podcast that can discuss the complexity of the climate crisis while addressing the complicated human needs behind current CRM-dependent technologies. This podcast hopes to contribute to shifting the mindset and lifestyle of the listener to a more sustainable one.

Appendix A: Project Brief

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name	Meijer 5914
initials	J.H. given name Judith
student number	4342682
street & no.	
zipcode & city	
country	
phone	
email	J.H.Meijer@student.tudelft.nl

Your master programme (only select the options that apply to you):

IDE master(s): ( ) IPD (★) DfI ( ) SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: ( ) Honours Programme Master

specialisation / annotation: ( ) Medisign ( ) Tech. in Sustainable Design ( ) Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair	David Keyson	dept. / section:	Human Centered Desig
** mentor	David Peck	dept. / section:	BK, (Critical Materials)
2nd mentor			
organisation:			
city:		country:	

comments (optional): David Peck is from BK, but he has been part of IDE before, and he is an expert on Critical Materials and the Built Enviroment (precicely my project topic). The BoE has already approved him as my mentor.

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair David Keyson date 16 - 09 - 2022 signature member: 75D504DE-F858-4A2A-B868-52DEC022C5C0 C7DDC9B4-208F-47E4-80A2-421EB0571F32 Digitally signed by member: 75D504DE-F858-4A2A-B868-52DEC022C5C0 C7DDC9B4-208F-47E4-80A2-421EB0571F32 Date: 2022.09.16 13:04:16 +02'00'

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 12 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 12 EC

List of electives obtained before the third semester without approval of the BoE

★ YES all 1st year master courses passed

○ NO missing 1st year master courses are:

name C. van der Bunt date 19 - 09 - 2022 signature C. van der Bunt Digitally signed by C. van der Bunt Date: 2022.09.19 10:15:45 +02'00'

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ★ APPROVED ○ NOT APPROVED

Procedure: ★ APPROVED ○ NOT APPROVED

- mentor Bk has already been approved by the BoE

comments

name Monique von Morgen date 04 - 10 - 2022 signature

Initials & Name J.H. Meijer 5914 Student number 4342682

Title of Project Living Sustainably in a Tiny House with less reliance on Critical Materials

Personal Project Brief - IDE Master Graduation

TU Delft

Living Sustainably in a Tiny House with less reliance on Critical Materials — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 16 - 09 - 2022 — 06 - 04 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

In this Graduation Project I want to explore the notion of 'sustainable living' in regards to the use and reliance on Critical Materials (CRMs). Many new houses, products and services call themselves 'sustainable' because they use Solar Panels to supply the energy needed and make everything 'smart' by adding sensors and computer chips to automate processes. Over the past decades we have started using many more elements to make more complex and high tech products (See figure 1). Sensors, computer chips and solar panels are very important in our energy transition, however, they currently use many critical materials and are often not recyclable (see figure 2). Even though depleting the earth of these materials is not likely going to be a problem in the foreseeable future, our current over-reliance on these products will become a problem in the very near future: The EU Green Deal strives for 'no net Green House Gas emissions by 2050'. In order to achieve this the plan relies heavily on the use of Solar and Wind energy. So much so that in order to reach the goals set by the Green Deal, we would need orders of magnitude more Critical Materials than we use now. This is simply not feasible. It is not as easy as 'crank up the production'. We simply cannot fulfill our current energy needs with the use of Solar and Wind power because we cannot supply the construction of the amount of solar panels and wind turbines needed.
So I want to see if there is a way to live sustainably without relying on CRMs as much. I chose the context of Tiny Living because Tiny Houses often strive for high sustainability, and people who live in a Tiny House are already doing something quite out-of-the-box. So this is the perfect area for me to come up and test some more radical ideas. On top of that Tiny Houses have 2 solution spaces: 1) A clearly defined and confined living space, usually mostly self-sustaining with clear boundaries. 2) A Tiny House is usually part of a community. Which opens up the opportunity for shared resources and services. This gives me flexibility to pivot to either side depending on what my research suggests as the best solution space.

The first area to look at is CRMs. Which materials are critical, and which are relevant for Human Building Interaction (HBI)?
The second area to look at is Climate Change. We need to change our current ways or we will be faced with 6 to 8 degrees of global warming, making large areas of the world uninhabitable. Where in the current trends do CRMs play an important role, and which other areas are there?
The third area to look at is Tiny Houses. Where in the Tiny House itself, its services and its products are CRMs present? How do people live in a Tiny House, and what are their needs?

The first constraint is that concepts like passive heating or cooling often rely on scale. A large scale cathedral stays cool in the hot summer days, partly because of it's huge volume of air inside acting as a temperature buffer. The very nature of a Tiny House dictates that it has a small floor plan (usually <50m2 of surface area) and thus a small volume.
A second constraint is that the nature of critical materials is that they are not easy to substitute. And the lack of supply of 1 critical material in a product will usually make that entire product useless. So it's not about just 'reducing' the amount of critical materials used in the current products and services. That only solves part of the problem.
A third constraint is that looking at the current trends where the world is failing our climate goals and we are rapidly approaching the tipping point for halting climate change within the next decade. So we do not have time to make small gains of a few percent. We need changes that can achieve 50-80% reductions.
In order to reach this I will probably have to think either radical, or large scale. The problem of CRMs is already a wicked problem and my project might lead me into the solution space of systems thinking, making this project rather complicated. So I need to keep an eye out to make sure it stays achievable within 100 days.

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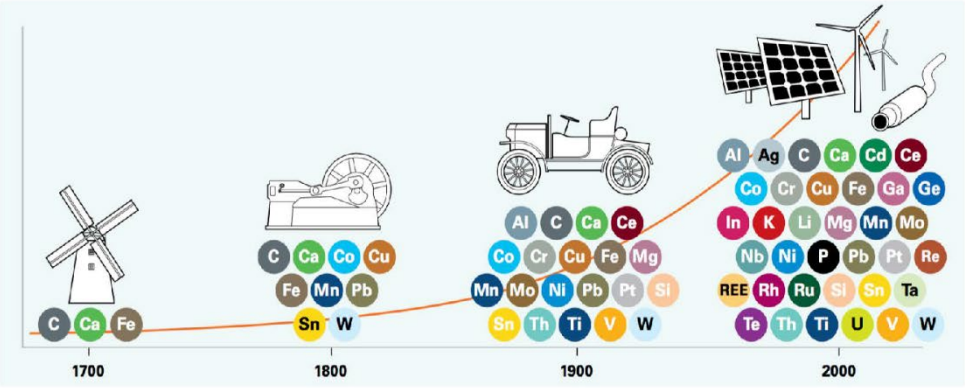

image / figure 1: (Armin Reller, Volker Zepf, 2014) Materials critical to the energy industry. Elements used per decade.

Figure 2: Recycling's contribution to meeting materials demand (Recycling Input Rate)[26]

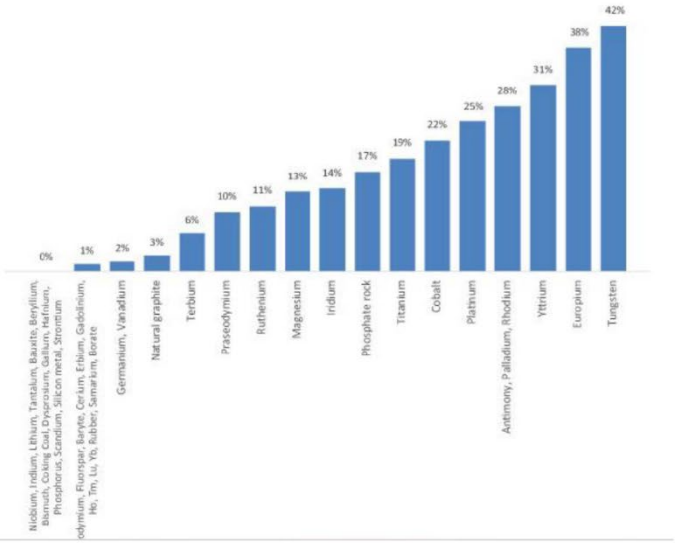

image / figure 2: Recycling input rate of Critical Materials (European Commission, 2020)

Personal Project Brief - IDE Master Graduation

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The scope of this project will be limited to three areas: and one user group:
Climate change, critical materials and tiny houses; And the inhabitants of Tiny Houses (students).

This project will address the issue of climate change and living sustainably with regards to Critical Materials in the context of Tiny Houses. The ultimate aim of this project is to contribute to halting or stopping climate change. It will focus these efforts in the built environment. Specifically in tiny houses.
The problem I will address comes from the current EU goals of stopping climate change. These plans focus heavily on digitizing the world and drastically increasing the amount of energy we get from renewable sources. These plans themselves would probably have the desired effect on stopping climate change, however, they are ignoring their over-reliance on critical materials. We simply cannot supply that many critical materials to reach these goals. So a solution is needed to reduce our greenhouse gas emissions according to those goals set, in spite of these critical materials constraints.
I will focus on Tiny houses in the Netherlands. The designs will have to be low-budget since most tiny houses cost between 30.000 and 60.000 euro, the design needs to fit within that budget. The target user will be students because students are a huge target group that will need housing in the next few years. They are also easy to contact, they collaborate easily with each other and they are often willing to tackle a challenge.
Since it is a Design For Interaction project, I will not focus on the building materials of the tiny house itself but on the Human Building Interaction. In terms of shearing layers: I will focus primarily on the space plan, services and stuff.
It is also possible that I look into the possibilities of using the community behind tiny houses. Tiny houses are usually placed in groups of around 10 on a shared terrain. Sharing products or services is a very likely possible solution space. That also opens up one more possible solution space: small student housing and community.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

I will research where the problems lie with Critical Materials in the Human Building Interaction of sustainable Tiny Houses. The aim is to come up with a solution or design that will allow the user to live in their Tiny House sustainably without relying on Critical Materials too much.

I will do research into the three areas and the target user. I will come up with solution spaces and ideas. I will make low-fidelity prototypes for these ideas and test them with the target user to get proof of concept. I will come up with one or more final designs or recommendations. With the constraints and background knowledge I have now I suspect it will most likely be a system or service since a single product will probably not have a big enough impact. I will not provide high-fidelity prototypes of this. Instead, I will use approximation, low-fidelity prototypes, and user testing to prove the validity and potential of the design; not it's exact detailing. I will deliver a final report, with illustrations and appendix, made in InDesign. I will supplement this report with suitable deliverables, this could include for example a video or a written story to further show the intended interaction of the final design. I will of course also create and hold a presentation on my graduation to show my research, findings, design and recommendations.

The nature of my topic makes it so that I will not deliver an app or other 'smart' solution. If anything, I am hoping to 'dumb down' under the motto: less is more. However, using electronics or 'smart' systems is still a possible solution space. I am hoping to deliver a nature inspired, or even a bio-mimicry solution. Since delivering proof of concept(or proof of failure) is so important, my planning includes fast ideation, prototyping and evaluation cycles. This also means I heavily rely on relevant participants. So finding a group of Tiny House inhabitants willing to participate is important very early on.

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PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 16 - 9 - 2022 6 - 4 - 2023 end date

The basic structure of this project will follow the double diamond approach. Diverging through research, converging through analyzing and drawing conclusions, then diverging in ideation and prototyping again, and finally converging to one final concept. I like doing user research and user testing, so in my planning there is quite a lot of emphasis on that. I am also quite sensitive to getting overworked so I will work 4 days per week, and plan in enough breaks to make sure I will not get burnt out. Before the develop and deliver phase I planned an extra week to dive deeper into new research depending on where my project takes me. That also gives me time to re-plan to make sure I keep my project manageable in 100 days. During and at the end of each phase I planned time to reporting my findings and progress. The final 4 weeks are dedicated to creating and finalizing the deliverables.

My scope is very broad, and is liable to drive me into for example the area of energy systems that need extensive knowledge and calculus to prove its validity (which is not possible for me to complete within 100 days with my current skill set) So, I have agreed with my team that I will take 2 weeks to do research, and after those 2 weeks present a very precise, narrow and tight scope to focus on. This will sadly probably mean the impact to be had will be less, but it is necessary to make the project doable for me within 100 days.

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MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

The reason I chose this graduation project is firstly because I have been interested in sustainability for the past years. Having a particular interest in green roofs. Which later expanded to nature inspired, nature based and biomimicry solutions. In the Master's elective sustainable design strategies for product development I was introduced to the concept of critical materials. And it immediately piqued my interest because it gave a voice to my gut feeling that putting a solar panel on every product and making everything smart is not the right way forward. I have been interested in tiny houses for a few years now because of the radical way of life that is often focussed on being close to nature and being highly sustainable. So, when looking for a graduation opportunity I looked for projects that allowed me to focus on sustainability related to critical materials. Since I could not find any projects on this matter I decided to formulate my own project. I chose the context of tiny houses since I think it will give me a lot of flexibility and potential to come up with impactful ideas.

During my studies I have discovered that I struggle a lot with making prototypes, often causing mental blocks which prevented me from delivering convincing proof of concepts in my projects. However, I have discovered that that issue is much less present if I make low-fidelity prototypes. So I want to use that knowledge to my advantage and further develop my currently lacking prototyping competence through low-fi prototyping.

In the earlier mentioned SDS elective I was introduced to three sustainable design strategies. I want to use this project to further explore and pracitce earn these (or related) strategies.

My passion and strengths as a designer lie primarily on doing (user) research and user testing. So I want to leverage that and dedicate a lot of my time to research and testing.

I have a passion for good storytelling. So I dedicated time to try to use storytelling techniques to analyze and present my findings.

This leads to the following personal ambitions for this project:
- Gain in-depth knowledge on the topic of sustainable living and critical materials through qualitative (user) research.
- Implement my passion for storytelling into my project
- During the ideation phase, put emphasis on nature inspired solutions and bio-mimicry.
- Focus on low fidelity prototypes to generate proof of concept.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

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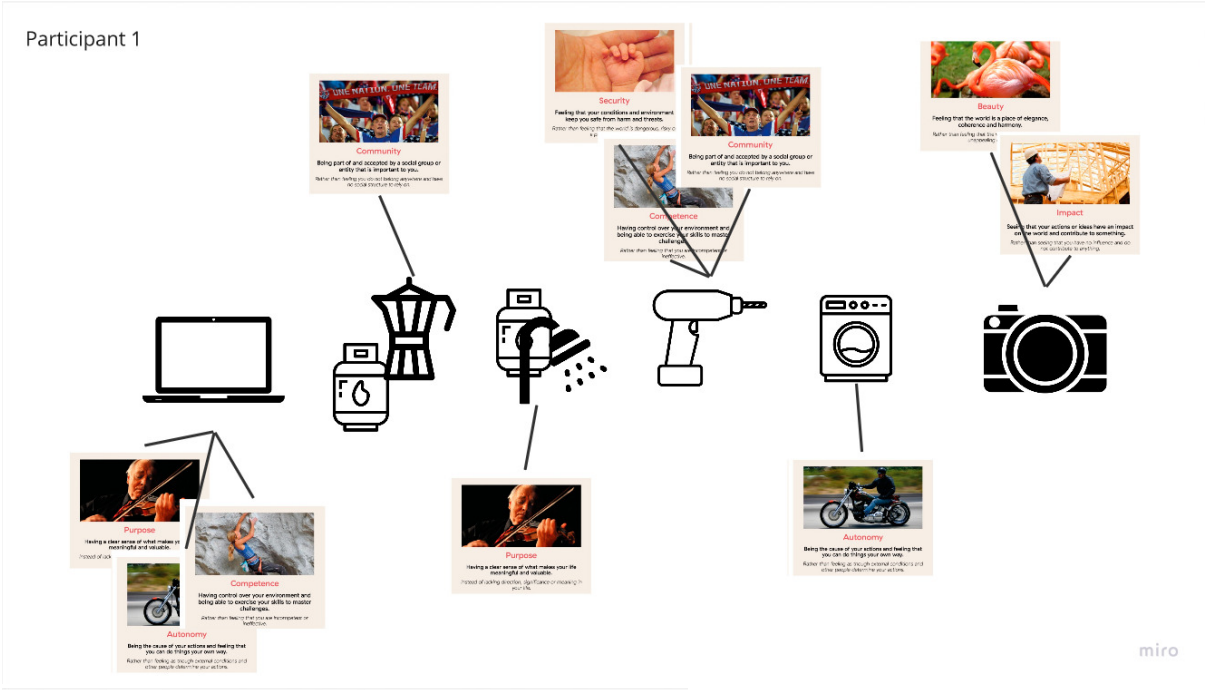
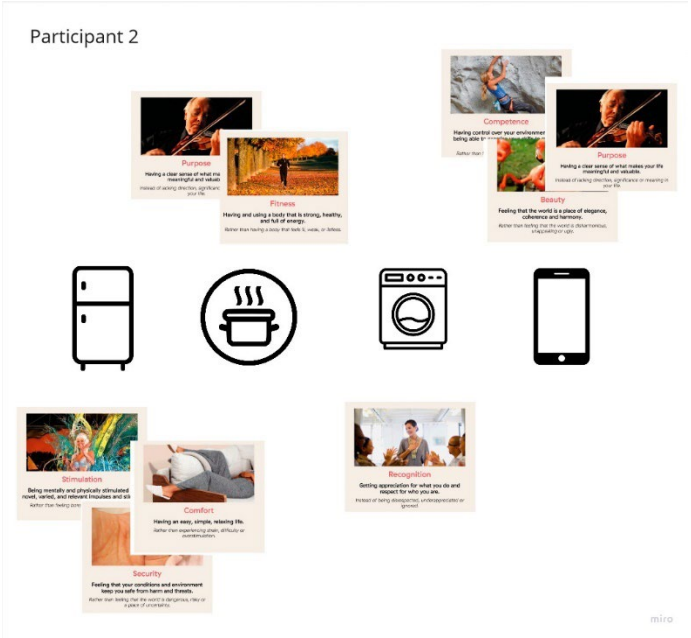
Appendix B: Research results





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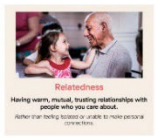

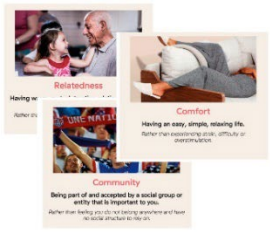

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