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The Solar Tree
A Solar Cell Demonstrator for Roskilde Festival

Bachelor Thesis

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Abstract

This thesis examines the re-design of an organic solar cell installation made for Roskilde Festival 2019 called the Solar Tree. The goal of the Solar Tree is to educate, engage and inspire festival goers in organic solar cells and engineering. The re-design was achieved by applying methods learned from the BSc. Design & Innovation. The project utilizes a user-oriented design philosophy, thus user feedback is central for the understanding of requirements for the product. User studies show that interactivity is essential in engaging festival guests in a conversation and that an aesthetically pleasing, organic and novel design would be eye-catching and attract users. Ideas were then generated and further evaluated using different design methods and tools. Lastly, the chosen idea was conceptualised by investigating its individual components through basic structures, quantitative structures as well as testing and prototyping. The result of the bachelor thesis is a Solar Tree concept consisting of benches, green energy charging, interactive sun tracking and an aesthetically pleasing design resembling a palm tree. The final concept hereby fulfills the requirements set forth by the user study and is presented through a CAD model, a scaled model and a product catalogue.

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Contents

1 Introduction

1.0.1 About The Project

This bachelor project is a collaboration between the institutes of DTU Energy and DTU Mechanical Engineering.

Climate change is one of the most pressing challenges of the current century. In order to combat climate change we are often told to mind our consumption of meat, gas, plastics and so on, and rightly so. However, when we sometimes fail to live up to these ideals, it can cause feelings of guilt and consequently feelings of cynicism and resignation can arise. It is therefore important to also inspire people through positive reinforcement. This project aims to educate people about the potential of organic solar cells. Our goal is to inspire people to get more involved in combating climate change by showing the possibilities of this novel technology.

To do this we will re-design and build a novel solar powered installation for the Science Pavilion at Roskilde Festival 2020, displaying the features of organic solar cells. We will do this in co-operation with two PhD. students from DTU energy, Michael Korning Sørensen and Anders Skovbo Gertsen, as well as our counselor Torben Anker Lenau. Michael and Anders work with conduction research, focused on improving the efficiency of bulk heterojunction organic solar cells. At Roskilde Festival 2019 they built their own solar tree, which was sadly discarded after the festival. For Roskilde Festival 2020 they have recruited the design team to improve upon their previous design. The criteria for the installation are that it should be self-sustained, self-explanatory for users, and suitable for a festival environment. The installation should also promote organic solar cells by showing off novel ways of using them. This is a multidisciplinary project, where design, innovative ideas, choice of materials, assessment of socio-technical relations, intuitive user-interaction and fundamental education of organic solar cells and their properties are in focus.

Due to the outbreak of the COVID-19 pandemic some aspects of the project has been changed. This includes postponing the final phase of the project, including virtual user interactions and making new arrangements concerning gathering feedback on the final prototype. The changes are further described in section [6].

1.0.2 General method

The design process covered in this project will adhere to a series of three diverging and converging phases as well as a fourth and final phase, where the product will be finalized. The three phases will culminate in milestone-meetings with supervisors, where we will present our findings. The following text covers subject and methods of each phase.

The subject of the first phase will be to define the problems from a user perspective. This includes a full-fledged understanding of the earlier product and its faults, as well as alternative opportunities for improvements. This will be achieved by first diverging and gathering as much empirical data as possible, through interviews with different actors. Then converging by consolidating the data using methods like interpretations, function tree, stakeholder analysis and the KJ-technique.

The subject of the second phase will be to generate ideas, evaluate those ideas and finally to combine those ideas into a concept idea in co-operation with supervisors. For this, methods like brainstorming, morphology, PUGH, WOM and mock-ups, design workshops are used.

The subject of the third phase will be to conceptualize the product. Alternative solutions will be generated, discussed and chosen through methods like, basic structures, quantitative structures, material testing and prototyping. This will result in a product catalog containing documentations on prototypes, scripts and CAD drawings.

The subject of the fourth phase will be to document the building process and explain the reasoning behind any changes to the design that might occur.

Through the project certain tools will be used to structure workflow. An active GANTT chart and a Daily Agenda document provide macro and micro management of our time. Worksheets will be used as documentation for the work during. Google Drive will function as work-folder to keep order and back-up of all material and documentation. The thesis will be written in Overleaf. Discord will be the main tool for communication when physically meeting is not an option.

In relation to the bachelor thesis four main chapters will cover the following:
Chapter 2. covers discovering and defining the problem resulting in a Design brief.
Chapter 3. covers idea-generation and evaluation resulting in a chosen concept idea.
Chapter 4. covers conceptualization and results in a complete vision for the final product.
Chapter 5. summarizes the final concept an results in a product catalogue.

1.0.3 Abbreviations and Terms

The following list contains abbreviations and terms used through out the thesis.

Abbreviation / Term	Definition
BOM	Bill of Materials
CAD	Computer Aided Design
EOL	End of Life
EPBT	Energy Pay Back Time
GANTT	A project schedule developed by Henry Gannt
IoT	Internet of things
KJ	A brainstorming method developed by Jiro Kawakita
LCA	Life Cycle Assesment
OPV	Organic Photovoltaic
PUGH	An idea evaluation tool developed by Stuart Pugh
PV	Photovoltaic
WOM	Weighed Objectives Method
WS	Worh Sheets

2 | Discover & Define

This Chapter will cover conducted research and interpretation of user needs resulting in a problem definition.

2.1 Defining Stakeholders

To get an overview of which actors and actor-worlds have a stake in the Solar Tree on Roskilde festival an Actor Network was created. An actor network provides an overview of relevant stakeholders as well as their relations and intentions. Through the use of Actor Network Theory (ANT) [9] a network with the relevant actors, both non-humane and humane was constructed. A translation between each actor was created, with the Solar Tree in the middle as a boundary object between all the relevant actors.[30]

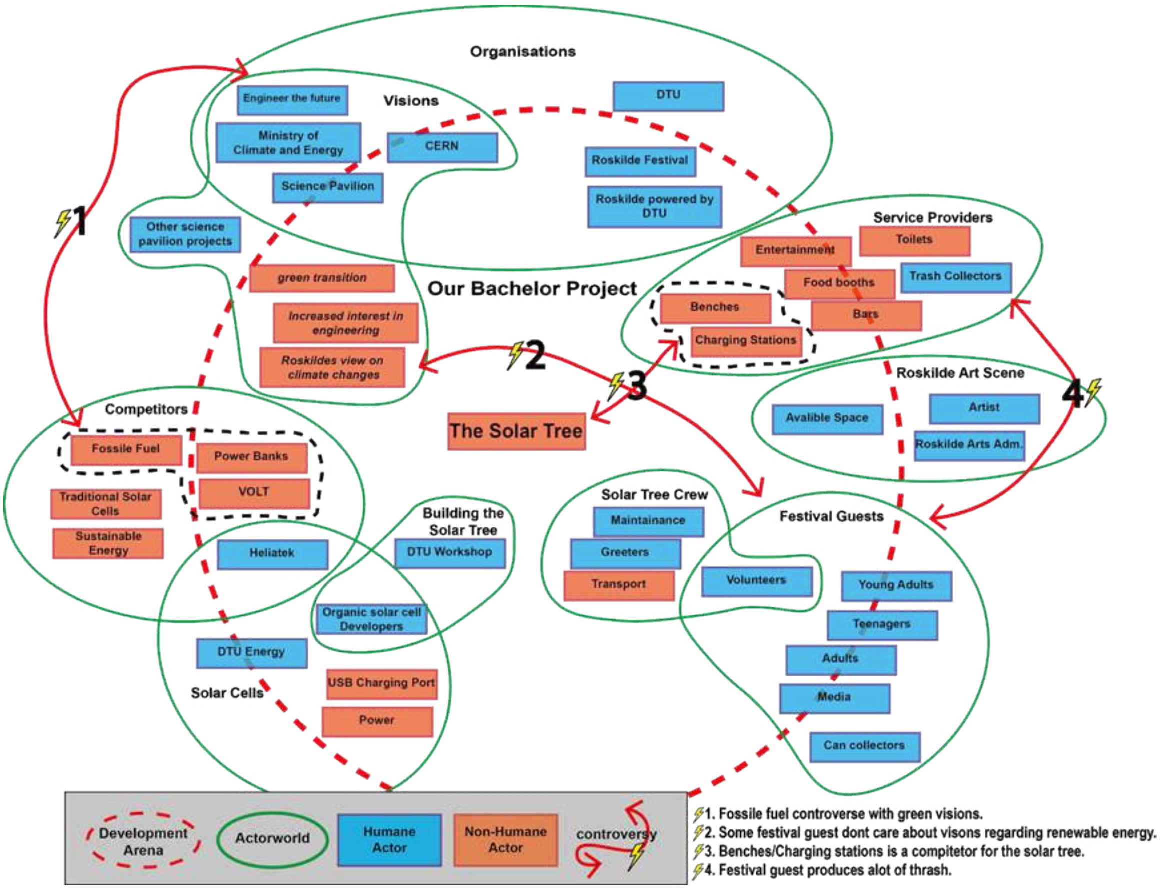

Figure 2.1: Development Arena constructed by the design team in the course 42062 Arenas and Concepts

Through the use of the actor network it was made clear, that some stakeholders have more influence than others. The developers Anders and Michael are key actors in the network, due to the fact that they affect many of the other important actors. The festival guests are also significant actors, since they will be the actual users of the product and the desired consumer of the information mediated. It was therefore important to fully understand this group of actors and its range of various desires, which is why the festivals guests were divided into different sub-groups. The sub-groups are based on different age groups, since it was assumed that the different age groups act differently on a festival. The groups are divided into teenagers (16 - 19 years), young adults (20 - 29 years), and adults (30 years). This was done because it was believed that these different groups behave very differently and have very different habits at Roskilde Festival. For example the design team goes to Roskilde Festival and know that the different age groups tend to stay in different areas of the Festival. Camping area L where the Solar Tree is placed is predominately inhabited by high school students. [WS-2.1]

2.2 Gaining insight in user needs

After stakeholders were defined and found, data was gathered through qualitative interviews [5, Page 102]. The design team found festival goers(users) to interview within their own social network. Fieldwork took place at different locations to the comfort of the user. A member of the design team guided the conversation and took notes[WS-2.2]. The interviews were performed using an open conversation interview style, where relevant subjects were touched upon naturally. If conversation stalled the interviewee could use a list of prepared questions to restart the conversation. The conversations continued until all questions were answered desirably and the user didn't have more to say. It was desired that the user should talk as freely as possible about their experiences at festivals and that they should not be biased by the phrasing of our questions. These interviews gave a unique opportunity to gain insight in user-needs, since through open conversation the users spoke very frankly about their experiences.

From the interview it was desired to gain information about the users habits, needs and desires at festivals. The interview could also provide information about which groups of people are more open to experience projects such as the Solar Tree, when they are attending a festival.

Since festivals are an annual event, it was not possible to observe the existing solar tree in its working environment and how the users interacted with the tree. Therefore festival goers were interviewed about their general behavior at events, use of facilities, and art installations.

Lastly the data collected through these interviews were discussed in an interpretation session[16, Page 81-105]. The findings from this session were summarized in persona worksheets[5, p. 132]. These personas provide a stereotypical picture of the tendencies, needs, worries and desires of the different groups of festival goes.

2.2.1 Field interview with The Solar Tree developers

Through an interview with the developers of the Solar Tree Anders and Michael[WS-2.3], some problems were made clear. The focus of the interview was mainly the use and the design of the Solar Tree.

The Solar Tree was placed in camping area L, which is mainly populated by Teenagers. The users primarily utilized the charging function, whilst using the benches. The Solar Tree was in use all the time during the week, and some can-collectors used it during the night. The Solar Tree was primarily used as a bench for eating, which resulted in a lot of garbage around the Solar Tree. The intention of Anders and Michael was to educate and inspire the users about renewable energy and organic solar cells. The users' degree of interests in the project was varied, but young high school girls were most interested in the project. Through the week Anders and Michael had no experiences with vandalism or abnormal use of the solar tree. From the hopes, concerns and expectations that Anders and Michael expressed in this interview a design brief was created[WS-2.17].

2.2.2 Field interview with male teenage festival goers

Six high school boys were interviewed in groups of two and four. Their answers were summarised in the persona Anton[WS-2.7]. Anton is 18 years old and is in his second year of high school. He is majoring in social studies and uses a lot of free time with his friends. Anton attends Roskilde festival because all of his friends are there. From his point of view the festival is a holiday with all his friends around him, free from parental supervision. He likes concerts, but the social aspect is more important.

Habits
Anton eats homemade breakfast on Roskilde festival and he showers in the the morning. He gets one hot meal a day, which he buys at the food markets in the evening. He charges his phone on his friends' portable chargers,

which gets charged at the Volt booth. He only leaves his camp, when he has a purpose like going to a party in another camp, attending concerts or if he needs to do something practical, like taking a shower or getting some water.

Interests
Anton likes partying and hanging out with his friends. When he is on Roskilde, he wants to feel present in the moment and doesn't plan his day. The campaigns[24] and the art at Roskilde Festival does not interest him very much. He does not go to Roskilde Festival to be politically correct, but to have fun and party. Anton thinks the sports facilities on Roskilde are a positive feature, and believes that more facilities like this would improve his experience on Roskilde Festival.

Attending events
Anton doesn't visit many events throughout the festival, but if he does, it is usually in the morning, when the camp is still relaxing and waking up. He tracks events on Facebook and only follows them, when something is free, or when it has something to do with partying.

2.2.3 Field interview with female teenage festival goers

Two high school girls were interviewed in order to summarise in the persona Klara[WS-2.8]. Klara is an 18 years old student studying social studies in her second year of high school. She went to Roskilde Festival with her friends to go to concerts, meet new people and have fun. She has attended Roskilde festival twice now.

Habits
Klara wakes up early and eats her homemade breakfast. She buys two meals every day at the market. She likes exploring what options she has when she goes out to eat, and she always eats it away from the camp, preferably a place with seating. If nothing is happening in her camp, she likes to go exploring or visit her friends' camp before 3 pm, where the partying starts. Klara uses all the practical facilities at the festival.

Interests
Klara likes that people are very social at the festival. She enjoys how easy it is to meet different types of people. She likes going to concerts with friends and partying at the different camps.

Attending Events
Klara keeps track of interesting events on Roskilde festival over Facebook, but she usually only attends if nothing happens in her camp or if her friends are attending. She likes that Roskilde takes a social responsibility through campaigns instead of just being "a week-long party on a field"[WS-2.4].

2.2.4 Field interview with young adult male festival goers

Through interviews with two male university students, the persona Thomas was created[WS-2.9]. Thomas is a 26 years old university student that goes to festivals to hang out with his friends and for musical events. Thomas has a preplanned musical schedule, that he tries to maintain.

Habits
Thomas likes to explore in the warm-up days on Roskilde, but tries to save energy for the concerts. He buys one meal a day and eats it wherever he can sit down. He does not use volt to charge his phone because he has power-banks, but he does charge them in the 3-booth when necessary. Thomas does not like leaving the camp too often in the warm-up days and would rather just relax and enjoy the camp atmosphere.

Interests
Thomas is prioritising the music highly as well as having fun with his friends. He likes that Roskilde provides facilities and events other than just concerts, even though he might not attend many of them. He likes that Roskilde provides alternative options to sitting in your camp or partying.

Attending Events
Thomas attends a fair amount of events on Roskilde Festival. He hears about a lot of great events from his friends and wants to attend all of them, but he does not always have the time and energy to do so.

2.2.5 Field interview with young adult female festival goers

Two female university students were interviewed to create the persona Caroline[WS-2.10]. Caroline is 25 years old and studies mathematics at the university of Copenhagen. She attends Roskilde festival to hang out with friends and listen to some artists.

Habits
Caroline makes her own breakfast and lunch on the festival. She uses the practical facilities at the festival and eats near the food-booths. She has attended Roskilde festival many times and she does not want to party as much as she used to. She parties with friends, but also tries to relax in the days before the music begins. Through the warm-up days Caroline goes home to rest for a day. Caroline likes exploring the festival before the concerts begin.

Interests
Caroline is very politically active and has great interest in projects that aim to change the world for the better. However, she also likes to party when she is at Roskilde Festival. She wants to be politically active, but it shouldn't take up too much of her time, because she is at Roskilde Festival to have fun.

Attending events
Caroline likes to use the warm-up days on attending different events and parties at dream city. She finds the events on Facebook or through talking to friends. Caroline usually has too many plans to be able to attend to all of the events. She likes the art on Roskilde, when it is politically relevant and when it is simple to understand.

2.2.6 Field interview with Adult festival goers

Two women and two men were interviewed aged above 30. The habits and interests of adults aged above 30 did not vary much between the two genders. Because of the common needs, interests, fears and goals of the age-group one persona[WS-2.11] was made to define the whole age-group. Anne is 52 years old and goes to Roskilde festival with a one-day-ticket. She has a few specific artists she wants to experience at the festival, but meets early in the day to get the "Orange feeling"[20] and explore the arts and alternative events. She likes meeting up with her children for lunch and walking around a bit in the market areas.

Habits
Anne arrives at the festival early so she has time to explore the festival. She doesn't have a plan about what to see other than the concerts in the evening. She likes to meet up with friends and her kids at the festival, which happens by using meeting points. She is not fond of the garbage on the festival and doesn't like to waste time on queuing. She usually doesn't know what is happening on the festival so she goes to the first interesting events and installations she sees.

Facilities
Anne uses a lot of different facilities during Roskilde festival. She likes exploring what the festival offers other than music. Anne gets tired from being so active on the festival and therefore wants a place to relax and retreat from all the noise and dirt on the festival. Anne likes to go to the booths and installations on the festival, where she can interact with the installations.

2.3 Interpretation of interviews

From the fieldwork it was desired to obtain a clear definition of the users' habits and needs. This was executed through the use of an Affinity diagram[16]. The Affinity diagram is used to create a scope of the problems in the network of the product. It is used to "[...]reveal all the issues, worries and key Quality requirements of the product"[16, p. 127].

Figure 2.2: Walking the affinity diagram

From the Affinity diagram, correlations between different statements were assembled, which led to finding the essence of the problems, constraints and areas of opportunity. The Affinity diagram resulted in the following summarized statements:

"I need a break"
There was a pattern amongst the festival goers, that they needed to be relieved from the festival environment. This implied noise, garbage, social aspects and the music.

"This is where I'm often found"
The festival goers have different needs throughout their day nudging them to visit specific areas. Placing the installation in these areas will increase its exposure. Festival goers also don't want to stray too far away from their camps. It is therefore important to consider that some demographic areas only will result in exposure of a certain group.

"I'm at Roskilde to have a good time"
Every type of festival goer had the desire to get the "Orange feeling", which meant that they did not want to plan or be met with too many challenging tasks at the festival. It is an opportunity to mediate information to reach the users in an optimal way.

"I check social media for events daily"
Even though many users didn't attend all the events, almost all of the younger users used Facebook to track events[W-2.4 to W-2.6]. If they attended an event they had most likely seen it on social media before.

"This made me tell other people about the solar tree"
Many users had recurring preferences to what attracted and inspired them. Festival goers usually go to Roskilde to experience something new and unique.

2.4 The Existing Design

The existing design was a showcase of organic solar cells, named the Solar Tree. The Solar Tree was part of Science Pavilion at Roskilde Festival 2019, which was placed at the camping area L. It was showcased during the warm-up days and was a part of a workshop, where the users where able to build their own Solar Panel to charge their phones. During the week the creators of the Solar Tree interacted with the users, to inspire and educate them about the technology of organic solar cells.

Figure 2.3: Existing Design

The design consisted of two benches with seating space for approximately 8 people. The benches were connected to a main box containing the electrical components. Solar panels were attached to the main box through a pillar. [WS-2.12]

The Solar Tree had one big traditional 160 Watt silicon solar panel charging the battery. Beside the silicon solar panel organic solar cells were placed, which were not connected to the battery. The purpose of the organic solar panel was primarily to showcase the technology, due to the fact that the organic solar panels were very inefficient. The silicon solar panel was connected to a converter which charged a small car battery with approximately $50Ah$. The Solar Tree had 8 high output USB charging ports for charging smartphones. The Solar Tree had a transparent piece of PET plastic sheet, for mounting the users home built solar panels, which was a part of the workshop. The solar panels were placed strategically to obtain the maximum amount of sun, while providing shading for the users.

The aim of the design was a sturdy built suited for an environment for Roskilde Festival. The material used for the boxes was plywood, and the benches were built from impregnated wood. The "trunk" of the solar tree was made from a wooden pillar, which was later decorated with floorboards found on the Festival Site. Stone tiles were placed in the bottom of the main box to obtain stability, while keeping the electronic components away from water.[WS-2.13]

Figure 2.4: Use of existing Design

2.5 The Organic Solar Cell

2.5.1 The Conventional Solar Cell

At their most basic level solar cells consist of a semiconductor, which is able to create electric energy by absorbing photons[7]. Conventional solar cells use silicon as their semiconductor. The silicon atoms are arranged in a crystalline lattice structure, which is divided into two regions called the n-type and the p-type region. These regions are doped with a very low concentration of impurities to create a directional electric field. The n-type region contain phosphor making it negatively charged and the p-type region contain bor making it positively charged. Where the regions join is called the np-junction. A depletion zone with no charge surrounds the np-junction. Photons which is absorbed in this zone will free up an electron/hole pair called an exciton. Because of the directional electrical field created by the n- and p-type regions the hole and the electron then travel to the anode and the cathode respectively. This will create a voltage differential between the electrodes. 2.5

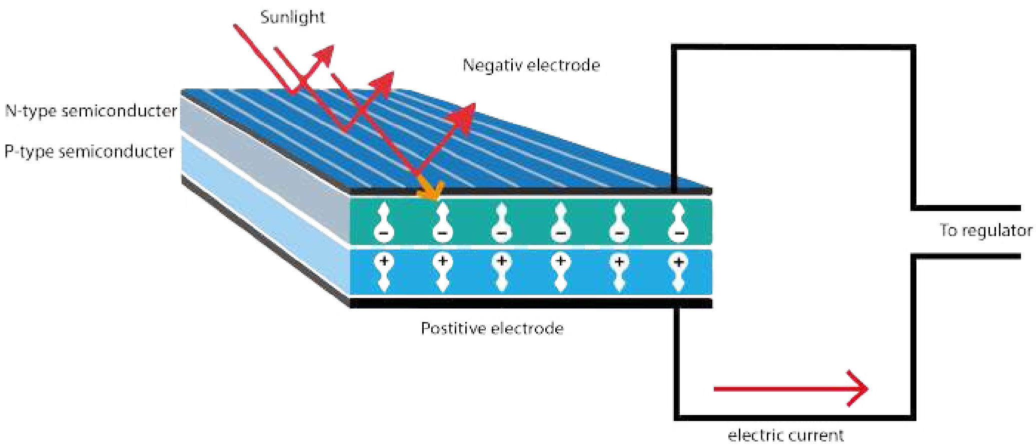

Figure 2.5: Cross section of conventional solar cell

To understand what an exciton is, it is necessary to delve into some solid-state physics[8]. It is widely know that electrons orbit around atoms in different bands. There can be two electrons in the inner most band, eight in the next etc. The outer most band containing electrons is called the valance band.

Between the bands there are band gaps and the size of these gaps depend on the energy differential between the bands. There is also a band further out than the valance band, which is called the conduction band. It is called the conduction band, because electrons are able to move freely between atoms, thus making the atoms conductive. In insulators the band gap between the valance band and the conduction band is very big, thus making the material very bad at conducting an electric current. In conductors like cobber or gold the bands overlap making them really effective at conducting currents. In semiconductors there is a relatively small band gap making them able to conduct only when the right amount of energy is applied. This is why the photon needs just the right amount of energy in order to free an electron into the conduction band. The energy of the photon needs to match the energy difference in band gap. An electron/hole pair is an electron, which has absorbed the energy of a photon kicking it from the valance band to the conduction band leaving behind a hole.

2.5.2 The Organic Solar Cell

The conventional understanding of an organic product does not apply to organic solar cells. The organic in their name refers to organic chemistry, meaning all the materials used in the solar cell are organic compounds[WS-2.15]. An organic solar cell functions much like a conventional silicon solar cell. It is also made from semiconductor with donors and acceptors. However in the organic solar cell the donor and acceptor are not confined to two distinctive regions. Instead they exist in a nanoscale blend called a heterojunction. There are many different ways of making organic solar cells, but all the viable ones have a heterojunction surrounded by some type of conduction polymer, which transports the charges to electrodes. They also need to have some type of transparent protective barrier to shield it from the environment and provide structural integrity. The organic solar cells which are used in the solar tree use a bulk heterojunction with PEDOT:PSS as the conduction polymer, a silver substrate as electrodes and PET plastic as it's protective barrier. 2.6

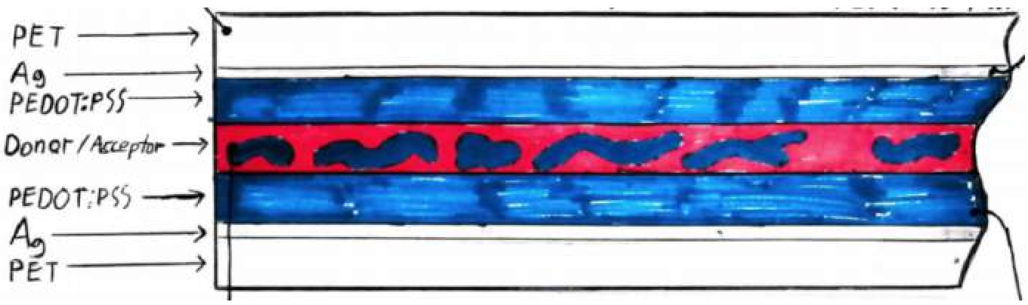

Figure 2.6: Cross section of organic solar cell used in the solar tree

2.5.3 Advantages & Disadvantages

Even though organic solar cells are not organic in the conventional sense, they still have some features, which make them very attractive from a sustainable point of view. The organic compounds used in the cell are not particularly bad for the environment and majority of the mass of the cell is actually the PET-plastic barrier. Some organic solar cells are considered normal waste and can simply be burned along side other waste in a power plant. However, organic solar cells are less efficient than their silicon counterparts. Whereas off-the-shelf silicon solar panels have efficiencies of 16-22 %, large-scale organic solar cell panels only have an efficiency of 7-10 %. Encouragingly, however, the current efficiency record for laboratory-scale organic solar cells is now above 18 % [25], making upscaling the next big challenge in the field [3]. This is obviously a major disadvantage, but the hope amongst organic solar cell producers is that organic solar cells will be much cheaper to produce, when large scale manufacturing plants are build. Economical analyses suggest that the levelized cost of electricity, which takes both production cost, efficiency, and lifetime into account, will be equal for silicon solar cells and organic solar cells when large-scale fabricated organic solar panels reach efficiencies of 10 % and lifetimes of 10 years, which is believed to be within reach in the next decade. [6]. Organic solar cells are manufactured by printing the different layers directly on the PET plastic. The process is very efficient and doesn't require high heat as the silicon solar cells does, making the production less environmentally harmful.

As a result of production method, organic solar cells are very thin, lightweight and can bend easily without breaking. This opens up many potential application that silicon solar cells cannot perform eg. wearable solar panels and solar cells incorporated in architecture. Organic solar cells will be easy to transport and install due to the roll to roll production method. [26]

2.6 Life Cycle Assessment

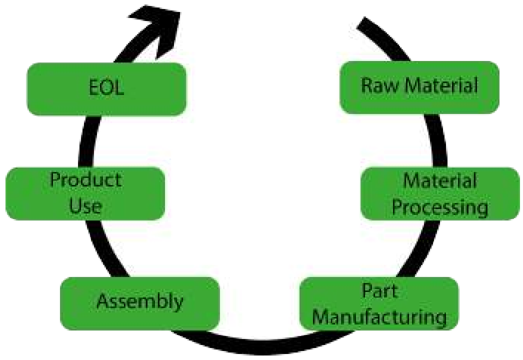

Figure 2.7: LCA

Life cycle assessment (LCA) is an analysis of a products' enviormental impact through the entire life phase, also known as "cradle to grave". This includes the extraction of the raw material, material processing, part manufacturing, assembly, use and eventually "End Of Life" (EOL). By doing an analysis it is possible to define the crucial steps in the life cycle, and then improve upon it. LCA is defined with an ISO standard. [17]

2.6.1 LCA of organic photo voltaics (OPVs)

Organic solar cells has the potential to greatly reduce the environmental profile of photo voltaic (PV) devices, compared to traditonal PVs. OPVs require less material to produce and are sturdy, light and flexible. Because of this they don't require an aluminium frame or a glass cover like conventional solar cells. OPVs also have a great EOL potential, hence the primary material used is PET plastic which can be recycled. Furthermore, the transportation and assembly of OPVs also has a relatively low impact due to the weight and the roll to roll production.

2.6.2 Energy Payback Time (EPBT)

Energy payback time defines the amount of time required to compensate for the energy used during the life-cycle. The payback time in years can be defined as followed. Where E_P is the energy used for production, transportation and material use, E_G is the annual amount of energy generated and E_M is the annual energy used for maintenance.

$$EPBT = \frac{E_P}{E_G} - E_M \tag{2.1}$$

The following table contains EPBT for different PV technologies.

Energy Source	**EPBT (Years)**
Silicon mono- and polycrystalline	1.65 - 4.12
Amorphous silicon	1.13
GaAs PV	2.36-5
GaInP/GaAs	2.14-4.6
CdTe	0.73–1.61
CIS	2.02–2.26
OPV	0.2–4

Table 2.1: EPBT [23]

The EPBT of OPVs is much lower as seen in figure 2.1. The time varies widely for OPVs. This is due to the fact that organic solar cells are still a novel technology, that hasn't yet been industrialized like traditional silicon PVs. By up-scaling the production of OPVs it has the potential to lower the EPBT with the use of roll to roll production [6] [23] [26].

2.7 Defining the problem

At the heart of the Solar Tree lies a desire to inspire, excite and educate people about green technology, organic solar cells and engineering. The goal of the project is that festival guests who experience The Solar Tree have a feeling that they understand the pros and cons of organic solar cells and think that green technology and engineering is interesting. This goal has been summarized in the following statement:

The project can be considered a success if festival guests are easily invited to converse about organic solar cells, inspired by green technology and excited about engineering while experiencing The Solar Tree.

Through empirical data gathering and analysis, it has been determined, that in order to do this the Solar Tree must provide certain sociotechnical functions. It is desired that the design of the product reflects the use of green energy and cleantech[10] through an organic design. The Solar Tree should attract the user without direct contact, through an aesthetic design, marketing strategy and by offering some basic facilities such as seating and charging. Users should be encouraged to strike up conversations regarding the Solar Tree and its purpose, preferably by their own initiative. The tree should leave an impact on the user through a novel design and some unique and exciting features.

In order for the Solar Tree to attract and inspire festival goers at Roskilde Festival, it should also offer a wide range of technical functionalities. It should provide seating along with some type of protection from the elements. When people are sitting they should be able to charge their phones with power generated from the solar cells and the structure of the installation should be strong enough to withstand the sometimes chaotic environment that is Roskilde Festival. It should also be relatively easy for operators to transport and conduct maintenance on the Solar Tree. Lastly the Solar Tree should perform whatever function, which we deem necessary from a sociotechnical standpoint within some degree of reason.

2.8 Design Brief

Through a design brief meeting[WS - 2.17] with The Solar Tree creators Anders and Michael the problems were defined. This was further simplified by creating a list of specifications for each functions divided into "*minimal viable product*" and "*optimizing product*". The *minimal viable product* contains elements that are essential in order for the product to succeed. *Optimizing the product* describes elements that will help differentiate and evaluate the concepts later in the design process. The Solar Tree project has two main goals. The first goal is to find a way to use the Solar Tree to inspire and engage festival guest in the green energy movement, as well as educating them on organic solar cells and engineering. The second goal is to build the actual Solar Tree as an artefact and solve any challenges that this might entail. To properly address these different goals the design brief was divided into two categories; sociotechnical and technical specifications.

2.8.1 Sociotechnical specification

Function	**The minimal viable product**	**Optimizing the product**
Inspire	The Solar Tree must inspire the users to be optimistic about- and explore the opportunities of renewable energy.	
Excite		It is desired that the product excites the user through unique features.
Educate	The Solar Tree must educate about organic solar cells and sustainability in general.	
Organic Design	The design of the Solar Tree takes shape as something organic.	
Invite conversation		It is desired that the Solar Tree invites conversation about renewable energy.
Commercial	The Solar Tree must have a strategy to reach the users before they see the actual tree.	
Attraction	The Solar Tree attracts the user through visual attraction and the users' needs on the festival.	It is desired to have an aesthetically pleasing design.

2.8.2 Technical specification

Function	**The minimal viable product**	**Optimizing the product**
Charging ports	Must provide at least 8 high charging USB ports for smartphones.	With more than 8 charging ports the Solar Tree will be able to service more people.
Robust structure	Secure for normal use on a festival.	Secure for vandalism and abnormal use on a festival.
Seating Space	Must provide at least 8 seating spaces.	With more than 8 seating spaces the Solar Tree will be able to service more people.
Weather proof	Electricity and wiring is safe from rain and other liquids. The tree must not be able to be overthrown by the weather.	-
Installation	The installation must be done by two installers in under an hour.	A faster installation time is always desirable.
Weight	The Maximum weight of any one component should not exceed 70 kg.	Lighter components are always desirable.
Transportation	The transportation can be done using a van.	Easier transport is always desirable.
Generating electricity	The solar cells should provide as much power as used in a normal day of charging.	If the solar cells create more power than is used in a normal day of charging this would also be desirable.
Storage of electricity	The battery must contain power for one day, without charging.	If the battery contains more power than used in a normal day of charging this would also be desirable.
Maintenance	All electronic parts are accessible.	Accessibility and fast replacement of components is desired.
Design		Organic design is desired.
Sociotechnical functions	The Solar Tree should perform any functions provided for sociotechnical reasons.	
Materials		It is desired that the materials of the Solar Tree are sustainable.
Trash	The tree should provide easy options for disposal of trash.	It is desired that the tree invites users to dispose of their trash properly.

3 | Idea Generation & Evaluation

This chapter covers the second design phase called Idea Generation and Evaluation. The chapter includes a range of creative ideation methods as well as methodology that enables evaluation of concepts idea.

3.1 Idea Generation

3.1.1 Mood board

Since the visual aspect is big a part of the design a Mood Board was created [WS-3.1]. The aim of the mood board is to visually illustrate the desired style and feeling of the product. Since this is a group project, a unified vision is desired, which the mood board created. Images from the internet were put together, in order to set the mood.

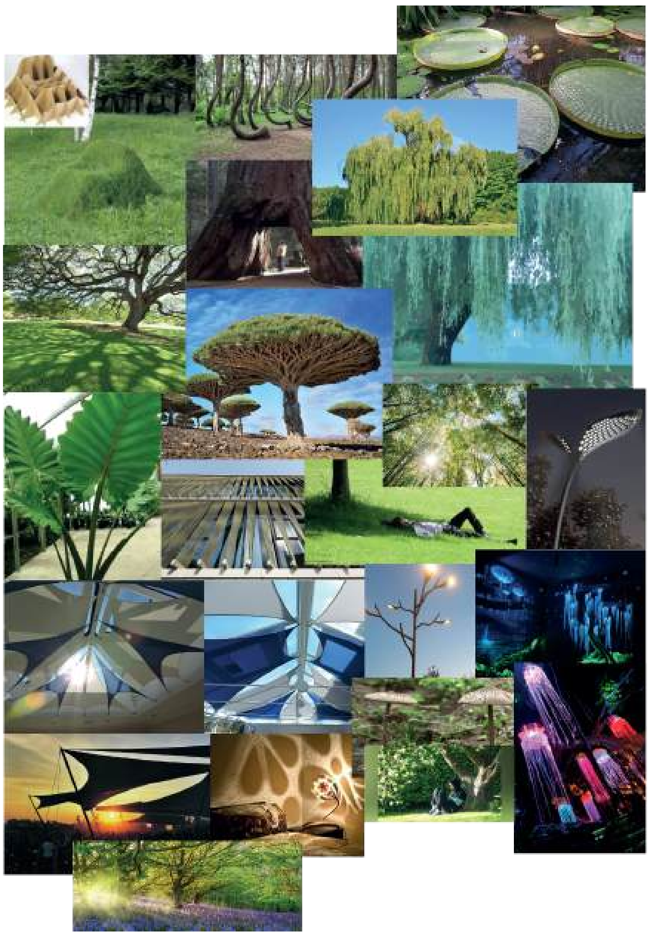

Figure 3.1: Mood board

The Mood board created a common understanding of the feeling the user should have when experiencing the Solar Tree. The mood board also inspired ideas and features for the Solar Tree like LED-light garlands imitating a willow tree.

3.1.2 Brain walk

To expand research of idea generation a Brain walk was constructed[WS-3.2]. This method was used to control and utilize the priming eachother gradually when brainstorming. The Brain walk was achieved through a Google drive program, where multiple people could add sticky notes to a board. Three subjects were distributed between the three idea boards, being **Design**, **Info sharing** and **User Needs**.

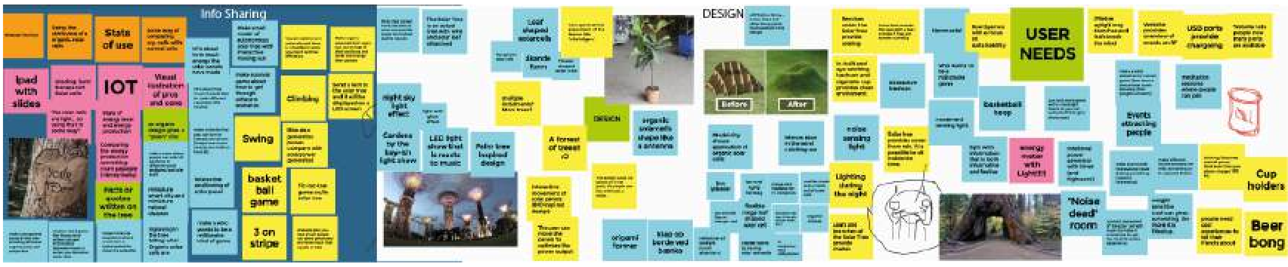

Figure 3.2: Brainwalk

The Brainwalk provided a wide range of ideas and enabled gradual inspiration instead of priming. The Brainwalk was used to initialize the idea generation, whilst getting an overview of ideas that had been developing whilst analyzing the project, and to inspire new ideas from these. Conceptual ideas like making the Solar Tree modular, and smaller feature ideas, like having an Ipad with information and games were created. The Brainwalk helped make a strong and wide range of ideas to work with.

3.1.3 Negative Brainstorm

When idea generating it can sometimes be challenging to come up with new ideas, and one often finds themselves stuck in the same path. Negative brainstorming can be a great method to get alternative ideas. This is done by intentionally creating "bad" or odd ideas. When doing the negative brainstorm quantity is the priority and judgement is deferred.

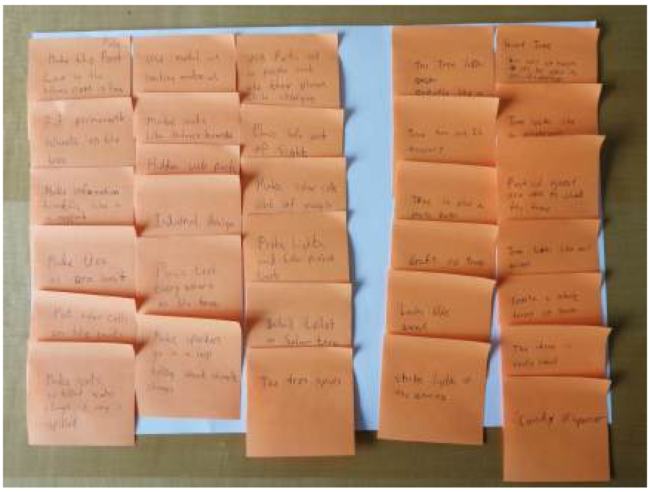

Figure 3.3: Negative Brainstorm

The method did not necessarily provide any useful or good ideas, but instead broadened the perspective and opened up for some new aspects of the problems. For example, the negative brainstorm made it clear that the

Solar Tree should radiate the message of the installation, instead of radiating something that had no relevance to the goal of the Solar Tree. In other words, the image of the Solar Tree should be an advocate of its purpose.

3.1.4 Bio Brainstorm

The Solar Tree is meant to take inspiration from nature in order to reflect its green image. The bio-brainstorm exercise starts with creating an overview of all the functions of the product[WS-2.14]. The designers then use different search engines like *AskNature*, *ProQuest* and *DTU Findit* to determine how nature performs the same or similar functions. This can be a very useful tool because nature has had millions of years to perfect its solutions to various problems. Nature can therefore sometimes have elegant and simple solutions to very complex problems.

Nature will inspire many aspects of the Solar Tree. The visual and aesthetic aspect of the project is most heavily influenced. It is desired that the users of the Solar Tree should feel like they are secluded in a quiet place in the woods, away from all the hassle of the festival. To accomplish this, the Solar Tree could take inspiration from the willow tree with overarching branches.

In order to better educate people about solar cells, the Solar Tree could also provide examples about how nature collects energy from the sun. The Tree could take inspiration in sunflowers and be able to track the sun during the day. This might get people interested in the project and make it more than just a beautiful charging station.

3.2 Concept Ideas

3.2.1 Morphology Diagram

To get a clear overview of the available ideas, a morphology diagram was created. The ideas were divided into different groups, solving different problems, defined by previous work [2.7]. Furthermore, five concepts were created by combining different solutions. Each concept strives to succeed in the different aspects of the Solar tree's problem space and does so through unique characteristic themes.

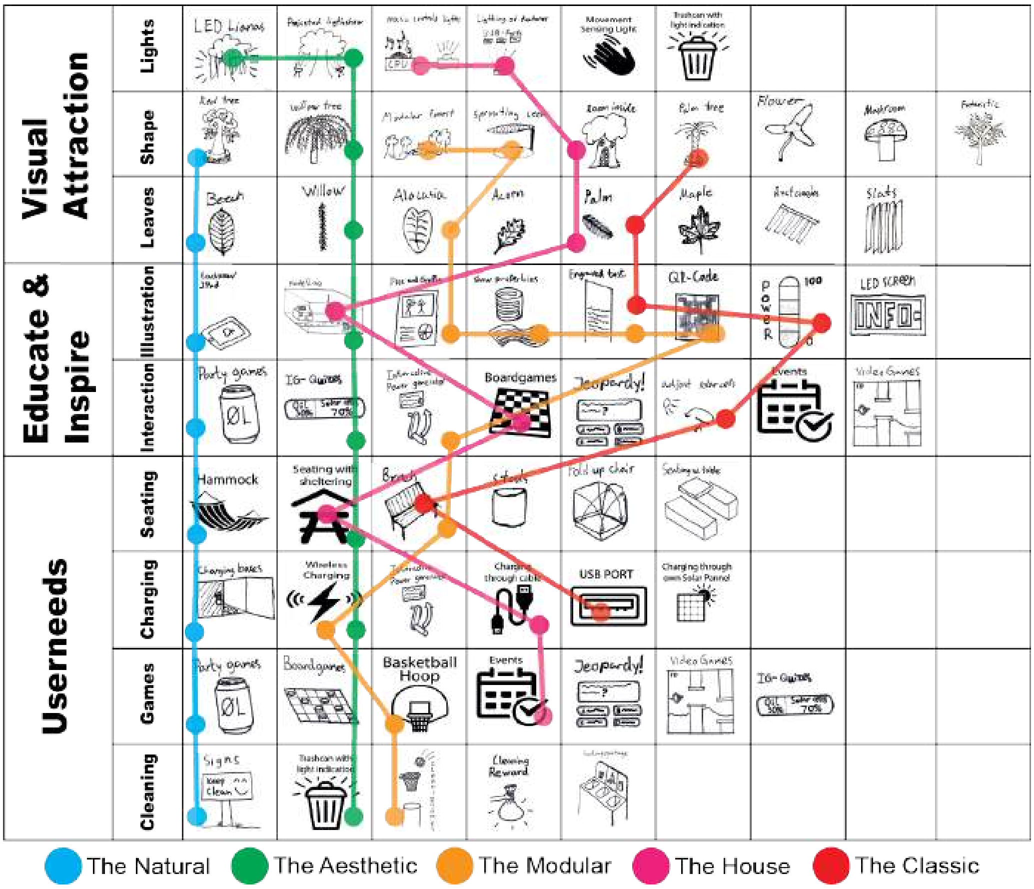

Figure 3.4: Morphology diagram of ideas

3.2.2 The 5 Concepts

The Classic Tree

The focus of the classic tree is to create a minimalistic design that is obtainable and simple, hence the name *the Classic Tree*. This includes a design that imitates a palm tree with benches surrounding the trunk of the tree. The concept contains a handle for rotating the angle of the solar cells, thus optimizing the power output of the organic solar cells. The power output is shown on a scale with light indication, thus making it clear for the user which angle is optimal. Furthermore, the trunk of the tree also contains engravings regarding information, and/or inspiration about organic solar cells and renewable energy.

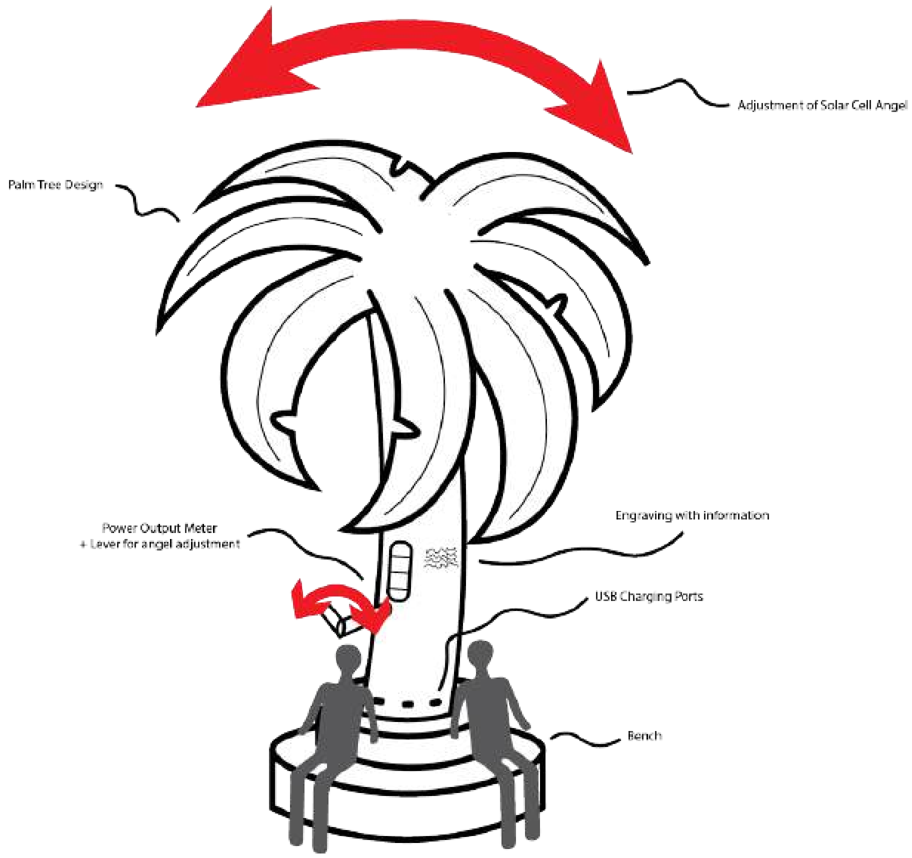

Figure 3.5: The Classic Tree

The Tree House

The focus of the Tree House is to create a tree that provides a very good shelter from the environment. In order to do this the tree design resembles a tropical hut with palm leaves on top. The Tree House uses LED lights to light up features like charging cables and trashcans. Inside the tree, board games provide entertainment and an event calendar is displayed. A miniature city showcases the possibilities of organic solar cells.

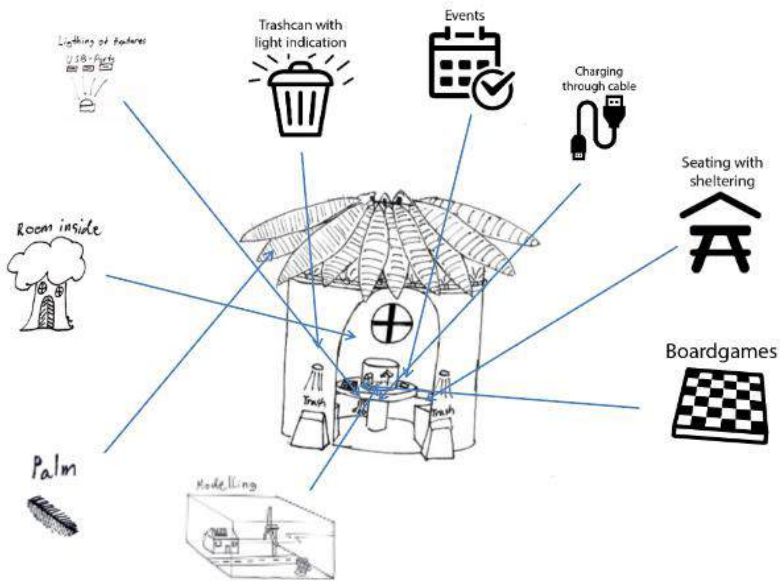

Figure 3.6: The Tree House

The Aesthetic Tree

For the Aesthetic Tree the focus was to create a tree that is as visually pleasing as possible. To accomplish this, the tree must imitate the shapes of a real tree. It should also have an LED light show running at night. The leaves should look like palm leaves with many small leaves attached to a stem. The tree should have a miniature city to show off the possibilities of organic solar cells. The tree also has wireless charging and an Instagram account. Board games provide entertainment and signs remind people to throw their trash in trashcans.

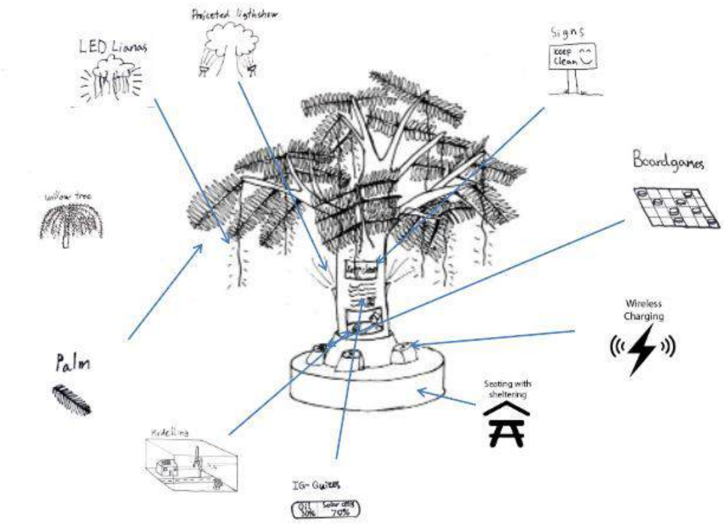

Figure 3.7: The Aesthetic Tree

The Modular Trees

The Modular tree is designed as an area with more than just one installation that inspires people to care for the environment and engineering. The Modular Tree would therefore be three to five modules placed around an area creating an organic environment with seating for multiple groups of people. Each module will have different features making each module unique. The Modular Tree has shading at the seats and displays the organic solar cells in a way that the user gets to feel and interact with the material. Furthermore, a game built on porper disposal of litter will assist in keeping the are clean. Wireless charging separates users from their phones making them more prone to start up conversations.

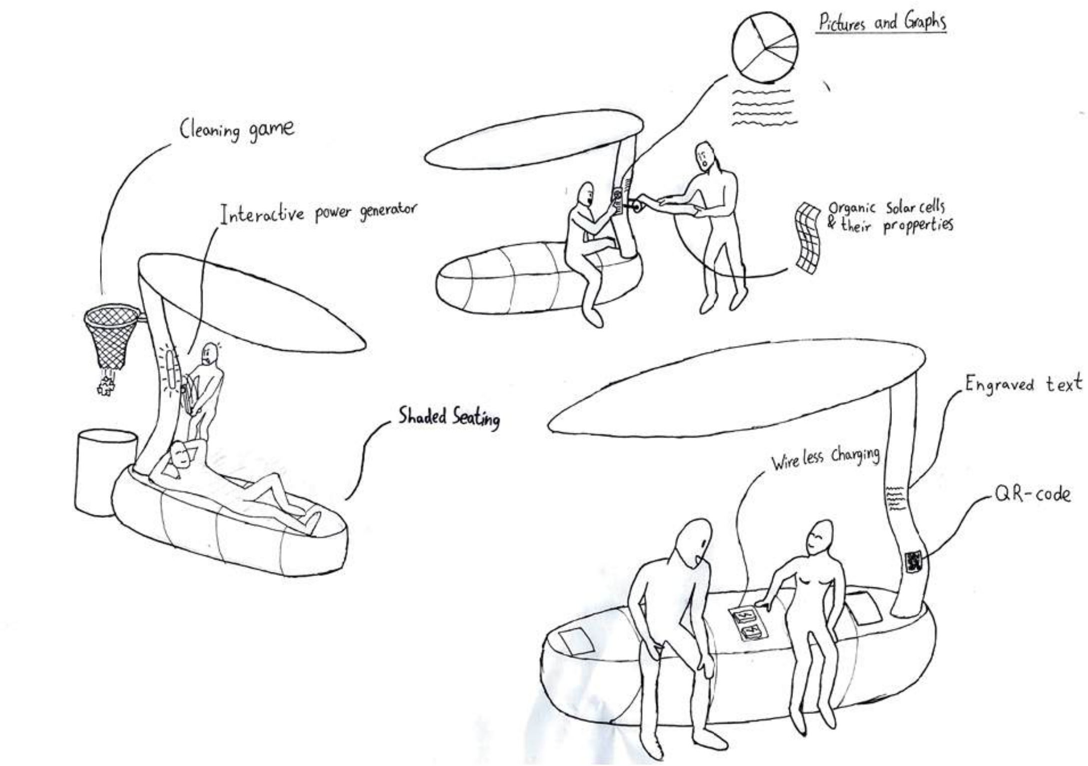

Figure 3.8: The Modular Tree

The Natural Tree

The Natural Tree was based on the idea of making a design that imitated a tree as much as possible. The Natural tree is therefore constructed as a module attached to a tree on the festival. The Natural tree will have hammocks attached between the tree and poles in the ground. Ipads and Charging boxes, where phones can be locked in for charging, would be attached to the tree. The Ipads will display live-stream of the Orange stage, as well as games and information about sustainability and organic solar cells. The tree will also have a range of party games to attract more users to the area. Lastly the tree would be equipped with a trashcan and a sign asking people to keep the area clean so others also could enjoy the area.

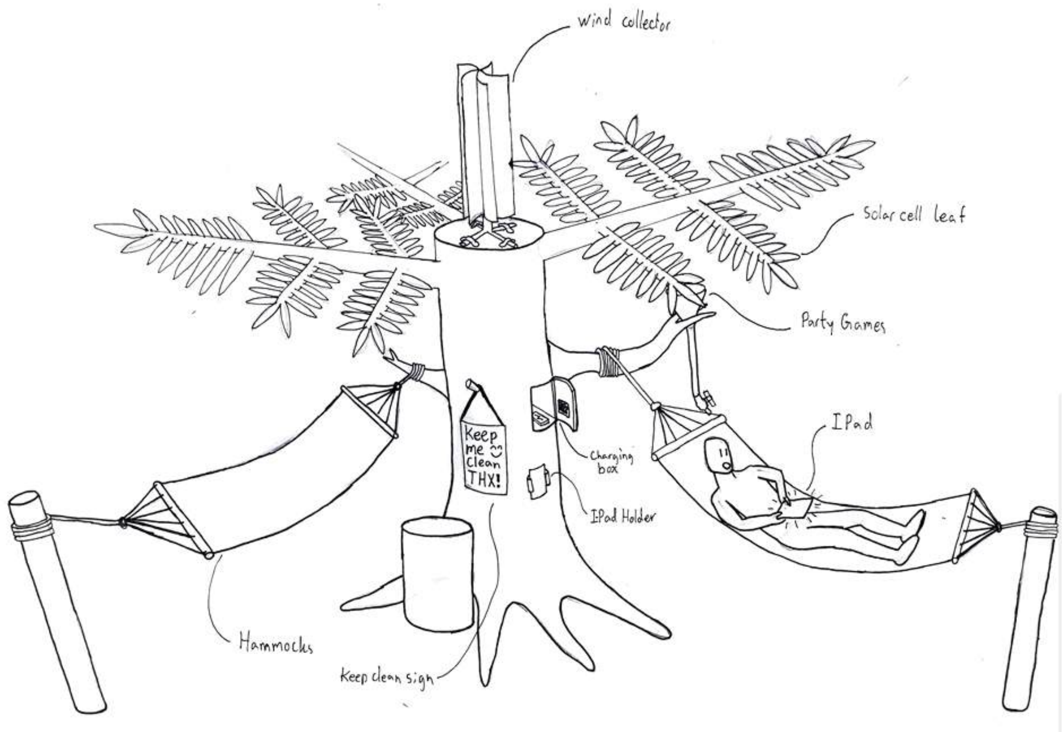

Figure 3.9: The Natural Tree

3.3 Idea Evaluation

This section will cover the process of evaluating the concept ideas which have been generated during the idea generation phase. The concept ideas will be judged based on the criteria in covered in the design brief[WS-2.17].

3.3.1 Decision Matrix

In order to evaluate the different concept ideas fairly, a decision matrix was applied, inspired by the the PUGH-matrix [13]. The traditional PUGH-matrix compares each concept to a *baseline* concept, and rates the concept as *better*, *worse* or the *same* as the chosen baseline. Since the design-team did not want to compare each concept to a baseline, a new decision-matrix method was applied. The decision-matrix has the designers rate concept ideas on a numeric scale. Two concept ideas must not have the same numeric value for a given criteria. In order to score a criteria all members of the group had to agree. Some criteria from the design brief were excluded from the PUGH matrix. For example Charging ports were excluded because all the concept ideas had the same possibility to add more or less charging ports.

Decision Matrix

	The Classic Tree	The Natural Tree	The Modular Tree	The Tree House	The Aesthetic Tree
Sociotechnical criteria					
Inspire	1	5	2	3	4
Excite	1	2	4	3	5
Educate	5	4	3	2	1
Organic Design	2	4	3	1	5
Invite conversation	3	1	5	2	4
Commercial	-	-	-	-	-
Attraction	2	4	1	3	5
Technical critiria					
Charging ports	-	-	-	-	-
Robust structure	5	3	2	4	1
Seating Space	2	1	5	4	3
Weather proof	2	1	3	5	4
Installation	5	3	4	2	1
Weight	5	4	3	1	2
Transportation	5	2	4	1	3
Generating electricity	3	1	5	4	2
Storage of electricity	-	-	-	-	-
Maintenance	5	3	4	2	1
Design	3	4	2	1	5
Sociotechnical functions	-	-	-	-	-
Materials	-	-	-	-	-
Trash	2	3	5	4	1
Score:	51	45	55	42	47

Figure 3.10: Decision matrix

From the decision matrix some important observations can be made. The first thing to notice is that the concept ideas that scored highly in the sociotechnical criteria did not necessarily score high in the technical criteria. This is because fulfilling some of the sociotechnical criteria makes it harder to perform the basic technical criteria. For example the many leaves and tree-like structure of The Aesthetic Tree might be very beautiful and eye-catching, but it also makes the tree more fragile and requires higher maintenance than other concept ideas. The opposite is true for The Classic Tree which performs poorly in the sociotechnical criteria, because of its lack of extra functions, but performs very well in the technical criteria because of its simplicity.

From the decision matrix we can conclude that The Modular Tree scored the highest. This is because it did fairly well in both the sociotechnical and technical criteria. Second came The Classic Tree which had a very high score in the technical criteria, but less so in the sociotechnical criteria. The Natural tree and the Aesthetic Tree both did really well in the sociotechnical criteria and The Tree House performed poorly over all.

However, it should be noted that there are more technical criteria than sociotechnical criteria, which makes this decision matrix biased towards designs that perform well in the technical criteria.

3.3.2 Weighed Objectives Method

To further investigate the functionality and value of the different concept ideas a Weighed Objective Method(WOM)[13] was initialized and completed[WS-3.13]. The WOM was based off of the titles and appertaining descriptions of the design brief, since these aspects of the Solar Tree were found vital or favourable. It was found that the most valuable properties were inspire and excite, since these aspects would make the user remember and maybe even seek sustainable products and engineering in the future.

WOM - Weighed Objective Method

Objectives (colonne er dem der får point)	Inspire	Excite	Educate	Organic Design	Invite conversation	Attraction	Robust structure	Seating Space	Weather proof	Installation	Transportation	Generating electricity	Maintenance	Trash
Inspire	-	0	0	0	0	0	0	0	0	0	0	0	0	0
Excite	1	-	0	0	0	0	0	0	0	0	0	0	0	0
Educate	1	1	-	0	1	1	1	0	0	1	0	0	0	0
Organic Design	1	1	1	-	1	1	1	1	0	1	1	0	0	0
Invite conversation	1	1	0	0	-	1	1	1	0	1	1	0	0	0
Attraction	1	1	0	0	0	-	1	0	0	0	0	0	0	0
Robust structure	1	1	0	0	0	0	-	0	0	0	0	0	0	0
Seating Space	1	1	0	0	0	1	1	-	0	1	0	0	0	0
Weather proof	1	1	1	1	1	1	1	1	-	1	1	0	0	0
Installation	1	1	0	0	0	1	1	1	0	-	0	0	0	0
Transportation	1	1	0	0	1	1	1	1	0	1	-	0	0	0
Generating electricity	1	1	1	1	1	1	1	1	1	1	1	-	0	0
Maintenance	1	1	1	1	1	1	1	1	1	1	1	1	-	0
Trash	1	1	1	1	1	1	1	1	1	1	1	1	1	-
Score:	14	13	6	5	8	11	12	9	4	10	7	3	2	1
Priority number	1	2	9	10	7	4	3	6	11	5	8	12	13	14
Weight	0,13	0,12	0,06	0,05	0,08	0,10	0,11	0,09	0,04	0,10	0,07	0,03	0,02	0,01

Figure 3.11: WOM Weighed objectives-matrix

In general the sociotechnical objectives were highly rated since these were the objectives that ensured that the Solar Tree would leave an impact on the user. The technical criteria in general, were necessary for the Solar Tree to be viable, but the scaling of how well the Solar Tree performed within the different objectives was not as important, with the exception of the robustness and easy installation. The evaluation of the different objectives enabled an evaluation of the concept ideas, that were used to scale the scores of the concept ideas. This resulted in a different order of which concept idea seemed favourable.

WOM - Weighed Objective Method

Conceptidea:	The Classic Tree	The Natural Tree	The Modular Tee	The Tree House	The Aesthetic Tree
Sociotechnical criteria					
Inspire	0,13	0,67	0,27	0,40	0,53
Excite	0,12	0,25	0,50	0,37	0,62
Educate	0,29	0,23	0,17	0,11	0,06
Organic Design	0,10	0,19	0,14	0,05	0,24
Invite conversation	0,23	0,08	0,38	0,15	0,30
Attraction	0,21	0,42	0,10	0,31	0,52
Technical critiria					
Robust structure	0,57	0,34	0,23	0,46	0,11
Seating Space	0,17	0,05	0,43	0,34	0,26
Weather proof	0,08	0,04	0,11	0,19	0,15
Installation	0,48	0,26	0,38	0,19	0,10
Transportation	0,33	0,13	0,27	0,07	0,20
Generating electricity	0,09	0,03	0,14	0,11	0,06
Maintenance	0,10	0,06	0,08	0,04	0,02
Trash	0,02	0,03	0,05	0,04	0,01
Score:	2,905	2,829	3,248	2,838	3,181

Figure 3.12: Rating of the concept-ideas

The highest rated concept was the modular Tree while the second best had now become the Aesthetic tree. The WOM shows a different rating in which concept is best, but overall has some concept ideas that show more promise than others. Furthermore, the concepts might have some applications that make them seem more favourable in some aspects. Therefore, it is important to reevaluate the composition of the concepts after the evaluation. The WOM has also been framed from the evaluation subject to the view of the design team. Therefore, it is also important that the concepts get feedback from the actual user to confirm that the assumptions made by the designers to evaluate performance of feature ideas are feasible.

3.3.3 Workshop feedback

In order to get some feedback on the concept ideas a workshop with some potential festival goers was conducted. Each of the users were given a piece of paper to take notes on. They were then showed each of the concept ideas and given a short explanation. They were then asked to make notes of three things they liked and three things they didn't like about the concept ideas. Useful lessons learned are as follows[WS-3.14]:

The Classic Tree: The users really liked the interactive movement of the leaves to optimize efficiency. Otherwise they thought that the concept idea is a bit boring. This is to be expected since the concept idea is meant to be as realistic to produce as possible. Users also thought that it lacked entertainment, which they could use while their phones were charging.

The Tree House: The users liked that the house provides shelter and they also thought it might be cozy to sit inside. However, they were afraid that it could become dirty inside during the festival. They also would not go into the house if another group was already there. They did not really understand the function of the model city.

The Aesthetic Tree: The users were very pleased with the look of the Aesthetic tree. Especially at night when there are lights on it. However, they thought it might be boring because there was no way to interact with the tree. They also wanted the seating to be more organic. The users also expressed concerns about the Instagram quizzes, as they thought people might not use them, unless the Solar Tree Instagram account was really well fleshed out.

The Modular Tree: The users liked that the trees could seat different numbers of people and that the Solar Tree felt more like a space as compared to just a single tree. They recommended that the leaf should be rotatable in order to provide better shade from the sun. They also thought the modules should have wheels and that the users should be able to move them around freely. At last they also mentioned that there could be a lot of smaller stools around the modules so that larger groups could sit together.

The Natural Tree: The users thought that it might be very beautiful to have the Solar Tree built around a real tree and they recommend that it should be combined with *The Modular Tree*. They were concerned about the hammocks because they thought they were too secluding and did not have enough seating capacity.

3.3.4 Survey feedback

To verify the value of the different concept-ideas a quantitative survey was produced[WS-3.15]. The survey was conducted on three classes of high school students, who were asked to rate the concept ideas from one to five, one being the best idea and five the worst. Furthermore, they were questioned about what made the best and worst concept ideas stand out from the rest.

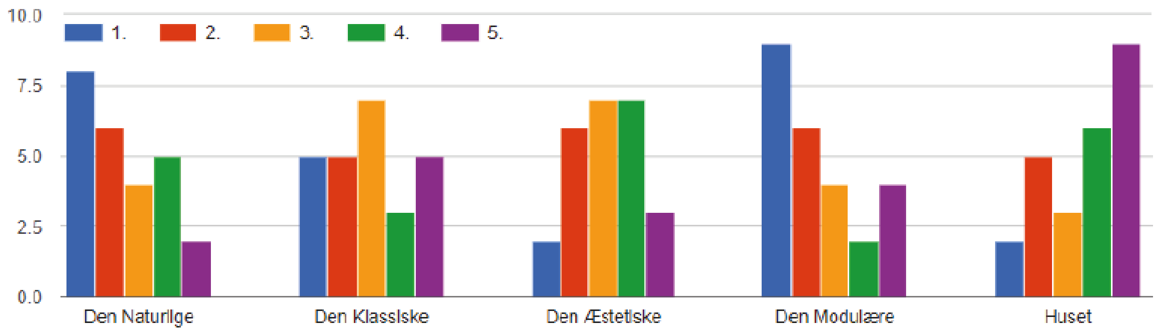

Figure 3.13: Graph over the rating of the Idea concepts

The Modular tree: was ranked as being the best concept idea. Users found that it was very good that there was seating for multiple groups and that it was an area you could hang out at. Users found it attractive that it wouldn't feel crowded if multiple groups of people were there. The mobility of the Modular tree was also seen as a positive aspect.

The Aesthetic tree: was ranked in the middle. Users who voted it highly did so because they found it aesthetically pleasing. "I think that what you are used to see is boring. I like new concepts and designs." [WS-3.15] The aesthetic tree got low scores because users valued the seating areas very highly and didn't find the seating to be sufficient.

The Natural tree: was rated as being the second best concept. This was mostly because of it being aesthetically pleasing. The hammocks had dividing opinions. Many users found it very attractive, however due to a lack of seating capacity it was also seen as a downside to the concept. They also found it to be less complicated. Users emphasize that when they are on a festival they want to be relaxed and live simplistically. Users also liked that they either could relax in a hammock or use the party games to entertain themselves. They liked that whatever mood they were in, there was place to facilitate this.

The Classic tree: was also ranked in the middle. Some people found it attractive because of its simplicity and attractive features. However other thought of it as being too simple and boring. The palm tree design was also attractive to the majority.

The Tree House: was generally ranked the lowest even though some users rated it very highly. The positive aspects users found in The Tree House were that it was weatherproof, cozy and a nice place to take a timeout from the festival atmosphere. However, the users were not very pleased with the design, worrying that it would be too closed off and would not enable more than one group to use it at a time.

The survey showed different desires, some more relevant than others. Applications that were important to the users were words like **simple, smart & functional**. The users wanted to have a **hang-out area** where they could talk to friends in smaller groups without getting too close to other groups of people. They valued a good **design** that looked **unique** and **organic**, which would make them more likely to check out the installation. They found that it was also very desirable that the installation was **weatherproof** so that it would be comfortable to stay at the installation in any type of weather. Users also found that facilities to different kinds of moods were wanted, but it was important that the user didn't feel that they were isolating themselves when interacting with the tree. Lastly it was important that the place was kept clean so that it always appeared as a welcoming and comfortable atmosphere.

3.4 Final Concept Decision

Through a meeting with supervisors the results from the second phase *Idea Generation & Evaluation* were presented. The five concepts were presented together with the idea evaluation and our own thoughts on the project. Furthermore, through a workshop with supervisors, different applications and elements for the Solar Tree were discussed. This was done through an interactive drawing where it was possible to drag and drop different functions from the morphology diagram 3.4. The result is shown in figure 3.14.

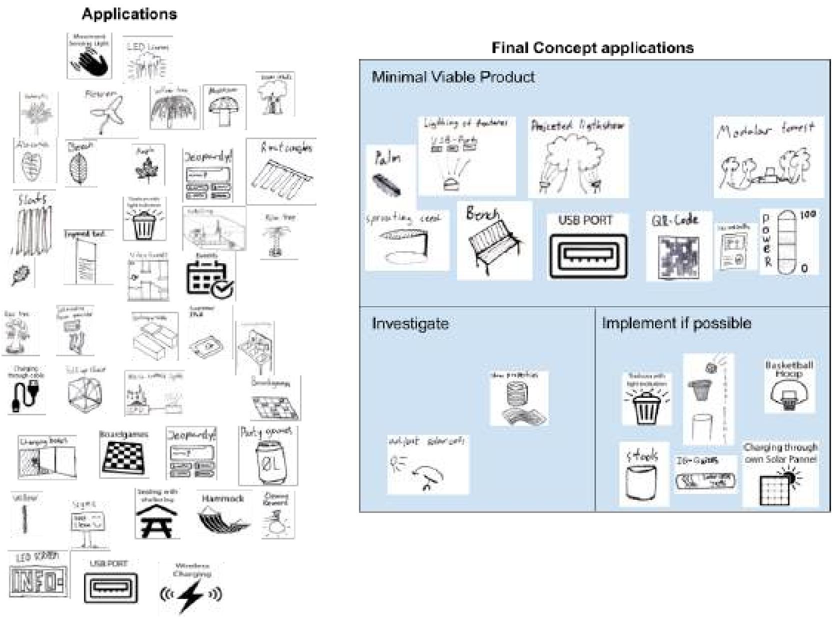

Figure 3.14: Final Concept Decision

As seen on figure 3.14 the final concept is relative simple. The different elements were further divided into categories; *minimal viable product*, *investigate* and *implement if possible*. The minimal viable product contains functions that were found essential for the product such as a *bench* for seating, *USB ports* for charging and a *palmtree* design for the leaves. Other functions such as adjustment of the solar cell angles and trashcans with light indications were added to *investigate* and *implement if possible* due to its potential. These elements will be further investigated in the next phase.

4 | Conceptualization

This chapter covers the third design phase of the project called Conceptualization. The aim of this phase is to mold the final concept idea into a tangible and realisable final concept.

4.1 Biologically inspired design

Prior to the bachelor thesis, the course 41084 Biologically Inspired Design was completed with the goal of implementing results and methods in the Bachelor project. The course set the base of imitating plants which is rooted in the idea of the Solar Tree.
The course presented different cases with the relevant case being autonomous sun tracking. In the course different methods in biomimicry[WS-3.4] were used and the final outcome of the project was a functioning autonomous sun tracker imitating the evening primrose as well as the sunflower. The sun tracker would consist of two hydraulic systems that moved the solar panel on one axis, by obtaining heat from the sun. It accomplished movement through heating of two heat collectors, that were strategically placed so that they would be in the shade at different times of the day. The heat collectors would therefore only obtain the amount of heat needed to track the position of the sun.
The course induced an organic approach to the bachelor project, but the actual idea of implementing autonomous sun tracking was tossed due to the Solar Tree becoming a hazard, as well as the function not adding much value to the users. The heat collectors would become a danger to users, due to the extreme temperature and fragile glass. The automation of the sun tracking would also take away an opportunity of adding interactive features to the Solar Tree. The autonomous tracking of the sun was the seed that grew into the idea of having interactive sun tracking.

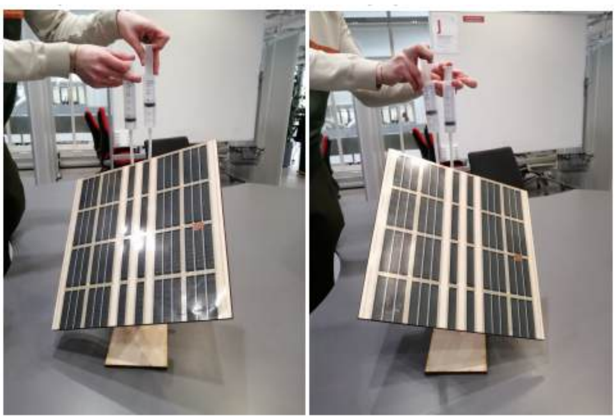

Figure 4.1: Autonomous sun tracking concept idea

4.2 Base

The base refers to the bottom structure of the Solar Tree, which functions as a stable foundation for the stem and crown. The base also functions as a bench which holds the USB charging ports as well as the LED projectors.

4.2.1 Design thoughts

Shape

The base will consist of three oval benches extruding from a central cylindrical hub. This makes the base resemble the leaves of a sprouting seed and provides a stable foundation for the stem and crown. To determine the shape of the three benches, a morphology of basic structures[28] was made.

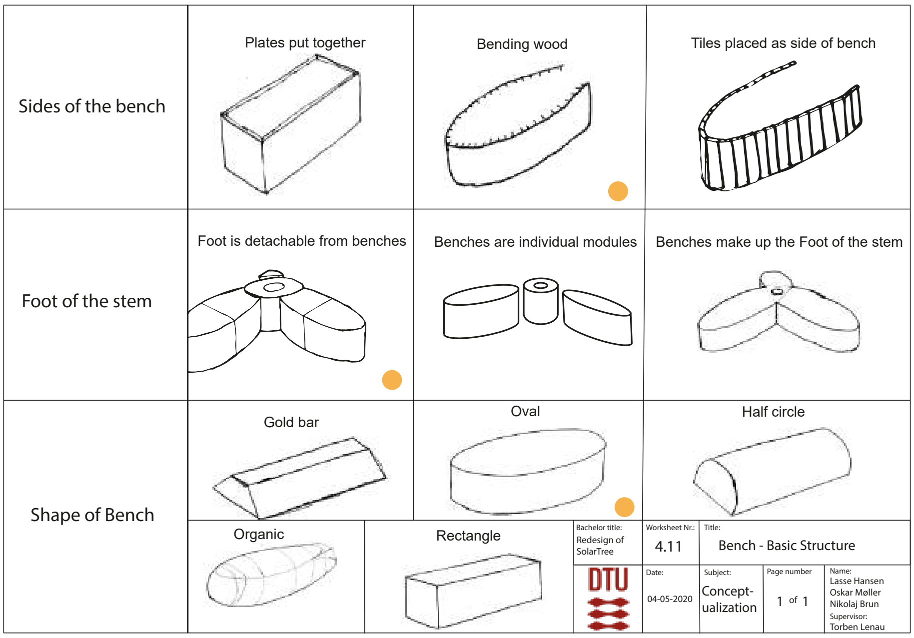

Figure 4.2: Bench - Morphology of basic structure

In line with the Solar Trees biologically inspired design, it was desired that the benches have an organic form. They should also be stable and relativity easy to build. Therefore, it was decided that the benches should have an oval shape.

Installation

For easy transport and installation the base needs to come apart in modules. To this end, it was decided that the benches should be able to detach from the central hub. It was The benches are connected to the base through a system of locking poles in the hub, that are only accessible by the crew to avoid theft and vandalism.

Wiring

The benches will contain USB-charging ports(5v) and LED lights(12v), which will be controlled from inside the hub. Therefore, it is necessary to have a two electrical connections between the benches and the hub. One 5v connection and one 12v connection. To make it possible to detach the benches from the hub, these connections will be made with cable connectors as shown in the final form. To make sure that the electronic components are safe from the elements, each component will be enclosed in separate boxes and will be stored in the central hub. It is therefore important that the hub is rain proof.

4.2.2 Final form

The base consists of four modules; one hub and three benches. When joined together the hub and benches form a tripod resembling the leaves of a sprouting seed. The benches contain USB charging ports on the side walls and LED lights covered by Plexiglas on top. The wiring for the ports and lights is connected with the hub through cable joints. Inside the hub is a framework to hold up the stem as well as locking mechanisms for the benches and all electronic components. The hub will be rain proof and therefore has to be built with very high tolerance.

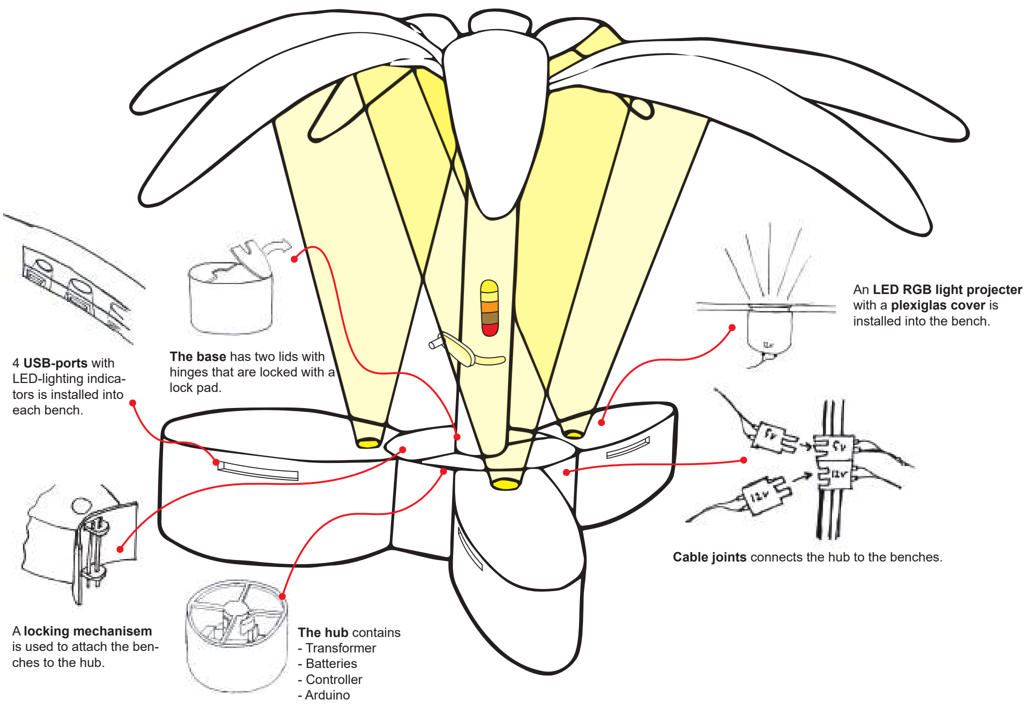

Figure 4.3: Base Final Form

4.3 Stem

The stem of the Solar Tree imply the interactive sun tracking mechanism as well as the shaping of the stem. In the process of actualizing the stem, different processes and design thoughts were considered.

4.3.1 Design thoughts

For the stem to become a successful result the stem needs to enable interactive rotation of the crown. It also needs to enable **cabling** between solar panels and the controller. The stem needs to be **robust** enough to withstand its environment and comply with the criteria of **installing** and **transportation**.
The stem of the Solar Tree is the component with the greatest mechanical challenge. The stem is required to have an interface, that enables the user to position the leafs in accordance to the sun. The basic structure of this function was brainstormed upon and research on alternative solutions was collected. It resulted in a morphology diagram showcasing alternative solutions on important parts of the mechanism [WS-4.2].

Sun Tracking mechanism

Decisions made on the mechanism's user interface, the rotational transfer and bearings ensured a fully functional mechanism. From the Morphology diagram three ideas were constructed in which each were tested for actualization by building mock-ups of each of the components see figure 4.4.

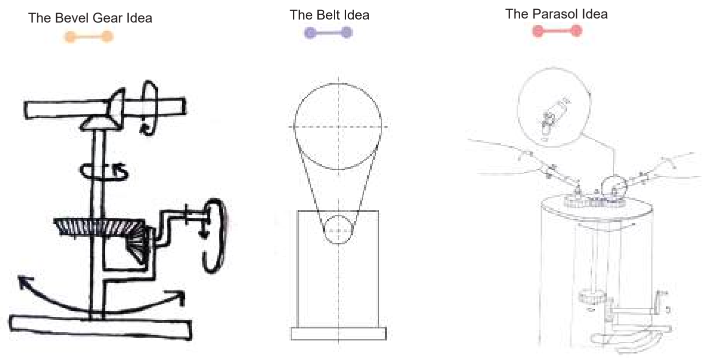

Figure 4.4: Morphology of rotation transfer

The Bevel Gear Idea - transfers the rotational force from the handle into angling the solar cells by changing the rotational axis 90 degrees twice. The bevel gear has common components that with the right tolerances can function as intended. The bevel gears enables a gearing of the handle to make it easier for users to interact with the Solar Tree. A mock-up made of Lego was constructed to prove that it is possible [WS-4.6]. The bevel gears would require multiple gears and bearings and a high tolerance where bending parts could make a vital error. The many gears might also create friction making the rotation of the solar panels inconveniently harder to interact with.

The Belt Idea - would transfer the rotation of the handle to the rotation of the solar panels through the use of two gears and a belt. The belt idea requires fewer components and can tolerate more inaccuracies than the bevel gear. The Belt Idea was actualized through building a functional prototype from 3D-printed components[WS-4.7].

The Parasol Idea - transfers the rotation of the handle to the individual solar panels through gears like the bevel gears. The parasol idea uses gears to transfer the rotation out to each individual solar panel, but replaces bevel gears with universal joints. The parasol idea was proved realizable by making a mock up out of Lego[WS-4.6]. A downside to the parasol idea is that each solar panel would need an individual gear and universal joint, making it expensive. Furthermore, the idea would work with two leaves but adding more leaves would require further thoughts on making all the leaves tilt a unified direction. Lastly, the parasol idea would require many bearings and a smooth rotation would require high accuracy manufacturing.

The chosen function for the Solar Tree is **the belt idea**. It was chosen because it was superior on production costs and maintenance. The Belt Idea has a lower lifetime on the belt than the other options, but the lifetime is still admissible for the Solar Tree because of its limited amount of wear over time[WS-4.4].

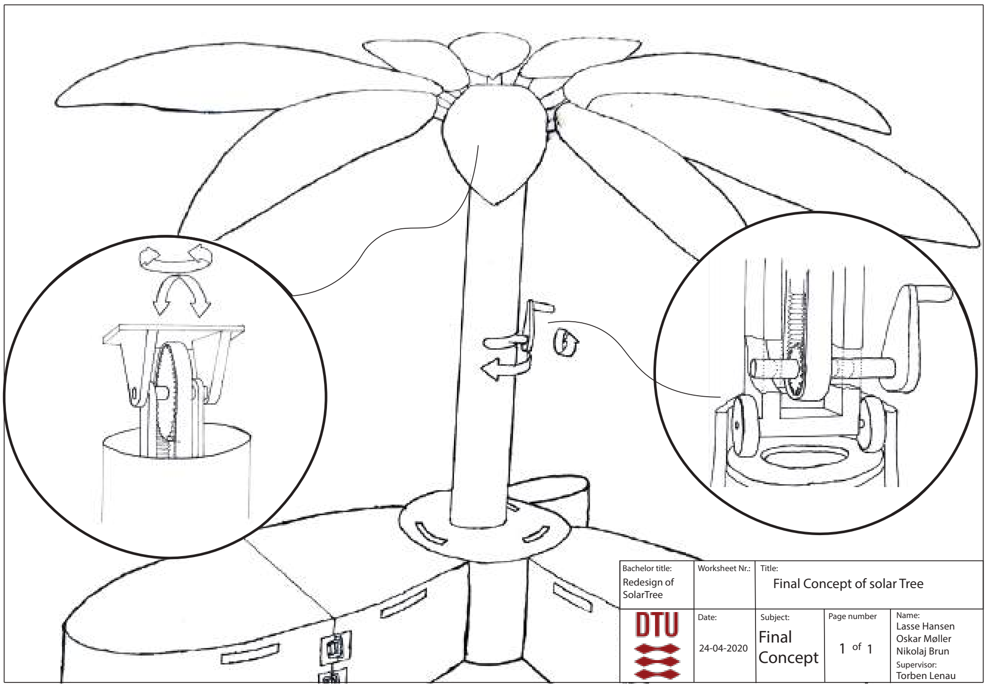

Figure 4.5: The chosen structure

Bearings

After choosing the basic structure a variation of Quantified structures were initialized to experiment with how the construction would be most favourable[WS-4.5]. Out of the five option the fifth option was chosen giving the mechanism two sets of full bearings(one set being four bearings surrounding the mechanical structure) to make the construction more resilient and less prone to break. Fewer barrings would be too big of a risk of vital components breaking. The four bearing set-up was chosen because it is much cheaper then a full size bearing. In the bottom of the base a cup-like foot is placed, where the rotating structure can rotate without causing too much friction see figure 4.6. The bottom of the rotating inner pole is made with a point for easy rotation.Above the handle another bearing-set is placed to keep the structure in place. The closer to the crown the bearing-set is placed, the more stability the bearing will give.

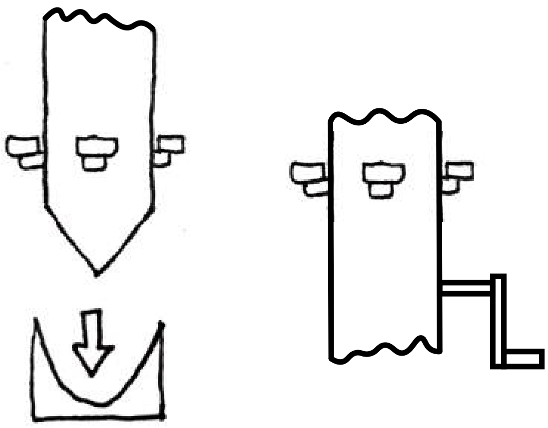

Figure 4.6: Bearings

Banned Area

The reason the bearings not being at the top is due to the top gear using up the available space. Placing the bearing-set above the middle, while having a bottom bearing-set should be sufficient to withstand strong winds and miss use of the handle. The positioning of the bearings is decided using the methods of *banned areas* [28], which are areas not to be obstructed by other structural elements. The banned area is shown below in figur 4.7.

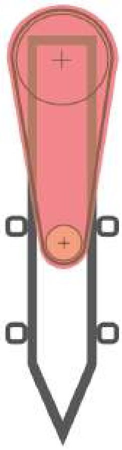

Figure 4.7: Banned Area

The Chassis of the Stem

The chassis of the stem has the criteria of being aesthetically pleasing and strong enough to provide cover for- and stabilize the mechanism. This means that it should be strong enough to withstand the force of a strong wind as well as miss-use from users. To make the stem aesthetically pleasing it was decided that the stem should resemble the trunk of a real tree. Therefore, plywood was chosen as material.

Interface

The users will need an interface to enable positioning of the solar panels correctly. For this they would need an interactive intuitive interface and some feedback that rewards the user. The Interface was decided upon in the Morphology diagram [WS-4.1]. For interface it was decided that one point of interaction would create the most intuitive and simple structure[WS-4.2]. Having more than one interaction point would also complicate the structure and construction of the sun tracking. It was therefore decided that one handle would be the interaction point for both tilting and rotating the Solar Tree. Lastly, the feedback from interacting with the sun tracking was decided to be shown through a level meter [WS-4.1](Structure 2 was the chosen combination of principles). All the variations were reasonable options, but the level barometer was chosen because of its aesthetically pleasing look.

4.3.2 Final form

The stem consists of one pole made from plywood and an interactive mechanical feature, that enables users to optimise the effectiveness of the solar panels. With a handle and a level-barometer showing the efficiency of the positioning the solar panels, users are able to rotate and tilt the crown of the Solar Tree. The rotation of the handle will be transferred to the crown through two gears and a belt[WS-4.4]. The construction will be secured by bearings in the top and bottom by having a rack.

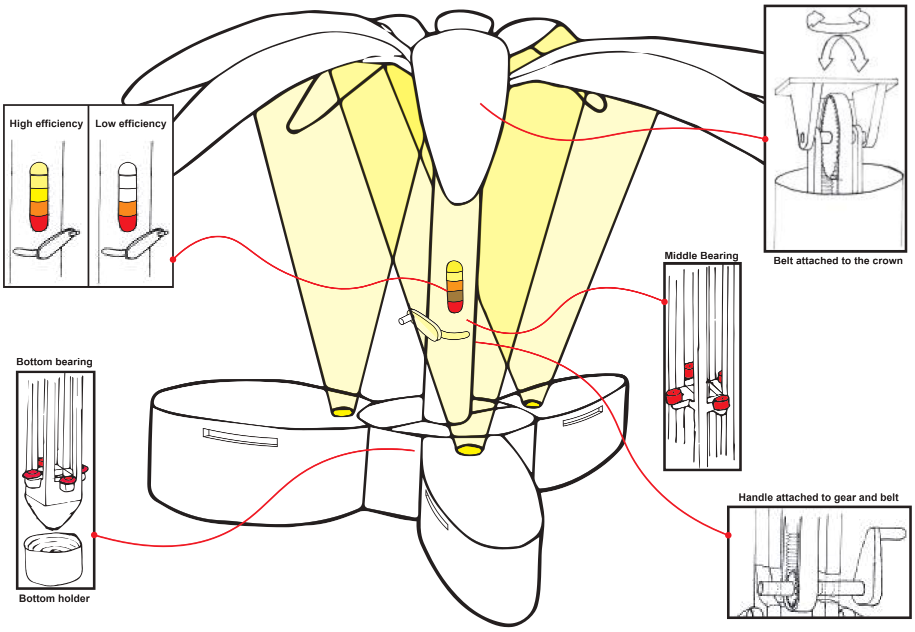

Figure 4.8: Total form of the stem

4.4 Crown

The crown refers to the top of the Solar Tree which holds the leaves. The crown also attaches to the mechanism in the stem to allow it to tilt and rotate.

4.4.1 Design thoughts

Installation

For easy transportation and installation each of the leaves will be detachable from the crown. The crown will therefore have eight tubes where the leaves can connect. The power output wires from the leaves will run through this tube into the stem and cable connectors allow detachment[WS-4.20]. The leaves will be held in place with screws.

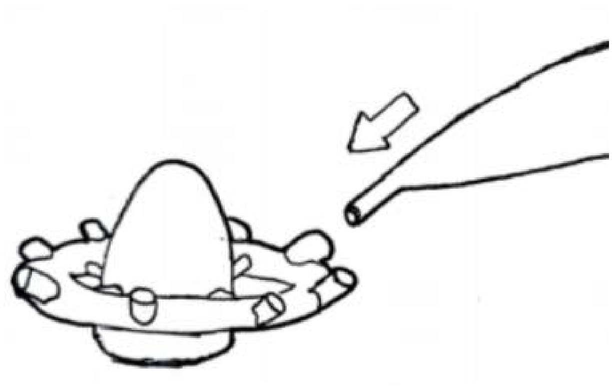

Figure 4.9: Leaf/Crown connection

The rod

At festivals vandalism often occurs, whether it is intentional or not. There is a worry that a festival guest might try to climb the tree and hang from its leaves. If this happens the stem might break or fall over. It is important that the leaves break before this happens. To this end the leaf rods should be made from a material that is strong enough to handle strong winds, but weak enough to break in case of vandalism. For the leaf prototype two PVC electrical installation tubes with a receptive diameters of $16mm$ and $22mm$ were used. The Ø$22mm$ tube had a length of $1\,meter$ and the Ø$16mm$ tube had a length of $2\,meters$. The Ø$22mm$ tube was fitted around the Ø$16mm$ to provide extra strength at the base of the leaf. The leaf successfully hung outside a window for seven days as a prove of concept.

Figure 4.10: Leaf prototype strength test

The shape of the leaves

In line with the Solar Trees organic design its solar cells should resemble palm leaves as much as possible. This will be achieved by cutting the sheets of OPVs into the desired shape. The best way of cutting the OPVs is with a laser cutter, which will melt the plastic in the edges thus preventing delamination.

The organic solar cell circuit

For optimal performance the leaves needs to output a current at a voltage of $12v$. This is because the solar cell controller has a $12v$ input and would otherwise need a transformer to bring the voltage to the required $12v$, losing energy in the process. Each of the individual cells in the organic solar cell outputs between 0.15 and $0.3\,volts$. It is therefore required to create a serial connection of approximately 53 cells to create a voltage of $12v$.

$$\frac{Required\,Voltage}{Average\,Voltage\,Of\,Cell} = Number\,Of\,Required\,Cells \rightarrow \frac{12v}{\frac{0.15v+0.3v}{2}} = 53.333\,Required\,Cells$$

On the leaf there is room for two $0.3m$ x $2m$ of organic solar cells sheets. After the ends are cut to resemble leaves $0.3m$ x $1.4m$ of usable sheet is left. On 1.4 meters of sheet 4 rows of 54 serial connected cells are available creating current with a voltage of $12v$. These 4 rows are connected in parallel to increase the current, without increasing the voltage as shown in the figure below.

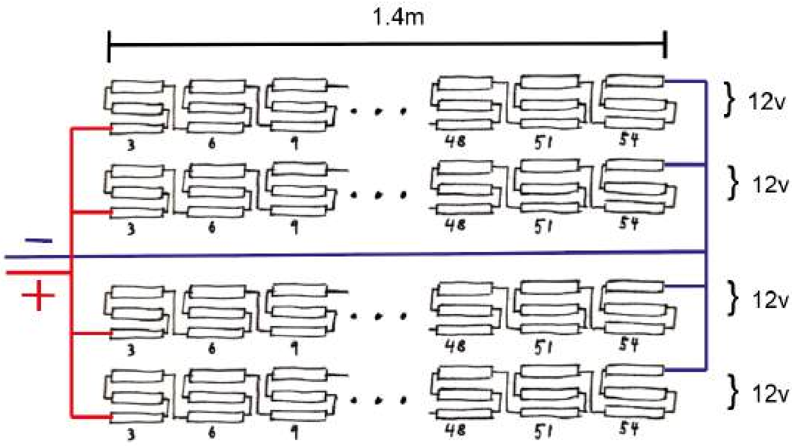

Figure 4.11: circuit of one 1.4m sheet of organic solar cells

To connect wires to the leaves sandpaper will be used to remove the top layer of plastic, the wires will then be attached using conductive tape.

4.4.2 Final form

The leaves

To create the leaves in the shape of a palm leaf two $2m$ x $0.3m$ organic solar cell sheets were used and cut to resemble a palm leaf. The sheets were connected to a central tube made from PVC plastic with strips and held up by sticks also connected with strips. Wires will run trough the PVC plastic and connect the rows of solar cells to create a $12v$ circuit like the one showed in figure 4.11. The wires will be connected to the organic solar cell using conductive tape.

Figure 4.12: Leaf prototype

The crown

The crown will be a steel structure and hold the leaves of the Solar Tree. It will be attached to the mechanism through bearings and a gear. Screws will hold the leaves in place, in the tubes of the crown. The rods of the leaves will be made with two tubes of PVC plastic and are designed to break if too much force is placed upon them.

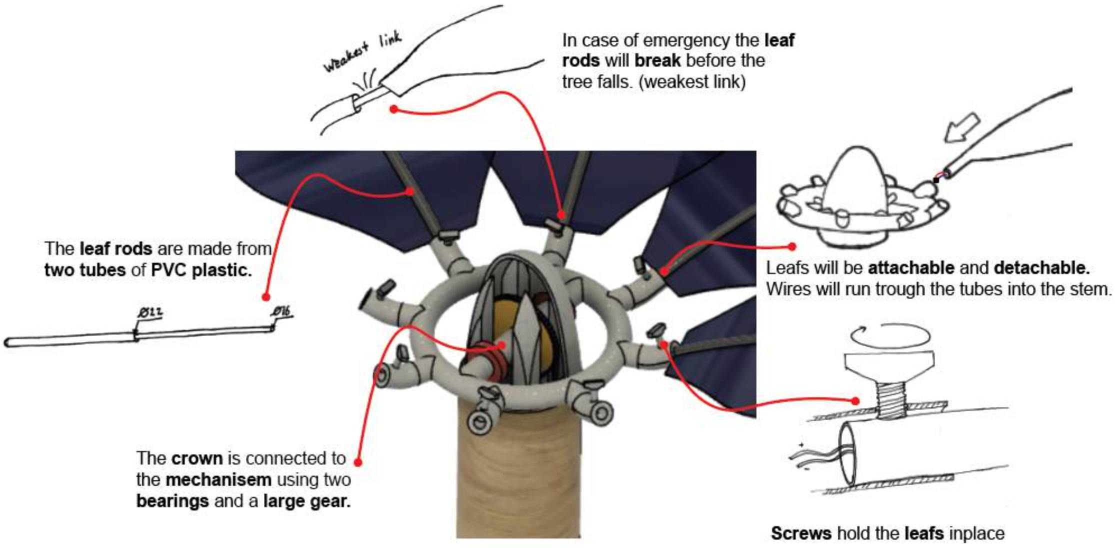

Figure 4.13: Final form Crown

4.5 Stools

The Solar Tree is equipped with mobile stools, that can be moved around to make enough seating available to any group. It is important for the Stools to be movable, robust and secure against larceny.

4.5.1 Design thoughts

Chassis

The chassis needs to be in line with the aesthetic and organic design of the Solar Tree. To this end the stools have been made cylindrical and minimalist as to not grab to much attention. Furthermore, it needs to be robust and mobile. Different designs were discussed and a concept was chosen[WS-4.13]. A Circular design would make the stool robust and mobile as well as maintaining the organic design of the Solar Tree. The stool will have a top and a bottom plate, where screws will hold the structure together and an inner structure helps make it more robust, see figure 4.14.

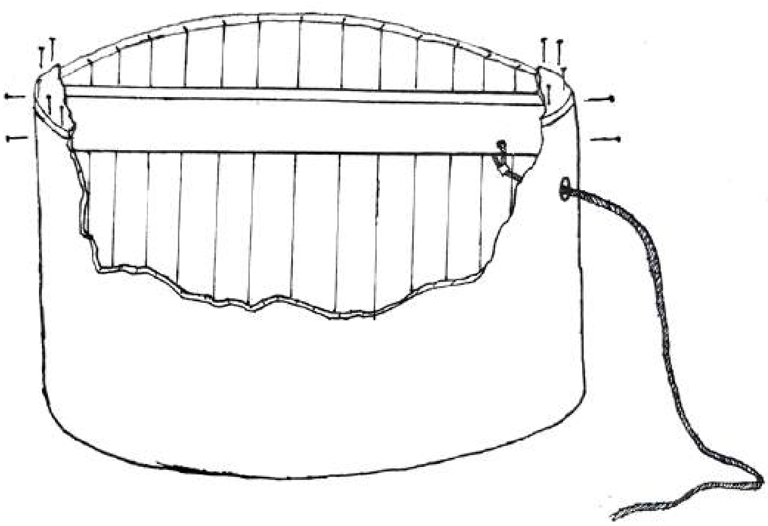

Figure 4.14: Construction of the Stool.

Security

On festivals camping chairs are often used since festivals offer a scarce amount of seating. Festival goers, therefore, bring cheap camping chairs to the festival in order of having a place to relax away from concerts. Unfortunately these chairs often break, which results in a lack of chairs on the festival. Therefore, it is very important to secure the stools from theft.
One way of doing this is to make them **immobile**. This would also render it impossible to move the stool around at the Solar Tree resulting in loosing one of the desired features.
Another way of keeping the stools from being stolen could be to **store the stools**, when greeters are not around. This would prevent them from getting stolen, but would also require storage facilities and would result in greeters having less time to do their priority work.
A final option is to **secure the stools** with steel wire attached to the Solar Tree. This would not require anything from the greeters, other than to move the stools back to the original position every now an then. The wire will be attached to the Solar Tree with a padlock, making it possible to remove the stools if needed.

4.5.2 Final form

The Stool is constructed to be robust an mobile within the parameters of the Solar Tree. It is achieved through a circular design that is supported by an inner wooden structure. The stools will also be attached to the Solar Tree with a steel wire, making sure that the stools are unable to leave the area. In addition the greeters will be able to add or remove stools based on the number of people using the tree.

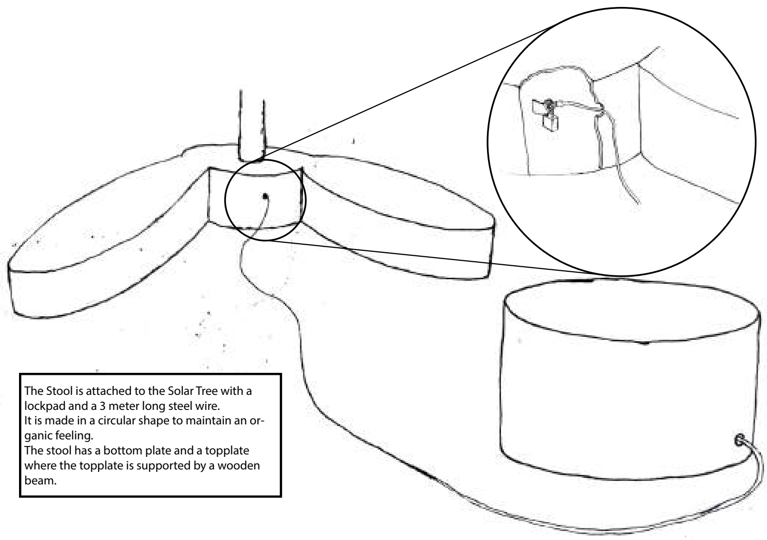

Figure 4.15: Final Form of the Stool

4.6 Entertainment & Interaction

To build a social area around Science Pavilion the Solar Tree has supplied interactive options of entertainment. This section covers stool games, cleaning games and OPV samples.

4.6.1 Design thoughts

Stool Games

The Solar Tree is striving to become a social place of exploring. Because of this it need to have features that entertains the users and makes them want to return to the tree. It was decided that the stool should be equipped with individual games, that users easily could learn to play with strangers and friends. It would be beneficial to have a variation of games, so that users can choose from their preference of what to play. Furthermore, it is important that the games can be played without the use of props, since the risk of loosing vital pieces is too high.[WS-4.16]

Cleaning Games

The Solar Tree will attract festival goers to the area in front of the Science Pavilion and make a cozy area, where people will come and enjoy themselves. This combined with the general festival attitude will result in a large amount of littering[WS-2.7]. If the area gets overflown with trash it will scare off users. Because of this it is important that the Solar Tree encourages users to properly dispose of their own litter.
Alternative ideas for how to nudge users into throwing out their trash has been set up in a morphology diagram[WS-4.1]. When deciding which game to go with. Three game options were the most promising. The chosen game needs to be interesting, easy to understand and require low maintenance.

A Happy Message on a sign could be constructed in order to encourage users into disposing their trash. This could be made with facts about the importance of properly disposing ones trash and how it helps others. A collection of posters should be made and regularly switched out to keep it engaging.

A Basket Hoop game would encourage people to throw out their litter properly by setting up a basket hoop above the trashcan. This would be attractive to competitive people and would make a fun game for users to interact with while disposing their trash. A problem with the hoop might be that people will miss the target and be too lazy to pick up their trash and try again. The net might also become very dirty.

A Voting game fixed onto a sign would encourage users to chose between two trashcans instead of choosing between throwing their trash on the ground or in the trashcan. It would require that the posters get replaced frequently to keep it exciting for returning users.

Interactive OPV

In the problem definition phase the importance of users interacting directly with OPVs was discovered. The greeters should therefore present samples of OPVs when greeting users. Different ideas for these OPV samples were presented[WS-4.14]. In line with the biologically inspired design of the Solar Tree, the design team has made leaf cutouts from the OPVs, see figure 4.16.

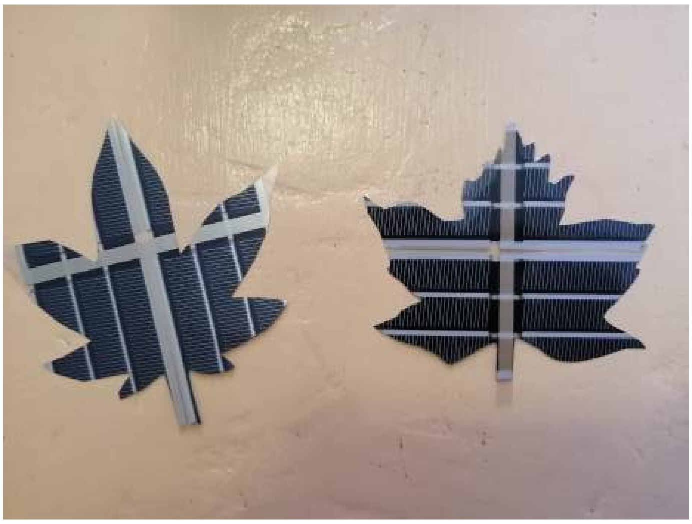

Figure 4.16: OPV leaf samples

4.6.2 Final form

The Solar Tree will have games engraved into the seat of the mobile stools supplying users with fun games like, Guess the animal, Ultimate Ninja and 20 questions to the Professor. The Games will be engraved with laser cutting [WS-4.16].
The Solar Tree is also equipped with a sign and two Dropbuckets[14], creating a Voting game. The voting game consists of a wooden sign and different posters that gets stamped to the sign. The posters regularly change to keep relevant and interesting. the Dropbuckets will have transparent plastic bags making it possible for people to see the score of the present vote[WS-4.15]. OPV sampels will to cut in the shape of leaves and presented by the greeters during conversation.

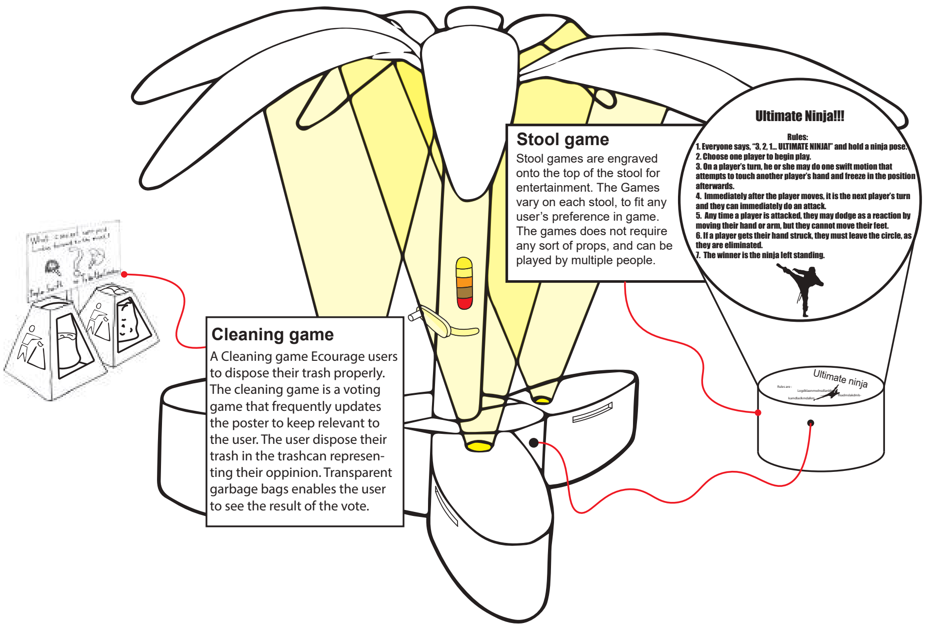

Figure 4.17: Final Form of Stool- and Cleaning Games.

4.7 Electronics

The main function of the Solar Tree is to charge mobile phones with energy created from organic solar cells. In order for this to occur the Solar Tree requires a system to transform, store and distribute the electrical energy as well as collect and store data. This section will provide an overview of that system.

4.7.1 Circuit

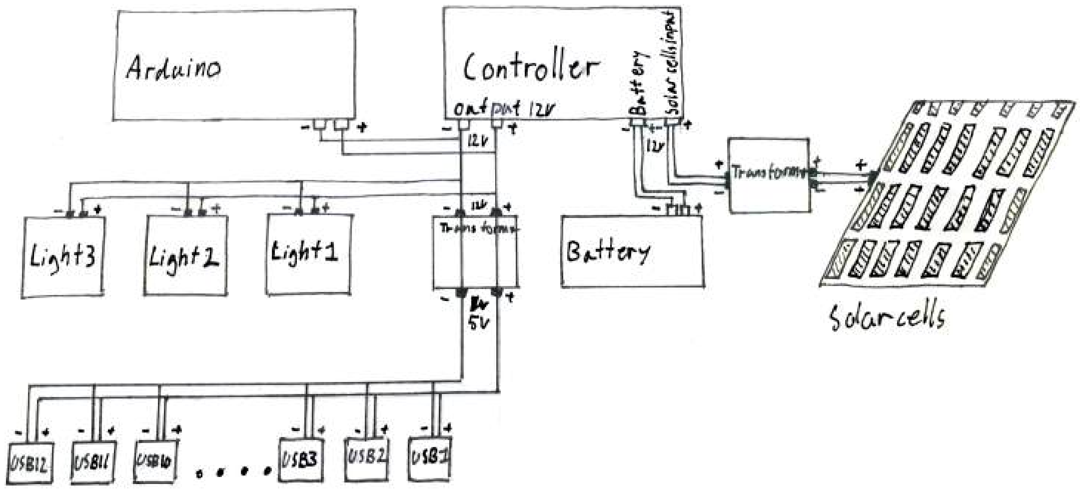

Figure 4.18: Diagram of the complete circuit of the Solar Tree

At the heart of the Solar Tree lies the solar cell controller. This is an electrical component which controls and optimizes the flow of power between the solar cells, the battery and all electrical components of the tree. The controller has a 12 v input and output.

The solar cells will be wired in a system of serial and parallel connections in order for them to reach a voltage of 12 v. However, experience from the previous developers, indicates that the OPVs might output quite a varied voltage. Therefore it might be necessary to place a transformer between the solar cells and the solar cell controller to reach the necessary 12 v voltage.

The controller will output a 12 v current which will power the arduino computer, as well as the tree LED lights. The 12 v output will also power a 12 v to 5 v transformer which will power each of the USB charge ports.

4.7.2 Cabling

To transport the energy generated in the leaves, a system of cabling is needed. Each of the leaves will be connected in parallel connections into a single wire, which will run down trough the stem into the controller in the hub. From the controller the cables will run to every component in need of power at the hub. Since the Solar Tree will be modular cable connectors are required to allow disassembly. The cables will run to these cable connectors(see figure 4.19 between the hub and the benches. The cable connectors will also be used to connect the wires in the leaves to the wires in the crown as shown in [WS-4.20].

Figure 4.19: 2pin cable connectors that will connect different modules of the Solar Tree

4.7.3 Internet Of Things

Internet of Things (IoT) is an interrelated system of computing and mechanical devices, that has the ability to transfer data across a network. By applying IoT to the concept it makes it possible to keep an overview of the use and the power output of the Solar Tree.

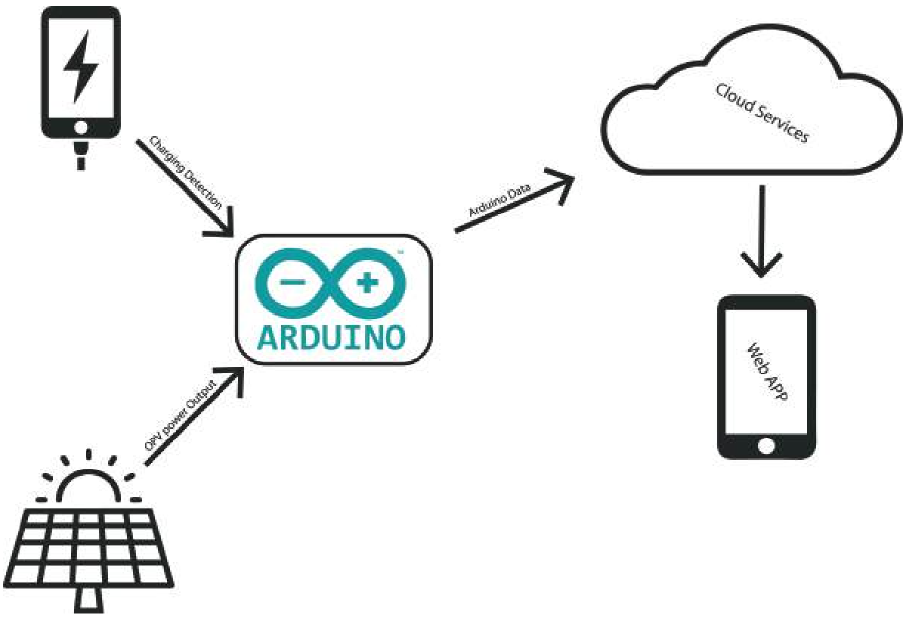

Figure 4.20: IoT infrastructurem [WS-4.17]

The infrastructure of the IoT system consists of an Arduino micro-controller connected to multiple current sensors that detects if a phone is connected to the charging hub, as well as the power output from the OPV. The data from the Arduino is sent to a web app through a MQTT server, that is easily accessible through a smart phone. Through the web app it is possible to see the current output from the OPV as well as the number of available charging ports. In case the users is not near the Solar Tree, it is possible for the user to see if there are any available charging ports. Furthermore, the web app also contains information about OPVs and renewable energy. The web app can be accessed through a QR-code engraved in the stem. The QR-code and examples of the web app can be seen in the following figure 4.21.

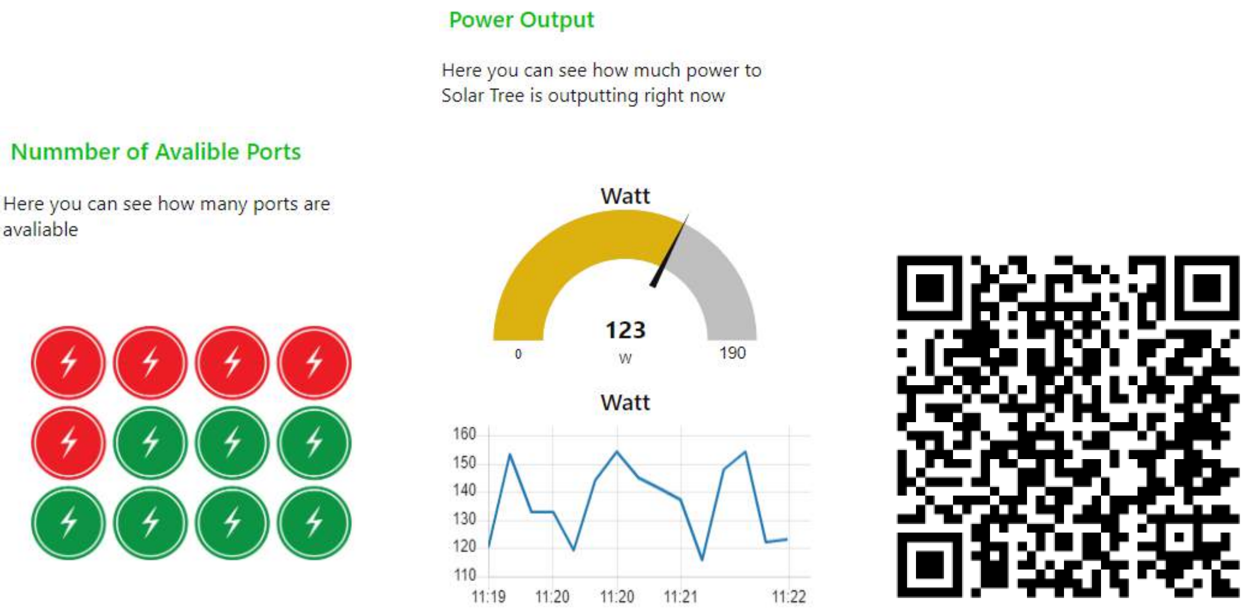

Figure 4.21: The web app example

The implementation of IoT also gives the opportunity to save the data for later use. This is a great way of collecting quantitative user data, which will be essential for further development of the Solar Tree. The data can also be a proof of the interest in OPVs and renewable energy, which is valuable information for DTU energy and the developers, Anders and Michael.

4.7.4 Arduino

The micro-controller used for the IoT setup is an Arduino Mega 25560 with a builtin ESP8266 wifi module[4], that has the ability to connect to a WiFi connection. The micro-controller is connected to multiple sensors, as well as an LED Screen, as seen in figure 4.22. To connect the Arduino to the internet it is required to have a WiFi hotspot near the Solar Tree. If there are not any hotspots avalible a phone with a hotspot can be used.

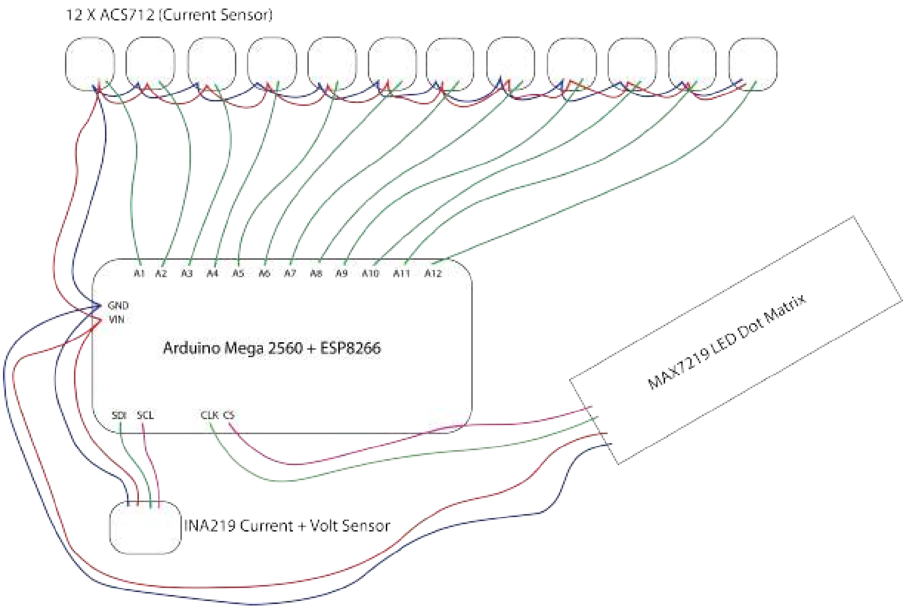

Figure 4.22: Arduino Schematic [WS-4.18]

An ACS712 current sensor [1] was used, because it only requires a single analog input, thus allowing 12 sensors to fit on a single Arduino Mega controller. The sensor transforms the amount of current into voltage by using a hall effect sensor. This voltage can be interpreted by the micro-controllers analog input. It will be used to detect if a phone is receiving current through the charging cable. The sensor is connected between the power source and the phone as shown in figure 4.23.

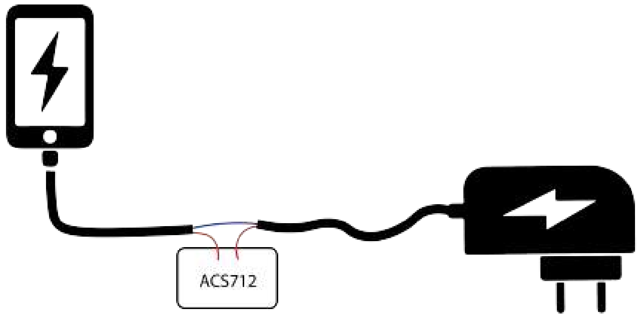

Figure 4.23: ACS712 Connected [WS-4.18]

Since it requires a relative precise measurement of the Solar Panel the INA219 sensor [2] is used. The sensor can be used to measure both the current and voltage up to $26\,VDC$ with a 1% precision, which makes it ideal to measure the solar panels. The sensor is connected to the micro controller via the digital input SDA and SCL.

To get an instant visual feedback of the output from the solar panel an LED screen is used to indicate the power output. A MAX7219 Dot Matrix LED [21] display-module is connected to the micro-controller that shows the output from the solar panel measured from the INA219 sensor.

4.7.5 IoT/Arduino Functional Prototyping

To test if the IoT/Arduino setup was realistic a functional prototype was made with a single current sensor connected between a phone and a powerbank, as seen in the figure 4.24. The Arduino was connected to the IoT infrastructure and the data was successfully displayed on the web app. The functional prototype can be easily up-scaled with multiple sensors, thus fitting our needs for the project.

Figure 4.24: Arduino Prototype

4.8 Materials

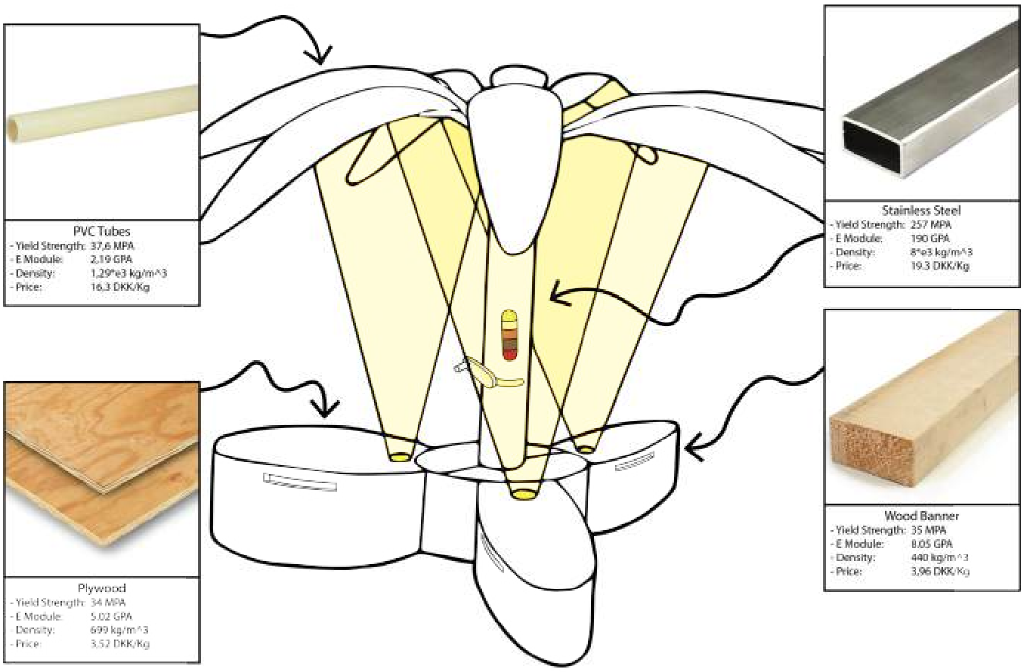

Figure 4.25: Materials [WS-4.28]

The benches, base and stools are primarily made out of plywood and wooden banners. Wood working is affordable, sturdy and contributes to the environmental friendly image of the Solar Tree. The round shapes can be done by using the kerf bending method, described in section . The sides are made out of $9\,mm$ plywood and the top are made out of $18\,mm$ plywood because the top of the benches and stools, are naturally exposed to more stress.

The stem of the Solar Tree supports the rotating mechanism and is made from plywood. The mechanism supports the weight of the crown, and should therefore be sturdy and stiff. Steel is chosen because it is mechanical properties, affordable and is easy to process with the right tools and experience.

The supporting branches of the solar leaves, needs to have the right amount of flex as further described in the section regarding the crown 4.4. PVC plastic has a relative low E-module on $2.19GPA$ and is therefore a great solution. It also comes in a variety of lengths and thickness, which is suited for the needs of this project.

4.9 Prototype construction

This chapter will covers the construction methods that the design team will use in building the first full size prototype.

4.9.1 Musicon

The original plan was to build the Solar Tree at a workshop at DTU. However because of the the COVID-19 outbreak (see section[6]), DTU has denied access to all workshops until the end of the semester. Alternative options for building the Solar Tree have therefore been sought out. Musicon[22] is a new part of Roskilde city, that seeks to support innovation and sustainability. The design team and Musicon have made arrangements to build the first prototype in their workshop. Arrangements have also been made to test the prototype in the Musicon city space during the summer vacation, which will allow the design team to acquire user-feedback.

4.9.2 Wood working

The main body of the Solar Tree is made from sheets of 18mm and 9mm thick plywood. Rectangular sheets of plywood are bought from construction depots with the standard measurements of 2440x1220 mm. The Plywood will be cut into the required parts using a jigsaw. Some of the parts will need to be bent. Eg. the stem, base and oval sides of the benches. This bending of the plywood will be achieved by a wood working method called *kerf bending*. *Kerf bending* is a method of cutting groves into the plywood allowing the wood to bend as shown below[19]. The spacing and width of the groves will be calculated using the website *blocklayer.com* which has a kerf bending cut calculator[18].

Figure 4.26: Kerf bending plywood chair

4.9.3 Metal working

To make the moving mechanism and crown strong enough to hold the leaves and be able to rotate requires that these parts are made from steel. The design team does not have experience in forming or welding steel. We are therefore hoping that some of the personal at the Musicon workshop will have the know-how and time to help us build the steel components. If the DTU workshops open up in time it might also be possible for them to help. If not it will be necessary to hire a professional steel worker.

4.9.4 Electronics

To connect all the electronic components of the Solar Tree will require the use of cable joining and soldering. The design team has a lot of experience in this area learnt trough the course 41030 Mechatronics Engineering Design. To make sure the cables are organised inside the structure, cable clips and strips will be used to fasten the wires.

5 | Final Concept

Due to the COVID-19 pandemic the final phase of the design process has been postponed until after the end-date of the bachelor thesis. This chapter will instead present the final concept as envisioned by the design team.

5.1 Product catalogue

For pitching the Solar Tree to potential investors a compressed presentation is required. Therefore the design team has chosen to produce a product catalogue (see Product catalogue). The purpose of the product catalogue will be to display the selling points of the Solar Tree in a manageable and stylish manner. The product catalogue should also ensure potential investors that the design team has thought out every aspect of the product. The product catalogue will contain a mission statement, user scenarios, a component overview as well as an overview of the team.

5.2 The Script

The Solar Tree strives to satisfy a wide range of user needs depending on the situation and the user. The goal is to inspire users into acting more sustainable. The Solar Tree will achieve this through its many functions that each will have an impact on the users experience. This section will cover how the design team intends the Solar Tree to be used, also known as the script.

5.2.1 Inspiration and awareness

The Solar Tree's main function is to inspire and spread awareness of the novel technology, OPV panels, and engineering [WS-5.1].

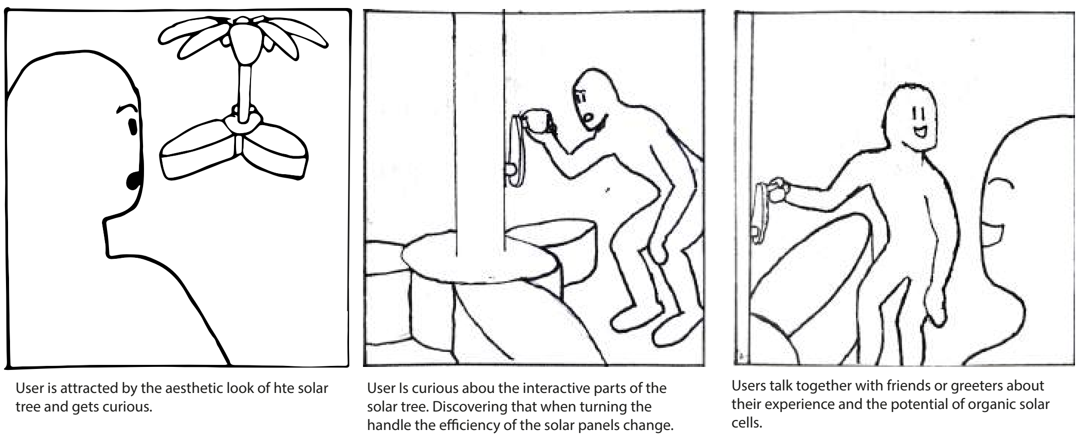

Figure 5.1: Awareness and inspiration

As seen on the figure the script of the Solar Tree is to attract users with it's novel organic design. From this, users get curious and explores the interactive features of the Solar Tree. Users also learn more about solar panels and engage conversation with friends or with the greeters. The experience leaves the user with more knowledge about sustainable energy and ways to tackle climate change.

5.2.2 Phone charging

Users on Roskilde festival are dependent of their phones and it is therefore important to be able to charge them when running low on battery. The Solar Tree will satisfy a user-need by offering free charging at the installation[WS-5.4].

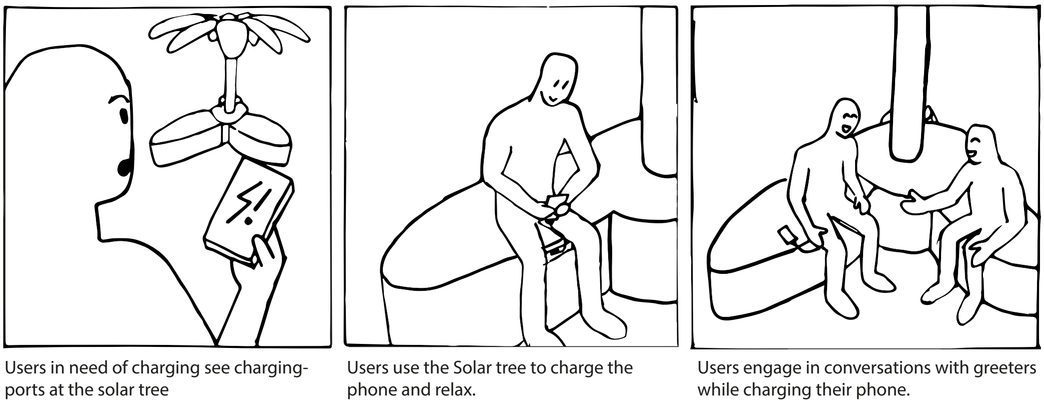

Figure 5.2: Charging phone

As seen on figure[5.2] users in need of charging will be attracted to the visible solar panel leaves and be inclined to explore what the Solar Tree might offer. The LED lights makes the user aware of the USB-ports and the user walks over to charge their phone. While charging their phones users might be more open to alternative entertainment. Therefore, the interactive features like the stool games can keep the users interested. Greeters will also find it easy to engage in conversation with users charging their phones, which will help spread awareness.

5.2.3 Installation

When assembling and disassembling the Solar Tree it was emphasised that simplicity was desired[WS-2.3].

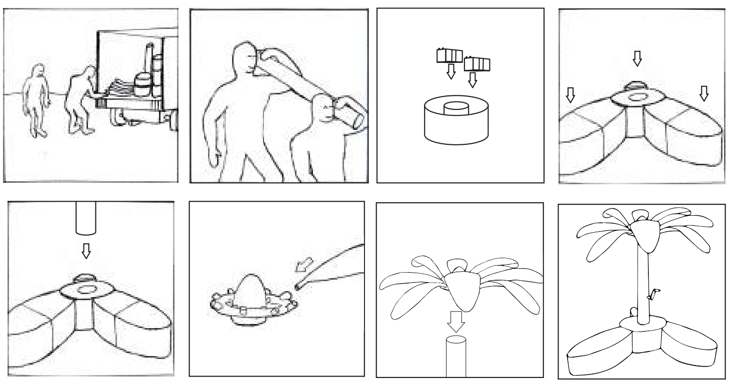

Figure 5.3: Installing the Solar Tree

When installers carry out components of the Solar Tree only two people are needed to carry even the heavy parts. Each part is easily attached with the use of simple tools[WS-5.3].

5.2.4 IoT

The users have the ability to access a web app by scanning the QR code on the stem of the tree. The web app provides information about the use and power output of the Solar Tree, as well as information about OPVs[WS-5.5].

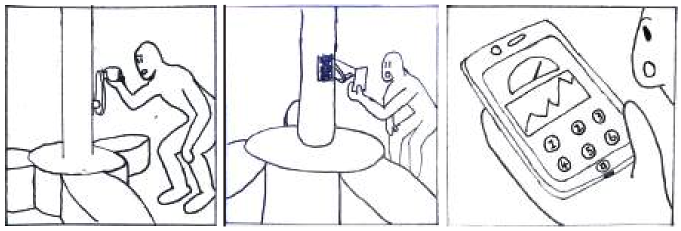

Figure 5.4: IoT

Figure [5.4] shows the user interacting with the Solar Tree. The user scans the QR code with his phone, which leads him to the web app. The user also has the ability to access the web app while away from the Solar Tree, thus knowing if charging ports are available.

5.2.5 Trash disposal

The Solar Tree is a great place to hang out and eat. However, as shown in the problem definition phase, festival guests at Roskilde Festival have a tendency to leave their trash lying around[WS-2.3]. The design team aims to combat this by nudging users to properly dispose of their trash using cleaning games[WS-5.2].

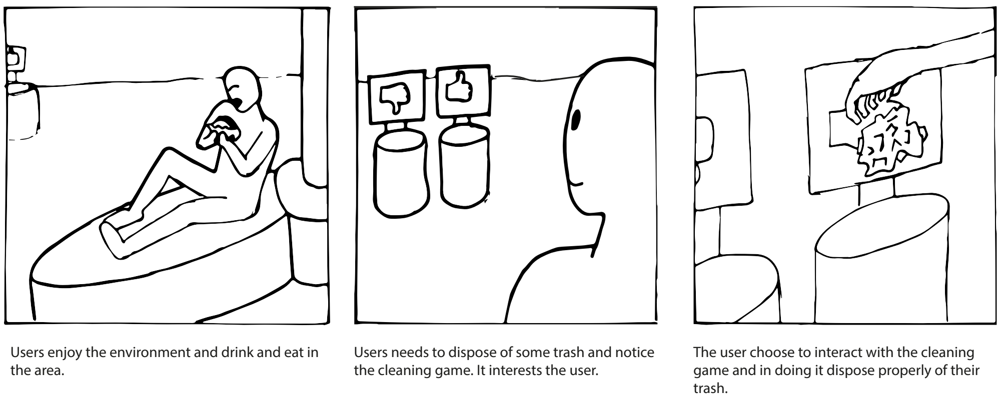

Figure 5.5: Cleaning game

5.2.6 Games

The Solar Tree strives to produce a creative social area around Science Pavilion. Games engraved in the stools provide entertainment while users charge their phones. This will also contribute to a positive social space around Science Pavilion [WS-5.6].

Figure 5.6: Stool Games

Users socializing in the area of the Solar Tree wants to be entertained. They choose to play one of the games engraved on the stools. Users have fun playing the game and attract more interested users to the area.

5.2.7 Greeters and OPV samples

To ensure that users learn about OPVs greeters are present at the Solar Tree. The greeters strive to make users think about the possibilities of the novel technology and awaken interest of solving its problems. To help greeters achieve their goal they will have leaf shaped OPV samples to show the properties of the material.

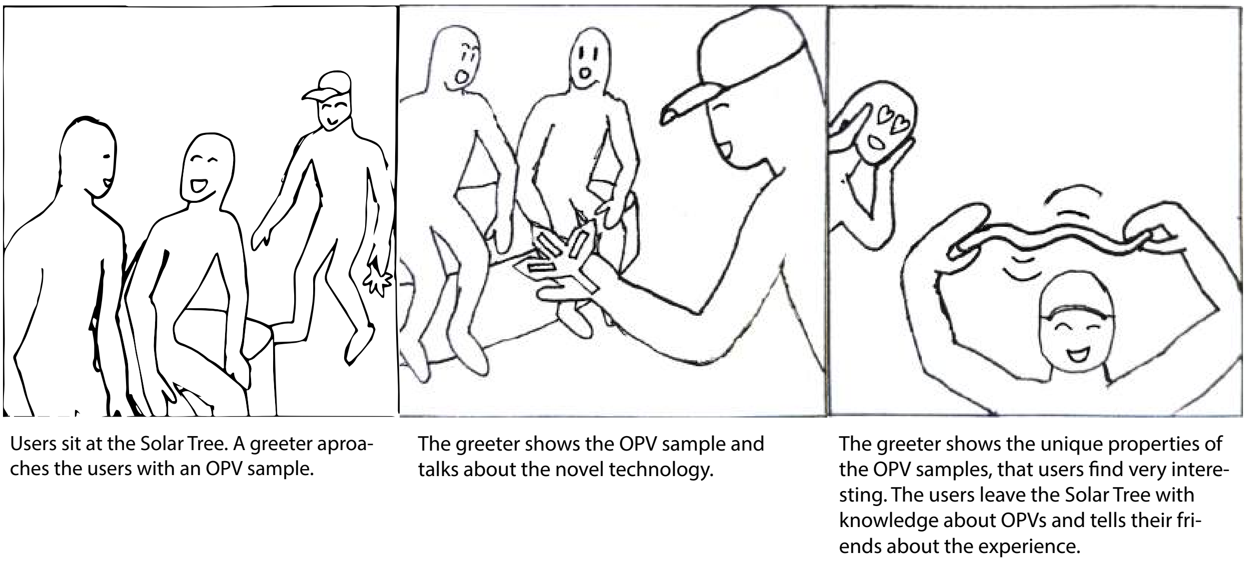

Figure 5.7: Greeters educating and inspiring users

Greeters will approach users around the Solar Tree to talk to them about the project. The greeters will talk about OPV samples while maintaining a casual attitude to make sure the users do not feel like the greeter is trying to lecture about or less something. The OPV samples helps explain the concept of OPVs leaving the users inspired and with more knowledge about organic solar cells.

5.3 Product Overview

To summarize the conceptualization and provide an overview of the final product, the following part list has been made. The table shows each part and its subparts, as well as relevant worksheets for further clarification. CAD illustration can be found in the product catalogue.

Part	WS	Subparts	Dimensions	Material(s)	Function
Hub	4.23, 5.11	Chassis	height: 600mm diameter: 800mm	Plywood	Protects electronics from outside enviroment.
		Frame		Steel	Holds the stem in place.
Leaves	4.25, 5.16	Rod	lenght: 2000mm width: 60mm	PVC tubes	Holds the OPVs and bends to imitate real leaves.
		OPV sheets		OPVs	Generates electricity.
Bench	4.23, 5.12	Chassis	length: 1800mm width: 800mm	Plywood	Provides seating and stablizes the foot.
		USB ports		Electronic	Charge outlets
		Light projectors		Electronic	Provides seating and charging USB-ports
Stem	4.4, 4.24, 5.13	Chassis	height: 2550 mm diameter: 250mm	Plywood	Projects colored lights onto the leaves.
		Rotating mechanism	height: 2850mm length: 160mm width: 160mm	Steel	Allows useres to rotate and tilt the crown.
Stools	4.16, 5.17	Chassis	height: 600 mm diameter: 800 mm	Plywood	Provides seating space
		Games		-	Provides entertainment
Electronics	4.19	Transformers	length: 82mm width: 90mm height: 36mm	Electronic	Transforms voltage of current
		Controller	height: 140mm length: 77mm width: 30mm	Electronic	Controls power flow between OPVs, battery and other components
		Battery	height: 257 width: 172 length: 220	Lead acid	Stores the electric energy generated in the leaves.
		Arduino	width: 50mm length: 105mm	Electronic	Moniters power use and communicates with web app.
Crown	4.25, 5.15, 5.16	Frame	diameter: 400mm	Steel	Holds leaves and connects to mechanism.
		Leaves	length: 2000mm width: 600mm	PVC plastic tubes & OPVs	Generates electricity
Cleaning	4.15	Sign	height: 1500 mm width: 420 mm	Plywood	Showcases the Poster
		Poster		Paper	Informs users of voting options
		Drop Bucket		Cardboard	Collects trash and shows active score
OPV Samples	4.27	OPV sheets	length: 100mm width: 100mm	OPVs	Inspires and attracts users

5.4 Scaled Model

To get an understanding of the aesthetic expression, as well as the relative size of each component, a scaled 1 : 10 model was made. The model was made using 3D printing, decorative tape, real OPV sheets, sewing strings, bearings, nuts and bolts.

Figure 5.8: Picture of the scaled 1:10 model

The model has the ability to rotate and tilt just like the Solar Tree. It can therefore be seen as a functional prototype and proof of concept for the full size mechanism. The scaled model is also a great tool when presenting the product for potential buyers or investors, because it provides the observer with a feel for the product and an opportunity to interact with its features.

5.5 Bill of materials

To provide an estimate of the material cost of building a prototype of the Solar Tree a bill of materials(BOM) has been produced. The BOM is a list of all the materials needed to build the product as well as estimated prices based on websites.

A	B	C	D	E	F
Part number	Part name	Quantity	Material cost per unit	TOTAL	Links
Arduino					
1.1	Current + Volt sensor	1	kr 22,85	kr 22,85	https://www.banggoo
1.2	Micro controller	1	kr 69,81	kr 69,81	https://www.banggoo
1.3	USB Charging Hub	1	kr 159,00	kr 159,00	https://www.24hshop.c
1.4	USB Cable	12	kr 33,06	kr 396,72	https://www.aliexpress
1.5	Wiring	1	kr 3,46	kr 3,46	https://www.alibaba.c
1.6	SD card	1	kr 48,00	kr 48,00	https://itdeals.dk/prod
1.7	SD card reader	1	kr 15,00	kr 15,00	https://www.banggoo
1.8	LED lamps	1	kr 201,30	kr 201,30	https://www.amazon.c
1.9	LED power output screen	1	kr 190,00	kr 190,00	https://www.banggoo
1.10	Current sensor	12	kr 18,80	kr 225,60	https://www.banggood.co
1.11	USB-port Led indicator	3	kr 38,66	kr 115,98	https://www.banggood.co
Structure					
2.2	Base cylinder	1	kr 103,66	kr 103,66	https://www.gqmqastro.c
2.3	Ply wood 18x1220x2440 mm	5	kr 404,96	kr 2.024,80	https://www.silvan.dk/kef
2.4	Ply wood 9x1220x2440 mm	5	kr 251,96	kr 1.259,80	https://www.silvan.dk/kef
2.5	Steel profiles 20x20x2 x 6000mm	3	kr 806,98	kr 2.420,94	https://www.staalbutikken
2.6	Steel tubes 1500mm, Ø50mm	1	kr 675,73	kr 675,73	https://www.staalbutikken
2.7	Screws 4 x 45 (100stk)	2	kr 36,33	kr 72,66	https://dk.rs-online.com/
2.8	PVC tubes 20x1.4 x 5000	5	kr 95,00	kr 475,00	https://www.lavprisvvs.dk
2.9	large bearing	2	kr 104,56	kr 209,12	https://dk.rs-online.com/
2.10	small bearing	10	kr 66,75	kr 667,50	https://dk.rs-online.com/
2.11	60 Tooth sprocket	1	kr 74,57	kr 74,57	https://www.amazon.de/
2.12	9 Tooth sprocket	1	kr 22,15	kr 22,15	https://dk.rs-online.com/
2.13	96 link chain	3	kr 10,65	kr 31,95	https://www.aliexpress.co
Solar Power					
3.1	Transformer 12v to 5v	1	kr 136,00	kr 136,00	https://www.elfadistrelec.
3.2	Battery 60ah	1	kr 749,00	kr 749,00	https://www.biltema.dk/bi
3.3	Solar Cell Controller	1	kr 108,99	kr 108,99	https://dk.grandado.com/
Wiring					
4.1	cable 1m	120	kr 3,46	kr 415,20	https://www.tme.eu/dk/en
4.2	5x 2pin Cable connectors	4	kr 96,90	kr 387,60	https://www.amazon.de/
4.3	200x nail-in cable clips	1	kr 67,00	kr 67,00	https://www.amazon.com
4.4	100x strips	1	kr 29,00	kr 29,00	https://www.av-cables.dk
Misc					
5.1	Steel wire 1m	12	kr 2,30	kr 27,60	https://www.el-grossisten
5.2	Lock	4	kr 9,50	kr 38,00	https://hverdag.dk/shop/
5.3	Hinge	4	kr 9,50	kr 38,00	https://dk.rs-online.com/
5.4	Wood protection	2	kr 249,00	kr 498,00	https://www.google.com/
				total =	kr 11.979,99

Figure 5.9: Bill of materials for construction of prototype

Early in the project budgeting was discussed with the supervisors, and a guideline budget of around 10.000 DKK was set for the project. Furthermore, DTU facilities would be able to provide materials like, plywood, metal profiles and PVC tubes to the project. With this in mind the final budget of 12.000 DKK is deemed reasonable.

6 | Effects of COVID-19

Due to recent outbreak of the COVID-19 pandemic changes has been made to the scope of the project. [27]. When Denmark went into lockdown, a revaluation of the project plan was initiated changing some key factors. Overview of changes to the timeline can be seen in the original GANTT versus a updated GANNT [WS-1.1 & WS-1.2]

Effects on designing the Solar Tree Mette Frederiksen, the Prime minister of Denmark, chose to put Denmark in lock down on the eleventh of March[11]. This resulted in the closure of all public institutions, including DTU and the public was advised to have minimum physical contact with each other[12]. In accordance to the advisory the bachelor project continued on virtual platforms like Skype, Zoom, Google Drive, Discord and Overleaf. When brainstorming a design team often draws on each other for inspiration and feedback. It is therefore a problem when the design team is unable to physically meet. Despite this obstacle brainstorming was successfully accomplished through the aforementioned cooperative programs. Some processes were distributed between individuals in the design-group and reflected upon plenary. The user oriented approach to the project called for frequent user feedback. Because of COVID-19, contact with the different user groups was foreclosed, limiting user feedback in the evaluation and testing processes. Evaluation was possible through online surveys[WS-3.15]. In addition frequent talks with family members and friends that fit the user groups were conducted. Milestone meetings with supervisors were still held as originally planned on online platforms.

Effects on prototyping
Since DTU closed down due to the pandemic, no workshop, materials or equipment have been available to build the Solar Tree. Therefore it was not possible to build the Solar Tree within the time limit of the thesis. Prototypes and a scaled model were still required as proof of concept and was made with the tools available in the design teams parents garages :). Materials were bought from home depots to build the functional prototypes and scaled models.

Effects on Further work
Roskilde Festival was forced to cancel their 2020 festival. The Solar Tree had arrangements with Science Pavilion and Powered by DTU to conduct user testing on Roskilde Festival. The agreement with Science Pavilion still stands for next year, while Powered by DTU is still interested in the project and are accepting application next year. Furthermore, an arrangement has been made with Musicon in Roskilde city involving prototyping and user testing.

7 | Reflection

This section will cover reflections on the work process and how well the final product has fulfilled the criteria defined in the design brief. Lastly reflections on if learning objectives for the project have been accomplished.

7.1 Processes, methods and workflow

By the start of the Project certain processes and tools were chosen to structure and shape the process of realizing the project.

Diverging and converging phases
The project had three diverging and converging phases, ensuring that the design team fully explores all options in a given phase before moving on. The phases were structured with milestone meetings, where conversations and feedback were exchanged between the design team and the supervisors. The phases helped provide a good overall structure of the project, while the meetings contributed to ensuring a steady flow of documentation. Due to the diverging and converging nature of the phases each phase had a natural flow of exploring, evaluating and delivering a concrete sub-product. In general, this has worked quite well.

Structural Tools
To structure the daily work of the project a range of tools were used for different objectives with varying success rates. A GANTT chart was used as the main project plan, where phases and objectives were scheduled with start dates and end dates. The GANTT was difficult to restructure, when the scope of the thesis changed, and it was important to frequently update it for it to stay useful. In general it was a good tool, to get an overview and to make sure that useful methods were not forgotten. The Daily Agenda document worked great as a micro management tool keeping the design team productive throughout the day. It was very efficient through the project but was difficult to use when physical prototyping started. In general, the daily agenda was a great tool and could also have been of use when testing and building if more strictly enforced.
Worksheets were used as documentation and worked great to make sure that all relevant thoughts and research were documented in a clear manner. In general, Worksheets were very useful and worked as a great tool. If changes should be made, some worksheets could have explained more through illustrations rather than text.

Design methods
The majority of methods like, KJ-method, brainwalk and basic structures, worked great to their purpose and supplied the design team with valuable information to work with. Making a workshop where users interact with the scaled model and the prototype could furthermore supply the product with interesting feedback.

7.2 Success of the Solar Tree

The first phase resulted in a Design Brief stating the success criteria of the Solar Tree in relation to relevant actors. The final product will therefore be compared with the criteria to reflect on the success of the final result.

Sociotechnical success
In its minimal form the Solar Tree should fulfill a certain range of criteria[WS-2.17]. The Solar Tree should inspire, educate and attract users, while having an organic design. By imitating a palm tree and by having organic solar panel leaves, the Solar Tree attracts users from a distance.
The Solar Tree is deemed successful in its sociotechnical aspects because of its aesthetically pleasing design and interactive features, which invites conversation and inspires users. The Solar Tree also educates users by its website, interactive positioning of its solar panels and attracts users with seating, games and charging.

Technical success
The Solar Tree fulfills its minimal criteria through a range of features. The modular design and installation requiring few tools marks that the Solar tree fulfills criteria on installation, transportation and maintenance. The hub of the Solar Tree secures the electronics from the weather and theft, whilst still being accessible to the greeters with a padlock. Trash disposal is made accessible and a cleaning game engourages people to keep the area clean. Stools makes space for more than 8 people enabling the Solar Tree to become a social place for users to learn, explore and relax. The Solar Tree is deemed successful by fulfilling its technical requirements and supplying optimizing features such as extra seating and USB-ports, as well as easy accessibility to electronic components and an organic design.

7.2.1 Learning goals

The design team stated a range of goals for the project relating to what skills the design team should acquire by completing the project. These learning goals are described in the [REF]. The design team has successfully structured a larger project and gathered empirical evidence and analysed it to define parameters and criteria for the product. The product was created using a range of design methods including bio-inspired design methods, like bio-brainstorming and biomimicry. This resulted in an installation that imitates the silhouette of a palm tree and solar tracking of the evening primrose. The project resulted in an improved installation that will replace the old Solar Tree when built.

8 | Further Work

It is the intention of the design team to create a small start-up in cooperation with the Solar Tree developers Anders Michael. To achieve this the following plan is put forth. First, a full scale prototype will be built and tested in Musicon in Roskilde city. Musicon will provide a workshop, where the design team can construct the prototype and will also host a number of events during the summer. At these events the Solar Tree can be tested in an environment similar to Roskilde Festival. The knowledge collected over the summer can be used to iterate and improve upon the Solar Trees design. A market analysis also needs to be made. The first prototype is funded by Science Pavilion, as the organisation acknowledges the Solar Tree's ability to attract, educate and inspire guests. The design team believes that other similar organisations will see the same value in the Solar Tree. As of writing this thesis, DTU energy and Muscion has also expressed interest in the product. However more market research is required to help attract funding to the project. To this end the design team will explore opportunities with other Festivals and organisations. For example *Tinderbox, Musik i lejet, Copenhell* and many more. To further accelerate the project, the start-up team will also be applying for the next *mikrolegat* from *Fonden for entrepenørskab* in September[15]. This funding will help in the production of multiple Solar Trees, which will hopefully be sold to the aforementioned festivals and organisations.

9 | Conclusion

This conclusion will present the goal, product and lessons learned from each phase of the project. The goal of the *Discover & Define* phase was for the design team to get an understanding of the Solar Tree and find out what problems it should solve. To this end, empirical data about the Solar Tree was collected, interpreted and analysed. The product of the phase is a problem definition in the form of a design brief. To fully understand the user base the design team conducted interviews with festival guests of all ages. Interviews were also made with the developers of the Solar Tree, Anders and Michael, from DTU energy, which determined the minimal requirements for the product. It was found that festival guests are generally open to new experiences and very willing to support the green energy movement. However, they did not want to feel *like they were back in school* or *trapped listening to greeters for long sessions of time.* It was therefore determined that the Solar Tree should passively engage and inspire guests, thus easing the engagement process for the greeters. To do this it was found that interactivity was important because it engages users much better. The importance of a good first impression was also established, resulting in an emphasis on a beautiful and eye-catching product.

To determine which functions the Solar Tree should have in order to fulfill the goals of the problem definition, the *Idea Generation Evaluation* phase was commenced. To generate the ideas, different brainstorm tools like bio brainstorm, brain walk and negative brainstorm were used. The ideas were combined into five different concept ideas which all focused on specific user needs. The five concepts were then evaluated using design theory methods and user feedback. Once the feedback was analysed, the design team held a meeting with the supervisors in order to determine the functions and shape of the final concept. It was decided that the form of the Solar Tree should take inspiration from a sprouting seed and palm leaves. It was also found that the Solar Tree should include lighting, interactive user-controlled sun tracking, a modular seating area, games and a QR code leading to a website displaying information about the project.

In order to realize the final concept idea, the *Conceptualization* phase was initiated. In this phase the concept idea was divided into its parts and a plan was made for how each of the parts should perform their individual functions. Different solutions to functions were analysed and tested. To prove that the components would be able to perform their functions prototypes, scaled models, calculations, diagrams and research was made. The final concept consists optimal solutions for the individual components.

To present the final design and showcase its features a product catalogue was made. The product catalogue contains the mission statement, a value proposition, user scenarios and CAD models of the final design. The user scenarios showcase how the Solar Tree will address the sociotechnical functions of the project. The CAD models will showcase the Solar Tree as an artefact and the address its technical functions. The design team intends to build the first full-scale prototype as envisioned in the product catalogue in the workshops at Musicon.

Based on the work of this thesis the design team concludes that the Solar Tree does fulfil its purpose as stated in the problem definition. The design team looks forwards to building the first prototype at Musicon and to continue the project as a start-up.

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Appendix

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