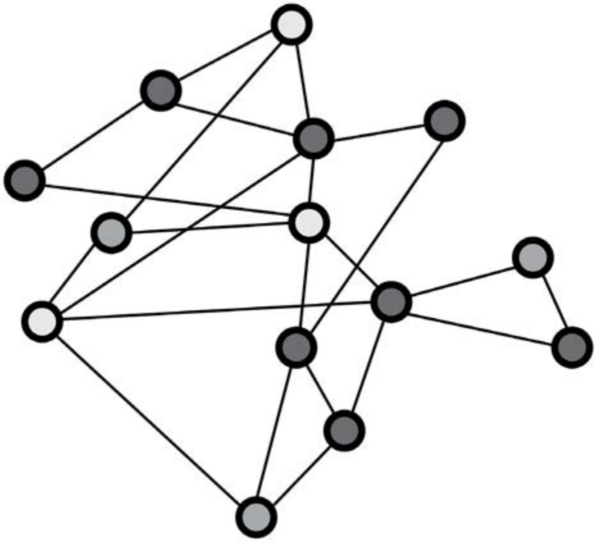

Finite Design

for a sustainable internet

J. van der Heide

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FINAL BACHELOR PROJECT

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preface

In this retake, I will address the feedback on my initial report in an attempt to improve my work. In this preface, I want to discuss some of the feedback and explain my intentions for the specific comments for this retake.

> *Should have shown more technology aspects in depth, mainly focused on the societal aspects.*

I agree that the technological efforts I have taken in this project were insufficiently documented, and didn't showcase my T&R competency well. I tried to implement more in-depth explanation for all iterations, with a focus on iteration 2 (hardware) and iteration 3 (software).

> *Several perspectives and gathered a lot of information, it would help to show a visual design process.*

A visual design process was added, and the areas of expertise were implemented in the process visualization as well.

> *Lack of evidence, doesn't show technical elements on how they are implemented in the demonstrator/design.*

I want to stress that I purposefully did not put a lot of effort to create a physical demonstrator, as the circumstances did not allow for any physical interaction with the demonstrator. Instead, I tried to demonstrate my design as much as possible though my demo day video and posters, since these were viable formats. Nevertheless, I tried to add as much evidence of my iterations in this retake, I just want to ask you to take the circumstances into account.

Needs to focus and to speed up, more attention to expertise areas.

I agree on the disappointing quality of my presentation, and it is a shame I can't make it right in this retake. Unlike most students, I do not usually prepare presentations in much detail. Because I know what I am talking about, I rely on my audience to understand if I have made myself clear, and whether or not I have to move on to the next topic. Due to the online format, I have struggled with this during my presentation more so that I could have imagined. I hope you can understand this.

Doesn't show the whole process and a lack of information, report is too much focused on the societal aspects and forget to explain all the steps that has been made in the different expertise areas

I agree that my focus is too much on the societal aspect. I saw my report less as a way to convey my knowledge and expertise in the several areas of expertise, and more so as a means to show what I learned in this specific project. I have tried to improve on this in this retake by including a clear design process that also includes my efforts made in the areas of expertise.

Show progress every week, only got problems with deliverables, draft report and final report to finished completely on time.

I have been struggling with some aspects of this for a while now and especially with finishing deadlines in time. I will be tested on ADD near upon, and hope I will be able to tackle this problem in the future. For now, even this retake will be delivered late again; I'm very sorry.

Good cooperation, but outside the University it seems to be harder the find collaboration. Also the use of a simple survey hasn't been used.

I agree that not much user involvement was present in this project. I partly want to blame this on the future oriented and speculative nature of this project, but I agree there could have been more interesting collaborations made.

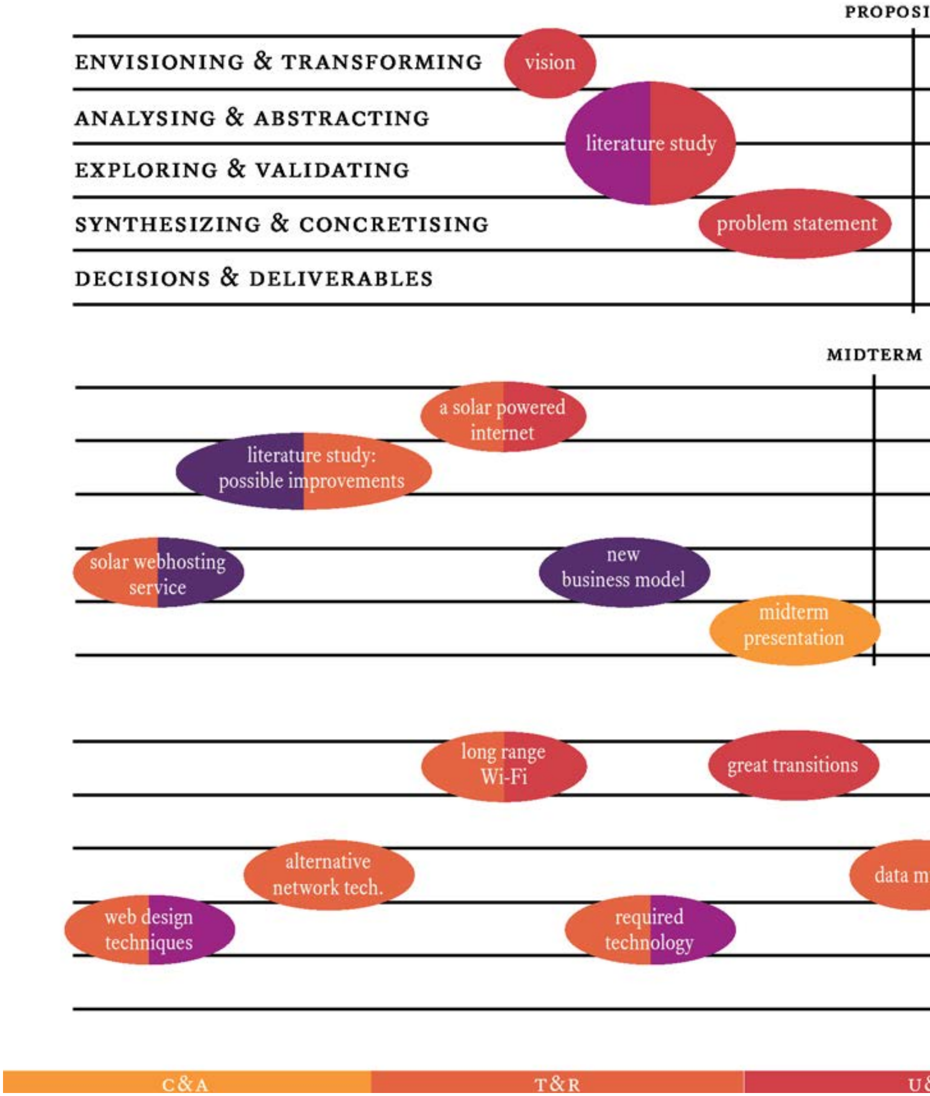
Clear overview of your development and depth in the area B&E.

Although this development has been made clear, I hope this retake also shows the depth in my T&R and C&A competency.

I hope this makes clear where I aim to improve, and I also hope you enjoy the rest of this retake. Note that the gray text is the content of my original report, while the black text is new content that was added for this retake.

\- *Jorrit van der Heide*

design p


PROPOSI
ENVISIONING & TRANSFORMING
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SYNTHESIZING & CONCRETISING
DECISIONS & DELIVERABLES
vision
literature study
problem statement
MIDTERM
a solar powered internet
literature study: possible improvements
solar webhosting service
new business model
midterm presentation
long range Wi-Fi
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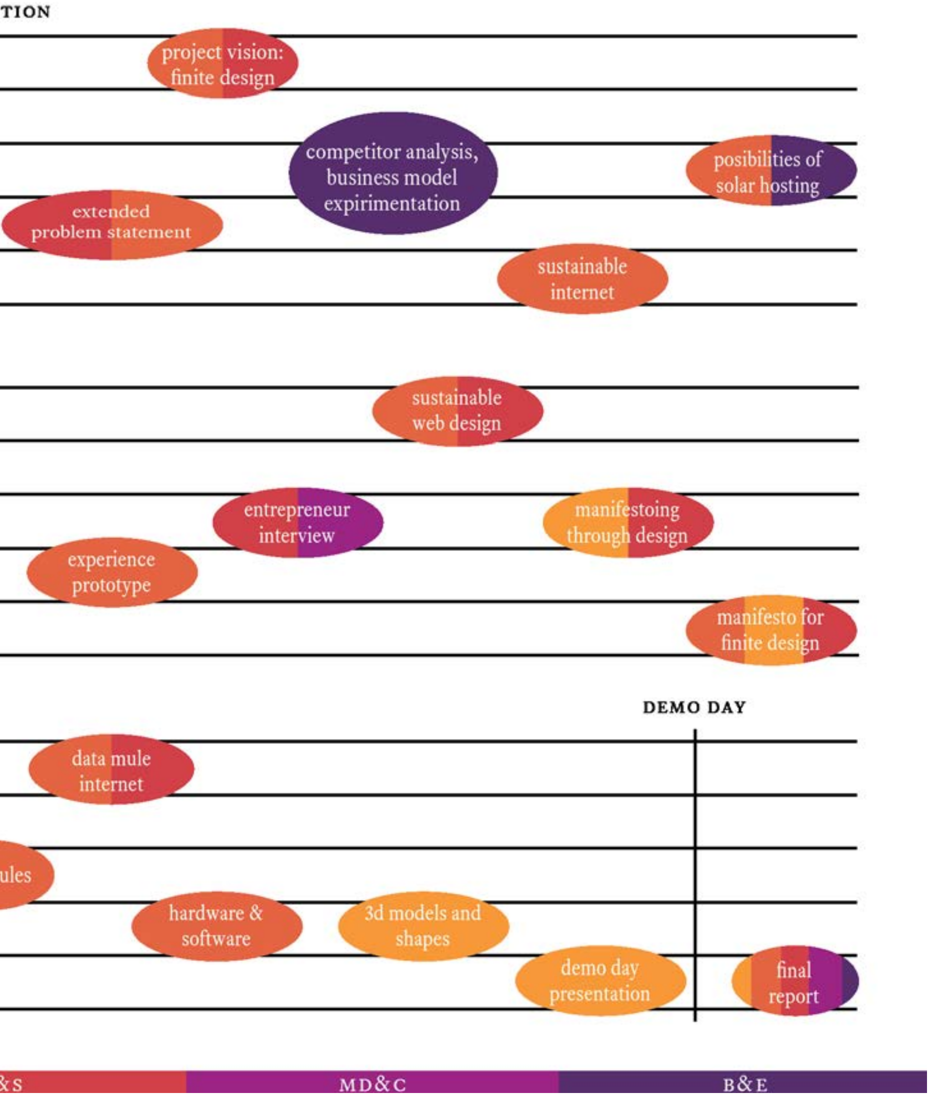

TION
project vision: finite design
competitor analysis, business model expirimentation
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extended problem statement
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summary

The internet is in poor condition. More and more energy and resources are used yearly to account for the enormous growth the web has been experiencing the last decennium. With global heating forming a serious threat to our daily lives, we should think about ways to create a society that sustains itself as well as the earth. It is this cause, that this project aims to explore.

With the internet as a case study, the concept of finitude was explored. Our thinking in terms of growth and progress seems problematic and not in line with the nature of the renewable energy that we increasingly rely on for sustaining our lifestyle.

> *We should ask ourselves: shouldn't we rather embrace our finite reality as opposed to discard it?*

With this in mind, 5 iterations were created, that each tried to implement ecological values into the functioning of the internet while keeping in mind the need for a finite experience in using the web. The ultimate result is Muleswarm, an urban communications network that embraces the finite nature of our planet and is 30 times as efficient as the current internet.

In the report, we will go into detail on the methods used in the design process, as well as the technological background and exact functioning of each proposed network. The energy use of each solution will also be calculated and discussed, and an attempt is made to design the most optimal and energy-neutral solution. The advantages and disadvantages of the final design are then explored and discussed.

Nobody knows how much energy the internet consumes. Due to its fast-changing nature and the complexity of the network, estimated consumption differs significantly in each study on the topic.

An important cause for this is that there is no agreement on what exactly should be measured. Most studies in this field have been focusing on the energy consumption of data centers (The Guardian, 2018), but the energy use of end-user devices, as well as that of the manufacturing process of both server and client hardware, should also be taken into account to come to a sensible conclusion (De Decker, 2009).

A second reason is the dynamic nature of the web. Advances in energy efficiency seem to have a reverse effect on the web, as its total size and energy use are ever-growing (HTTP Archive, 2020) and making it hard to make static estimates.

What seems to be the most complete and transparent report of the internet's footprint that also takes into account the end-user consumption and hardware manufacture, tells us that the internet consumed roughly 1.815 TWh of electricity in 2012, about 8% of the global energy consumption hat year (Fuchs, 2016). Since then, estimations were made that this increased to 10% in 2019 (Jensen, 2019) and by 2025 almost 20% of the world's electricity will be consumed by the global communication network, even surpassing aviation and shipping (The Guardian, 2018). And that latest report did not even take into account the consumption during manufacture.

The reason for this enormous growth of the internet consists of several factors. Because more people get access to the web globally, the total volume simply increases both for users, servers, and client hardware (HTTP Archive, 2020). More importantly, though, is the increase caused by more data spend per person. Especially because of video streaming technology, the average page size has increased from 600KB in 2012 to a staggering 2000KB in 2020 (HTTP Archive, 2020).

And this growth is problematic, for what is at stake is the stability of nature itself. A report from the ITRS (Diebold, 2009) warns:

> *Limitations on sources of energy could potentially limit the industry's ability to expand existing facilities or build new ones.*

What becomes clear from this statement is the finiteness of the earth and the unsustainable nature of the internet.

finitude and the problem of the infinite

I believe the main reason for most problems with our current digital infrastructure is our thinking in terms of the infinite. We consider the earth to be a boundless resource, while it is not (figure 1). We believe that the possibilities of us and our species are endless. For any solution to any problem, we can only think in terms of what we know, which is in terms of technology and terms of economic growth. There are two problems with this:

Heidegger writes in 'The Question Concerning Technology' (Heidegger, 1954) that the essence of (modern) technology is not something that we make, but something that he describes as a 'mode of revealing'. Technology is an event and a way of structuring and observing the world, to which we belong. This 'mode of revealing' claims technology is a lens through which we look at the world. It reveals us parts of reality, but it keeps most of it veiled. And is in this singular perspective that technology locks us in, that is the problem with technology lies:

> *For example, we challenge land to yield coal, treating the land as nothing but a coal reserve. The coal is then stored, "on call, ready to deliver the sun's warmth that is stored in it," which is then "challenged forth for heat, which in turn is ordered to deliver steam whose pressure turns the wheels that keep a factory running." The factories are themselves challenged to produce tools "through which once again machines are set to work and maintained." (Blitz, 2014).*

This example brings us to the next problem, which is our thinking in terms of growth. We live in a world where machines produce new machines, which introduce new challenges that re-

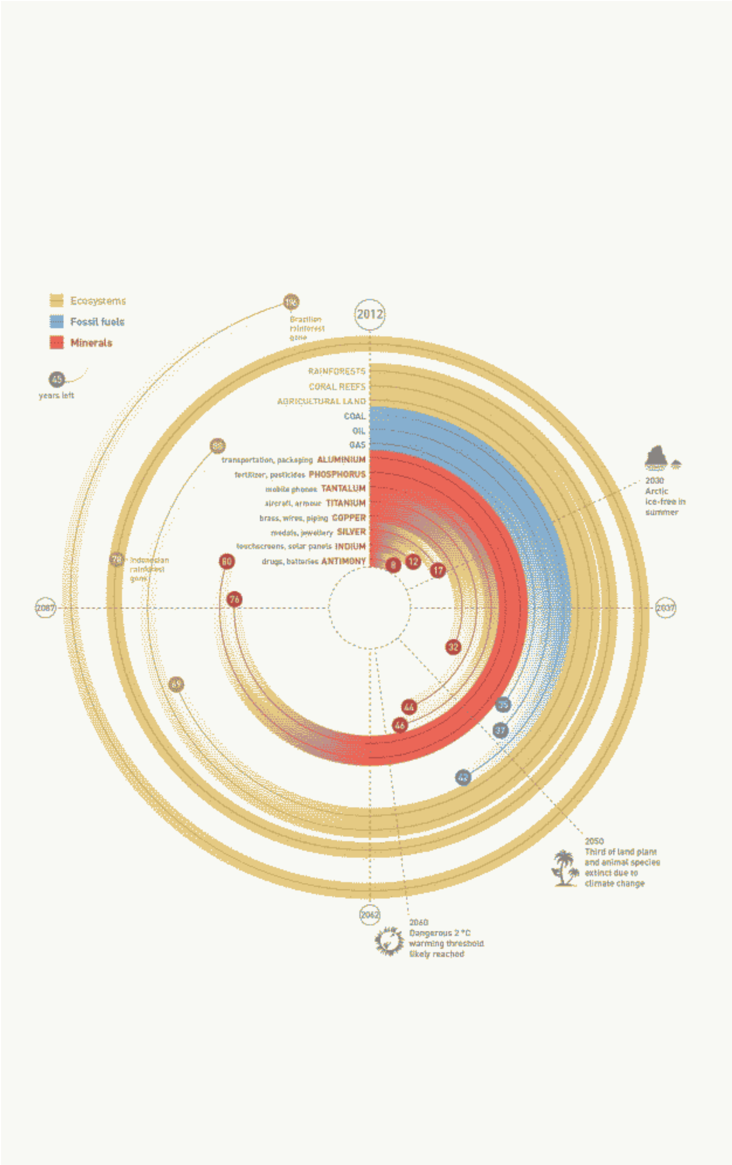

Figure 1. Estimated world supply of non-renewable resources (BBC, 2012)

quire more machines – and thus form a vicious circle, which once again shows how technology locks us in a certain perspective. This reminds us that boundless and continuous growth is an impossibility in a finite and bounded world, and thus unsustainable and undesirable.

Movements exist that try to address this issue, such as the circular economy. Although such goals will improve the sustainability of our way of life, it tries to align sustainability with economic growth (De Decker, 2018). This creates a paradox that counters itself, and which will not lead us towards an energy-neutral society.

It is therefore important that we realize these limitations, that exist in our reality and our thinking. We should try to work around these to progress as a species, and how this project aims to do that, is through the potential of design.

the power of design

One of the greatest misconceptions in design is that the role of designers should be to create more commodities (Marx, 1867), to try to resolve the problems that technology created through increased technologicalization. I however think that design has the potential to improve the world we live in and that it has two great things going for itself in particular.

① Design is rooted in creativity, enabling designers to break free from the restraints that technology as a mode of revealing forces upon us. Through ideation, critical thinking, and communication skills, designers possess the tools needed to work question the status quo and think in refreshing ways.

② Design has the power to reform social opinion and propose new values. Through the popularity of commodities, as well as the ability to communicate ideas, designers can propose novel ideas and concepts to a wide audience, that can contribute to social opinion change how we think about and interact with the world.

With this in mind, this project aims to use these strengths of design and apply them in an attempt to design a truly sustainable future for the internet.

The finitude of our reality shows us that we should embrace the world as it is given to us. One could even argue that this finite world is what defines us, determining what being human even means. Thinking about the earth in this manner brings us to two realizations:

① We should accept the earth as the human condition (Arendt, 2013). This is a conviction of German philosopher Hannah Arendt, who says that our being on earth has defined who we are and is thus also what makes us human.

② We should embrace the finiteness of the earth, and understand its limited carrying capacity. The stock of some vital resources is more depleted then one might think (BBC, 2012), and we need to make changes in the way we live if we want to progress.

These beliefs clearly show the need to focus on ecological values in technology and design, as a means to stay true to our essence and the essence of the planet.

It is with these values as a top concern that his project was commenced.

iteration 1

An eco-centric design approach was taken by rethinking the current internet from both a business and an ecological point of view, with web hosting as a focal point. A competitor analysis was executed, a method by O'Shaughnessy (O'Shaughnessy, 2014) and Nusem and Wrigley (Nusem & Wrigley, 2017) used to understand where a product or service fits in the market. Based on the results, a Business Model Experimentation was executed. This is a method by Wrigley and Straker (Wrigley & Straker, 2016) that uses iteration to compare and improve business models. A Business Model Canvas (Osterwalder & Pigneur, 2010) was then used to frame and communicate the designed business model.

A striking result after doing the Competitor Analysis in the sustainable web hosting branch was that a lot of the so-called 'green' web hosting companies claim their servers run on renewable energy, while they merely offset their CO2 emission by planting trees. It also often concerned companies that have a 'green' energy contract, which doesn't mean that their energy is actually from renewable sources (Van de Graaff, n.d.). Ultimately, none of the companies generated their solar power on-site.

To account for this gap that was identified in the market, an initial concept for a solar hosting company was developed. Initial values were that all power should be generated on-site and that it should be comparable in its functionality and price as regular web hosting (TransIP, n.d.). To study the feasibility of such a company, Business Model Experimentation was used to come up with several business models, which were then combined into a final concept that was expressed in a Business Model Canvas.

The result was a business model (see Appendix A) for a fully self-sufficient solar hosting company, that solely uses renewable energy. A key feature of such a company is the use of small-scale solar-powered web servers to host customers' websites. This makes it a combination between a photovoltaic power station and a data center where efficiency and optimization are the key values. Because a minimal amount of energy must be wasted, a shared power bank is used to store the energy of an array of solar panels, which is then distributed on a per-need basis to several servers.

From a business perspective, a solar hosting company has a specific place in the market. Because of the nature of renewable energy sources, the concept suits itself mostly for smaller-scale web content. This is because the finite nature of these resources will likely show during use, by web content becoming unavailable for a certain amount of time. This can be managed and thus might not matter for HTML / CSS / JS-based websites (which make up the majority of the internet), but it is problematic for heavier content such as web apps or video streaming. The target audience was therefore chosen as entrepreneurs who need a website for professional purposes and care about the sustainability of their enterprise.

The functionality of the proposed network differs only minimally from how end-users experience the internet currently.

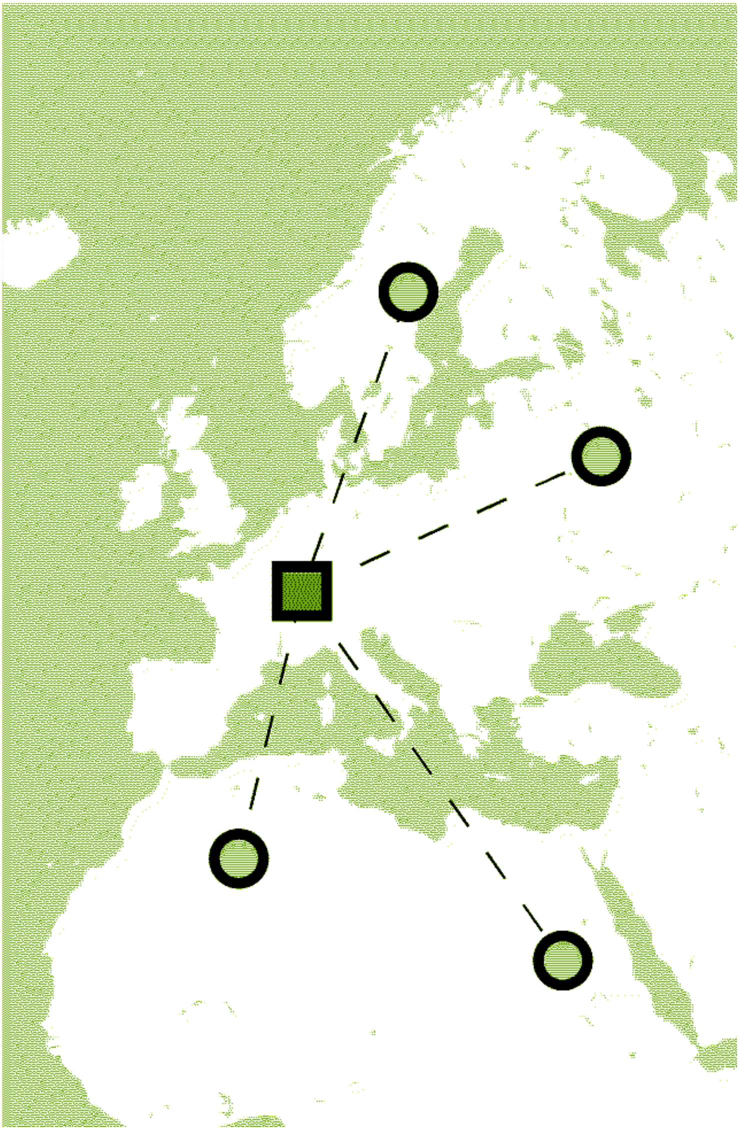

Figure 2. Network map for a solar-powered data-center where multiple clients connect to a single server.

They can request data from a server, which is then sent via the usual infrastructure to their device. The only difference is where the servers receive their energy from.

For the sake of understanding the functionality and feasibility of the solar server, a hardware study was executed. The result of which, will be described below.

The materials for this setup were chosen for the following reasons:

- Solar panels in parallel to maintain voltage, used to generate electricity from sunlight.
- Batteries in parallel to maintain same voltage, used to store energy from the solar arrays.
- Combiner box that combines multiple solar arrays into a single output.
- Charge controller to prevents batteries from overcharging, connects batteries and solar arrays to the server.
- Development board with Gigabit internet to run the server.
- Storage devices to store hosted content and operating system.
- A stable and fast internet connection.

A simple visualization (Appendix B) was made to illustrate this setup. Although not detailed enough to start building it right away, it is sufficient for this iteration. I will go more into detail on the exact functioning of a solar web server in iteration 2.

A calculation was made to estimate the amount of time needed before the material and energy investment pays itself back. Because this design is a more sustainable way to run the internet, the result of this calculation is very important. For this equation, a Single Board Computers (SBC's) instead of regular web servers was taken for the solar setup due to its compatibility with renewable energy sources. The informed assumption was made that a regular server uses about 1 kWh to run 500 domains (Maddox, 2013), while a single SBC uses 1 Wh to run a single domain. For the embodied energy of the solar setup required to run 500 SBC's, a value of 170 kWh/year over 5 years was found (De Decker, 2020). The embodied energy of the other components will roughly single out, and will thus not be taken into consideration in this equation.

*1 kWh * 24 hours * 365 days * = 8760 kWh per year*

*1W * 24 hours *365 days * 500 SBC's = 4380 kWh per year*

*170 kWh * 5 years = 850 kWh embodied energy in total*

8760 kWh - 4380 kWh + 850 kWh = 3530 kWh difference

*3550 kWh / 1 kWh * 24 hours = 147 days until profitable*

From this we can see that for a simple website, it takes about 147 days to become energy neutral while running on solar power when at least 500 domains are hosted on a single solar setup. This number means it is realistic to try and implement this in a web hosting company.

The concept was validated through an interview with a local entrepreneur from the Eindhoven region (see Appendix C). The need for sustainability and the effects of solar hosting for business were discussed in an interview with open questions (Jacob & Furgerson, 2012), and this provided several insights:

① Not all entrepreneurs realize the carbon footprint of their online presence. This means communicating this is vital for the success of solar hosting.

② Entrepreneurs, especially start-ups and small-scale entrepreneurs often work on a tight budget. This means the network solution must be available for roughly the same fee as regular web hosting.

③ Businesses their online activities should be dependable and entrepreneurs like to have some degree of control over their website. This means the finite nature of solar power might be difficult to sell to business since income is important to them and this is often based on the reliability of their online services.

This interview provided important insights into the further development of the solar web server and was a source of inspiration for the second iteration.

From this first iteration, I learned that it can be interesting to approach a challenge from a business point of view initially. I believe it makes the transition that I propose feasible since the economy is the driver of capitalist society and thus hugely influences what policies and ideas are realized. A problem with this approach, however, is that the scale on which transition is proposed can only be limited and that it has to be economically profitable to commit to this change. Furthermore, the current business model did not offer a tempting enough value proposition to entrepreneurs, because of the relative unreliability of the solar setup. Also, the type of business proposed is in essence non-transparent in the sense that users have no control or insight over the actual sustainability of their servers and their web content. These are factors that were important to improve in the second iteration.

iteration 2

The goal of the second iteration was still to make sustainable self-hosting accessible, but besides using the Business Model Canvas, the concept was realized through Experience Prototyping (Buchenau & Suri, 2000). This is a method used to create an experience-able concept that can be used for validation or presentation purposes, but because of the Covid-19 virus, it was used as a proof of concept for the proposed hardware solution instead.

To strive towards a more personal, sustainable, and transparent network solution, the business model was changed to a non-profit for the second iteration. It is focused around tech-savvy entrepreneurs who care about their company's carbon footprint and want to be in control of the changes they make. Instead of a service, a solar hosting kit was developed, which enables entrepreneurs to start hosting their businesses' web content from their backyard, balcony, windowsill. The device is to a high degree a Do-It-Yourself product and is meant to empower people to take control of their internet presence in a very hands-on way.

An Experience Prototype was made and used as a proof of concept for the proposed hardware kit (see figure 3). This solution consists of a 50Wp solar panel, a Linux-based Open-Source SBC, a solar controller, and a lead-acid battery. To account for different user needs, the capacity of the battery, and the capacity of the solar setup can be increased or decreased. An example of such a situation is the climate, which determines the amount

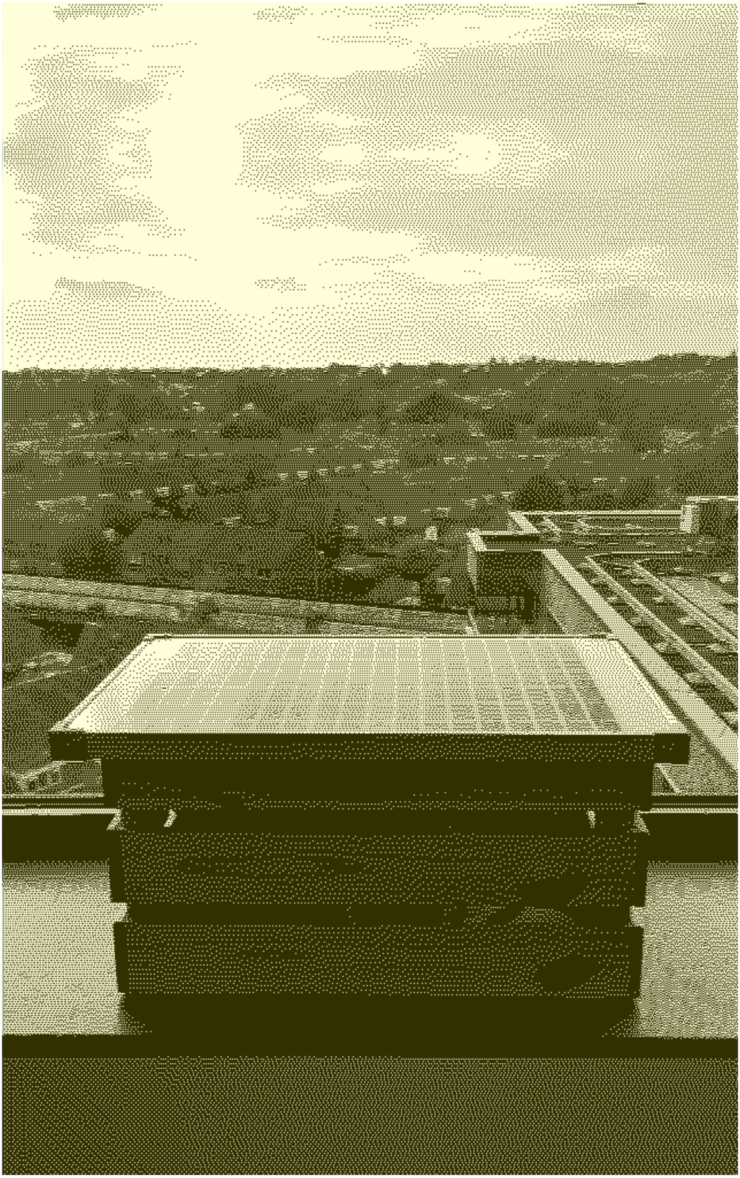

Figure 3. Fully functional prototype for a solar-hosting kit

of sun one gets and thus influences what capacity is needed for the desired uptime. Although more testing in the Dutch climate is needed before this can be determined for the prototype that was built, such experiments have been done for the Spanish climate (De Decker, 2020), providing a certain understanding to what capacity one might wish for.

Software-wise, the device functions on an NGINX HTTP2 server hosted on a minimal Linux distribution. Web content is only served in an HTML / CSS / JS format to minimize page size.

Because this design considers a kit and not a specified product, the setup will differ on a per-case basis. What is described below, is a technology overview of the most rudimentary setup possible and the one that I made a functioning prototype of.

- Olinuxino A20 LIME2 development board
- SD Card
- A fast and stable internet connection
- 50 W solar panel
- 20 A charge controller
- 12 V / 8 Ah battery

The material list is based around the LIME 2 embedded ARM Linux computer (Olimex, n.d.). I chose this because it uses open source hardware, has a low power consumption, and has other useful features such as Gigabit internet and a charging circuit with an AXP209 power management chip. This makes it the perfect base for a lightweight web server, and all other components are fit to this requirement.

The operating system runs of an SD card, which is limited in size but uses both lower power and has a higher operating speed.

A Gigabit Ethernet connection is made with a non-solar powered router. This means the server is still reliant on energy from the grid to function. The throughput of this connection is more then enough for it not to be a bottleneck in the functioning of the server.

The rest of the system is centered around the LIME 2 board, which draws 1 - 2.5 watts of power. Because of the community aspect of the solar hosting kit, where other users mirror your website when your server is down, the capacity of the solar panel and battery are not that important. I set myself the goal that it should have an uptime of at least 50%, which seems reasonable in the Dutch climate.

To calculate this, we assume the average uptime to be 2 W, which is a high estimation. According to (Time and Date, 2020), Eindhoven has a pretty good distribution of hours of sun over the year, so a moderate size battery should be enough. With 1604 hours of sun a year, this means:

1604 hours / 365 days = 4.4h hours of sun a day

To have a 100% uptime, we need:

*24 hours * 2 W = 48 Wh of energy a day on average*

To overcome the longest night a year (Time and Date, 2020), we need:

*15.7 hours * 2 W = 31.5 Wh of battery capacity*

A 48 Wh battery can overcome a full day of bad weather, which for 12 V means a 12 V / 8 Ah battery.

With 4.4 hours of sun, a battery of 48 Wh and a server that is running on 48 Wh a day, and an assumed solar panel efficiency of 75% (Solar Panel Consulting, 2020) we need a solar panel of:

48 Wh + 48 Wh = 96 Wh total
*96 Wh * 100% / 75% = 128 Wh*

When we include a 15% assumed system loss (Photovoltaic Software, n.d.), we get:

*128 Wh * 1.15 = 148.5 Wh*

To calculate the needed Wattage of the solar panel, we divide by hours a day:

148.5 Wh / 4.4h = 33.75 W

A slightly bigger panel of 50W was chosen to also provide enough power on days with up to 3 hours of sun a day, which is common in the Dutch climate.

A 20A charge controller was chosen to match the discussed hardware, and the result is the system in figure 4.

From a software point of view, the Lime 2 board runs on Armbian, a Debian based Linux distribution for ARM development boards. On this runs a NGINX server, which is software opti-

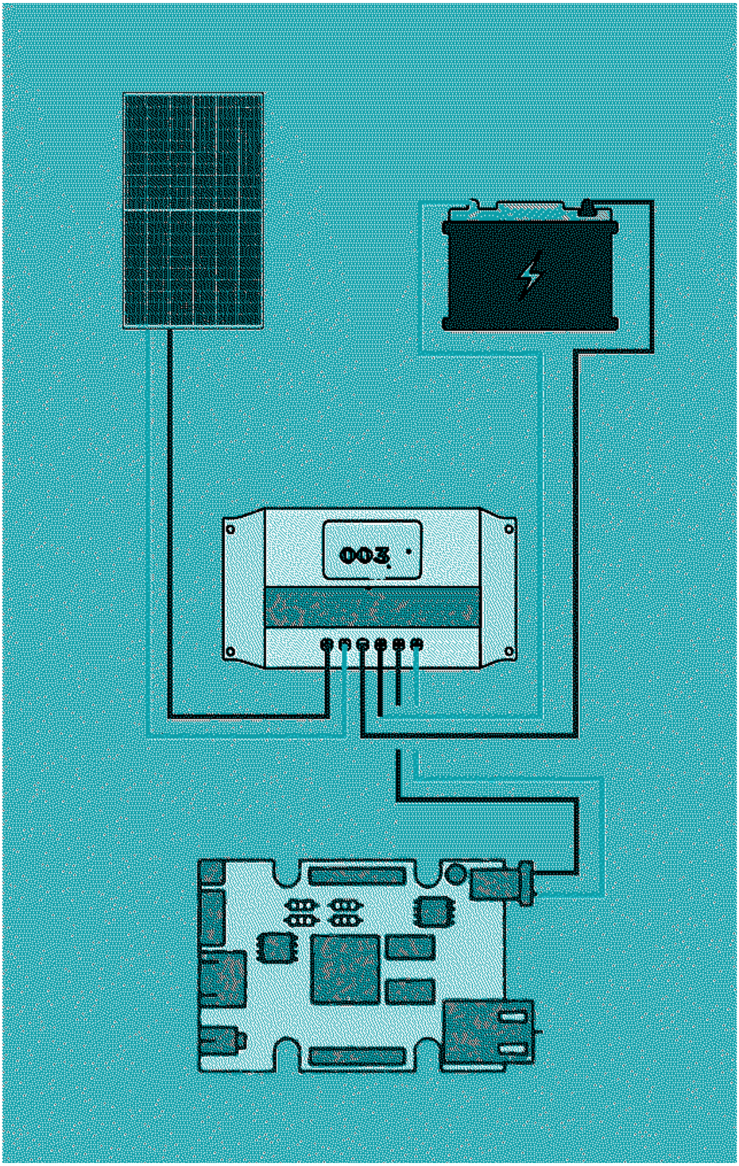

Figure 4. Schematic iteration 2

mized for high performance with low RAM devices and is perfect for our board. Setting up NGINX is rather easy, but fully configuring it for use with the solar server was a bit trickier. The configuration in the appendix eventually worked for me (see Appendix D).

For NGINX to function properly, a static IP address (WhatIsMyIPAddress, n.d.) is necessary. In this way, request from outside your local network can be rerouted to the correct IP in a hard-coded way, which is not possible with a dynamically changing IP address. Also, the correct ports of your router must be forwarded (Wikipedia, 2010) to allow the incoming traffic. For an overview of the forwarded ports, see Appendix D.

Connection to the server is possible from the server itself (by connecting a screen, mouse, and keyboard to the board); implementing an FTP solution (Wikipedia, 2001), which is common for most web servers, was not desirable for this specific solution, as data transfer via a network is less sustainable than on a local device. It also isn't supported by NGINX by default.

A key service that is also provided by the non-profit in this business model (Appendix E) is providing digital instructions that enable a wide public to start hosting themselves. Moreover, a usability aspect will inevitably play a huge role in providing a fluid experience in the act of managing something very technical in essence by an inexperienced user base. Because of this, a UX interface was designed (see Appendix F) that better communicates the finite nature of energy and allows entrepreneurs to connect globally to minimize this finiteness in their customers' web browsing experience.

The solar hosting kit is a server node that is connected to the backbone of the regular internet. The device – once installed – functions as a regular web server, but initially hosts a single domain. When it is sunny, the server will run and the battery will be charged. When it is cloudy or dark, the battery will discharge to power the sever until depleted. This means that the server can become unavailable during a prolonged period of bad weather. To account for this, a community-driven mirror-network is the answer. If each user mirrors the websites of a few like-minded entrepreneurs from over the world, significant benefits could be gained for the user and the network:

① High uptime could be reached. If servers on different meridians of the globe mirror each other's content, 24/7 uptime can be ensured since there is always a mirror where there is daylight. This reduced the experience of finitude in accessing web content.

② A network of servers will reduce overall energy wastage. By reviewing which server has the most energy stored and which server has the most sunlight exposure, the best server to access web content at any given moment can be determined. This will reduce how often energy is wasted due to a full battery in combination with low nearby network traffic.

The energy use of this system will vary based on the efficiency of the network, but will otherwise be comparable to the energy use of the first iteration due to similar hardware specifications.

The most obvious insight from this iteration is that the choice of hardware will greatly impact the result of energy savings this concept does. To improve the energy efficiency of the prototype, I propose several hardware changes that I was unable to implement in the scope of this project. Most notably, the SBC could be replaced by a Micro-controller Unit (MCU) such as the ESP32 (Espressif, n.d.), which is more bare-bones and will need additional hardware components and tweaking as a trade-off. Also, on a more conscious note, the lead-acid battery should be traded in for a more sustainable alternative. A lithium-ion battery could be used, but even better would be a solution like a small scale Compressed-air Energy Storage (CAES) device, which boasts a longer lifespan and does not require any rare or toxic materials (Wikipedia, 2020).

A dilemma I had after this iteration was on the implementation of finitude in the design. By coming up with the idea to mirror websites of other users, I had effectively eliminated the finite element in this design, for a more technological solution. I had however also made the system more efficient by doing so, so how to proceed? Above all, this iteration also taught me that solar-powered web hosting might not enough. Although it has the potential to reduce the symptoms of our internet usage, it does barely change how we perceive the internet as end-users. The finitude is still detached from the experience, which I think is caused by the concept being a physical product. This is still an example of 'solving the problem of technology through increased technologization' – just as iteration 1 – and as such not able to really solve the problem. This is something I aim to improve in the 3rd iteration.

iteration 3

To embrace the finitude of the internet, a ‘manifestoing through design’ approach was used. This method was coined by Pierre Lévy in the course ‘Perspectives on Aesthetics’ an is a way to develop written statements through previously made designs.

For the third iteration the business approach was abandoned. To think outside the box – as mentioned in the paragraph ‘the role of design’ – this was a necessary step and more possibilities became clear after doing so. I had to reevaluate the values I had been designing with so far. Although I set clear values at the beginning of this project, I caught myself searching for increasingly technological solutions, and I wanted to break free from that through design. By also abandoning the physical form of my previous concept, I forced myself to thread on a new path, which I found in ‘manifestoing through design’, and applying this method I created a set of guidelines for the transition of humanity towards sustainable network solutions. This was then communicated as a manifesto (see figure 4) and posted online, to inspire web designers to rethink the values they keep in mind whilst creating content for the internet.

Although the designed manifesto certainly embraces the finitude of the earth, it is on the other end of the spectrum from solar hosting. The purely political essence of the statements I wrote was frustratingly non-actionable! I had to reevaluate the point of view that I wanted to design from. So far, that had been Business-enabled Eco-Design, but the ‘manifestoing’ inspired me to look into the perspective of Speculative Design.

Using the manifesto created, a set of guidelines was set up to allow designers to have a handhold when designing sustainable web content. A lot of technology is very energy inefficient because of the way in which we create technology (Prokopov, 2018), and by reevaluating common design techniques, I found novel ways to reduce the footprint of web content.

① *Usage of content delivery networks (CDN).* A website can only supply 6 resources simultaneously in most web browsers (Hall, 2016). This means that if your website consists out of a lot of data, it takes longer for it to load, even on fast internet connections. To make websites sustainable, it should be encouraged to keep the total amount of resources low, because every byte of data cost energy. CDN should therefore not be used, because it negates the limit (and thus the finite nature) of our web browsers. On the other hand, CDN networks also have something to offer. They can be used by web designers to import commonly used functionality into their website, such as certain JavaScript or CSS files. This can also be hosted on a self-owned website, but the benefit is that users who visit multiple sites that use the same CDN-imported functionality do not have to download these resources again, since they are already stored on their computer. This saves a lot of data and thus energy, but the risk is the quality of these files, since it one should make sure they are also programmed in a sustainable way. This brings me to the next point.

② *Self-made software.* To ensure the sustainability of your

Figure 5. Manifesto of Finite Design

web content, going fully self-made ensures you know what everything on your site does and that there is no data on your server that isn't used. This seems obvious, be there are a lot of tools that web developers use that causes lots of residual data on your server. An example is CSS frameworks (Wikipedia, 2009), big CSS files that make it easy for any website to become pretty with a minimal amount of programming. A trade-off between convenience and sustainability. As discussed in the paragraph above, these frameworks can be distributed using CDN and thus posses both good and bad qualities when talking about website sustainability. To make CDN and community-made resources a success, I propose open-source curated CDN content that consists out of many smaller files. Open source content can be peer-reviewed and in such a way curated on its sustainable quality. Using many smaller files ensures that the functionality which these files add to the website is as specific as is practical, leaving the least amount of residual data on the server as possible. The size of all content on a web page can be easily measured using digitally available tools like Pingdom (Pingdom, n.d.).

③ *Asynchronous networks.* The internet is an example of a synchronous network. This means that data can flow in two directions simultaneously without any gaps, comparable to a two lane highway (Adams, n.d.). This is also why fiber-optic cables have two internal strands - one to receive and one to transmit data - and why internet providers usually offer plans with a different up- and download speed. In transfer, the data is split into packets. There are several reasons for this, but the most important one is that corrupted packets can be re-send quickly because of their size, and there is no need to re-send the whole file. Because of this packeting of the data, the receiving end must piece it back together and for this, a signal clock is needed that is the same on both sides of the connection. This clock adds a traceable element to the signal that allow the receiving end to piece together the data that was split for transfer and restore it to its original. This is how synchronous networks work, and they allow for always-on connectivity, two-way traffic and higher access speed and thus enables us to make video calls and play online games. In contrast to synchronous networks, there is asynchronous networks, that are low-tech. These networks only allow for one-way data traffic at a time, and data is not split into packets. This has both advantages and disadvantages. The infrastructure for such networks is cheaper and very energy efficient and combines well with renewable power production (De Decker, 2015). Communities can build their own networks easily because of low cost and a lower technology level. On the other side, the networks are more prone to errors because data is not split. The network is also more restricted that some types of usage are not possible anymore, such as big file sizes, two-way communication, or super high-speed connections. This means some things will no longer be possible under an asynchronous network. The benefit from a sustainability point of view however is great. The network very easy to maintain and can be repaired rather simple. The energy usage is a lot less and is discourages unsustainable behavior that go against the finite ideal, such as using big files and doing activities that require lots of data.

④ *Image dithering.* Video does not work well on an asynchronous network, so images will be the main way to communicate visually. On modern websites, images use a lot of data and are often the Largest Contentful Paint (LCP) (Google Dev, 2020) on a website, which on itself mostly decides page loading times. There are several ways to make images smaller in size, such as using a certain file format or simply by lowering the resolution. The way I think we should go about this, is by means of a technique called dithering, in combination with the previously mentioned. According to Wikipedia, "Dithering is used in computer graphics to create the illusion of 'color depth' in images with a limited color palette" (Wikipedia, 2004). It analyses a picture and picks a limited number of colors as a base. All the colors in the original picture that do not match this base are diffused by means of transparency, so they come closer to the original and an illusion of color depth is created. To dither an image, several algorithms exist, each generates slightly different looking results (Alexharris, n.d.) . For my portfolio website,

Figure 6. Normal image, dithered image, colorized dithered image.

the most efficient 2-color-only (black and white) dither was used. This makes the image into a gray scale image and removes a lot of detail by doing so (see figure 6.1). By making smart use of CSS however, both color and detail could be partially retained (see figure 6.2). How this works, is by making use of the transparency of some of the colors in the dithered image. Using CSS, a colorized background can be put behind the dithered image. This allows the background color to become visible through the dithered image, and thereby effectively colorizing it with a very minimal increase in file size. An example of the required HTML and CSS for this can be found in the appendix (Appendix G).

⑤ *Battery bar.* The main purpose of this intervention of networking technology is to make people aware of the network's finite nature. A prominent display of this in web content therefore seems an important aspect of the design. In my case, I decided to make this visible by means of a battery bar on my portfolio website. Instead of using a small bar on the side, which is a common practice in modern design, a semi-transparent overlay was created that overlays the whole website. The height of this bar represents the current battery level, which is in the picture below around 70%. The battery level functionality is done by making use of the AXP209 power management chip that is on the LIME2 board. This enables you to read power statistics from both the battery and the DC-barrel jack, which can then be used by the website by importing their sysfs files (Wikipedia, 2005) via JavaScript. By overlaying all the content on the web page, the battery becomes visible and present (see Appendix H). By clicking the sun icon, people can read more about the sustainable features of this website.

⑥ *Page size.* Another feature that is meant to communicate this finiteness is the page size that is present on each page. Not only does it remind the user of this, but it is also a way for web designer to stay aware of this during the development process. It is also used to communicate the efforts of the developer to her audience.

⑦ *Dark theme.* Darker colors use less power than lighter colors, especially on AMOLED displays that have become common in most mobile devices (Android Authority, 2014). The website has a built-in dark theme that is automatically enabled based on user device settings, so it automatically turns dark in the evenings on most devices. This is done by adding a meta tag to the head of the page HTML and making a separate CSS for your dark theme (Appendix I).

⑧ *Data compression & cache expiration.* The transmitted data is compressed by software called gzip. Using this software, the data can be packed into a denser format. For a small increase in processing power can save around 60% in total data transfer size. Also in this category is cache duration. Websites cache resources so they do not have to be downloaded for a second time when regularly visiting (partly) static web pages. The resources are then stored on the end-user device and can be retrieved without an internet connection. This is a simple way to reduce the data footprint of a website, but setting it right is important. By default, caching is done regularly, because most sites are dynamic in nature. For our website, the period files are cached can be extended greatly, to ensure low internet usage. The settings of my website for compression and cache duration, see Appendix J.

It is hard to guess or calculate how much of a difference these improvements make on a website's total power consumption, because it is device and user dependent, but by using the web analysis that Pingdom and Google provide, we can see the low total data footprint of the device, which is an excellent number (Appendix K).

iteration 4

The Delft Design Guide describes Speculative Design as 'seeking to create and promote critical discourse by giving future possibilities a tangible form' (Van Boeijen & Daalhuizen, 2014). In this project, however, it was not used as such. Instead of critical discourse – which is used to spread a message to people - focal point has been on its use in imaging possible future values in global communication by a speculative scenario – which is as such used as a means to find context instead. For this fourth iteration, a literature study was performed on the technologies needed in this speculative context, as well as an adaptation of Root Cause Analysis (Rooney & Heuvel, 2004).

For this fourth iteration I tried to go back to the root, the essence, of the internet. I asked myself questions like: 'Why do we use the internet?' and 'What is the most important feature of the internet?' The result of these contemplations was the idea to focus on designing a new and energy-neutral communication network that could be used on a global scale, instead of finding ways to make the existing internet sustainable.

Important however was the need for a finite essence in my design. And to do that, the key in this exploration was chosen to be the asynchronous networks. As the name 'asynchronous networks' suggests, several different types of networks can be distinguished by looking at their constitution. Modern internet networks are an example of a synchronous network (Wikipedia, 2020). These devices run on an external clock, which determines when certain data is transmitted. This is necessary because to transfer data, the receiving device needs to know when each unit of data begins and ends. This allows them to be always on and continuously transmit data. T his is different in the case of asynchronous networks (Wikipedia, 2020), which are known to be delay-tolerant. Here, data synchronization happens utilizing a signal along the transmission medium, meaning that these networks are only available on-demand; when a signal is sent.

This choice of network synchronization has several consequences for the designed network. Most notably, our existing web content should be adapted to an on-demand model. For most content, such as static sites, email, and search engines this is entirely possible. Other content, however, such as video streaming or online gaming will become unavailable in an asynchronous setting, because their functioning is determined by the synchronization between different devices.

These kinds of networks however do pair well with renewable energy sources, which is why they were chosen. This is closer to finite nature and – in the act of being not always available – will teach us how to embrace this finitude.

The designed network consists of several different nodes that are connected via long-range Wi-Fi connections (Wikipedia, 2020). The individual devices have a very low power consumption and can as such be reliably powered using renewable energy sources. To make this concept clear, we will differentiate between access nodes and relay nodes. An access node will consist out of a solar-powered omni-directional Wi-Fi access point. Users can connect to these nodes using their regular Wi-Fi enabled devices to access the network. When data is sent or

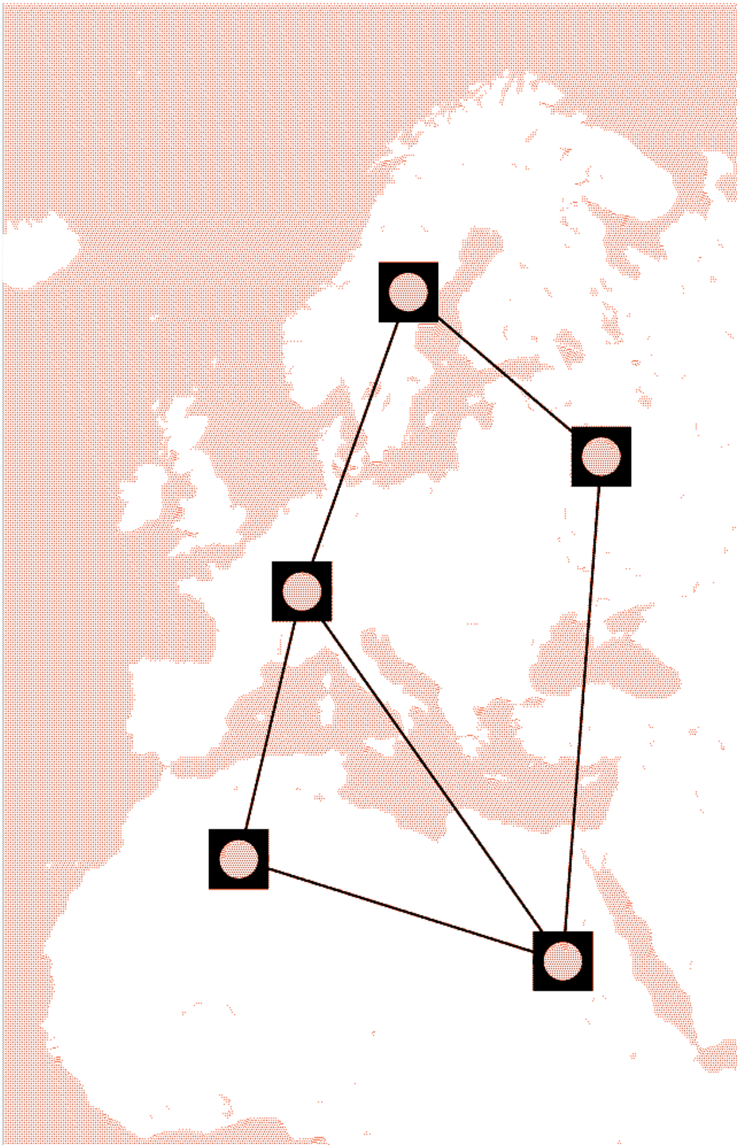

Figure 7. Network map for an asynchronous network of solar-powered long-range WiFi connections.

received, it is sent to the desired access node through a network of relay nodes. Next to omni-directional antennas, the access nodes are also equipped with directional Wi-Fi antennas for long-range data transmission. These will send the data in a straight line to a relay node, which can be up to hundreds of kilometers away (Wikipedia, 2020). This relay node, which is equipped with multiple directional antennas, can then send the data to the next node and be transported over any distance. In this way, the data hops over different nodes until it reaches its destined access node. The previous solar server iterations can be used within this network.

A hardware overview of the described setup can be read below.

Access node hardware:

- Omni-directional antenna
- Directional parabolic antenna(s)
- Development board
- Solar panel
- Charge Controller
- Battery
- Storage device

For a simple circuit of this node type, see Appendix L.

Relay node hardware:

- Directional parabolic antennas
- Development board

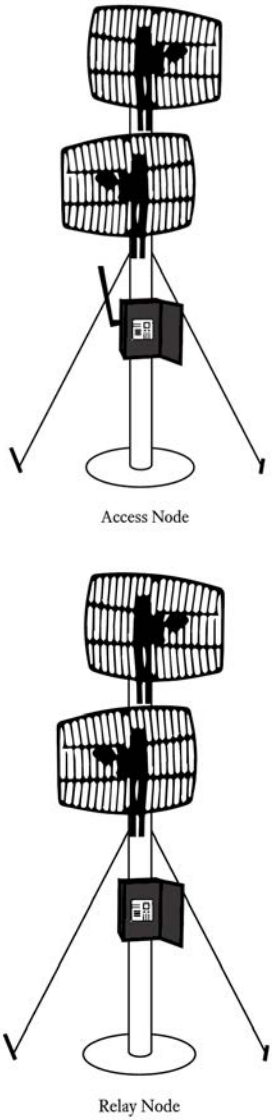

Figure 8. Sketch of an access- and relay node.

- Solar panel
- Charge Controller
- Battery

For a simple circuit of this node type, see Appendix M.

When data (take for example an email) is send from end-user device 1 to end-user device 2, it is first sent to the omni-directional antenna of the closest access node. Using the public IP address of the second end-user device and the DNS protocol, node A determines to which node the data must be sent by means of a directional data transmission. This can be in one transmission to the end-user's access node, but also along several access and relay nodes, until the final access node is reached. The data will then be broadcasted to the user's device using the omni-directional antenna.

The cost and energy use of operating this network is very small compared to our current internet infrastructure. A value of 5kwh per 1 GB of data was found as the estimated energy consumption of the internet (Costenaro & Duer, 2012). With an estimated 6 W power consumption per node and using the solar-powered server that runs at 1 kWh, we can calculate the efficiency of our network. In this equation, a network speed for long-range Wi-Fi of 54 Mbps (De Decker, 2015) was assumed.

*6 W * 2 nodes = 12*

*1GB / 54 Mbps * 3600 s = 67 s to transfer 1GB*

*12 W * 67 s = 0.8 kWh per 1 GB of data*

*This in an increase in efficiency of 5 / 0.8 * 100 - 100 = 525 %*

This shows the long-term energy use will be more then 6 times as low as it is right now.

Although these numbers look promising, the calculation does not account for the huge amount of hardware – with a huge amount of embodied energy – that has to be replaced. Although a lot of the current internet infrastructure can be re-purposed and reused, substantial material and monetary investments will still have to be made to adopt this networking technology. This is not the case software-wise, where only minimal changes to most programs have to be made. The fact that some software does not go well with asynchronous networks will however cause resistance in the implementation of this networking solution. People are so used to the idea of progress that they will not be willing to take a step back for a more sustainable solution. Society just isn't ready to invest that much in a network that performs in a less ideal way - despite the ecological benefits. Sadly, whether or not that will change in the future will probably depend on how the effects of global heating will affect our daily life.

From this, it becomes also clear that an issue with this networking method is that the finitude is not strongly enough present in the experience. Although a slight delay due to the multi-hop structure of the network will be present, a more direct and experience-able way to implement this should be found for iteration 5, the final design.

iteration 5

By exploring the fourth iteration design through Scenario-based storytelling (Carroll, 2000), points of improvement were found. These were then worked out utilizing mind- and network mapping (Kokotovich, 2008), to gain insight into the network's functionality.

In the final design, an important resource that has been used is the Great Transition Initiative (Great Transition Initiative, n.d.) They are an academic organization that recognizes the need for a Great Transition on several planes (Rockström, 2015) to improve the way we live. This is described by them as:

> *"an international network for the critical exploration of concepts, strategies, and visions for a transition to a future of enriched lives, human solidarity, and a resilient biosphere. By enhancing scholarly discourse and public awareness of possibilities arising from converging social, economic, and environmental crises, and by fostering a broad network of thinkers and doers, it aims to contribute to a new praxis for global transformation."*

Most notably, my inspiration has been on the different future scenarios that they predict (Great Transition Initiative, n.d.) for a planetary society.

I recognized my efforts in solar hosting as a clear example of the internet for the conventional worldview of policy reform. In this scenario, government-driven efforts strive towards sustainable goals. It is however a worldview that is conservative in nature, and a key aspect is an idea that the standard of our living should be kept intact. This can be seen in how the solar server does not

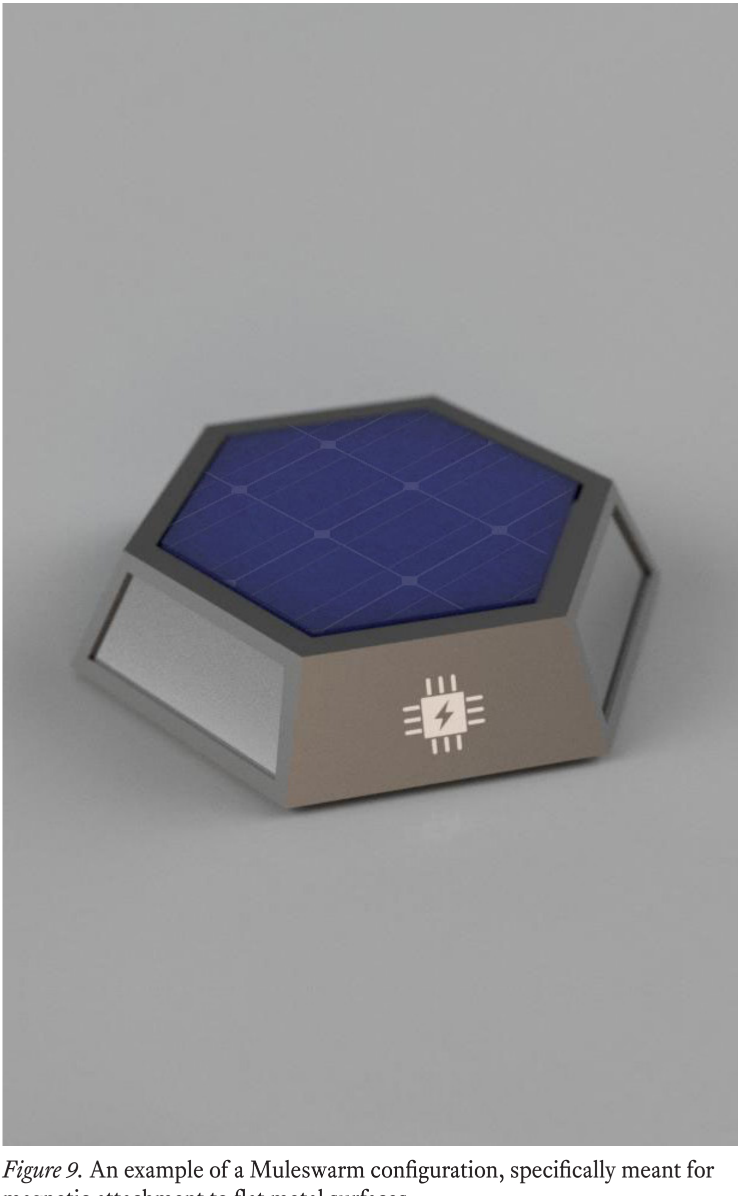

Figure 9. An example of a Muleswarm configuration, specifically meant for magnetic attachment to flat metal surfaces.

embrace finitude, but instead tries to make the finite internet more sustainable. The worldviews where the initiative strives towards, are not the conventional ones, but the worldviews that propose a Great Transition. One of the worldviews is that of an eco-communalist planetary society, where small scale politics and face-to-face democracy are key features. It is to this worldview that my final design was tailored.

The final design is an asynchronous network that functions on a mix of solar and human power and is called Muleswarm. Its name stems from the term 'data mule', which is a key aspect in the functionality of this on-demand internet surrogate.

A data mule is defined as a vehicle that literally carries data from A to B. In other words, people are responsible to physically take data to different locations. This means that long-range connections between remote locations are no longer necessary, as the only requirement to transfer data in an area is a sufficient amount of human traffic. This makes it especially suited for an urban environment, and most importantly, incredibly energy efficient in its use since it used the existing local infrastructure to substitute for a wireless internet link.

A Muleswarm device can have any shape or size. Instead of a physical product, what was designed is a hardware platform; a solution that can be adapted for a specific use and can be built, installed, and maintained by local manufacturers.

The kit consists of a solar panel, a lithium-ion battery, a charge controller, an omni-directional Wi-Fi antenna, an SBC, and a Solid State Drive (SSD). The exact specifications and the ca-

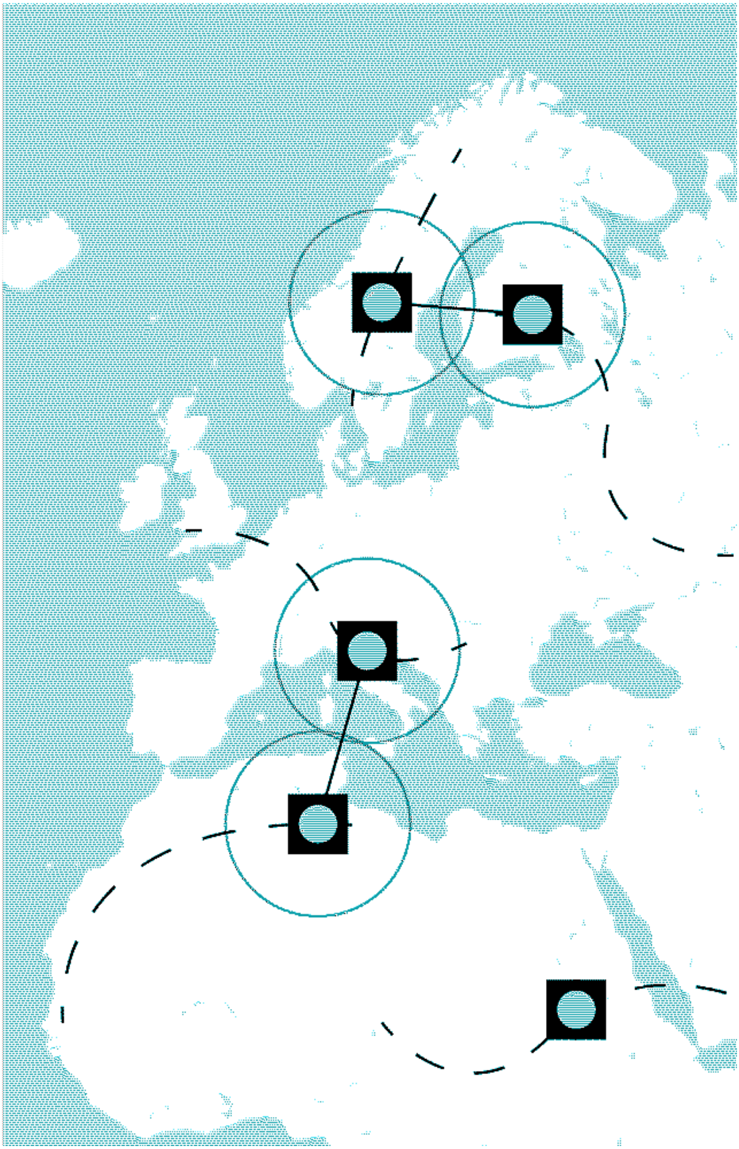

Figure 10. Network map for Muleswarm, where data-mules physically move around.

pacity of the device will however be determined by its purpose. For example, a Muleswarm node that will be installed on a car will have big solar panels, a big battery, and a faster processor so it can support a large capacity of data. It will also have a higher uptime and will be more reliable. A personal device, however – which could be implemented in a hat or on a bicycle – will have a focus on small-sized hardware and decreased weight.

The Muleswarm network is formed out of all the different Muleswarm devices that become a node in the decentralized network. These nodes are Wi-Fi enabled and can thus transfer data when connected, which is only possible while nearby because of the omni-directional Wi-Fi antenna. By doing so while the nodes move around, Muleswarm can pass data over any distance by 'hopping' it over its nodes. This setup effectively creates a dynamic web of interconnected links, especially suited to the local communities that are proposed in the eco-communalist worldview.

From a hardware perspective, the Muleswarm kit consists at least out of the following hardware:

- Solar panel
- Battery
- SBC / PCB
- Omni-directional Wi-Fi antenna
- Storage device

Because of the configuration of the Muleswarm kit, the capacity of some of the parts will differ. We consider a few scenario's.

① *High capacity: Muleswarm on the bus.* Buses drive all around the city and can provide a fast network between higher occupied locations. Because of their size, they can be equipped with large solar panels, powerful batteries and high storage capacity. They become hubs where data streams come together.

A bus can fit several 250W solar panels and with such a capacity, it can stay functional for several days of bad weather. For this, it needs big enough batteries, but as more and more buses are becoming electrical, this is not a problem. The size of these batteries is mostly determined by the other hardware on board. A bus can have several antennas for simultaneous up and downloads from several other nodes and user devices. Because of this, it also needs more data storage as it handles a lot of data each time. It also has some highly popular data stored so some data transfers become obsolete.

② *Medium capacity: Muleswarm on the bike.* A denser network can be made by making Muleswarm devices for personal modes of transportation, such as bikes or bicycles. These often travel along medium popular routes as well, and can bridge data transfer from suburban areas to city centers - or for short-range transfers.

They can be outfitted with a standard 30W solar panel a the most, and therefore they will have similar performance as the solar server discussed in iteration 2, minus the antenna instead of the Ethernet connection.

③ *Low capacity: Muleswarm wearables.* The most dense network can be achieved by outfitting people with Muleswarm devices. These are low capacity devices that will be often offline during bad weather or night-time. This does not matter however, since they are numerous and visit locations that would otherwise be left out of the network, for example because of a lack of infrastructure.

A personal device can only fit limited hardware. It seems most logical to put a device in a cap or shat, since it is exposed to the sun often and has spare space due to its shape. A 2,5W solar panel is with current technology the most that can be fit into this shape. A backpack is another alternative, and around 20W should be possible to achieve in that case, making it a viable option.

See figure 11 for an overview of the discussed setups.

The Muleswarm network is made possible by the Ethereum Swarm protocol (Wikipedia, 2020) – Muleswarm is a morpheme between the 'mule' from data mule and 'swarm' in Ethereum swarm' (Swarm, 2020). This is a blockchain-based technology that ensures data can be safely exchanged, without any privacy risks. This is because Swarm will splice the data is over several Muleswarm nodes, so no single node has access to the whole dataset and as such, any sensitive information. Another benefit is that All these factors make the Muleswarm network more secure, more resilient, and more sustainable than the internet.

In order to receive data over the network, you make a request

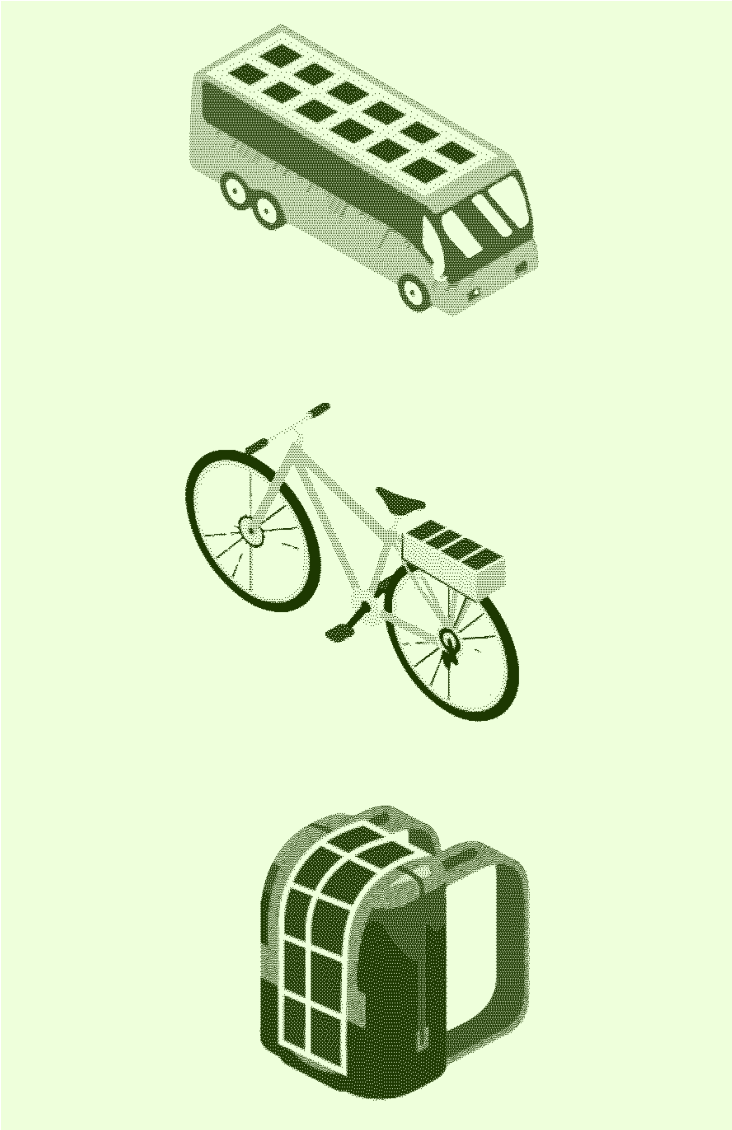

Figure 11. Several Muleswarm setups

with your personal device over Wi-Fi, to nearby Muleswarm nodes, just as you would communicate data to a NAS device (Wikipedia, 2005). These nodes will then store this request in relation to your unique device number - like a MAC address (Wikipedia, 2001) - which is roughly based on your devices location. It will then pass this request to other nearby nodes in the network using their directional antenna. These nodes will keep relaying the request until the requested data is found on an end-user device. When the data is found, it will be send to the requesting device as described below.

In order to send data over the network, the receivers MAC address must be known. This can either be manually, or via a DNS service, which would make looking for an address be as simple as typing in a regular website's address is now. When the receiving address is known, the data will be split and using the Ethereum protocol into encrypted packets using blockchain technology. These packets are then send to nearby Muleswarm devices. Each Muleswarm carries an encrypted database of previously made connections to end-user devices, and prioritizes its packet transfers according to MAC addresses that are known to be geographically close to the request device's location. Because this is all encrypted using blockchain technology, it is very safe to store this type of data in this way. When the several packets receive their destination, the devices that were used in the data transfer will receive some crypto-currency as per the Ethereum protocol (Milan, 2017) depending on the nature of the data.

Because of the use of human power to carry data around, the total energy use of the network is the sum of the energy needed for the several nodes to run. For the proposed components, a sum of 2.616 W was found. When we use the previously calculated time to transfer 1GB over the average Wi-Fi connection, we see the following result:

*2.616 W * 67 s » 0,175 kWh per 1 GB of data*

Compared to the previous iteration, this is an efficiency of:

*0.8 kWh /0.175 kWh * 100% = 450%*

The solution becomes less sustainable than iteration 4 after more than:

0.8 kWh / 0.175 kWh = 4.5 nodes are used for a single transfer

When we look back at the total energy use of the internet, we see a value of 1.815 TWh in 2012. When we estimate the number of nodes needed for the network and take the sum of these values, the total energy use of MuleSwarm becomes clear. As an estimation, the total surface area of all cities in the world was taken and multiplied by 100 nodes per square kilometer:

*0.175 kWh * 3 500 000 km2 * 100 nodes = 61 250 000 kWh*

*1 815 000 000 kWh / 61 250 000 * 100% = 2963% as efficient*

This is about 30 times as efficient. With these numbers, Muleswarm seems to be a worthwhile exploration for a sustainable internet, for times when we take the earth less for granted. And a first step has been taken since with this final iteration, I believe the finite nature of the fabric of our reality finally becomes clear.

discussion

Muleswarm is an elegant networking solution that has a lot of positives over today's internet going for it. What remained somewhat problematic throughout this project though, however, was that a single downside potentially makes this type of networking nearly impossible to implement into contemporary society.

"I will not be able to keep doing the things I like or want to do!"

Although the validity of this assumption should be verified by means of a quantitative study, it is safe to say that implementing Muleswarm would in a lot of ways be perceived as taking a step back, and 'back' is not progress and therefore not perceived as desirable. Although from an ecological perspective it would be a leap forward, from a user perspective this is not the case.

Because of this, I believe improvements to this project could be made. This networking solution - although speculative - will drastically change the way we interact, perceive reality, and how we live our lives. And by not including users in the design process, the 'power of design' that I addressed earlier was partly lost. Although creative in its process, this project has failed to communicate these believes and values to the public using the speculative approach. In fact, this project became more of an exploration of the viability of alternative networks. This is, of course, an aim in itself, and it might even pave the way for further developments, but in its current state, society will not adept this concept without a change of mindset.

A way to improve on this could be to make the finite nature of Muleswarm into an experience and a feature. People often feel overwhelmed by the pace of daily life, and finite experiences could therefore actually become valuable again. Whether or not this assumption is true could be tested by means of an experience prototype of a part of the Muleswarm network.

Another way to stimulate user input in the project could be realized by sparking a debate by means of storytelling, which has the potential to explain and discuss the concept in an understandable way. This could provide valuable insights into what drives people in their network use, and might also be a preamble to co-creation.

On a critical note, most of the calculations in this report are oversimplified. Predicting the use, scale, and functionality of a network is very much dependent on variables, and therefore hard to predict. To reach a better conclusion as to how much more efficient the proposed iterations are, further development and research should be performed before calculating and drawing conclusions.

This is also very much dependents on the hardware used. For the scope of this project, an integrated hardware solution was used, which made prototyping convenient and quick. In order to maximize the power usage of the network however, more specialized components, such as the ESP mentioned earlier, could be used.

From a software standpoint, Muleswarm is a challenging concept. An algorithm is necessary for its further development, that can determine the node density required, and streamlines ways to decrease the number of nodes needed during data transfer. Most challenging is the exact functionality of the network on a software level, as I determine the exact transfers the mules make, and these are vital to the stability and speed of the network. A next step in the development of Muleswarm should be to look at this challenge.

conclusion

To conclude, we can see that the concept of finitude was explored and implemented as a priority in the design process towards a more sustainable world. The internet was explored in a case study and judged for its finite experience and overall poor condition. Several iterations were made to seek how to redesign the global communications network in a finite way, each with different outcomes for different networks with different qualities and values. The final design was Muleswarm in which the finite experience reaches its peak.

Muleswarm is where the internet becomes a part of human traffic and interaction, and although very sustainable it is hard to implement into contemporary society. We thus see that merit can be found in exploring sustainable alternatives to boundless solutions, but to accommodate societal transformation, a lot more is needed. More research is needed to see how Muleswarm can contribute to this, but what is certain is that the means to a sustainable future are there. What remains needed, is a social transformation towards a more sustainable, finite future.

reflection

In this Final Bachelor Project, I attempted to showcase my development in the several areas of expertise. In this reflection, I hope to explain this integration.

① *C&A.* I individually decided on and used several design methodologies, that I acquired in previous projects and courses, showing that I can work with said methodologies for creativity purposes. I also tried to showcase my eye for aesthetic quality in my presentations and my deliverables, such as in this report and in my showcase.

② *T&R.* In this project, there has been a lot of focus on the T&R competency. The courses on electronics were useful for understanding specifications of hardware and invaluable for making decisions on what hardware to implement. Moreover, my experience in web design was a big inspiration to this project and I am very proud of the result of iteration 3 and my portfolio because of this.

③ *U&S.* I feel like I have not fully shown my U&S development during my FBP. At least, not very balanced. I believe I showcased how the philosophy minor I took last year shaped my vision and enabled me to make informed design decisions in this project. The societal side in this project is therefore very strong. The user side on the other hand was almost nonexistent. This was partly because of the COVID-19 virus and partly because part of my project concerns a future oriented approach that is irrelevant to contemporary society. I should however have also considered the need to showcase the user side, but I did not and I hop my previous project make my competence in this area of expertise clear.

④ *MD&C*. This project mainly concerns data transmission, and as such, I spend a lot of time programming, for example in setting up the server for iteration 2 or the web design for iteration 3. My knowledge of data management and computer systems in general helped me greatly in completing this feat successfully.

⑤ *B&E*. I tried to focus on the B&E area of expertise for the first half of this project. Having recently completed the courses 'introduction to business design' and 'design innovation methods' helped me to make informed design decisions from a business point of view. An entrepreneurial attitude was less relevant for this project, but by considering my iterations as a business viable product in the first place, I believe I showed this slightly as well.

⑥ *D&RP*. The design process of this project was the most independent, substantiated and flexible process I ever did. I believe this shows that I am adapt in making design decisions and experienced in the adaption of methodologies that aid to do so.

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appendix a - business model canvas iteration 1

<table>
<tr><th rowspan="4">key partners</th><th>key activities</th><th rowspan="4">value propoposition</th><th>customer relations</th><th rowspan="4">customer segments</th></tr>
<tr><td>The development and rental of solarhosting.</td><td>Our customers subscribe for our service, which is highly automated.

Repairs for the server kit will be handled by local partners and by self-care of customers.</td></tr>
<tr><th>key resources</th><th>channels</th></tr>
<tr><td>A manufacture facility to develop soft- and hardware is essential.

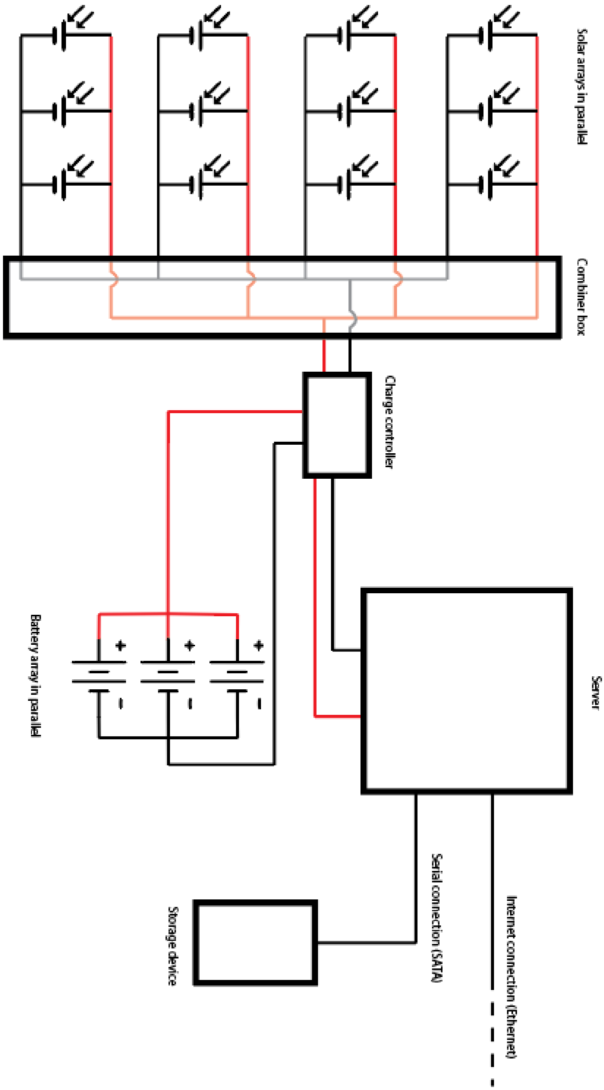
We also need our channels to make sales and provide customer support.</td><td>Our accuisition channels are webdesigners and -companies.

We deliver our value proposition through a web platform</td></tr>
</table>

key partners	value propoposition	customer segments
For the parts out of which the solar servers consistrs (solar panels, micro-computers) we will work together with component manufacturers. For reaching customers across the globe, local distribution partners are key.	Energy-neutral web hosting that is 10% renewable and sustainable.	Environmental conscious people who are looking into hosting a website andwant to help working on a more sustainable future. Hobbyists who are interested in hiosting their own blog or small website. They love that they are enabled to do so in a energy neutral way.

cost structure	revenue structure
The highest cost are the manufacturing and maintnance of the solar servers. The personell cost will be in customer support and the R&D team, as well as in customer relations.	Customers pay a monthly fee to host their website. The price of this subscribtion will depend on the amount of traffic and the desired uptime.

appendix b - schematic iteration 1



appendix c - entrepreneur interview

Q: You own a business in the mindfulness/coaching branch here in Eindhoven. Do you have an online presence?

A: Yes, I have two websites and several Facebook pages.

Q: Can you give me a link?

A: Yes: they are (calls names).

Q: What do you use your websites and Facebook for?

A: I mostly use them to let people know what I am doing and how they can reach out to me. My Facebook pages are for finding new customers and I use it as a blog for my business.

Q: What made you decide to start an online presence and how did you go about this?

A: I don't remember exactly why I started, since that is about 11 years ago…I think so people can find me online. I made my first website myself using website builder software and I work together with a web designer since a few years for my current websites. I also have a business coach that helps me think about what content should be on my site and such.

Q: What are important qualities for your website?

A: Since I get most of my new customers via my website or Facebook, it is very important that they can easily contact me and that I can establish a relationship. I like it to be easy to navigate and work with a model where each page of my websites encourages people to either visit another page or contact me directly.

Q: So where do you host your website? And have you arranged it yourself? What was your experience with this?

A: I host my website via (calls name). I have a very good experience with their hosting. I have a personal contact person that helps me with all my questions. They are a very reliable and will figure out technical things I cant do myself. I however do like it when I am able to do it myself, and try to do so as much as possible.

Q: Do you consider reliability to be an important factor when it comes to your online presence?

A: Yes, since I get most of my customers from my website and Facebook, I am very much reliable on these. If my site doesn't work, I can't reach new customers.

Q: Does sustainability play a role in your business?

A: Slightly, but I do not consider my business to be very wasteful. I consult and do activities with people and there is not much unsustainable about that. I do however find sustainability an important topic personally, and I always try to be mindful about that as a person.

Q: Would you be willing to invest in sustainable solutions if they would be able to make your business more sustainable?

A: I would, but I am not sure what could make my business more sustainable. Maybe solar panels, but that is a bigger investment than I am comfortable taking. I am a one man business and work from a rental office, so these kind of investments are not something that would be beneficial to me.

Q: Clear. Final question: Have you ever considered the carbon footprint of your website?

A: No. I have not. I wasn't realizing it had one, but it sounds logical..

Q: Okay, thank you for the interview.

appendix d - NGINX configuration

```
root@solarserver:/var/log/nginx# cat /etc/nginx/sites-enabled/solar.jorritvanderheide.com

# Expires map
map $sent_http_content_type $expires {
    default off;
    text/html 7d;
    text/css max;
    application/javascript max;
    ~image/ max;
}

server {
    listen 80;
    server_name solar.jorritvanderheide.com;

    location / {
        return 301 https://$server_name$request_uri;
    }
}

server {
    listen 443 ssl http2;
    server_name solar.jorritvanderheide.com;

    charset UTF-8; #improve page speed by sending the charset with the first response.

    location / {
        root /var/www/html/;
        index index.html;
        autoindex off;
    }


    #Caching (save html pages for 7 days, rest as long as possible, no caching on frontpage)
    expires $expires;

    location @index {
        add_header Last-Modified $date_gmt;
        add_header Cache-Control 'no-cache, no-store';
        etag off;
        expires off;
    }

    #Compression
    gzip on;
    gzip_disable "msie6";
    gzip_vary on;
    gzip_comp_level 6;
    gzip_buffers 16 8k;
    gzip_http_version 1.1;
    gzip_types text/plain text/css application/json application/javascript text/xml application/xml application/xml+rss text/javascript;

    #Caching (save html page for 7 days, rest as long as possible)
    expires $expires;

    # Logs
    access_log /var/log/nginx/solar.jorritvanderheide.com_ssl.access.log;
    error_log /var/log/nginx/solar.jorritvanderheide.com_ssl.error.log;

    # SSL Settings:
    ssl_certificate /etc/letsencrypt/live/solar.jorritvanderheide.com/fullchain.pem;
    ssl_certificate_key /etc/letsencrypt/live/solar.jorritvanderheide.com/privkey.pem;

    # Improve HTTPS performance with session resumption
    ssl_session_cache shared:SSL:10m;
    ssl_session_timeout 5m;

    # Enable server-side protection against BEAST attacks
    ssl_prefer_server_ciphers on;
    ssl_ciphers ECDH+AESGCM:ECDH+AES256:ECDH+AES128:DH+3DES:!ADH:!AECDH:!MD5;

    # Disable SSLv3
    ssl_protocols TLSv1 TLSv1.1 TLSv1.2;

    # Lower the buffer size to increase TTFB
    ssl_buffer_size 4k;

    # $ sudo openssl dhparam -out /etc/ssl/certs/dhparam.pem 4096
    ssl_dhparam /etc/ssl/certs/dhparam.pem;
```

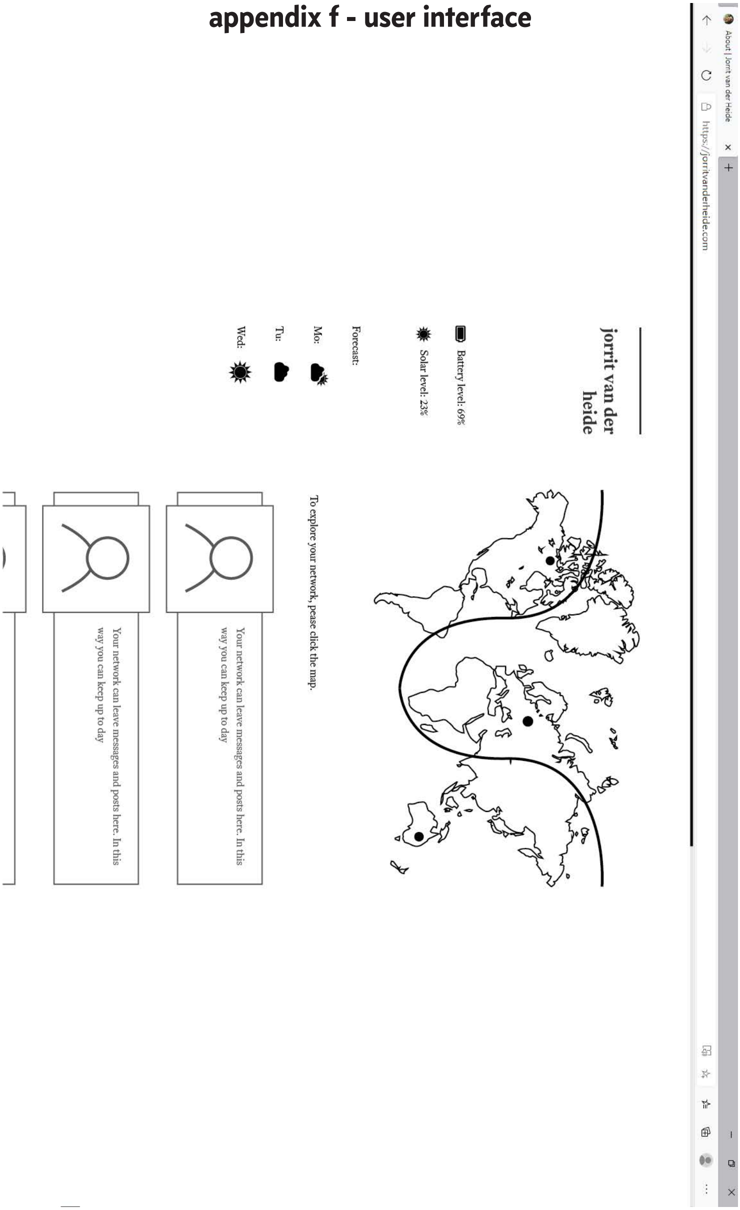
```
Port 80 to 80 for HTTP
Port 443 to 443 for HTTPS
```

appendix e - business model canvas iteration 2

key partners	key activities	value propoposition	customer relations	customer segments
For the parts out of which the kit consistrs (solar panels, micro-computers) we will work together with component manufacturers. For reaching customers across the globe, local distribution partners are key.	The development and sale of the solar-hosting kit is the main activity. Other activities concern building the community and providing customer support.	Energy-neutral web hosting as a hands-on experience.	Our customers subscribe for our service, which is highly automated. Repairs for the server kit will be handled by local partners and by self-care of customers.	Environmental conscious people who are looking into hosting a website, who posess technical affinity. They love being part of a community and that they can actively participate in working on a more sustainable future. Hobbyists who are interested in hiosting their own blog or small website. They love that they are enabled to do so in a energy neutral way.
	key resources		**channels**	
	A manufacture facility to develop soft- and hardware is essential. We also need our channels to make sales and provide customer support.		Our accuisition channels are webdesigners and -companies. We deliver our value proposition through package delivery and by means of video tutorials.	

cost structure	revenue structure
The highest cost are the manufacturing of the kit, shipping and repair it. The personell cost will be in customer support and the R&D team, as well as in maintaining the community.	Customers pay a for the kit. The price of this will depend on the amount of traffic and the desired uptime.

appendix f - user interface



appendix g - HTML & CSS dithering

HTML

```
<div id="about_01" class="img first tr"></div>
```

CSS for the pre-dithered image

```
#about_01 {
  padding-top: 66.6%;

  background-image: url("../img/about_01.png");
}
```

CSS for the background

```
.img {
  background-blend-mode: hard-light;
}
```

```
.tr {
  background-color: $accent2;
}
```

```
$accent2: #E36442;
```

appendix h - battery bar on jorritvanderheide.com

appendix i - dark mode

HTML

```html
<meta name="color-scheme" content="dark light">
```

CSS

```scss
@include dark {
  html {
    background-color: $background-dark;
  }
}

// Navigation
@include dark {
  #navbar {
    background-color: $background-dark;
  }

  #title {
    border-top: solid 3px $text-light;
  }
}

// Typography
@include dark {
  html {
    color: $text-light;
  }

  .menu-item {
    &.active {
      a {
        color: $text-light;
      }
    }

    a {
      color: $text-darkish;

      &:hover {
        color: $text-light;
      }
    }
  }

  .footnote-link {
    &:hover {
      background-color: $text-darkish;
    }
  }
```

appendix j - data compression & cache

Compression

```
<IfModule mod_deflate.c>
  <IfModule mod_setenvif.c>
    <IfModule mod_headers.c>
      SetEnvIfNoCase ^(Accept-EncodXng|X-cept-Encoding|X{15}|~{15}|-{15})$ ^((gzip|deflate)\s*,?\s*)+|[X~-]{4,13}$ HAVE_Accept-Encoding
      RequestHeader append Accept-Encoding "gzip,deflate" env=HAVE_Accept-Encoding
    </IfModule>
  </IfModule>

  <IfModule filter_module>
    FilterDeclare   COMPRESS
    FilterProvider COMPRESS DEFLATE "%{CONTENT_TYPE} = 'text/html'"
    FilterProvider COMPRESS DEFLATE "%{CONTENT_TYPE} = 'text/css'"
    FilterProvider COMPRESS DEFLATE "%{CONTENT_TYPE} = 'application/javascript'"
    FilterProvider COMPRESS DEFLATE "%{CONTENT_TYPE} = 'image/png'"
    FilterProvider COMPRESS DEFLATE "%{CONTENT_TYPE} = 'font/woff2'"
    FilterChain     COMPRESS
    FilterProtocol  COMPRESS  DEFLATE change=yes;byteranges=no
  </IfModule>
</IfModule>
```

Cache

```
<IfModule mod_expires.c>
ExpiresActive On
ExpiresByType image/png "access plus 1 month"
ExpiresByType font/woff2 "access plus 1 month"
ExpiresByType text/css "access plus 1 month"
ExpiresByType application/javascript "access plus 1 month"
ExpiresDefault "access plus 7 days"
</IfModule>
```

appendix k - test results

Pingdom

Your Results:

DOWNLOAD HAR SHARE RESULT

Performance grade	Page size
A 96	247.8 KB
Load time	**Requests**
3.67 s	13

Google

99

https://solar.jorritvanderheide.com/

0–49 50–89 90–100

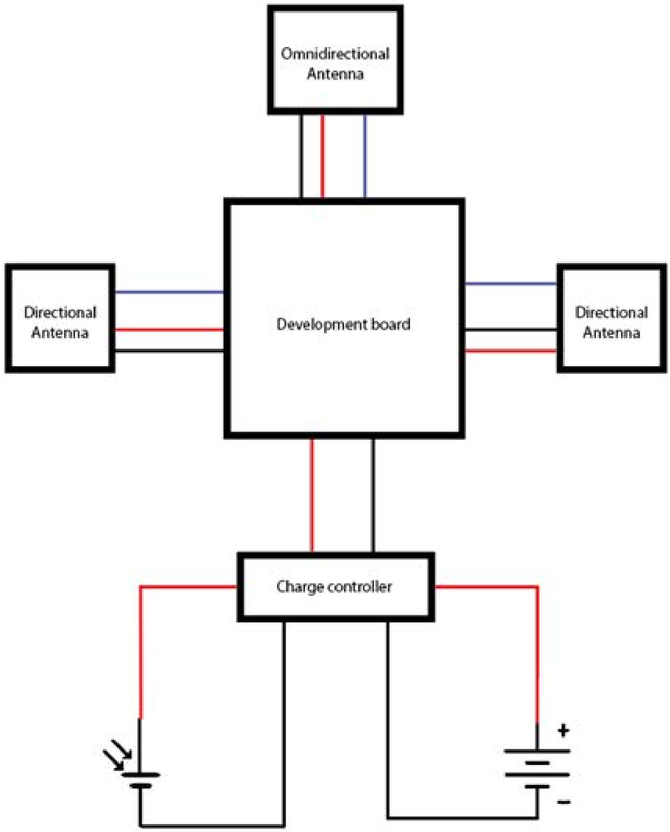
Veldgegevens — Het rapport Chrome-gebruikerservaring heeft niet voldoende echte snelheidsgegevens voor deze pagina.

Origin Summary — Het rapport Chrome-gebruikerservaring heeft niet voldoende echte snelheidsgegevens voor deze herkomst.

Labgegevens

Eerste weergave met content (FCP)	0,6 s	Tijd tot interactief	0,6 s
Snelheidsindex	0,6 s	Totale geblokkeerde tijd	0 ms
Grootste weergave met content (LCP)	0,9 s	Cumulatieve indelingsverschuiving	0,037

appendix I - access node schematic



appendix m - relay node schematic