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**Faculty of Electrical Engineering,
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Creating a physicalization showcasing the innovative heat network and energy grid of the new business park on Urk

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Abstract

The successful implementation of regional energy projects is crucial in achieving national climate agreements. The municipality of Urk is currently undertaking two significant energy initiatives: the establishment of a new heat network and a solution for net congestion issues. However, getting support for such projects can be challenging, as these topics are quite difficult to understand, particularly for individuals without a technical background. This research aims to address this challenge by exploring the potential of using a physicalization as a communication tool to explain such complex topics.

This research was conducted using the Creative Technology design method. The literature review revealed that there where three main components of a heat network, namely the heat source, the heat buffer and the households. Furthermore, net congestion was defined as an imbalance in electricity supply and demand. The ideation phase of the research unveiled that apart from the households in the Zeeheldenwijk area and the fish processing companies, there were other significant stakeholders involved, including other municipalities and the companies responsible for the implementation of the heat network. Furthermore, the specification phase resulted in 11 established functional and 12 non-functional requirements, using the MoSCoW method.

Based on these findings, a functional prototype has been designed and developed, which has given positive results. An evaluation conducted through a questionnaire revealed that participants did have a better understanding of the solution proposed for net congestion. Furthermore, results indicated that participants generally grasped the concept of a heat network. However, the current physicalization also has its limitations. The concept of utilizing cold in return, which are produced by the households within the heat network, was not fully comprehended. Furthermore, after interacting with the physicalization, participants still were not able to define the concept of 'net congestion'.

In conclusion, this research underscores the value of utilizing a physicalization to explain the new heat network and net congestion concepts. It serves as a model for future projects requiring clear explanations.

Acknowledgement

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Contents

Chapter 1

Introduction

This chapter will provide an introduction to the graduation project, starting with a comprehensive overview of the context. Subsequently, the problem statement will be presented, followed by the main research question and sub-questions. Finally, the chapter will be concluded by presenting the structure of this report.

1.1 Context Analysis

For the Netherlands, the Dutch municipalities play an important role in fulfilling the international climate agreements of Paris [1]. As a result of the agreements made in Paris, the Dutch government constructed the Dutch Climate Agreements [2]. The Dutch energy supply needs to be carbon free in 2050, with an important milestone in 2030, where greenhouse gas emissions must have been decreased by 55 percent compared to 1990. In order to achieve these agreements, the Dutch government implemented a strategy whereby the country was divided into thirty distinct regions. Each region will have their own Regional Energy Strategy (RES) [3]. To further delineate this undertaking, municipalities generate individualized plans via the Heat Transition Vision (Transitievisie Warmte) and the Neighborhood Implementation Plan (Wijkuitvoeringplan) [4].

The municipality of Urk has undertaken one of these transitions as part of their plans. The client of this GP, see section 1.2, has assisted the municipality of Urk with its latest project: the new port of Urk [5]. The new Port of Urk business park offers a unique opportunity to heat a nearby residential area with a sustainable exchange of heat and cold. Furthermore, the project also uses innovative solutions to reduce net congestion problems on the Dutch electricity grid.

The main initiative is the introduction of a new heat network, see figure 1.1. The

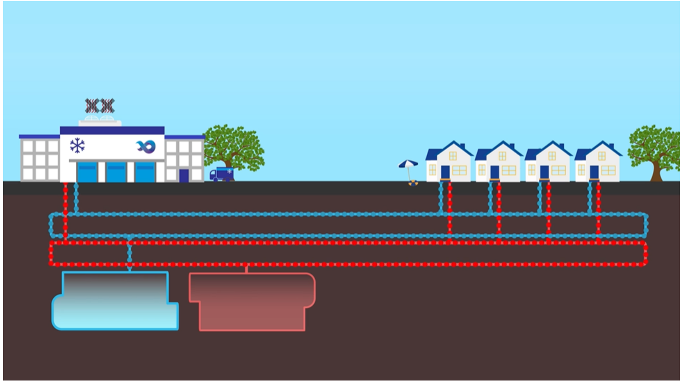

Figure 1.1: Heat network schematic

new port will be located closely to a residential area, the new Zeeheldenwijk. All of the houses within this area will not have any natural gas dependency [6]. They all will therefore be equipped with a heat pump and will be connected to a heat network. As the new fish companies on the business park will also be connected to the heat network, a possibility arises to create a closed energy system. The residual heat from fish processing companies can be used to heat homes in the nearby new Zeeheldenwijk. By utilizing this heat, the households produce cold. This cold goes back to the fish processing companies. They can use this cold for their chillers to let them run more efficiently. Depending on various weather conditions, the heat and cold supply and demands vary. Consequently, the system also utilizes thermal energy storage. More about this subject will be explained in subsection 2.1.2.

For the latter initiative one needs to have some understanding of the Dutch electricity grid. The original design of the Dutch electricity grid was created on the principle of ensuring a continuous supply of energy. As there is almost no storage and therefore buffer capacity to support the electricity grid, energy demand and energy supply need to be matched and balanced. As the general energy demand increases, and energy supply fluctuates more as a consequence of the transition to renewable energy supplies (like wind farms and solar panel parks), keeping this balance can be quite challenging. According to the report of Liander [7], a company that is responsible for power management and the placements of power cables, the area surrounding Urk already deals with structural congestions, which means the current electricity grid is not capable of handling all current and future energy requests. The introduction of the new business park will merely add to this issue. However, the business park can benefit from the new wind farm that will be placed on the business park. With the current infrastructure, the energy generated by the wind turbines will be transported via the high voltage grid to the north, subsequently directed towards the eastern locality of Emmeloord, and then ultimately routed back to the business

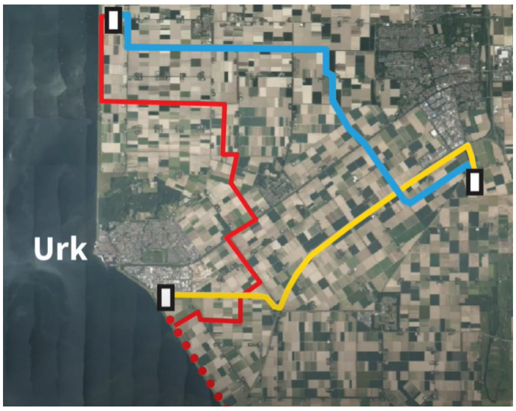

Figure 1.2: Old electricity trajectory

park, see figure 1.2. However, it may be feasible to bypass this circuitous 43 km trajectory by transporting the wind farm's energy output directly to the business park, thereby establishing a establishing a semi-independent energy grid, also referred to as a 'Smart Energy Hub'. This would potentially solve net congestion problems in other areas. For more information about this topic, see Chapter 2.

As this project is still in development, the fish processing companies still need to buy the ground where this new business park will be located. Therefore, the (soon-to-be placed) companies must be informed about the innovative developments, so they can cooperate with the planned projects and use its benefits.

1.2 The Client

The client of this graduation project is Enodes. Enodes is a consulting company specialized in sustainability. It helps organisations to lower their energy costs, make their buildings more sustainable, and tries to create a better indoor environment. Furthermore, the company helps municipalities to make business parks gas free. This can be in the form of giving advice after a thorough analysis, but the company also regularly guides the projects during the realisation [8].

1.3 Problem Description

The innovative heat network is a fairly new concept by Dutch standards, as Dutch implementation of heat networks was not financially feasible in the late 1900's because of the low gas prices back then [9]. Therefore, how a heat network works and the benefits of a heat network are not widely known. In addition, the solutions regarding net congestion proposed by Enodes require some underlying understanding of the

Dutch electricity grid. Explaining and showcasing how both the new heat network and the electricity grid work, and how their operations change in various weather conditions, can be quite challenging. Therefore, Enodes suggested to come up with a way to explain how the planned heat network will work and the solutions for the energy grid, regarding their project in the municipality of Urk. The solution proposed would have the form of a physicalization. This physicalization must be designed in such a way that people without a technical background can understand the proposed solutions.

1.4 Research Questions

The main research question of this research is:

> *"How can, using a physicalization, people without a technical background be well informed about the needs and benefits of the newly designed heat network and energy grid of the new Port of Urk business park?"*

To answer the main research question, the following sub-questions have been formulated:

1. "How is the electricity grid operated and what are its short-comings in relation to connecting new and renewable energy sources to the grid?"
2. "What are the primary components of a heating network, and how do these components interact with each other?"
3. "What are the various ways in which physicalization can serve as an effective means of communication, and what are the design patterns that underlie its efficacy?"

To help people understand the benefits of the proposed solutions for the Dutch electricity grid, it is important to first establish a clear understanding of the existing challenges. Sub-question one has been defined for this purpose. In addition, to explain the innovative, soon-to-be placed heat network of Urk, a clear understanding of the main components of a heating network is necessary. Sub-question two tries to provide this comprehension. As the product will be in the form of physicalization that tries to educate people on the difficult concepts, it is important that the message is clear and will be communicated effectively. To make sure this goal is met, literature research will be done on the topic of design patterns for physicalizations, with the help of sub-question 3.

1.5 Thesis Outline

In order to provide a satisfactory outcome and address the primary research inquiry, the following chapters have been structured in this thesis.

- Chapter 2: Background research
  This chapter is comprised of three sections, namely 'literature', 'state of the art', and a final section that concludes the preceding three sections.

- Chapter 3: Method and Techniques
  In this chapter, details regarding the design method and techniques to be employed in the graduation project will be presented.

- Chapter 4: Ideation
  The present chapter involves the identification and analysis of stakeholders, followed by the determination of requirements based on stakeholder interests and literature from chapter 2. Additionally, multiple concepts will be presented and evaluated, with a final concept ultimately selected.

- Chapter 5: Specification
  Upon defining the specifications, the final concept will undergo further refinement, resulting in a more comprehensive and detailed design. Furthermore, the requirements will be more specified.

- Chapter 6: Realisation
  This chapter describes the building process of the physicalization, the hardware, the software, and overall design choices.

- Chapter 7: Evaluation
  The evaluation chapter describes how the evaluation was conducted, the results of the evaluation, and reflects on the requirements which were made in Chapter 5.

- Chapter 8: Future Work
  Within this chapter, suggestions for future work will be made about better improving the current design, and suggest better ways for new informative designs.

- Chapter 9: Conclusion
  In this chapter, the research done trough out the entire project will be summarised. Furthermore, a final conclusion will be drawn.

Chapter 2

Background research

Chapter 2 is divided into three different sections: literature research, state of the art, and a conclusion. The literature review will focus on three parts: the Dutch electricity grid, the workings of a heat network, and the underlying design principles of a physicalization. The second section will present the state of the art. A conclusion and lessons learned will be presented in section three.

2.1 Literature research

2.1.1 Dutch Electricity grid

The Dutch energy grid has multiple voltage levels: high-voltage grids, mid-range grids, and low-voltage regional voltage grids. Each of those grids are connected to each other across the country, either via surface or subsurface cabling. Here, the high voltage grids main function is the transportation of energy across large distances. Regional distribution is the main function of the lower voltage grids. In order to interconnect grids with differing voltage levels, it is necessary to install intermediate stations, which convert the energy voltage for further transportation [10]. See Figure 2.1 for a clear depiction of how the Dutch electricity grid has been structured.

The existence of the current, unified and integrated electrical grid has not always been the norm. To understand the modern day problems with the grid, it is important to look at the development of the grid over the years, and at its inner workings. The upcoming part tries to give a better understanding of the grid, how it evolved, and where it is now.

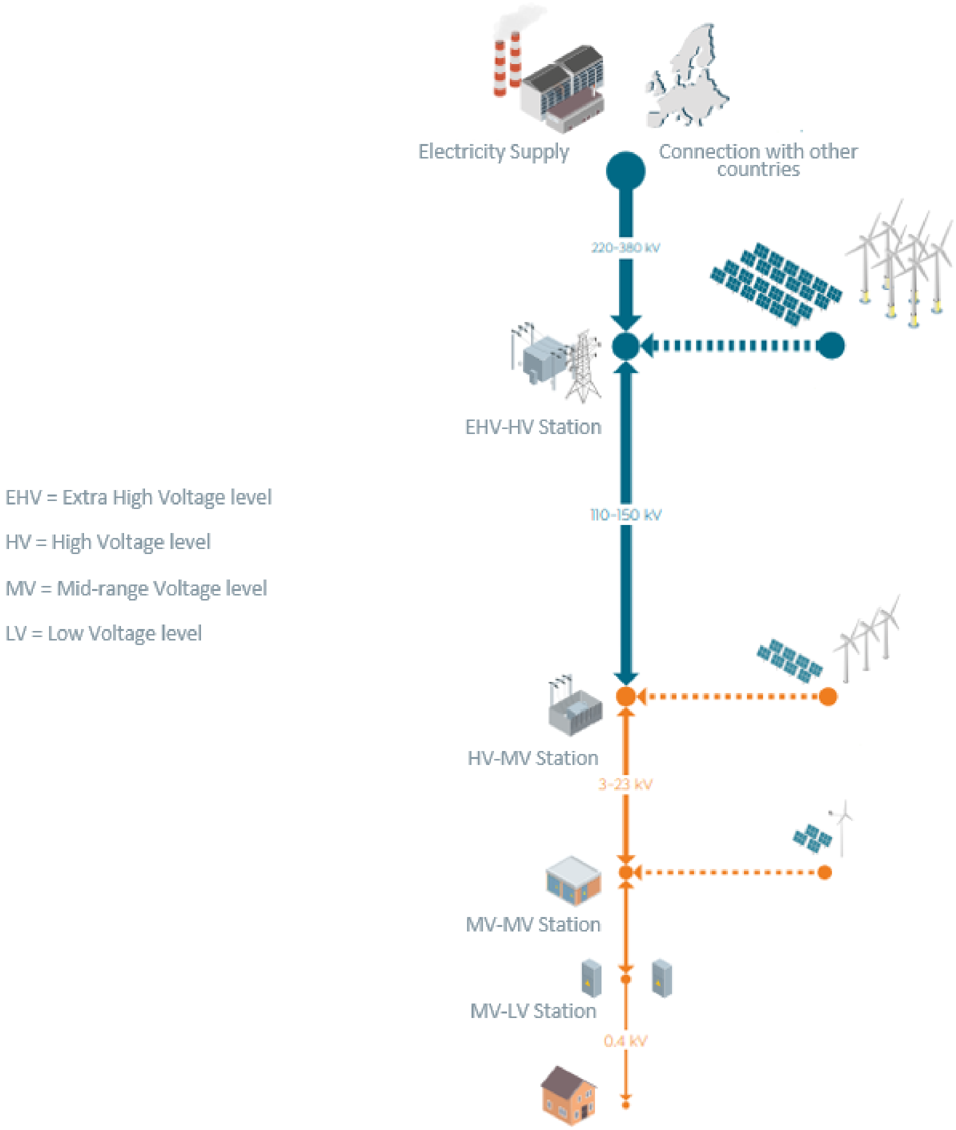

Figure 2.1: Energy voltages in the Dutch electricity grid

History

Prior to the 1960s, the electricity grid was primarily managed by regional and municipal utilities, and the majority of issues were addressed at a local level. However, with the implementation of a nationwide natural gas system, the Dutch government began to reassess its position in the energy sector and would gain a more prominent role. This resulted in a trend toward centralization of the energy grid in the following years [11].

The electricity sector would undergo further changes after the enactment of the Electricity Bill of 1998, which stated that production, trade and supply would become fully segregated from operating the grid. Grid operators would be responsible for connecting energy producers and consumers to the electricity network. Furthermore, it would be their responsibility to ensure a right balance of energy demand and supply [10].

The company responsible for the high-voltage grid in the Netherlands would become Tennet. It would be the Transmission System Operator (TSO) of the Netherlands [12]. Numerous other grid providers would be responsible for different lower-voltage grids in different parts of the Netherlands. Examples of regional grid providers are Enduris, Enexis, and Liander.

Another major change for the Dutch Electricity sector happened in 2009. Before 2009, Tennet was allowed to delay grid access to certain parties if insufficient network capacity was available. The Dutch Minister of Economic Affairs deemed this to be discriminatory towards new market entrants. Therefore, a connection policy got adopted, which states that the responsible TSO, which was and still is Tennet, is required to connect all new generation capacity to the transmission grid, regardless of whether sufficient transmission capacity is available [11]. As a consequence of this policy, the electricity grid in the Netherlands experienced ongoing issues with net congestion from that point on wards.

Net Congestion

Net congestion is defined, in line with existing literature, as a situation in which a power line has reached the limits of safe operation, as a result of which 'requests for transactions' cannot be physically implemented [11]. The underlying cause of network congestion lies in the fact that the original design of the Dutch electricity grid was based on the assumption of a constant energy supply. As there are no large scale batteries in place, to act as a buffer, supply and demand need to be exactly the same. Therefore, net congestion can happen because of two reasons. The first one is when there would be an energy shortage, when the demand is greater than the energy supply. The other is when there is an energy overload, when the supply is greater than the demand. With the increase of renewable energy supplies, like wind mills and solar panels, the energy supply will fluctuate even more, which will make the task of keeping this balance increasingly more difficult.

Current techniques

To ensure a balance between energy supply and demand, the Dutch TSO plans on investing billions to improve the current Dutch Electricty grid [13]. However, the placement of new stations and new voltage lines can take from 7 to 10 years [10]. As a result, Tennet employs several techniques to ensure this balance in the interim period.

The first technique, referred to as congestion management or redispatch, entails the use of financial incentives, in the form of redispatch bids, to match the energy demand and supply. In the event of excessive energy production, energy producers will get a financial incentive to produce less at a certain point in time, to avoid net congestion. In addition, large energy consumers in that region are asked to consume more. In the event of too much demand, the opposite is true [14]. At the moment, there are two companies that provide a platform for the trading of redispatch bids: GOPACS and RESIN. Tennet works together with both of those platforms [15].

The second technique is the placement of emergency electricity lanes at certain bottleneck areas. The placement of such lanes creates extra capacity for noncontinuous energy supplies, like windmills and solar energy. When a malfunction arises, those energy supplies are then turned off to make room again on the emergency lanes [16].

The last technique is called Dynamic Line Rating. The transportation of electricity heats the cables through which the current flow. This heat causes the cables to sag. As the high-voltage lines have a minimum height at which these cables constantly need to be, the amount of electricity that can be transported through the cables has a upper limit. However, when there is cold weather, the cables are cooled down, which allows for more electricity flow. Dynamic Line Rating uses the advantages of cold weather to further increase the electricity capacity of the cables [17].

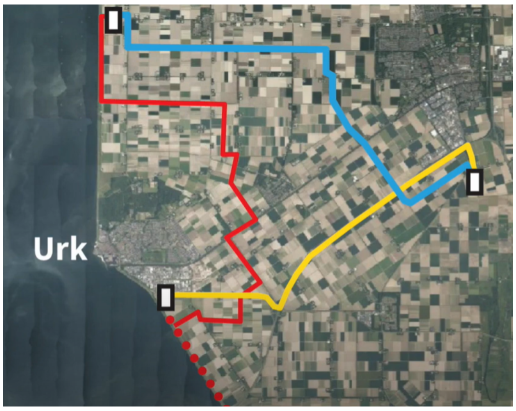

Figure 2.2: Old electricity trajectory

Current situation surrounding Urk

The Northeast Polder features extensive rural areas that are well-suited for the generation of sustainable energy. The number of wind turbines, solar panels, and solar fields that generate sustainable energy is, therefore, rapidly increasing. The placement of these sustainably energy supplies have a massive impact on the electricity grid in that area. According to a report of Liander [7], the grid operator in that area, the grid in that region was originally designed to only provide all villages of electricity, and not for the generation of energy in these villages.

With the currently in-place intermediate stations, which are connected to station in Emmeloord, the grid is not able to provide enough energy to the area surrounding Urk, including the new business park. This is because the current trajectory is a 43 km detour, see figure 2.2 [18]. The primarily reason for this detour is the conversion of energy to high voltage, as the grid distributes energy on this voltage level. Therefore, Liander is investing in the expansions of the electricity grid to overcome this and future problems in this area. One of these expansions is the placement of a substation at Domineesweg 29 in Urk, which will allow the development of the new business park of Urk [19]. However, net congestion problems will still arise as result of the size of these rural grids. Therefore, Liander is still looking into other solutions to avoid net congestion [7].

Summary

The electricity grid is divided into different voltage levels. Because of earlier design choices, all electricity first gets converted to high voltage, after which it is distributed and then lowered again to lower voltage levels. The situation in Urk is a great example where the trajectory of energy is quite insufficient, as the production of electricity and the consumption are right besides each other, but the distance traversed is 43 km.

The problems surrounding our electricity grid are mainly caused by net congestion. Net congestion can happen either by having to much supply of electricity and to little demand, or by having to much demand and a to little supply. Improving the electricity grid can take up many years. Therefore, short term solutions are established to deal with net congestion.

2.1.2 Heat Networks

Heat networks (also known as district heating or teleheating) supply heat from a central source to consumers, via a network of underground pipes carrying hot water. Heat networks can cover a large area or even an entire city, or be fairly local supplying a small cluster of buildings. This avoids the need for individual boilers or electric heaters in every building [20].

Most of the heat networks in the Netherlands have a collective source which provides high temperatures (90°C) to the network. Examples of such a source can be heath from industrial processes, deep thermal energy or waste heat from power plants. In addition to conventional networks, alternative systems are also feasible. A report compiled by CE Delft has summarized the various alternatives in the table below [21].

Type of heat	**Flow Temperature**	**Property**	**Heat Sources**
High-temperature heat network (HT-net)	>80℃	Suitable for all buildings, independent quality of isolation	- Waste incineration - Deep thermal energy - Residual heat (of the industry or power plants)
Middle-temperature heat network (MT-net)	>65℃	Most buildings can be directly connected to this heat network.	- MT-residual heat - Thermal energy - Return pipes of HT-net
Low-temperature heat network (LT-net)	>30℃	Only well isolated houses can be directed connected.	- Industrial chillers - Return pipes of MT-net - Shallow thermal energy
Very low temperature heat network (VLT-net)	<30℃	Heat first needs to be altered to a higher temperature to be used for residentual heating	- Sewage and surface water - Thermal energy storage systems

Table 2.1: Different temperature networks

The use of heat networks lower than 90℃ (MT, LT and VLT-heat networks) is increasing. According to the TKI Urban Energy report [22], this increase happens because of two main reasons:

1. A reduction in conventional HT-sources as a result of reduction in CO2-emissions and more efficient processes in the industry.
2. A reduction in heat demand as a result of better isolation in residential buildings (which give opportunities to other kinds of heat networks).

The network used by the client of this GP will be a VLT network. As English literature does not make a distinction between VLT networks and LT networks, the following part will focus on which kind of LT networks there are and which elements such LT networks have.

Kind of low-temperature heat networks

There are two main types of LT heat networks: direct heating or indirect heating with use of a heat pump. The latter happens when residential buildings need to receive a certain temperature which is higher than the temperature delivered by the heat source. In that case, the temperature first must be increased to the desired temperature.

With direct heating, the heat delivery from the heat network happens without the involvement of a heat pump for spacial heating. Therefore, the delivered heat needs to have a minimum temperature of 30℃. Furthermore, the buildings need to have a high level of isolation and proper release systems, like under-floor heating.

For indirect heating with the use a heat pump, there are two main approaches: a collective heat pump, or a individual heat pump. If a heat source is not able to heat residential buildings directly, the heat first needs to be increased by a heat pump. A collective heat pump is placed at the level of the **HTS!** (**HTS!**). Individual heat pumps can be placed at the level of the end-user (in a house or company building) or at the level of multiple end-users (in a apartment building or terraced houses).

Components of low-temperature heat networks

Figure 2.3 shows a schematic of a LT heat network. It consists of the following components:

1. Heat source(s)
2. Seasonal buffer (thermal energy storage) [optional]
3. Supplying net
4. Heat-transfer station (HTS) with heat exchanger or collective heat pump
5. Secondary net (main pipelines)
6. Substations (SS) with bigger networks
7. Distribution net from substations to households
8. Household installation with optional individual heat pump

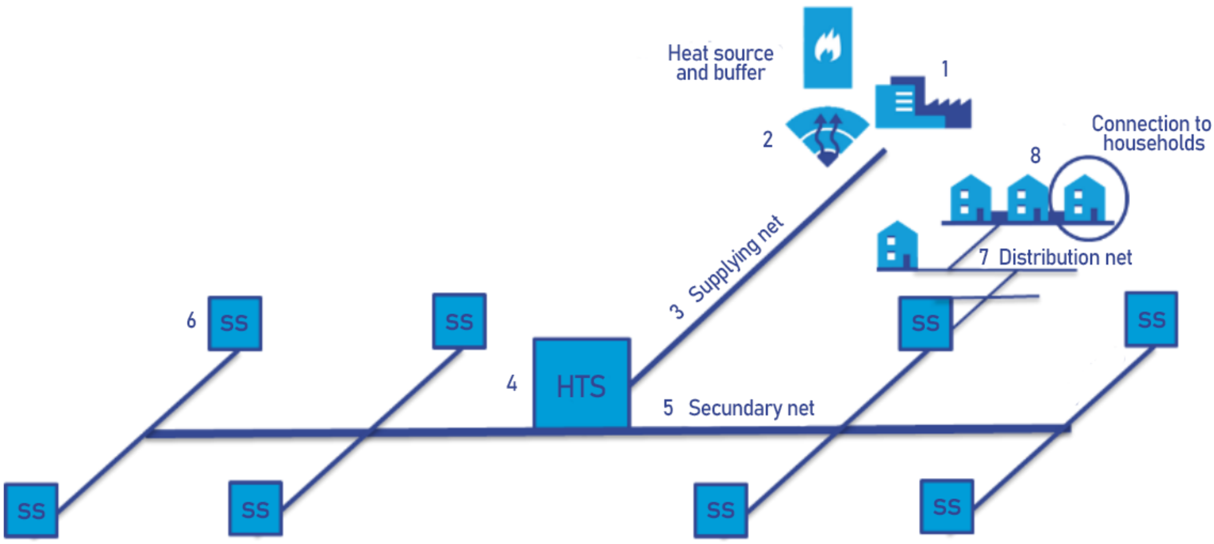

Figure 2.3: Components of a LT heat network - schematic

1. Heat source(s)
A low-temperature (LT) heat network utilizes low-temperature sources such as shallow geothermal energy, LT waste heat, or heat from sewage or surface water. As many of these sources have insufficient capacity to meet the heat demand throughout the year, LT district heating networks often connect multiple sources and/or incorporate peak demand installations.

2. Seasonal buffer
To overcome the (winter) peak demand, most heat networks make use of a heat buffer. There are three different forms a heat buffer can take: sensible heat, phase changing materials, and thermochemical storage [21]. At the moment, sensible heat storage is the only applied commercial form of storage. In sensible heat storage, heat is stored by raising the temperature of a liquid or a solid without phase change, and is released by decreasing the temperature when necessary.

Thermal energy storage (TES) uses water which is concentrated between 20 and 500 meter below the ground. During the summer, the cooler water is circulated through a heat exchanger to cool down the buildings, and then returned to the ground source. In the winter, the process is reversed to use the warmer ground water to heat the buildings. It is important to note that a balance needs to be maintained within this system, as the input and output of heat and cold must be the same. For example, in the cold TES gets filled, and the warm TES gets utilized. In the summer, this process is reversed. In practice, this means that TES only can be used when there is a relatively large demand of cold. Otherwise, the cold TES only gets filled.

3. Supplying net, 5. secondary net, 6. substations and 7. distribution net
The supplying net transports the heat from a heat source to a heat-transfer station. The distribution net is responsible for the transportation of heat from the HTS to residential buildings. If a heat network is of sufficient scale, it may accommodate a secondary net which contain substations that serve a cluster of 10 to 200 households.

4. Heat-transfer station (HTS)
At the heat transfer station, heat is transferred from the supply network to the distribution network. This process occurs either directly through heat exchangers or through temperature level enhancement using a central heat pump.

The operational mechanisms of a heat pump

In the latter section, it became clear that heat pumps play a crucial role in low-temperature heat networks. Despite their name, they transfer heat instead of generating it. Consequently, they can deliver 10-15 times more energy than they consume to power the compressor. Cutting-edge residential heat pumps can achieve an impressive 600% efficiency in heat delivery, surpassing the 50% to 95% efficiency range of gas heaters [23]. Furthermore, certain heat pumps can be reversed to provide cooling for residential spaces.

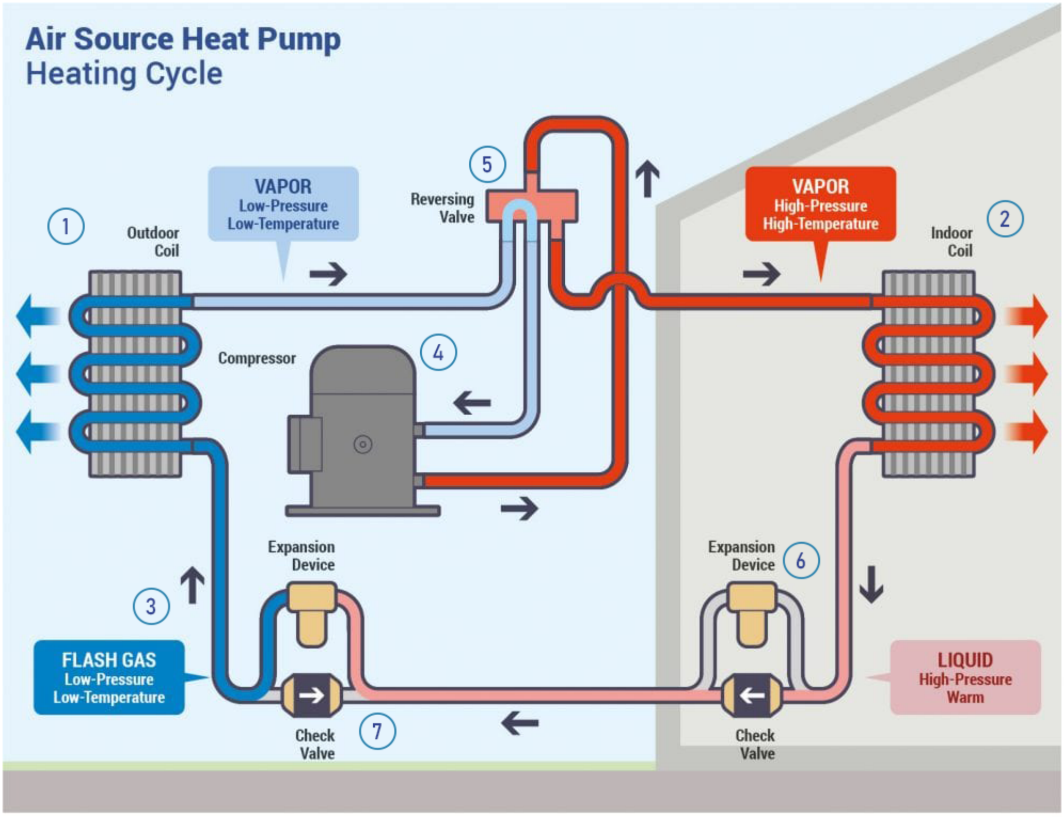

Figure 2.4: Heat pump schematic

A heat pump contains the following elements [24], also shown in figure 2.4:

1. Outdoor unit
   The outdoor unit contains a coil and a fan. Outside air, in case of a air-based heat pump, gets blown over the coil by the fan to facilitate the heat exchange. Depending on which mode the heat pump is in, the coil can act as a condenser (cooling mode) or a evaporator (heating mode).

2. Indoor unit
   Like the outdoor unit, the indoor unit also has a coil and a fan. Here the coil acts as an evaporator in cooling mode and as a condenser in heating mode, which is the reserve of the outdoor unit.

3. Refrigerant
   A refrigerant is the substance that circulates throughout the heat pump systems. The refrigerant absorbs and provides heat in either the outdoor or indoor unit. Most commonly used refrigerants are fluorinated hydrocarbons, such as HFCs and PFCs [25].

4. Compressor

The compressor pressurizes the refrigerant, increasing its temperature in the process, and moves it throughout the system.

5. Reversing valve [Optional]
   When a heat pump also needs the ability to cool down a building, a reversing valve is needed. A reversing valve acts like a switch, allowing the system to flow into the opposite direction.

6. Expansion valve
   The expansion valve has two functions. It decompresses the pressure of the refrigerant, making it possible again to absorb heat. In addition, it also regulates the flow of the refrigerant, by using a separate internal system that controls the size of the opening of the expansion valve.

7. Check valve [Optional]
   When a heat pumped is designed to also cool down a building, the system also needs a check valve, which is a valve that only allows flow in one direction. As an expansion valve only works in one flow direction, it can't be used when the flow is reversed. Therefore, a check valve is placed in parallel with the expansion valve. The combination of those two is then copied and placed in series with itself.

The basic physical property a heat pump relies on is that heat energy naturally wants to move to areas with lower temperatures and less pressure. The followings steps explain the basic process of a air-based heat pump in heating mode.

- STEP 1
  A liquid refrigerant is pumped through a expansion device toward the outdoor unit, which is functioning as the evaporator. Air from outside the house is blown over the coils, where the heat gets absorbed by the refrigerant. Even though the temperature outside can be quite cold, the boiling temperature of the refrigerant is even lower. Therefore, it can absorb the heat. The process of absorbing the heat energy causes the liquid refrigerant to evaporate.

- STEP 2
  The refrigerant, which is in gas-state, now passes through a compressor. The process of pressurizing the gas causes it to heat up. The hot, pressurized refrigerant moves through the system to the coil of the indoor unit.

- STEP 3
  A fan inside the house moves inside air across the coils, which are serving as condenser (in heating mode). Because the air inside the house is cooler than

the hot compressed refrigerant, the coil can give of its heat to the inside air. The refrigerant condenses into a liquid state as it cools and is then pumped through the system to the expansion valve.

- STEP 4
  If the heat pump is also capable of cooling, the refrigerant will first go through a check valve, as the expansion valve for cooling blocks the main route. It then goes trough the expansion valve for heating, which reduces the pressure of the refrigerant, which cools it down to a liquid state. It then is transported to the outside coil.

Summary

Heat networks have different components depending on the type of network used. In a LT heat network, there are eight components including the heat source, seasonal buffer, supply and distribution networks, Heat-transfer station (HTS), substations, and household installations. The main components to focus on are the heat source, seasonal buffer, and households. Furthermore, it is concluded that a heat pump is an essential part of a LT heat network, as the temperature of the flow is not directly suiting for heating or cooling.

2.1.3 Data physicalisations

Definition

As this graduation project is involved in the creation of a data physicalization, it is important to have a clear view of how data physicalization is defined in the field. The definition 'physical artifacts whose geometry or material properties encode data.' was first used by Jansen, et al. [26] by summarizing different definitions over the years. This definition gained widespread acceptance among academics in the following years [27] [28] [29] [30] [31]. Dumičić et all. [28] add that the term data physicalizations is only recently established and that other papers also refer to data physicalizations as data sculptures, data materialization, data manifestation, data edibilization, or data objects. Nevertheless, some of these terms are only closely related. For example, the term 'data sculptures', which was first used by Andrew van de Moere in 2008, has more of a focus on the embodiment of the data and its artistic side [32].

However, other recent papers argue that this definition does not include the whole scope of data physicalizations. Offenhuber [33] says that our concept of data physicalization needs to be expanded beyond just the physical artifact and include a broader understanding of data, which goes beyond external data sets. Through epistemological and ontological perspectives, Ofenhuber argues that several physicalization instances are not solely dependent on external datasets. Additionally, Ofenhuber highlights our implicit and explicit assumptions about data, particularly about what we consider data to be.

Another recent article authored by Sauvé and Strudee [34] reasons that the terminology of "data physicalization" is too constricted. The authors argue that all related terms, like data physicalization, operate within a wider ecological framework, namely the "physecology," which possesses attributes and characteristics that exceed the boundaries of the conventional definition of data physicalization. Sauvé and Strudee are not the only ones who claim that the term data physicalizations is limiting. Hogan Hornecker [35] elucidated that physicalization implies that something is physical, while data could also be audio based for example. Therefore, they use a new umbrella term: Multisensory data representations. All in all, a clear definition and terminology can not be established, as the definition and term itself varies among and even within the data physicalization field.

Within this graduation project, the term 'data physicalization' will be used, despite the debate within the field. Furthermore, the definitions of Jansen et al. [26] will be used, although it is acknowledged this definition is still lacking in some areas.

Design space

Different researchers have attempted to create different design spaces and categorizations for data physicalizations, as the concept encompasses a wide range of methods and techniques. Some papers only suggested one kind of categorization. Dragoicevic et al. [36], for example, proposed a distinction between data-driven presentations and data-showing physicalizations. The former involves the use of a presenter to convey the message of a particular data physicalization, while the latter relies on the data physicalization itself to be self-explanatory, rendering a presenter unnecessary.

Another categorization can be made by looking at the operations possible within a data physicalization. Jansen et al. [26] supposed that an operation can be either automatically triggered by the system (animation), or invoked by the user, either via sensing and actuation (synthetic interaction) or through purely physical manipulation (physical interaction). Examples of physical manipulation can be disassembling, reassembling, rearranging, or aligning. A categorization made by Dumičić et al. [28] is

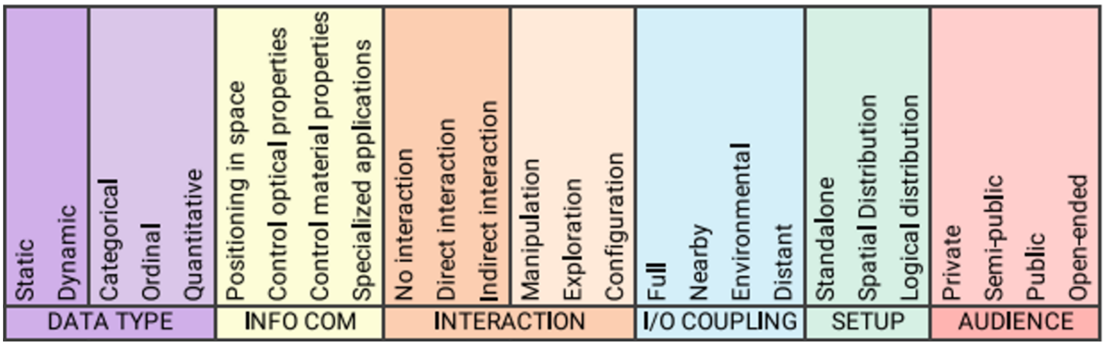

Figure 2.5: Design dimensions by Sauvé Sturdee

closely related, as they argue that data physicalization can either be static (the user can't interact with it) or interactive (the user can interact with it).

In contrast to the aforementioned papers, where these categorizations were only mentioned, other paper's entire goal was to establish an overview of all design spaces to help designing physicalizations. Bae et all. [37] created three classifications. First of all, they mention a data physicalization can either be bounded or unbounded. Bounded artifacts exist confined to a particular place and are not meant to be re-positioned. Unbounded artifacts are designed for mobility and may be relocated. Furthermore, Bae et all. argue that a data physicalization can be technologically-driven or contextually-driven. Technologically-driven physicalizations consisted of platforms where designers leveraged technology to encode data. Physicalizations whose embodiment was contextually-driven represented data through people, environments, or activities. At last, they argue that a physicalization duration can be one of these three types: ephemeral, persistent, and permanent. Data physicalizations that present data ephemerally are designed to collect and display real-time data. Alternatively, those that persist allow users to exert some degree of control over the duration for which the data is displayed. Lastly, physicalizations that display data permanently are those in which the data is permanently integrated into the physical structure of the object, for example, 3D printed objects.

Sauvé Sturdee [34] also created six different design spaces to help designers with decision making during the design proces of a physicalization, although they refer to them as design dimensions. The six design dimensions that have been specified are data type, information communication, interaction mechanisms, spatial input output coupling, physical setup, and audience. See figure 2.5 for a better overview.

For data type, Sauvé and Sturdee argue that data can either be static or dynamic. Furthermore, data can also be either categorical, ordinal, or quantitative. Information communication entails how the information is represented. Here Sauvé and Sturdee argue that there are four main categorizations of methods: positioning in space, control of optical properties, control over material properties, and 'other'. Regarding interaction, there are two kinds of classifications. An interaction can either have no interaction, direct interaction, or indirect interaction. Furthermore, an interaction can be one of three types: exploration, manipulation, or configuration. The coupling between the input and output was further categorized in sort of scale: full coupling, nearby coupling, environmental coupling, and distant coupling. The setup entails how data physicalization works and how it is placed. The design dimension, audience, is divided into four subcategories: private, semi-public, public, and open-ended. Hogan and Hornecker created more general design spaces. They established the design space of data physicalizations along three axes of dimensionality: use of modalities, representation intent, and human–data relations. These three dimensions are subdivided into different themes. The use of modalities is subdivided into multimodal representations, representation modalities, different materials in use, and data insight through experience. For representation intent, four themes have been established: casual representation, utilitarian representation (more of an artistic representation), revealing little data insight, and revealing large data insight. Human-Data Relations have also four sub-divisions: interactive systems, non-interactive systems, live data, and archived data. To conclude, there are many ways to categorize physicalizations and create design spaces for them. However, many design spaces resemble each other a lot, although the wording can be quite different sometimes.

Design principles

While the previously mentioned design spaces aim to provide designers with a better understanding of the available options and principles for designing data physicalizations, they do not offer any specific set of design guidelines. However, Dumičić et al. summed up five principles that offer useful insight for the design of data physicalizations concerning their size, level of abstraction, use of senses, choice of materials, and inclusion of personal data [28].

Regarding size, they mentioned that a physicalization's size requires consideration of its purpose and intended interaction. For example, large physicalizations elicit impressiveness but require effort for interaction and legibility. Furthermore, larger sizes of artifacts established more shared data experiences and stimulated discussions in communities.

Dumičić et al. noticed that the use of abstraction in the design of personal data physicalizations also provides function, rather than just aesthetics. This is because of two main reasons. Abstract design in personal data physicalizations provides privacy. Furthermore, questions about the meaning of abstraction in personal data stimulate engagement and reflection.

Regarding the use of senses, it was concluded that senses other than sight are not as direct in data communication but provide a qualitative experience of information. Here they saw that taste and smell assisted with data storytelling, that the surprise in the weight of artifacts made people pay attention, and that textures and tactility of data points in personal data physicalization assisted with storytelling and the recollection of experiences.

Dumičić et al. also saw that the use of unconventional materials for data representation encouraged engagement. The use of living matter encouraged emotional engagement through compassion. The use of food or drink engaged participants through fun and playfulness. At last, the embodying of data into one's body supports also resulted in higher engagement.

The final design principle is that the inclusion of participants in the production of their own personal data physicalization creates meaningful bonds between the maker and the artifact. It first of all encouraged reflection, as it requires data consideration and decision-making. It also allows for the personalization of the design artifact, adding value for the maker. However, the interest in production fades over time.

Summary

The definition and terminology surrounding data physicalizations is an ongoing debate. While some researchers agree that data physicalizations are physical objects that encode data using their material properties or geometry, others find this definition too restrictive. Additionally, the field is still working to define design spaces for data physicalizations, and no final framework has been established yet, resulting in multiple proposed variants. These frameworks will be utilized in the ideation phase of the graduation project. In contrast, there are several design principles in place regarding their size, level of abstraction, use of senses, choice of materials, and inclusion of personal data.

2.2 State of the Art

Currently, no physicalization that explains a heat network and electrical grid has been identified. However, there are currently various visualizations/physicalizations that use different techniques to explain difficult concepts. By analyzing multiple of these visualizations and by creating an overview of the advantages and disadvantages of each one of them, much can be learned.

2.2.1 Tinus Hammink Table

The Tinus Hammink table, shown in figure 2.6, is a modular smart grid table that explains the opportunities and challenges of the current energy transition [38]. The table visualizes the energy flow of a city. Users can interact with the table by placing and removing building, which are 3D-printed. Each of those building have a RFID tag, which informs the software of the overall structure of the city. The LED strips between the buildings represent the flow of energy. As all building have their own properties, like energy uses or production, the system can calcualate in real time how and where energy flows. It also can show when net congestion will happen. The different city blocks can also be reconfigured, as the whole system is modular.

Figure 2.6: Tinus Hammink table

Advantages

1. The installation is made modular.
2. The data type represented is dynamic.
3. The installation has a form direct interaction, as uses can interact with the data by placing/removing buildings.
4. The installation has both a configuration and exploration type of interaction.

5. The installation size allows multiple users to walk around it, stimulating debate.

Disadvantages

1. The realisation of the table took over 5 years, because of its complexity.
2. The only informational communication is done with optical elements.

2.2.2 Interactive scale models of TenneT

At the recently opened information center of the grid operator TenneT, an interactive model is displayed showcasing, among other things, the combined 380 kV/150 kV connection: the international power highway from Doetinchem to Wesel. Visitors can access detailed information by using the touchscreen interface and view it on the large screen above the model. The model also features controllable light lines that highlight the connections [**?**]. Furthermore, TenneT created another scale model, like the previous one, to show the connection between the 380kV power grid and a high-voltage substation [39]. Figure 2.7 shows both installations.

Figure 2.7: Interactive scale models made by Tennet

Advantages

1. The screen allows for additional information.
2. The use of a second screen allows multiple users to watch actions and information on the screen.
3. The visualized map helps with creating a mental image of the location and size.

4. The installation size allows multiple users to walk around it, stimulating debate.

Disadvantages

1. The use of a screen to convey information forces the installation to have a second screen, as more than 1 person should be able to read it.
2. The data type represented is static.
3. The use of a screen is necessary to convey all information.
4. The only informational communication is done with optical elements.

2.2.3 Scale Model with Interactive Mapping - Cubexis

Cubexis is a company that specializes in designing and buidling innovative technologies that create experiences for people in work and playfull envirionments [40]. In one of their projects they created a scale model with interactive mapping on top of it, see figure 2.8. Not much is known about the project, as the only source for the project are images on the portfolio page of the Cubexis website. Altough there is a lack of information, the installation is still included as it use a different technology, projection mapping, to visualize the information.

Figure 2.8: Scale model with interactive mapping

Advantages

1. The use of a projection allows for a variety of ways to convey information.
2. The use of a projection allows for additional aesthetics.
3. The use of a projection allows the users to focus on one point.
4. The installation has a form direct interaction

5. The visualized map helps with creating a mental image of the location and size.

6. The installation size allows multiple users to walk around it, stimulating debate.

Disadvantages

1. The use of a screen only allows one user to read and give input on that screen.

2. The only informational communication is done with optical elements.

2.2.4 Interactive scale model - MAKE Creative Spaces

The interactive technical scale model of a wastewater treatment system for Certh (a Greek sustainability company) was designed and crafted by the team of MAKE Creative Spaces [41]. The objective was to create an interactive model that demonstrates the steps involved in the process. The wastewater treatment process implemented in this model utilizes natural methods for filtering and purifying wastewater. The project involved the use of various digital manufacturing techniques such as CNC milling, 3D printing, laser cutting, and carving, see figure 2.9. The artifact required significant man-hours to design, model, assemble, paint, and finish. To further enhance the model, a multi-lined LED light circuit was incorporated which illuminates the filtering process steps with a gradual desaturation of the colored resin running through the tubes. A control panel with 10 push buttons was also integrated for easy operation.

Advantages

1. The data type represented is dynamic.

2. The use of buttons focus users attention on the installation itself.

3. The installation size allows multiple users to walk around it, stimulating debate.

Disadvantages

1. The information represented needs additional text or a presenter for a proper explanation

2. The only informational communication is done with optical elements.

Figure 2.9: Scale model of a wastewater treatment system

2.2.5 3D scale Model in AR

To visualize the construction of a tunnel and gain experience with Augmented Reality (AR), an interactive 3D model has been created in AR by Croonwolterdros, see figure 2.10. In an AR environment, unlike Virtual Reality (VR), you maintain contact with your surroundings. Through the lens, you can see both virtual images and the real environment.

For instance, with a HoloLens, a virtual 3D model can be projected into a real room, while communication is maintained among team members. The 3D model also visualizes the cables and pipelines that are casted in concrete and show how a project that is yet to be built will look like. As it is interactive, various elements in the 3D model can be clicked on to make the developing applications in a project even more tangible [42].

Advantages

1. The data type represented is dynamic.
2. The interaction in the data can be done directly.
3. The visualization can change during the experience.
4. Multiple users can see the 3D model (if there are multiple HoloLenses.

Disadvantages

1. The visualization can easily be moved, as only the AR glasses have to be moved.

2. The amount of users is limited by the amount of glasses.

Figure 2.10: Scale model in AR

2.3 Discussion and Conclusion

Within this chapter, multiple conclusions can be drawn regarding the different subtopics. As shown by the first part of this literature research, the Dutch electricity grid has problems with net congestion. A problem where the electricity supply and demand are not the same. A clear understanding of this problem is necessary to understand the solution. Therefore, the physicalization should explain what net congestion is. This will be one of the requirements.

The **TSO!** (**TSO!**) of the high-voltage grid, TenneT, is forced to use different temporally solutions, as our energy demand rises more and more, the production of energy fluctuates more throughout the day because of renewable energy sources, and the expansion of the energy grid can take multiple years to realise. The area surrounding Urk deals with net congestion problems, as the regional grid is not capable to handle the placement of all wind farms and new business parks. The primary factor for this is that the trajectory of the energy follows a deviation of 43 kilometers. Why this trajectory was there in the first place, and what the solution is, will both be visualized in the physicalization.

Regarding heat networks, it can be concluded that components of heat network depent on the type of heat network. The heat network that will be placed in Urk will be a low-temperature heat network. For a low-temperature heat network, 8 components have been identified: the heat source(s), the seasonal buffer, the supply net, the **HTS!** (**HTS!**), the secondary net, the substations, the distribution net, and the household installations. The main components to understand are the heat source, the seasonal buffer and the households. These should therefore be included in the physicalization. Furthermore, it has been concluded that it is essential to understand the concept of a heat pump, to understand how a heat network can work. Therefore, it would be preferable to add this information to the installation.

For data physicalizations, it can be concluded that the definition and terminology surrounding data physicalization is still an ongoing debate. Most researchers agree with the definition where data physicalizations are described as physical artifacts whose geometry or material properties encode data. Others think this definition and term is too limiting. The field is also in the process of defining design spaces for data physicalizations. Here no final framework is defined, and multiple variants of frameworks are proposed. These frameworks will be used in the ideation phase of this graduation project. In contrast to the design spaces, there are multiple design principles in place with regard to their size, level of abstraction, use of senses, choice of materials, and inclusion of personal data. As Dumičić et al. [28] concluded in one of these principles: a bigger size stimulates discussion and create a more shared experience. Therefore, it is preferable to make the size of the physicalization big enough so people can stand around it.

There are various ways to visualize the data in a physicalisation. Different techniques are shown throughout the state of the art. Examples are the use of projection, fully AR models, and interactive scale models with either an extra screen or buttons to interaction with. Although the first two mentioned have many possibilities when it comes to visualizing the data, they come at the cost that the realisation of such models can be very time consuming. Therefore, a simpler approach, like the one by MAKE, is more desirable for the scale of this graduation project. Another take away is that the size of all these models is rather quite large, which lets people walk around the model. As mentioned in the previous paragraph, a large size is also preferable for this project.

Chapter 3

Method and techniques

This chapter provides the methods and techniques used for this graduation project and provides an explanation why they have been chosen. It is structured into two section: the Design Method and the Techniques. The design method focuses on the use of the Creative Technology Design Process, while the latter goes over the various techniques utilized throughout the entire process.

3.1 Design Method

For this graduation project, the Creative Technology design method has been chosen, see Figure 3.1 [43]. This design method consists of four different phases: ideation, specification, realization and evaluation. During the process of going through these phases, it is always a possibility go back to an earlier phase, as this method is an iterative process. In the first phase, see Chapter 4, concepts for the physicalization are created. These concepts contain ideas of what the physicalization should look like and what kind of interactions there should be. This concept gets further specified in the next phase: the specification phase, see Chapter 5. Furthermore, the components used and the requirements will be specified here. In the realisation phase, see Chapter 6, the specified concept is turned into a working prototype. The next phase is the evaluation phase, see Chapter 7. During this phase, the prototype will be evaluated with the help of user tests and via a functional evaluation by the author.

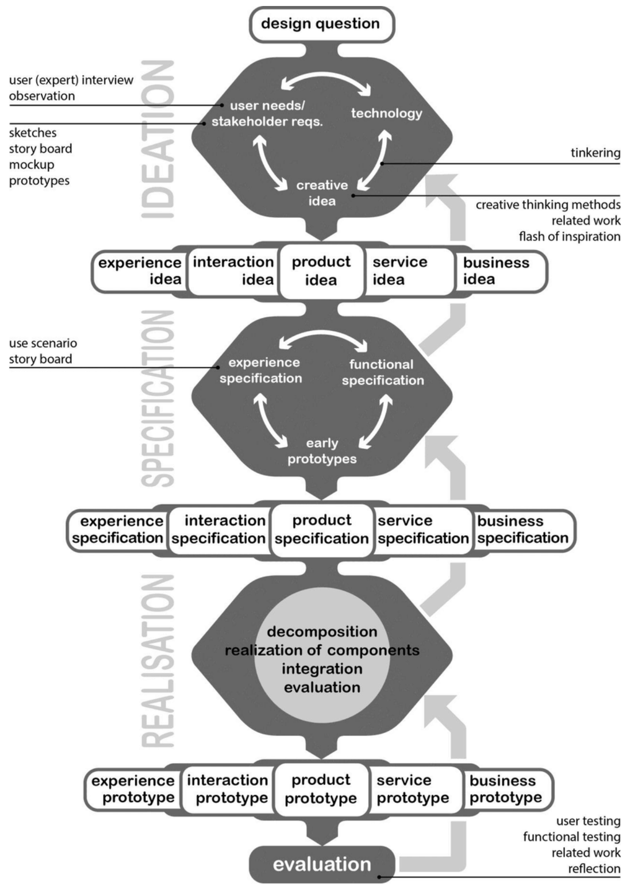

Figure 3.1: Creative Technology design method

3.2 Design techniques

3.2.1 Stakeholder identification and analysis

To identify all stakeholders, the method presented by [44] has been utilized. First, a list of all stakeholders who are affected by this project or who have a vested interest in its success or failure is created. After the creation of this, all stakeholders are divided into one of three subgroups (active stakeholder, conscious stakeholder, and alterted stakeholder), based on their level of influence and level of interest. Active stakeholders possess extensive knowledge of the problem and demonstrate a significant level of commitment. Conscious stakeholders also possess considerable knowledge about the problem, but their level of commitment towards this graduation project distinguishes them from active stakeholders. While conscious stakeholders may not have a direct interest, they are well-informed and highly educated. Lastly, alerted stakeholders have limited knowledge of the problem, yet their involvement is substantial due to its significance to them. At last, the different interests of all stakeholders are evaluated.

3.2.2 Requirement elicitation and categorization

In the ideation phase, the requirements have been elicited by using the MoSCoW method [45]. In the MoSCoW method, requirements have been subdivided under four different categories: 'must have', 'should have', 'could have' and 'would have'. The requirements categorised as 'must have' have been implemented into the final design of the physicalisation.

3.2.3 Brainstorming techniques

During the ideation, different brainstorming techniques have been used to come to different concepts. Although brainstorming can be an ongoing process, two well-known techniques are utilized: mind mapping and rapid ideation.

Mind mapping

To better get a picture of my own mental image, mind mapping was used as a brainstorming technique. As the Tony Buzan popularised this technique, his ten 'laws of mind mapping' are used during the whole process [46].

Rapid Ideation

When it comes to exploring effective ways to collaboratively generate ideas or solutions, there are a lot of activities and exercises that design thinking can offer. The one used in this project is rapid ideation, which is a form of divergent and converting thinking. This technique uses a time limit to promote divergent thinking. After all ideas were written down (on post it notes for example), a selection was made to gather the best ideas [47].

3.2.4 Personas

Three personas have been created for this graduation project. A persona refers to a fictional character that represents a specific user type or target audience. These personas were developed based on research about the intended users. Each persona includes demographic information, personal characteristics, professional background, goals, challenges, and some less relevant details like fictional names and photos to make them more relatable.

Chapter 4

Ideation

In this particular chapter, a range of techniques discussed in the previous chapter will be applied to create concepts. The initial step involves identifying and analyzing stakeholders. Following this, concepts will be presented based on the information collected from Chapter 2, where one concept will be chosen. Lastly, the identified interests will be translated into requirements and sorted in order of priority using the MoSCoW method.

one chosen concept will be explained in detail.

4.1 Stakeholders

4.1.1 Stakeholder identification

A stakeholder for this project is identified as any individual or group that has an interest in any decision or activity within the realisation of this project. The method used is further described in chapter 3. The stakeholder identification and prioritisation are shown in table 4.1.

Table 4.1: Stakeholder identification

Involvement level of stakeholder	Stakeholder
Active stakeholder	- Enodes - Researcher of this project (Louis van Maurik) - Supervisors (E. J. Faber, C.M. Epa Ranasinghe)

Continued on next page

Table 4.1: Stakeholder identification (Continued)

Conscious stakeholder	- Dutch municipalities - Fish Processing industries - Grid operators (Liander, Tennet, etc) - Industries responsible for the placement of the heat network
Alterted stakeholder	- Households of the new Zeeheldenwijk - Other industries in the port of Urk

4.1.2 Stakeholder analysis

With the establishment of a list of stakeholders, it is important to analyse the interest of each stakeholder, see table 4.2. The following list is ordered on involvement from top to bottom.

Table 4.2: Stakeholder analysis

Stakeholder	Interest in physicalisation
University	University refers to both Erik Faber, the supervisor of this project, and Champika Epa Ranasinghe, the critical observer of this project. They guide the researcher of the project and deliver feedback accordingly.
Client	Enodes is interested in receiving a working end product, in the form of a physicalisation, to showcase the innovative project of Urk. This would help realizing this project, as it could inform fish processing companies what is expected from them. Furthermore, it would also be an interest for Enodes to use this physicalisation as an example of what kind of innovative possibilities there are.

Continued on next page

Table 4.2: Stakeholder analysis (Continued)

Researcher of this project	Louis van Maurik is responsible for the realisation of the physicalization, by gathering information and building the product.
Dutch municipalities	As Dutch municipalities are expected to contribute to achieving specific climate agreements, it is considered crucial that they possess knowledge of the available solutions. The implementation of this process can help by informing them effectively.
Fish processing companies	As some to-be-placed fish companies will be located on the new Port of Urk, the involvement of these companies is necessary to realise both projects. Therefore, these companies should be properly informed.
Grid Operators	Current grid operators are facing difficulties with net congestion problems. Therefore, it is important for them that industries become more flexible with their electricity demand and know about the problem. Any form of attention to problem is advantageous for them.
Industries responsible for the placement of the heat network	As this project can only be realised with the cooperation of all parties, is important for the industries that place the heat network that all parties are well informed. Otherwise, the placement of the heat network would not be possible.
Households of the Zeeheldenwijk	All households of the Zeeheldenwijk will be connected to the heat network. The realisation of the heatnetwork depents on the cooperation of multiple parties. Therefore, it is also benificial for the households that all party's are well informed.

Continued on next page

Table 4.2: Stakeholder analysis (Continued)

Other industries in the port of Urk	Same applies for industries in the port of Urk as for the households of the Zeeheldenwijk.

4.2 Concepts

In this section, the methodology used to generate multiple concepts will be explained. First, the brainstorming sessions that were conducted will be outlined. Then, the concepts derived from those sessions will be presented. Lastly, the final concept that was chosen will be revealed, accompanied by an in-depth explanation of its characteristics.

4.2.1 Brainstorm

At first, a mind map, see figure 4.1, was created to get a full view on topic, and contextualize all concepts and ideas onto paper. The mind map also used imaginary to support explaining the different sub-topics of this project. The mind map was consequently used as an inspiration for the rapid ideation phase.

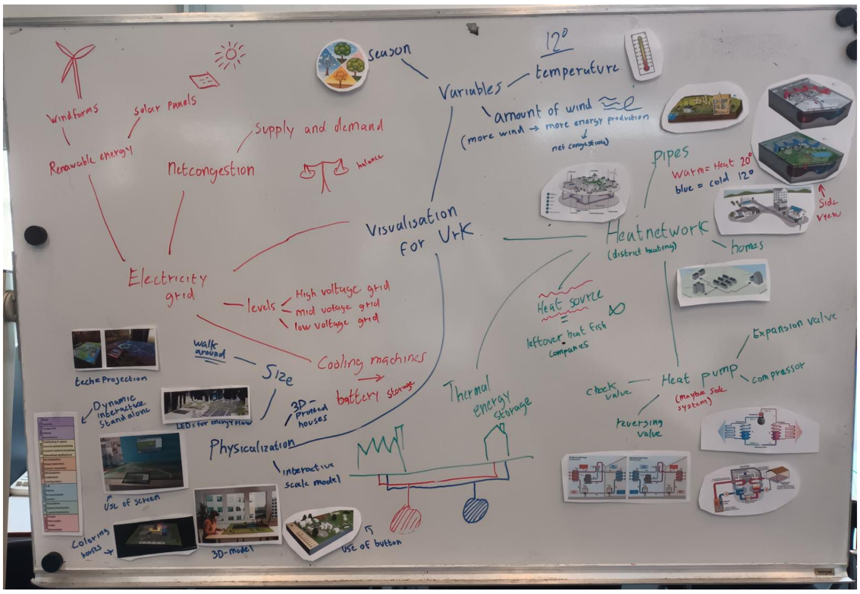

Figure 4.1: Mind map

4.2.2 Concept 1

The first concept has taken the form of an interactive scale model. To visualize and better understand this concept, a pen-and-paper prototype was made, see Figure 4.2. This concept tries to explain the heat network and the energy grid separately, by splitting the table into different sections. Furthermore, it also uses separate 'slices' of the table to explain a heat pump and the energy grid solution.

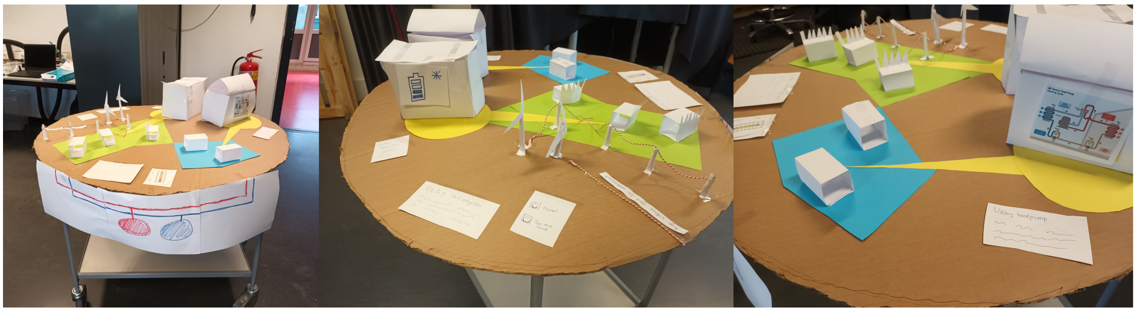

Figure 4.2: Pen-and-paper prototype of concept 1

In this concept, the ground of the table would be a map of Urk. In the pen-and-paper prototype, the new Port of urk is visualized with a light green shape, and the Zeeheldenwijk is visualized with a blue shape. The heat network, which is connected between the two areas, is visualized on the side of the installation, where the viewer could look into the ground. Here, the warm pipelines are visualized in red, and the cold pipelines are visualized in blue. Right above the heat network, a button with text is present which lets the user switch between winter and summer, so he/her can see the change in flow.

On the left-hand side of the Port of Urk, the energy grid is visualized. Here there are two main paths. One of the electricity cables goes of the map, and the other one is directly connected between the fish companies and the wind turbines. This slice has also its own text explaining what is going on and has a button which let's the user change the electricity flow.

On the left of the explanation of the electricity grid, the solution for the energy grid will be visualized. One of the fish companies is scaled to a bigger size, so the user knows he/she is looking inside of one. When the user changes the wind speed, and therefore changes the production of electricity, he/she would see the temperature change of the fish cooling machines.

At last, the other house, which is scaled-up house from one of the houses in the

Zeeheldenwijk, has an explanation on it how a heat pump works. It too has an extra sign which explains the workings in text. However, in the current design no interaction is present within this slice.

4.2.3 Concept 2

The second concept is a side view from a wind turbine, a fish company, and a house. A 3D sketch and a side view were drawn, see figure 4.3. The inner working of each of the elements explained is done the same as done in concept 1. However, everything is done from a side view. This means the Zeeheldenwijk and the Port of Urk are only mentioned in text. Furthermore, the explanation about the electricity grid is fully done in text here, as it was not possible to incorporate this explanation into a 2D design.

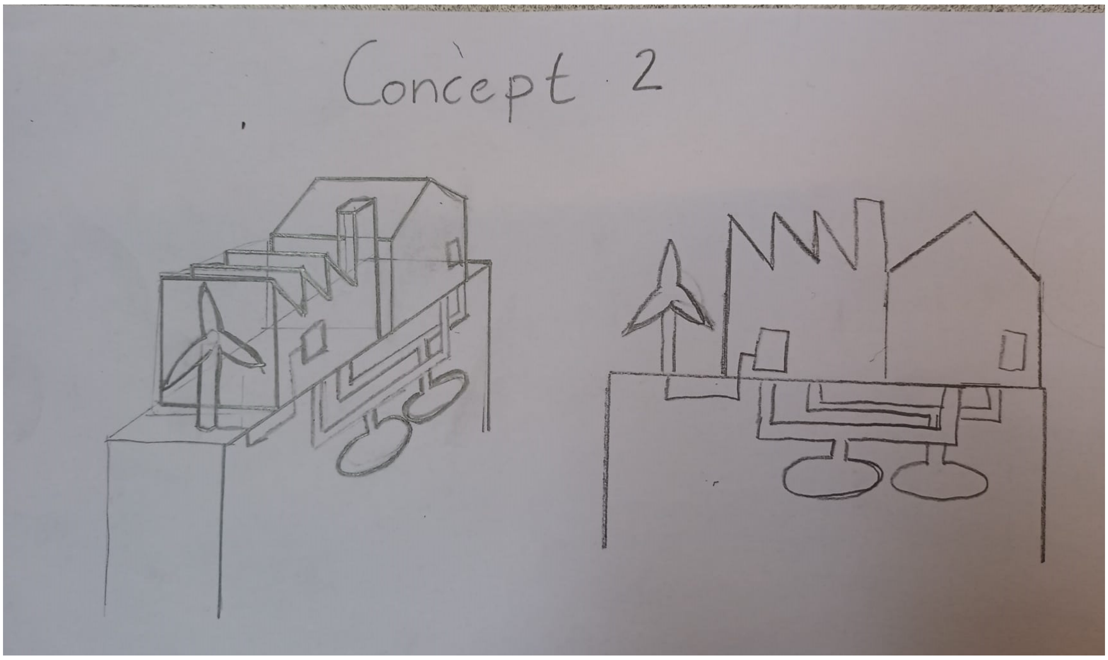

Figure 4.3: Sketch of concept 2

4.3 Final Concept

The final concept is highly based on concept 1 and the conclusions of Chapter 2. However, some changes to the design have been made. First of all, it was noticed that it was difficult to view the heat network. When one stands right next to the table to interact with the buttons, he/she is not able to see the heat network. Therefore it was decided to create a gap into the physicalisation which shows the inside of the ground.

In addition, one remark was made by the client of this GP that only the electricity grid showed how the old system would look like, while the heat network only showed the solution. To ensure a balance between the two, one feature was removed from the system, were the user could change the directory of the energy grid. Instead, this would be explained in words, and the focus would be more on the energy grid.

At last, it was noted by the external clients that the wind turbines were also placed on the Port of Urk, and not in the water. Therefore, this also changed in the design.

By implementing these changes, it was deemed necessary to create a final concept of what the installation would look like. Therefore, a 3D-model was made in fusion, which shows the top of of the installation, see figure 4.4. This model does not include imaginary on the side of the ground of on the side of the buildings, which means that the heat network, the explanation of the energy solution, and the heat pump are not visible.

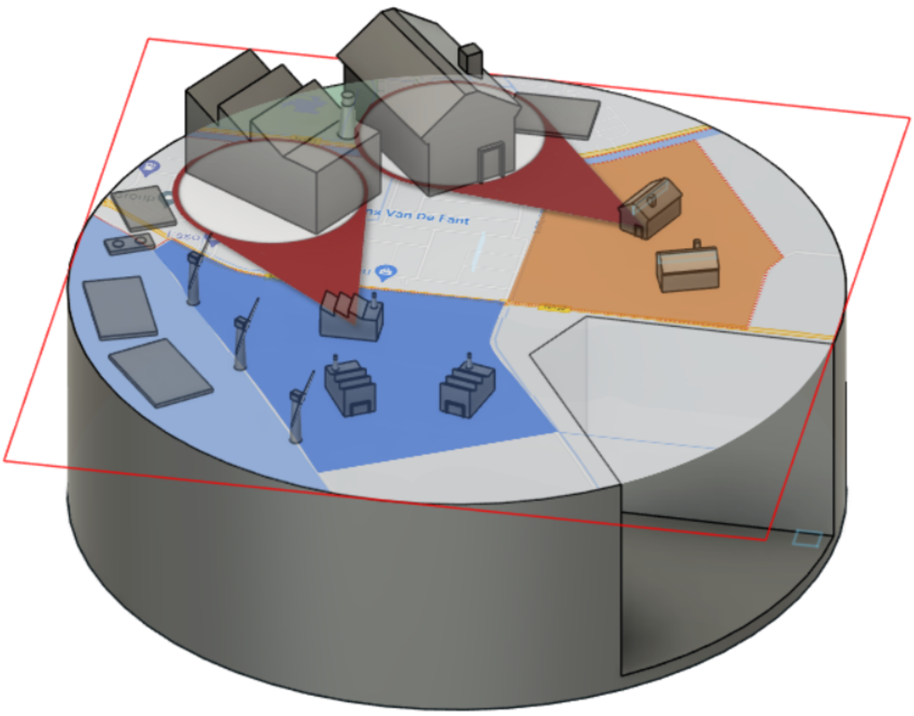

Figure 4.4: 3D model of final concept

4.4 Requirements

Based on the previously established stakeholders, the final design, and the conlusions of Chapter 2, multiple requirements have been established, see table 4.3.

Table 4.3: Requirements

Requirement	Must	Should	Could	Would
- Be a physical visualization (physicalization)	X			
- Be explained in Dutch	X			
- Explain the concept of 'net congestion'	X			
- Explain how a heat network works and show its energy flows	X			
- Explain how the solution presented helps in regard to net congestion	X			
- Be comprehensible enough for a non-technician to understand	X			
- Mention what the source energy is in the heat network		X		
- Mention what the seasonal buffer is in the heat network		X		
- Mention how a heat pumps function relates to a heat network		X		
- Be visually attractive		X		
- Be a stand-alone installation, which doesn't need a presentator		X		
- Engage debate and interaction among viewers		X		
- Break up the total installation into smaller parts to decrease the cognitive load		X		
- Grab the attention of bypassing observers		X		
- Be interactive and dynamic			X	
- Stimulate spacial awareness of the area around the Port of Urk and the Zeeheldenwijk			X	
- Illustrate the amount of energy flow directly proportional to data				X

Chapter 5

Specification

During the specification phase, the final concept outlined in Chapter 4 will undergo further detailed specification. This will involve several steps, the first of which is the creation of personas. Next, several user scenarios will be explored. Furthermore, the systems architecture will be elaborated. At last, functional and non-functional requirements will be established.

5.1 Personas

5.1.1 Persona 1: CEO of a fish processing company

To facilitate the communication of the advantages and requirements of the new heat network and electricity grid to prospective fish processing companies, a narrative has been developed. This narrative features a persona named Hendrik van Bruggen, who is the CEO of Holey Fish and owns one of the aforementioned companies, see Figure 5.1. For a zoomed-in version of this persona, see appendix A.

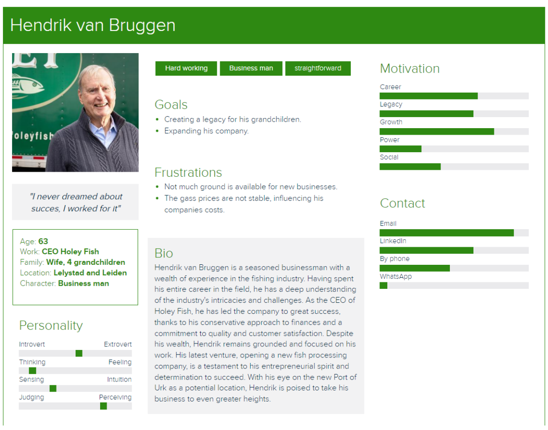

Figure 5.1: Persona 1: CEO of a fish processing company

Figure 5.2: Persona 2: Future household owner

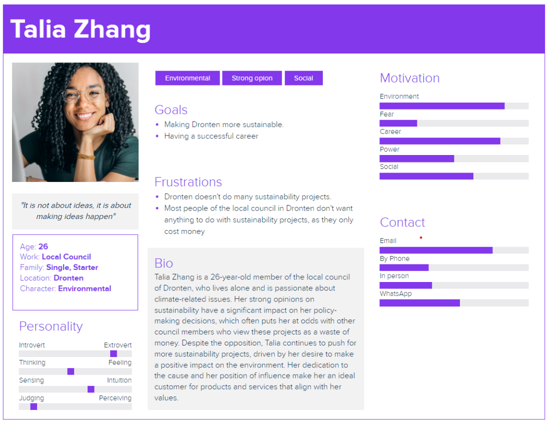

Figure 5.3: Persona 3: Local council member

5.1.2 Persona 2: Future resident of the Zeeheldenwijk

In addition, the use of physicalization is expected to educate prospective inhabitants of the Zeeheldenwijk. Consequently, a persona has been developed to represent an individual who intends to reside in the neighborhood. The persona in question is Robert van Zeulen, a long-time resident of Urk who works in construction, see Figure 5.2.

5.1.3 Persona 3: Local council member

Finally, the use of physicalization will serve as a model for sustainability initiatives in other municipalities. To this end, a persona has been developed to represent a local council member from a neighboring municipality, see figure 5.3. The persona's name is Talia Zhang, and the purpose is to gain a more comprehensive understanding of this objective.

5.1.4 Conclusions

The creation of the personas has resulted in the following conclusions. Firstly, it has been observed that the majority of individuals who will inhabit the Zeeheldenwijk are likely to be current residents of Urk. Accordingly, it has been determined that the 3D model homes should be modified to reflect a more traditional Urk-style architecture, in order to resonate better with the current population. Additionally, it has been noted that the existing design of the fish processing facilities is inappropriate. While the minimalist and abstract design resembling a factory may be acceptable to most individuals, it is unlikely to resonate with someone who owns a fish processing company, given that such structures have a distinctive appearance. Consequently, the 3D model of these facilities will also be revised. No alterations or adaptations were deemed necessary based on the persona representing a local council member from another municipality.

5.2 User scenarios

In this section, three user scenarios are explored. The use of a user scenario is to describe a realistic and relatable situation that illustrates how a future user will interact with the physicalization. The fictive characters used in these stories are the same personas that are created in the later section.

5.2.1 User scenario 1: CEO of a fish processing company

Hendrik van Bruggen, a seasoned businessman and the current CEO of Holey Fish, is currently involved in establishing a new fish processing company. One of the potential locations under consideration is the Port of Urk. Given his extensive experience, Hendrik prefers to personally assess locations before making substantial investments. While passing through Urk, he decides to visit the city hall of Urk. During his visit, he comes across an intriguing physicalization in the lobby. Upon closer examination, he discovers that the exhibit details the requirements and advantages of the upcoming heat network and the modifications to the energy grid, specifically related to the soon-to-be-established fish processing companies. Equipped with a clearer understanding of the situation, Hendrik concludes that the Port of Urk is the ideal location for his new venture.

5.2.2 User scenario 2: Future resident of the Zeeheldenwijk

Robert van Zeulen is a dedicated construction worker residing in Urk. He intends to relocate to the Zeeheldenwijk once the construction work there is completed. Unfortunately, Robert lost his identification card and needed to visit the city hall to obtain a replacement. While passing through the lobby, he noticed a physicalization with captivating lights, prompting him to take a closer look. Upon examination, he recognized the map displayed on top of the physicalization. Since his future plans involve moving to the Zeeheldenwijk, he read the accompanying text that provided information about the area. It informed him that the heat pump in his prospective house would be connected to a local heat network.

5.2.3 User scenario 3: Local council member

Talia Zhang, a 26-year-old member of the local council in Dronten, is deeply passionate about climate-related issues. As part of her work, she occasionally visits neighboring municipalities for meetings. While at the Urk city hall, she strolled through the lobby with an alderman from Urk, heading to grab lunch. As they passed by a physicalization display, Talia became captivated by the rotating windmills. Curious about the project depicted in the display, she inquired with the alderman. The alderman proceeded to explain the planned changes to the electricity grid and heat network in Urk. Inspired by these initiatives, Talia decided to arrange a meeting with the individuals responsible for these projects to explore the possibility of implementing similar endeavors in Dronten.

5.3 System architecture

The designed physicalization incorporates two distinct input factors. One input corresponds to the season, allowing for selection between winter and summer, while the other input pertains to wind speed, enabling differentiation between high and low wind conditions. The physicalization yields several outputs, including a visualization illustrating the flow of energy, a visual representation depicting battery charging or discharging, and the rotation of windmills. This structural arrangement is illustrated in Figure 5.4, denoted as the level 0 system diagram.

Figure 5.5 exhibits a system diagram at a more detailed level, illustrating the composition of the system itself, which consists of multiple hardware components. The inputs for season and wind speed are implemented in the form of buttons. These buttons transmit data to the system's controller, which subsequently directs the operation of various other components, based on the provided input. The first component

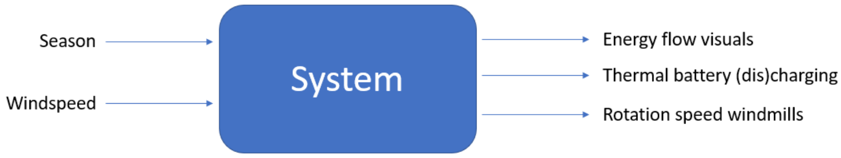

Figure 5.4: System diagram - Level 0

is an LED strip responsible for controlling the visualization of energy flow. The second component is also an LED strip, regulating the charging or discharging of the thermal battery. The final component consists of servos, responsible for rotating the windmills.

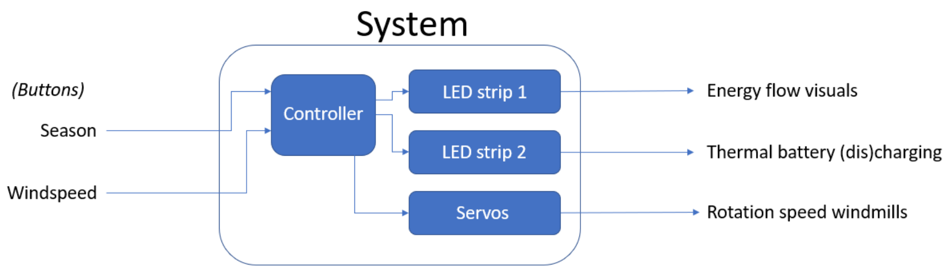

Figure 5.5: System diagram - Level 1

5.4 Requirements

With the help of the previously mentioned personas, the requirements mentioned in chapter 4 have been further refined and have been split up into functional and non-functional requirements. Furthermore, additional requirements have been added, which focus on safety, easiness of use, and resistance against vandalism.

5.4.1 Functional Requirements

Table 5.1: Functional Requirements

Functional Requirement	Must	Should	Could	Would
- Be a physical visualization (physicalization)	**X**			

Continued on next page

Table 5.1: Functional Requirements (Continued)

- Be explained in Dutch	**X**			
- Have the right American wire gauge (AWG) cable sizes to prevent overheating and melting of wires	**X**			
- Have a power supply that can handle the high currents the LED strip will require	**X**			
- Have a plug which can be plugged into a wall socket	**X**			
- Mention what the source energy is in the heat network		**X**		
- Mention what the seasonal buffer is in the heat network		**X**		
- Mention how a heat pumps function relates to a heat network		**X**		
- Include a secure mounting mechanism to prevent theft of the 3D printed buildings on top			**X**	
- Illustrate a map of Urk			**X**	
- Include moving parts			**X**	
- Illustrate the amount of energy flow directly proportional to data				**X**

5.4.2 Non-functional requirements

Table 5.2: Non-functional requirements

Non-functional requirement	Must	Should	Could	Would
- Ensure the user understands the concept of 'net congestion'	**X**			
- Ensure the user understands how a heat network works and show its energy flows	**X**			
- Ensure the user understands how the solution presented helps in regard to net congestion	**X**			
- Be comprehensible enough for a non-technician to understand	**X**			
- Be easy to power on	**X**			

Continued on next page

Table 5.2: Non-functional requirements (Continued)

- Be visually attractive	**X**	
- Be a stand-alone installation, which doesn't need a presentator	**X**	
- Engage debate and interaction among viewers	**X**	
- Break up the total installation into smaller parts to decrease the cognitive load	**X**	
- Grab the attention of bypassing observers	**X**	
- Be interactive and dynamic		**X**
- Stimulate spacial awareness of the area around the Port of Urk and the Zeeheldenwijk		**X**

Chapter 6

Realisation

In the following chapter, the realisation of the physicalization will be described, encompassing the physical construction, the hardware, the software, and the design elements of the physicalization.

6.1 Physical construction

The physical construction of the physicalization used multiple building techniques. Therefore, the following section is divided into three sections: laser cutting and woodworking, 3D printing, and sewing.

6.1.1 Laser cutting and woodworking

Laser cutting was the primary fabrication technique employed for various components of the physicalization. The initial focus was on creating the top layer, as depicted in Figure 6.1, which necessitated dividing the plate into four separate pieces due to the larger diameter of the circle involved. This division was accomplished by splitting the design vertically and horizontally, resulting in four individual plates. Subsequently, these plates were joined together, forming the complete top plate.

The same laser cutting technique was applied to the bottom plate, as displayed in Figure 6.2. However, unlike the top plate, the bottom plate featured pre-determined holes that facilitated the insertion of the legs. This design choice significantly sped up the assembly process by eliminating the need for precise measurements during leg placement.

In addition, the side plates and small plates utilized for text display were also subjected to laser cutting. However, the initial acrylic material did not adequately diffuse the light as desired. To address this issue, the acrylic plates underwent a sandblasting process. The difference between the untreated and sandblasted acrylic plates is illustrated in Figure 6.3.

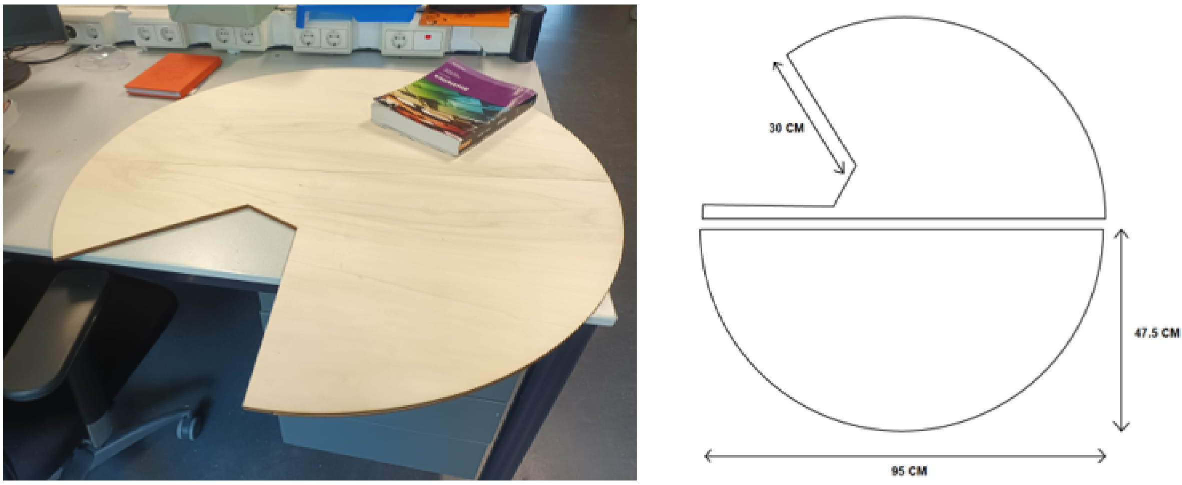

Figure 6.1: Laser-cutted top plate

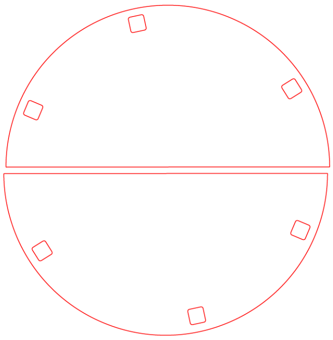

Figure 6.2: Illustrator file - bottom plate

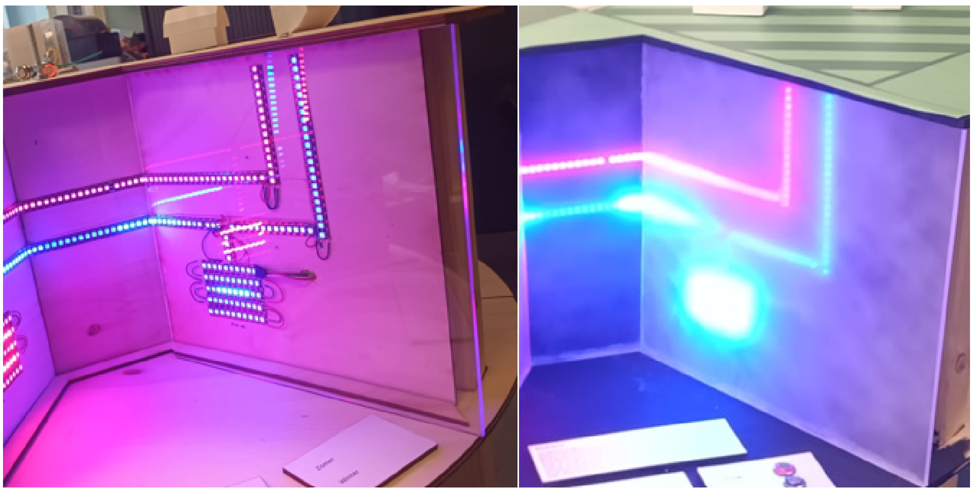

Figure 6.3: Sand blasting acrylic plates - before and after

In addition to the laser-cut components, the frame of the physicalization was constructed using 44x44 mm wooden beams. An early stage of development is depicted in Figure 6.4.

Figure 6.4: Wooden frame

6.1.2 3D printing

The fabrication process involved the utilization of 3D printing for manufacturing the fish processing companies, houses, and windmills within the physicalization. Each of these components underwent multiple design iterations to achieve the desired outcomes. Initially, the fish processing companies were conceived as small factories, as detailed in Chapter 4 regarding the initial concept. However, upon consultation with the client, it was revealed that most fish companies exhibited a box-like architectural structure. Subsequently, during a site visit, the architectural characteristics of existing fish processing companies were observed. The resulting redesign is depicted in Figure 6.5.

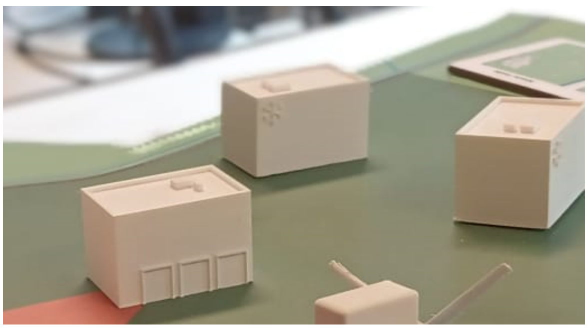

Figure 6.5: Redesign fish processing company

Moreover, in response to the client's feedback regarding the desire for a more personalized touch of Urk, modifications were made to the original house design.

The revised design used the architectural style characteristic of Urk, as depicted in Figure 6.6.

Figure 6.6: Redesign house in style of Urk architecture

Finally, the design of the windmills required careful consideration for the integration of a servo. Given the intention to maintain a relatively modest size for the windmills to avoid excessive attention, the physical design underwent multiple iterations due to the recurring issue of thin walls. Ultimately, the refined design that successfully resolved the thin wall issue is depicted in Figure 6.7.

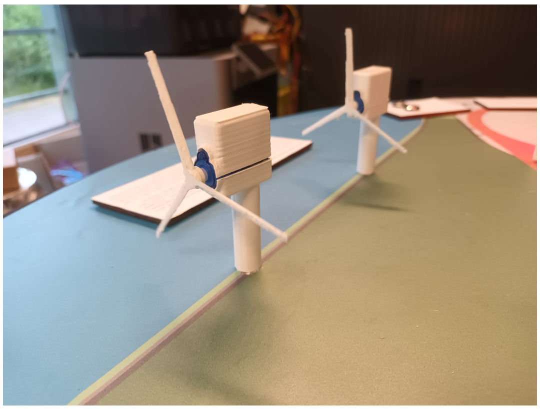

Figure 6.7: Final wind mill design

Furthermore, in response to the client's requirement for vandalism resistance, a strategic approach was implemented to secure the houses and fish processing companies within the physicalization. To achieve this, M8 bolts were utilized to fasten the 3D printed units to the wooden structure. The 3D printed units were designed with embedded threaded inserts, as depicted in Figure 6.8, ensuring a sturdy and secure attachment mechanism.

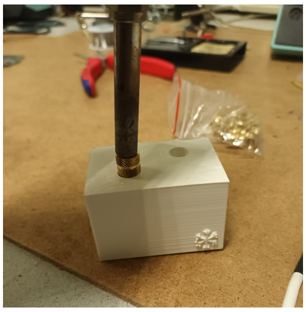

Figure 6.8: Threaded insert

6.1.3 Sewing

In order to ensure the concealment of the hardware components from the viewer's perspective, a curtain was placed around the wooden frame. Given the high cost that come with purchasing a pre-sized curtain, a decision was made to sew a custom-sized curtain. The process of this undertaking is shown in figure 6.9

Figure 6.9: Sewing process

6.2 Hardware

Different hardware components where used for the realisation of the physicalization. The following part will go into detail for each hardware component, explain the decision for the hardware component, and explain how it will be connected into the system. Figure 6.10 shows a full schematic of the whole system.

6.2.1 LED strips

To showcase the energy flow within the heat network, the (dis)charging of the battery, and the (dis)charging of the thermal energy storage's, the decision was made

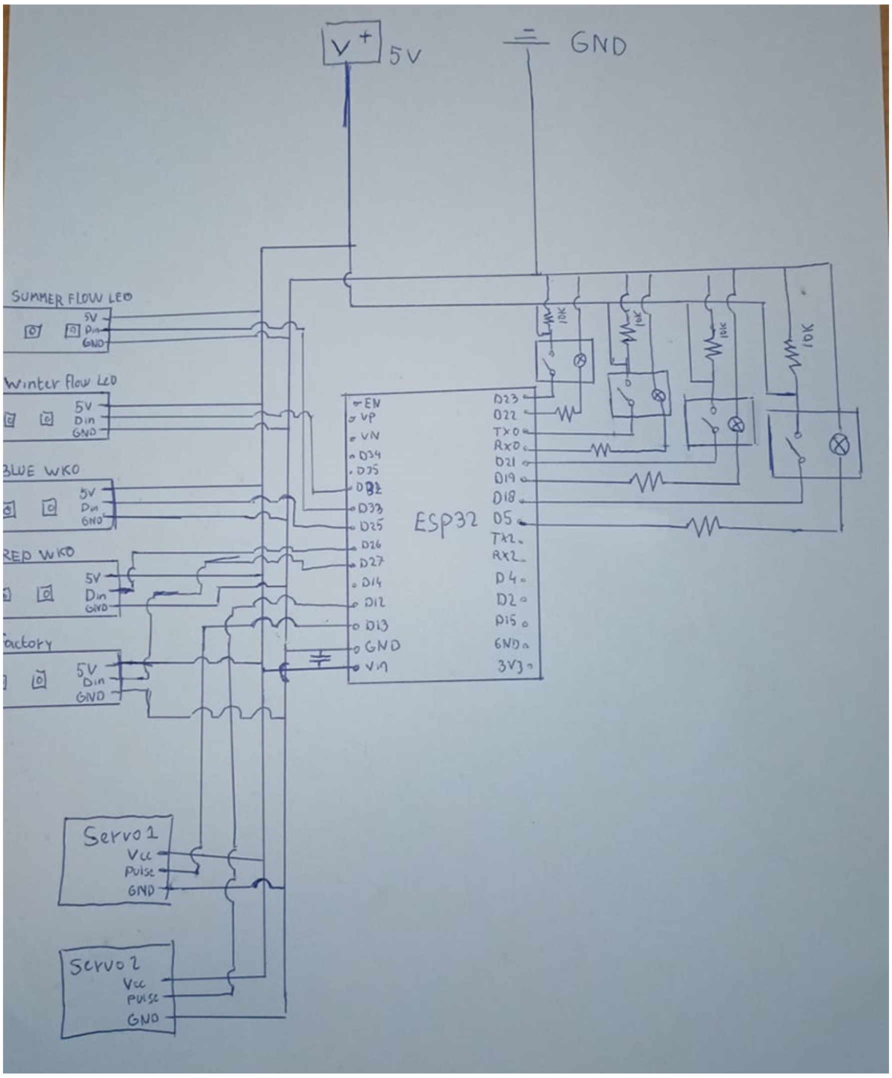

Figure 6.10: Schematic hardware

to use multiple WS2812 LED strips. A WS2812 is a RGB LED strip which can display different colors on each individual LED. To reduce costs, the decision was made to use an IP value of 30, which means the LED strip is not waterproof. As the installation will be located inside, this was not deemed a problem. Furthermore, the decision was made to use a pixel density of 144, as the LED strip would need to showcase a flow of energy in a rather small area.

Heat network

The configuration of the LED strips utilized for the heat network is visually depicted in Figure 6.11. Additionally, Figure 6.12 presents an illuminated representation of the aforementioned structure. Figure 6.13 showcases the charging animation of the thermal energy storage, which is also the discharging animation when reversed.

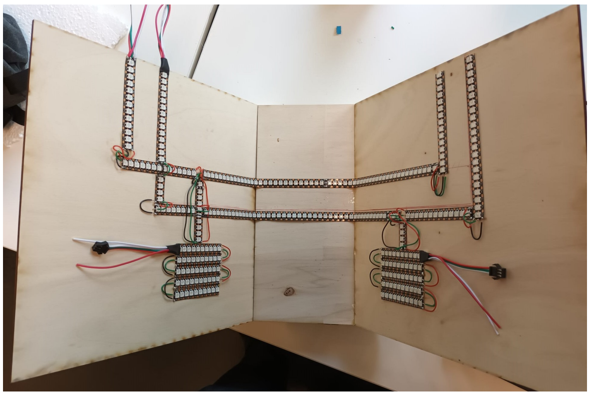

Figure 6.11: Structure LED strip heat network

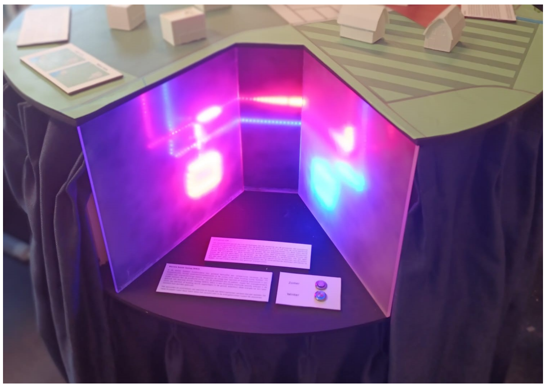

Figure 6.12: Illuminated heat network

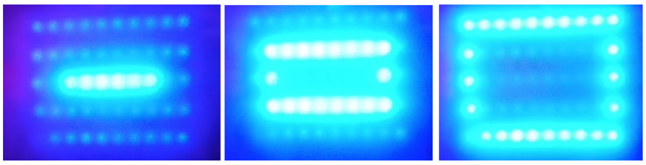

Figure 6.13: Thermal energy animation shown in 3 consecutive states

Battery visualization

In order to demonstrate the potential for energy storage by utilizing the cooling machines as batteries, three LED strips are arranged in parallel. These LED strips share a common digital pin for connection, as they exhibit identical behavior. Figure 6.14 visualizes the charging animation, and Figure 6.15 visualizes the discharging animation.

6.2.2 Servo

In order to facilitate the rotational movement of wind turbines within the installation, two Motor Servo SG90s were used. These servos can not fully rotate by default.

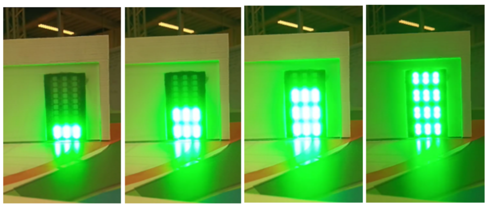

Figure 6.14: Charging animation shown in 4 consecutive states

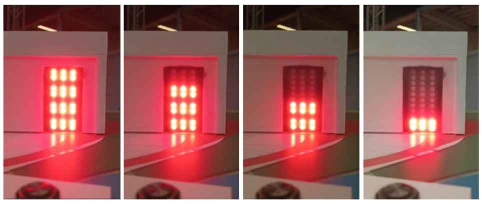

Figure 6.15: Discharging animation shown in 4 consecutive states

Nevertheless, a slight modification [48] was implemented to enable them to achieve full rotation. Both servos were connected to the 5V power supply and ground. Initially, the original design suggested connecting both servos to a single digital pin, assuming they would rotate at the same speed. However, it was observed that the rotation speeds varied between the servos despite having identical input values. Consequently, two separate digital pins were utilized to individually control each servo's input, ensuring that their rotation speeds were nearly identical.

6.2.3 Buttons

The physicalization uses four metal reset 16mm push buttons to give the user the ability to select between different modes. The first option the user has is to select between 'summer' and 'winter'. Each button also has an LED ring built into it. The color of the summer LED is red, and the winter one is blue. The other option the user has is to select between 'a lot of wind' and 'little wind'. Both those LEDs have a yellow LED ring, as the are in the electricity area of the installation. The integration of these buttons into the installation are visualized in Figure 6.16

As the power for each LED in each button will depend on the state of the system, each LED of each button will be connected to a digital pin. As the supply voltage is 3.3V, the forward voltage is 3V, and the forward current is 15 mA, a 20 Ohm resistor will be put in front of each buttons LED. Furthermore, a pull down resistor of 10k will be put after each button, connected to the ground, to prevent the digital pin from floating. For a visual representation, see the schematic in figure 6.17.

Figure 6.16: Integration of buttons

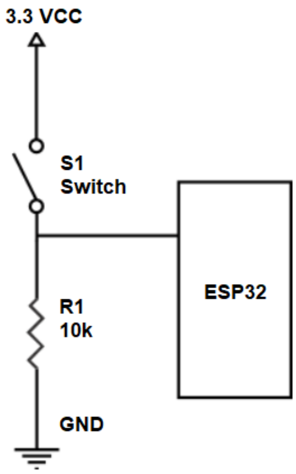

Figure 6.17: Schematic of the switch component within the button

6.2.4 ESP32

As the micro chips used in Arduino boards would not have the processing power to animate multiple LED strips liable at the same time, an ESP32 had been chosen. Furthermore, as the installation has multiple parts which require steered control from micro chips pins, it was deemed necessary to have a micro chip which has a wide variety of pins. Close attention was paid to the selection of digital pins used, as not all pins on the ESp32 can be used as either input or output [49]. See figure 6.18 for the pinout diagram of an ESP32. Fortunately, the ESP32 has enough pins that all pins used, see figure 6.19, can either be input or output. Furthermore, all pins have the capability to create a PWM signal. Some pins will also give a PWM signal at boot, like the D5 pin, but this is not deemed as a problem.

In addition, a capacitor was placed between the Vin and GND pin of the ESP32 module. This is due to the fact that a color change in the LED strip may result in a substantial voltage drop, caused by several factors such as resistance, inductance, and power supply quality. The smart LEDs are fitted with a small microcontroller that is susceptible to brownouts, resulting in unpredictable resets. The purpose of the capacitor is to mitigate such occurrences by buffering the voltage drops observed in proximity to the capacitor and, consequently, the first LED.

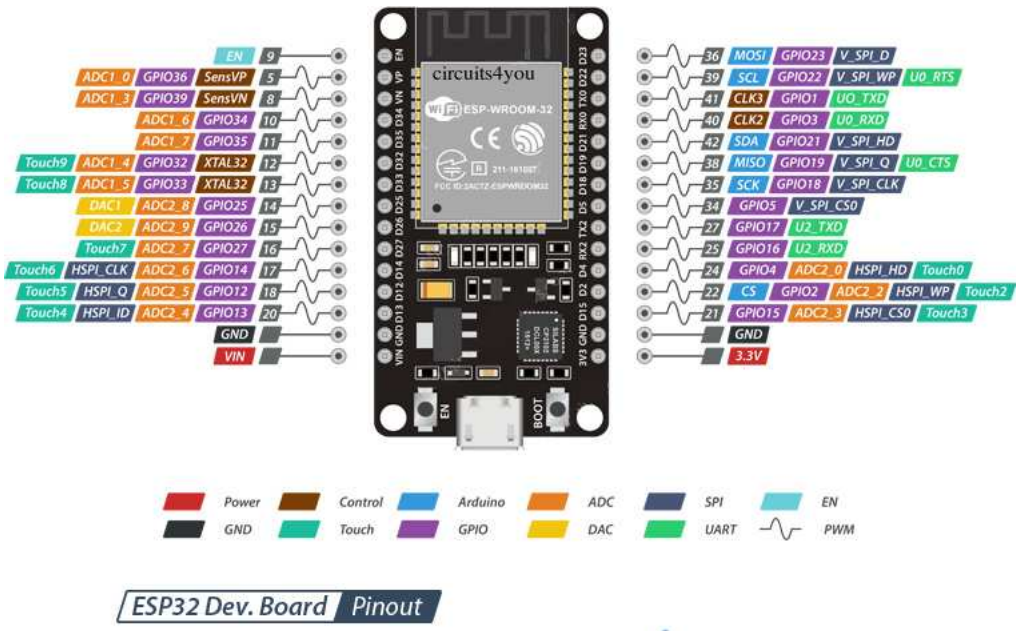

Figure 6.18: Pinout diagram of an ESP32

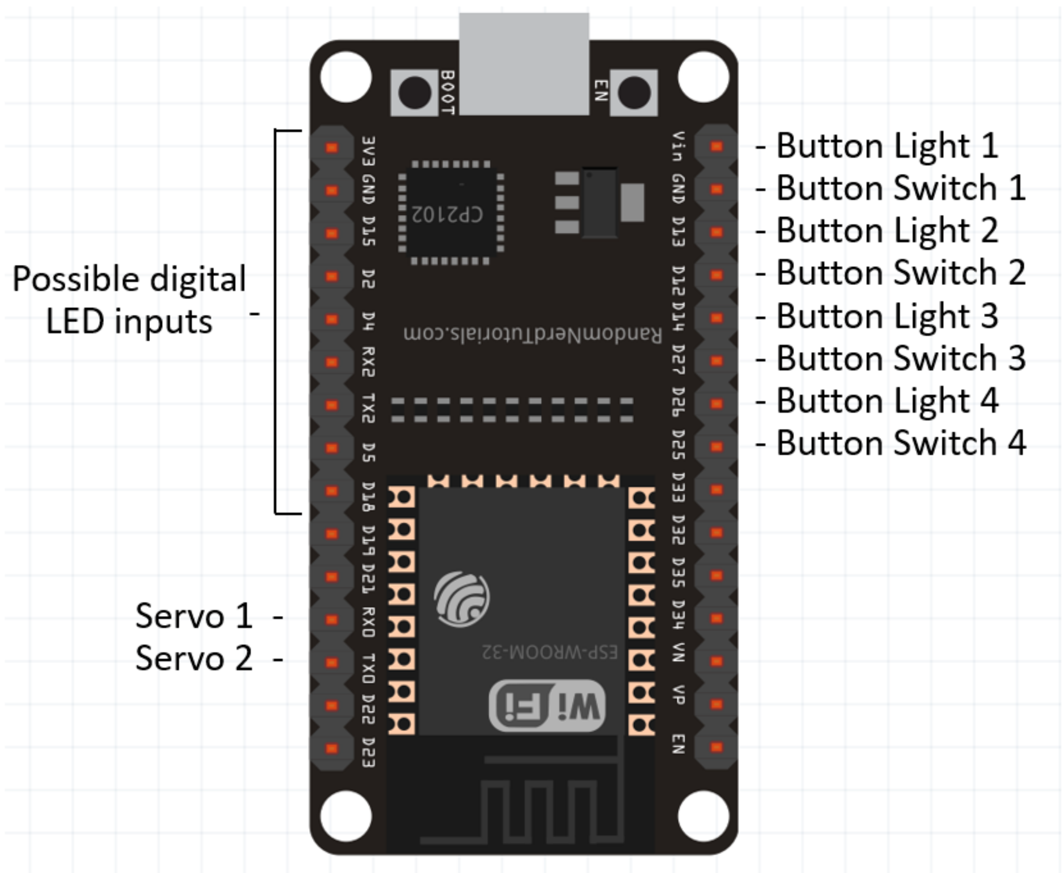

Figure 6.19: Selection of pins used on the ESP32

6.2.5 Power Supply

In order to ensure user-friendliness, the installation is powered by connecting a plug to a wall socket. To make this possible, a power supply is necessary to convert the supplied energy by the wall socket into a suitable form. As the system uses a lot of LED strips, it was deemed necessary to have a power supply which can handle a significant amount of current. Consequently, a 5V, 26A Mean Well switching power supply had been deemed appropriate for this task.

6.2.6 Wires

Due to the anticipated high currents involved in the physicalization process, appropriate wire sizing were deemed essential to prevent overheating and potential fire hazards. To ensure safe operation, reference was made to the wire sizing table provided by the American Boat and Yacht Council (ABYC), as depicted in Figure 6.20. Based on this guideline, it was determined that the wiring between the power supply and the PCB requires a wire gauge value of 14 AWG, while the connections linking the LED strips and servo demand wires with a value of 16 AWG. In contrast, standard 22 AWG wires can be used for connections from the digital pins.

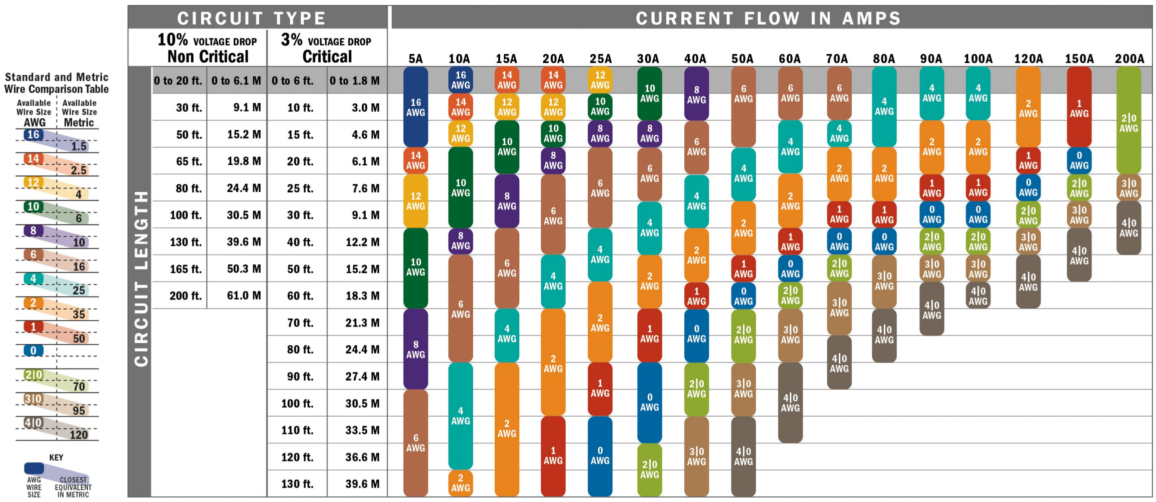

Figure 6.20: ABYC table for wire selection

6.3 Software

The software implementation for the ESP32 micro controller is developed using C++ programming language within the Arduino Integrated Development Environment (IDE). Given the complex nature of the installation, the software was composed incrementally, focusing on individual components. The software can be categorized into several distinct components, namely: button control, energy flow control, thermal energy storage control, charging battery control and servo rotation control. Each of these components will be briefly described in the subsequent section. The complete code implementation can be found in Appendix A.

6.3.1 Button control

The code responsible for button functionality is relatively straightforward and consists out of two main components: the button itself and the accompanying LED. The button is connected to a digital pin, which monitors its state. When the state of the pin is high, it signifies that the button is pressed, subsequently modifying the relevant global variable. On the other hand, the LED component is connected to a separate digital pin. Depending on the specific button and the system's current state, the pin may emit a voltage output, which results in the LED turning on.

6.3.2 Energy flow control

The energy flow is controlled by the 'Flow' function, which is responsible for creating a flowing pattern on a specific set of LED strips. It begins by clearing the LED strip and setting a default color for all the LEDs. The function then divides the LED strip into multiple flows based on the number of flows specified. Each flow is represented by a sequence of LEDs that gradually increase in brightness, creating a flowing effect. The flowing pattern is updated based on time, and the brightness of the LEDs is adjusted accordingly. The function finally displays the updated LED strip with the flowing pattern. The specific color and parameters of the LED strips are determined by the ledPin parameter passed to the function.

6.3.3 Thermal energy storage control

The control of the thermal energy animation is done with use of different stored patterns and the function 'wkoMovement'. The patterns are stored arrays of the index of each LEDs position, so all LEDs of that pattern can be turned on. For a better understanding, see Figure 6.21. The wkoMovement function takes parameters such as the LED strip object pointer, the pattern index, the RGB color values, and a boolean for reversing the pattern.

Inside the function, the strip is cleared by setting all LEDs to a default color, either red or blue. The appropriate pattern and its size are determined based on the pattern index. The LED strip is then updated according to the current pattern by

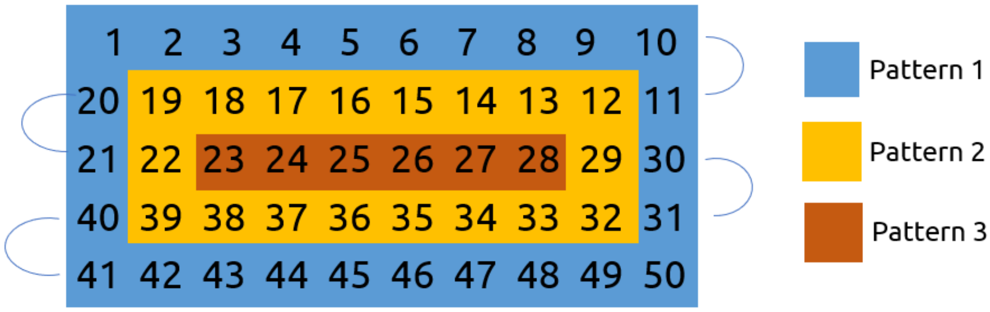

Figure 6.21: Patterns thermal energy storage

turning on specific LEDs based on the pattern array. The LEDs in the pattern are set to full brightness. Finally, the function increments the pattern index, wrapping around if necessary, based on the direction specified by the reverse boolean. Therefore, the discharging can also be animated with the same function.

6.3.4 Charging battery control

The (dis)charging of the battery on the side of the fish company is code-wise much like the Thermal energy storage control. However, instead of saving the patterns as list of index arrays, all the LEDs that need to light up are hard coded into a switch case.

6.3.5 Servo rotation control

The servo control is facilitated through the utilization of the servo library. By utilizing the servo.write function, the rotation of a servo can be modified by adjusting its position by one degree. The implementation of this functionality requires just a single line of code.

6.4 Design elements

Having covered the individual physical and hardware components, this section focuses on the design elements inherent in the physicalization. To provide a comprehensive perspective on the overall design, Figure 6.22 showcases the finalized physicalization at the city hall of Urk.

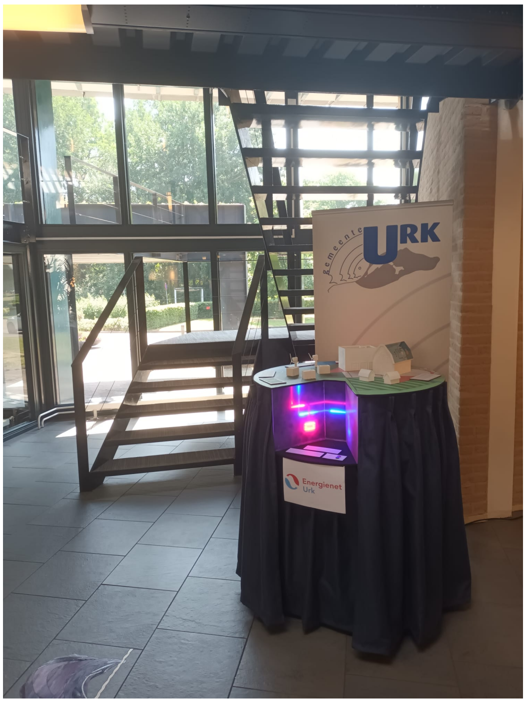

Figure 6.22: Physicalization at location

6.4.1 Map of Urk

In order to provide a clearer sense of the project's geographic location, a decision was made to include a map beneath the houses. This map was created using the online tool 'Snazzy Map' to achieve the desired look. The resulting map is shown in Figure 6.23.

6.4.2 Heat pump explanation

On the side of the bigger house, a depiction of the functionality of a heat pump works is given, see Figure 6.24. The illustration itself was created by modifying an existing visualization with Adobe Photoshop and is visualized in Figure 6.25.

6.4.3 Informational texts

In total, a collection of six distinct explanatory texts have been written, which can be found in Appendix C. Although it has been observed that the amount of text can be overwhelming, the titles of each text would limit the user to read unnecessary information for them. It is worth noting that these texts have been written in the Dutch language, aligning with the intended target audience of the physicalization.

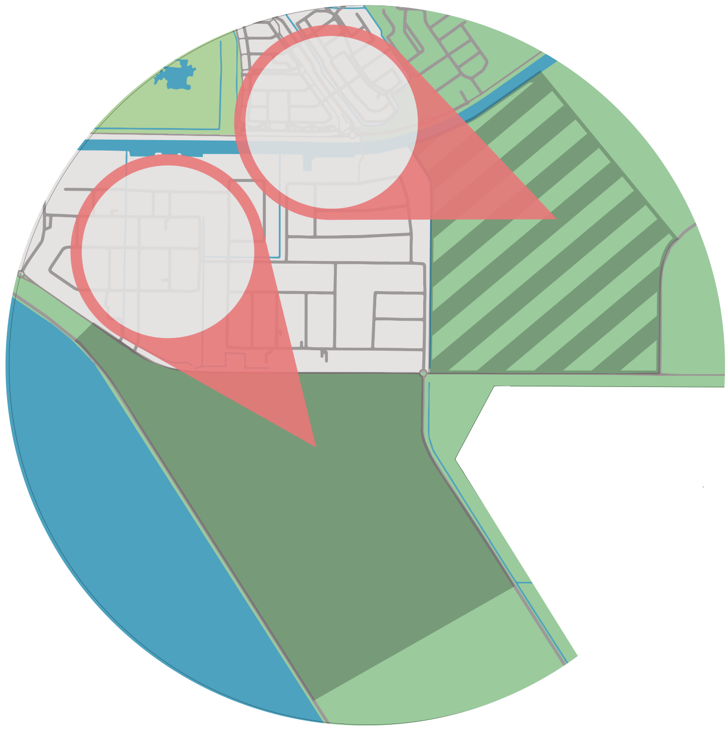

Figure 6.23: Map of Urk

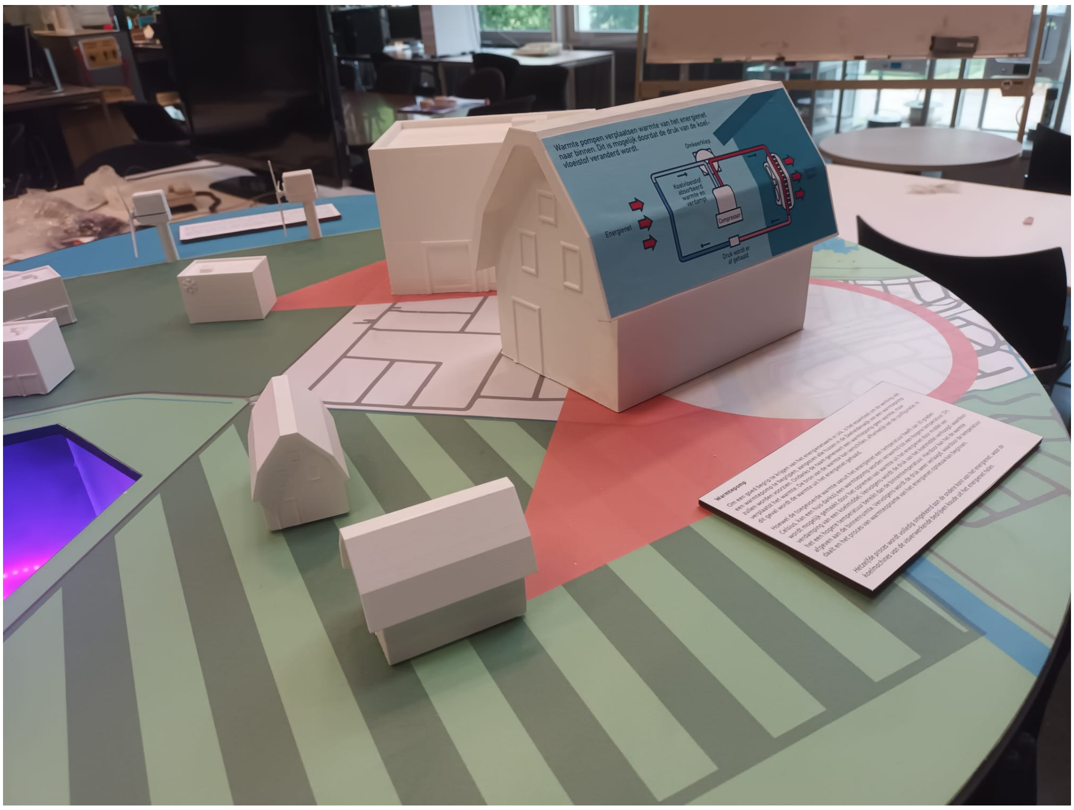

Figure 6.24: Side view of heat pump illustration

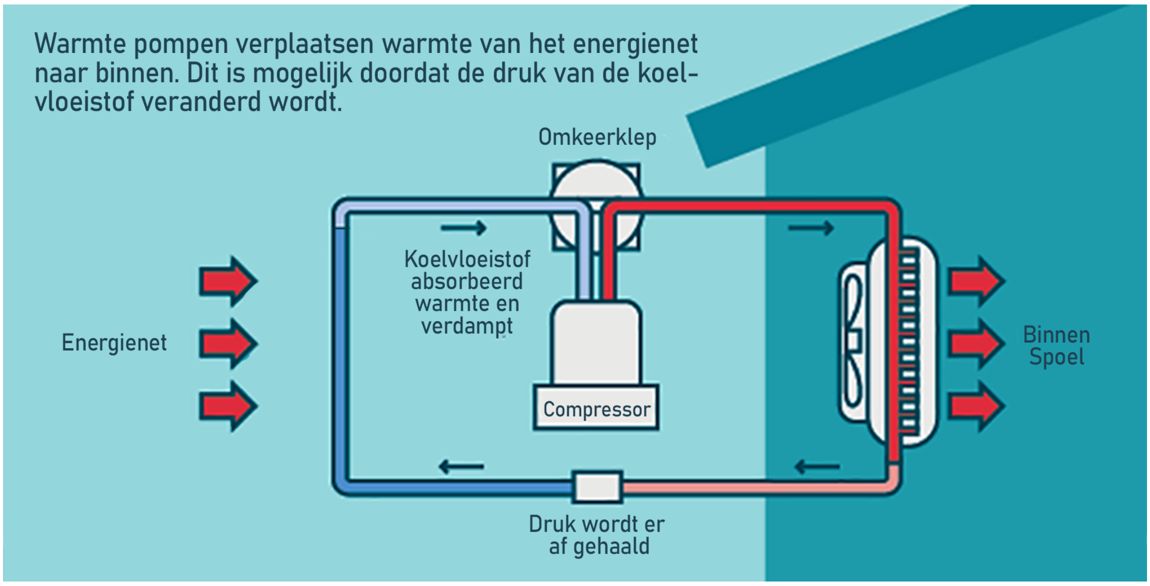

Figure 6.25: Heat pump illustration

Chapter 7

Evaluation

Within this chapter, a comprehensive evaluation of the physicalization shall be conducted. Primarily, the obtained evaluation results of the survey will be discussed. Subsequently, the consultation with the client will be presented. At last, both the functional and non-functional requirements will be assessed.

7.1 Survey

The evaluation was done in the city hall of Urk, at the place where the physicalization would be located. The evaluation had the following structure: first, participants would walk freely and interact with the physicalization. After some period, the participants where asked if they would like to fill in a survey about the physicalization. In total, 8 people filled in the survey (n=8). The main aim of the physical handed-out survey was to give an indication if the physicalization indeed helped observers better understand the presented subjects, like net congestion and the workings of a heat network. For a a clear overview of the survey, see Appendix D.

7.1.1 Results survey

Demographic questions

The first few questions of the survey where demographic questions. The age of the participants ranged form 27 to 56, with an average 46.3, a median of 51 and a mode 54 and 51 (each appeared 2 times). The division of gender was 50% male and 50% female. Moreover, it was observed that all participants were employed at the city hall of Urk, which was the reason they were present at that time. The professions of the participants varied, but none of them had a technical background.

physicalization-related questions

The rest of the survey focused on assessing participants' perceptions of the physicalization itself. Firstly, it can be concluded that the physicalization successfully grabbed attention of bypassing people, as the researcher only approached individuals who were already engaged with the physicalization to participate in the study. The question, which asked the participant what grabbed there attention, revealed that 2 (25%) of the participant were attracted by the lights, 1 (12.5%) participant was attracted by the aesthetics of the physicalization, and that 5 (62.5%) were attracted by the physicalization itself.

In terms of aesthetics, all participants (100%) answered they found the physicalization aesthetically pleasing. This founding is in alignment with results of the query which aimed to investigate the first impression of the participants about the physicalization. Here, 5 participants included in their answer that he physicalization is aesthetically pleasing (62.5 %). Furthermore, 4 answers to this question included that the physicalization was very clear (50%) and 2 participants included in their answer the physicalization was fun to engage with(25%).

One query aimed to assess the participants' comprehension of which location the physicalization displayed. All participants (100%) indicated that this was very clear. Notably, 1 participant (12.5%) added in their response that the clarity was more apparent when standing in close proximity to the physicalization, whereas from a distance, this would not be the case. However, it is important to acknowledge that all participants were employees of the city hall of Urk, thereby explaining their familiarity with the region surrounding Urk.

In order to assess participants' level of knowledge prior to engaging with the physicalization, the survey included a question about their familiarity with the topics presented. The findings revealed 3 participants (42.9%) knew already some basic principles, 1 participant (14.3%) heard about the subjects in the news, 1 participant (14.3%) indicated he had no prior knowledge, 1 participant (14.3%) knew about the heat network projects, and 1 participant (14.3%) stated he didn't knew much about the subject. As one participant answered yes to the open-ended question, it is assumed this participant misread the question and therefore the answer was excluded.

The following questions of the survey aimed to assess participants' acquisition of knowledge from the physicalization. Participants were posed questions about net congestion, the solution for net congestion, and the functioning of the heat network. The findings revealed that, following their interaction with the physicalization, 5 (62.5%) answers indicated that the participant did not possess a comprehensive understanding of net congestion, see Appendix D for the more detailed answers.

However, when asked about the solution for net congestion, multiple participants showed some understanding of one the two principles. 1 participant (16,7%) said you need to locally store and use the produced electricity, 1 participant (16,7%) mentioned the utilization of the fish companies, 1 participant (16,7%) mentioned a closed system where no transport was done on the high-voltage lines, 1 participant (16,7%) said that the electricity route was made smaller. One response (16,7%) mentioned the utilization of thermal energy storage and shortening the electricity route. However, this answer also included the use of heat pumps, indicating a slight blending of the understanding of net congestion and the heat network. Conversely, the final response (16,7%) provided an entirely incorrect solution, as the participant proposed their own alternative approach to mitigate net congestion, by lowering taxes.

When queried about the heat network, the majority of valid answers showed comprehension about the subject. Nevertheless, it is worth noting that three out of the eight answers were deemed invalid, as they stated they could explain how a heat networks work, but did not elaborate. Among the remaining five participants who provided detailed and informative responses, one response (20%) acknowledged the storage of energy in the ground, two responses (40%) mentioned the presence of a closed system where the excess heat generated by the port of Urk's cooling process can be utilized to warm the houses in the Zeeheldenwijk area, one response (20%) indicated an exchange of heat and cold, and the final valid response (20%) stated that companies generate both heat and cold which can be utilized by the houses, which is only partly correct.

At last, the survey investigated if the physicalization did not overwhelm the observer with information. A likert-scale assessed this aspect, where 1 was 'very clear' and 7 was 'overwhelming'. Answers ranged from 1 to 7, with an average of 3.25, a median of 2.5 and a mode of 2 (appeared 3 times). In a follow-up question, the 6 of participants (75%) indicated that no specific parts where unclear or difficult to understand. 2 participants (25%) stated they did not understand the workings of a heat pump after inspecting the physicalization.

7.2 Consultation client

The last consultation with the client took place on the same day of taking of the survey, at the city hall of Urk. The client indicated they were very positive about the end result. Earlier projects by other students had resulted into digital end results, like a video. The client highlighted that the physicality really helped sell the projects.

When asked about their expectations regarding the final outcome, the client responded by stating that they had a clear understanding of what to expect. This was attributed to the regular updates and progress reports provided to them throughout the process, which they regarded positively.

7.3 Functional and non-functional requirements evaluation

In Section 5.4, a set of requirements was outlined for the project. In order to assess the fulfillment of these requirements, each one will be assigned a rating. A rating of three stars (***) will signify that the requirement has been fully met. A rating of two stars (**) indicates that the requirement has been pursued, but cannot be deemed fully satisfied. A rating of one star (*) signifies that the requirement has not been fulfilled.

7.3.1 Functional requirements

The evaluation of the functional requirements, being in the form of a checklist, was performed by the researcher himself. This evaluation took place once the construction of the physicalization had been completed.

Table 7.1: Functional requirement evaluation

Functional Requirement	Execution	Must	Should	Could	Would
- Be a physical visualization (physicalization)	***	**X**			
- Have the right American wire gauge (AWG) cable sizes to prevent overheating and melting of wires *(Despite the physicalizations overall safety in terms of cabling, it is worth noting that certain low AWG cables are redundant, as higher AWG cables are placed in series with them)*	**	**X**			

Continued on next page

Table 7.1: Functional requirement evaluation (Continued)

- Have a power supply that can handle the high currents the LED strip will require	***	X		
- Have a plug which can be plugged into a wall socket	***	X		
- Mention what the source energy is in the heat network	***		X	
- Mention what the seasonal buffer is in the heat network	***		X	
- Mention how a heat pumps function relates to a heat network	***		X	
- Include a secure mounting mechanism to prevent theft of the 3D printed buildings on top *(The houses and fish processing companies are securely fastened using M8 bolts and threaded inserts. Therefore, it can be assumed those are secure. However, the wind mills are glued on due to wiring constraints)*	**			X
- Illustrate a map of Urk	***			X
- Include moving parts	***			X
- Illustrate the amount of energy flow directly proportional to data *(As indicated by the Moscow rating of this requirement, this requirement is not full filled)*	*		X	

7.3.2 Non-functional requirements

The evaluation of the non-functional requirements is based on the results of the survey, the observations made during the evaluation, and the latest consultation with the client.

Table 7.2: Non-functional requirement evaluation

Non-functional Requirement	Execution	Must	Should	Could	Would
- Ensure the user understands the concept of 'net congestion' *(Although the physicalization did mention what net congestion is, 62.5% people did not grasp the concept after their interaction)*	**	**X**			
- Ensure the user understands how a heat network works and show its energy flows *(83% of the participants had a basic understanding after their interaction with the system. However, they did not fully understand the concept)*	**	**X**			
- Ensure the user understands how the solution presented helps in regard to net congestion	***	**X**			
- Be comprehensible enough for a non-technician to understand	***	**X**			

Continued on next page

Table 7.2: Non-functional requirement evaluation (Continued)

- Be easy to power on *(Although this requirement was not tested in the survey, the researcher asked multiple people to power the system on during the building process, where all were successful)*	***	**X**	
- Be visually attractive	***		**X**
- Be a stand-alone physicalization, which doesn't need a presenter *(The majority of information was readily understood by the participants without any direct interaction with the researcher. However, certain topics required additional clarification)*	**		**X**
- Engage debate and interaction among viewers *(During observation of bypassing people, it was noticed most people talked about the project with each other)*	***		**X**
- Break up the total physicalization into smaller parts to decrease the cognitive load *(The results showed that half of the participant found the amount information overwhelming)*	*		**X**

Continued on next page

Table 7.2: Non-functional requirement evaluation (Continued)

- Grab the attention of bypassing observers	***	**X**
- Be interactive and dynamic	***	**X**
- Stimulate spacial awareness of the area around the Port of Urk and the Zeeheldenwijk	***	**X**

7.4 Conclusion

Upon evaluating the requirements and consulting with the client, it can be concluded that the final outcome has been well-received with the majority of the requirements successfully met. Nonetheless, the physicalization does exhibit certain limitations. The survey results revealed that participants possessed a general understanding of the heat network concept. However, the notion of utilizing the cold produced by the houses in return did not entirely resonate with them. Furthermore, most participants could not recall what net congestion was. Nevertheless, most participants could recall one of the solutions for net congestion.

Chapter 8

Discussion and future work

While the physicalization was regarded as a successful product by the client, there remains room for further improvements. However, since the physicalization has already been installed in Urk as the final version, this chapter will primarily concentrate on providing recommendations for a hypothetical version 2 of the product. Furthermore, it will look at the possibility of using physicalizations to visualize other projects.

First of all, improvements can be made to enhance the installation's resilience against vandalism. In its present state, the top is covered with paper, but placing an acrylic plate on top of it would mitigate the risk of scratches and prevent the removal of the paper covering. Similarly, the design of the windmills could be reassessed. Currently, the buildings are securely fastened with M8 bolts, but because of wiring, the windmills lack the same level of security. Lastly, although the hardware is concealed by a curtain, it remains accessible by pulling it away. Introducing a more concealed inner component would enhance overall security of the hardware.

Secondly, the evaluation showed that concepts as net congestion and the heat network were not fully comprehended by the participants. Therefore, future iterations can benefit by explaining these concepts in a different way. As the concept of returning cold was one of the major parts participants did not understand about the heat network, it is suggested that this part would be extra highlighted by emphasising the heat pump part even more.

Thirdly, the current physicalization merely illustrates the direction of energy stream. It is not based on data. This also raises the question if the installation even could be referred to as a data physicalization. However, future iterations could create a physicalization where the energy flows are based on data. Letting the brightness, for example, of the lights correlate with the amount of energy transported based on data could make the system a more accurate representation reality. Other variables, which the current installation already has, that could be used are the amount of flows and the flow speed.

At last, the current physicalization is tailored to the specific projects it wanted to visualize. Although this project has been finished, it can serve as a successful model for future physicalizations. Therefore, future research can be done in the use of physicalizations as a communicative tool, how such a tool stimulates comprehension within different topics, and for which topics physicalizations do not work.

Chapter 9

Conclusions

This research, commissioned by Enodes, aimed to explore the effectiveness of a physicalization in conveying information about current energy projects in Urk, such as the new heat network and the modifications to the electricity grid, to individuals without a technical background. In order to achieve this objective, a comprehensive understanding of the projects, background knowledge, literature on physicalizations, and the relevant stakeholders was necessary.

This research relied on a literature review to address the following three sub-questions: How is the electricity grid operated and what are its short-comings in relation to connecting new and renewable energy sources to the grid?; What are the primary components of a heating network, and how do these components interact with each other?; What are the various ways in which physicalization can serve as an effective means of communication, and what are the design patterns that underlie its efficacy?

Firstly, net congestion was defined as ”either too much supply of electricity and too little demand, or too much demand and too little supply”. Moreover, it was determined that understanding the various voltage levels of the electricity grid was crucial to comprehend the new energy path trajectory in Urk. Regarding the heat network, it was determined that a comprehensive understanding of its key components was essential. These components include the heat source, the seasonal buffer, and the households. Additionally, it was concluded that a deeper understanding about the heat network was not feasible, without an understanding of a heat pump. Regarding physicalization, no singular definition could be assigned to the term, but literature about design spaces and design principles for physicalizations have been utilized during the ideation phase.

The stakeholder analysis revealed that the impact of the proposed projects extended beyond the fish processing companies and households in the Zeeheldenwijk. It identified additional stakeholders, such as Dutch municipalities, including Urk, and the industries responsible for implementing the heat network. Later consultations with the client further emphasized the significance of these stakeholders. The client highlighted the need to convince the local council of Urk regarding the project and emphasized that the invitation to tender for companies interested in implementing the heat network is still open.

With help of the established background research, a successful prototype had been created, utilizing techniques as woodworking, laser cutting, 3D printing, sand blasting and sewing.

After the realization phase, an on-site evaluation of the physicalization was conducted, followed by the presentation of the physicalization to the client. The client's response to the physicalization was highly positive. Evaluating the survey results, it was found that a majority of participants found the physicalization visually appealing and that the presented information effectively informed them about the subjects. However, some shortcomings were observed. Participants did not fully comprehend the concept of net congestion and lacked a complete understanding of the workings of a heat network. Nonetheless, they did recognize foundational principles related to the subjects.

To address the research question "How can, using a physicalization, people without a technical background be well informed about the needs and benefits of the newly designed heat network and energy grid of the new Port of Urk business park?" the created physicalization serves as one solution. The prototype follows specific design principles. In terms of content, it visually depicts the components of the heat network, including the energy source, seasonal buffer, and households. It also explains the heat pump and clarifies the distinct trajectory of electricity in Urk due to the absence of a switch to the high-voltage line. Additionally, it emphasizes the significance of fish processing companies' cooling machines for network flexibility. Regarding the visual aspects, the physicalization aims to be visually appealing, with distinct sections to reduce cognitive load, and incorporates interactive elements to engage the viewer. While the current physicalization has been successful in its realization, it still possesses certain limitations, as mentioned in the previous paragraph.

Finally, the realization of projects like the new heat network and energy grid in Urk are crucial for meeting the national climate agreements. However, topics like net congestion and heat networks, can be quite challenging for individuals without a technical background to comprehend. Consequently, garnering support for these projects becomes more challenging. To ensure the success of such initiatives, the use of physicalizations like this one is invaluable. By employing various visual and physical tools, the significance and benefits of these projects can be effectively communicated, ultimately paving the way for a greener future.

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Appendix A

Personas

The following personas were created utilizing the online tool Xtensio.

Figure A.1: Persona 1: CEO of a fish processing company

Figure A.2: Persona 2: Future household owner

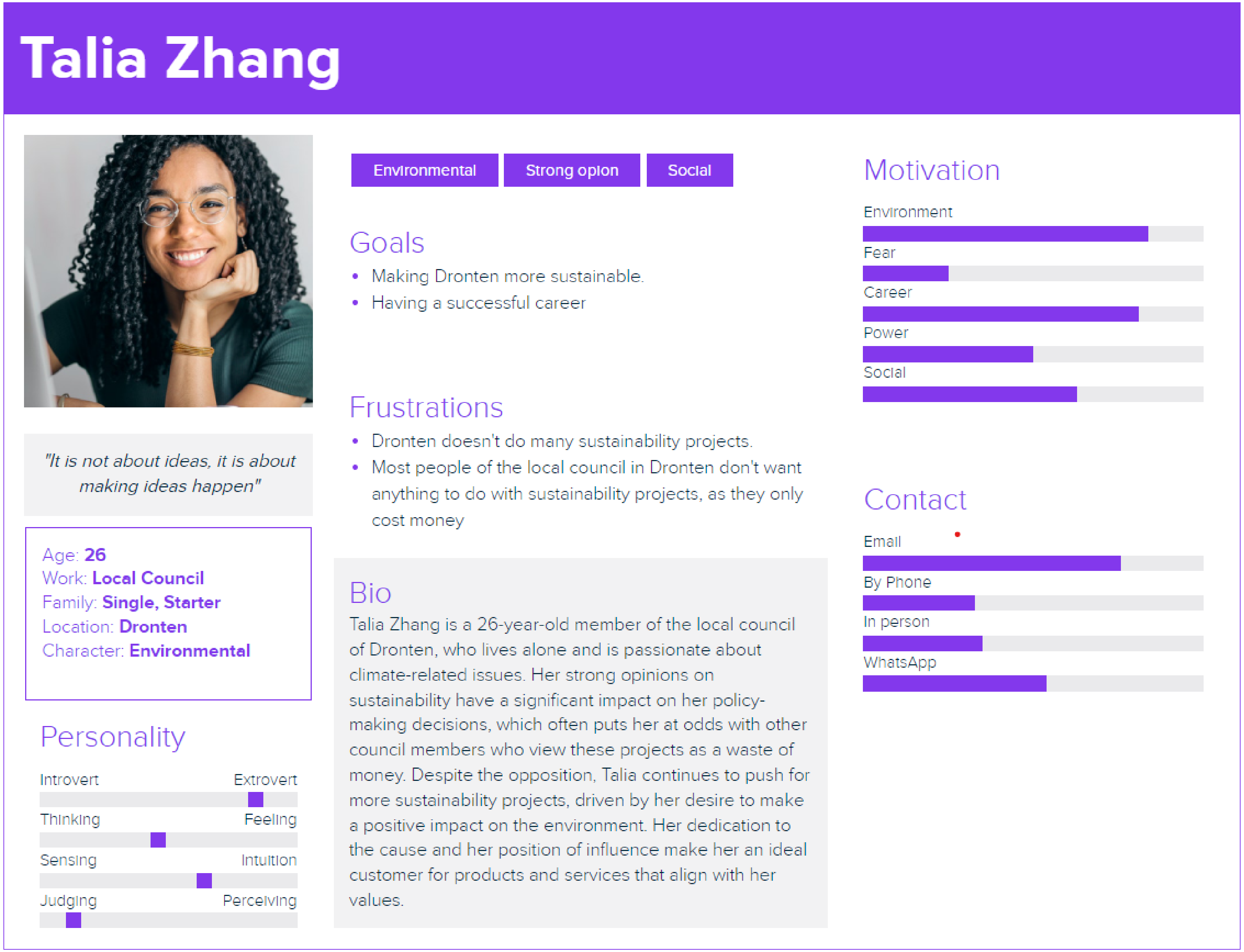

Figure A.3: Persona 3: Local council member

Appendix B

Code

```
#include <Arduino.h>
#include <Adafruit_NeoPixel.h>
#include <Servo.h>

#define SUMMER_LED_PIN 33
#define WINTER_LED_PIN 32
#define FACTORY_LED_PIN 27
#define servoPin1 13
#define servoPin2 12

#define TOTAL_NUM_LEDS_RED 107
#define TOTAL_NUM_LEDS_BLUE 110
#define TOTAL_NUM_LEDS_FACTORY 11

#define flowLength 15   // Adjustable flow length
#define flowDelay 50    // Adjustable flow delay in milliseconds

#define RED_WKO_LED_PIN 26        // Pin number connected to the RED WKO LED
    strip
#define BLUE_WKO_LED_PIN 25        // Pin number connected to the BLUE WKO
    LED strip
#define LED_COUNT_WKO 50     // Number of LEDs in the WKO strips

#define SummerButtonLEDpin 5
#define SummerButtonSwitchPin 18
#define WinterButtonLEDpin 19
#define WinterButtonSwitchPin 21
```

```
#define Wind1ButtonLEDpin 16
#define Wind1ButtonSwitchPin 17
#define Wind2ButtonLEDpin 22
#define Wind2ButtonSwitchPin 23

Servo myservo = Servo();

Adafruit_NeoPixel stripRedFlow(TOTAL_NUM_LEDS_RED, SUMMER_LED_PIN, NEO_GRB
    + NEO_KHZ800);
Adafruit_NeoPixel stripBlueFlow(TOTAL_NUM_LEDS_BLUE, WINTER_LED_PIN,
    NEO_GRB + NEO_KHZ800);
Adafruit_NeoPixel stripRedWKO(LED_COUNT_WKO, RED_WKO_LED_PIN, NEO_GRB +
    NEO_KHZ800);
Adafruit_NeoPixel stripBlueWKO(LED_COUNT_WKO, BLUE_WKO_LED_PIN, NEO_GRB +
    NEO_KHZ800);
Adafruit_NeoPixel stripFactory(TOTAL_NUM_LEDS_FACTORY, FACTORY_LED_PIN,
    NEO_GRB + NEO_KHZ800);


//FLOW PART

int LEDlistRedToWKO[36] = {
  1, 2, 3, 4, 5, 6, 7, 8, 9, 10,
  11, 12, 13, 14, 15, 16, 17, 18, 19, 20,
  21, 22, 23, 24, 25, 26, 27, 28, 29, 30,
  31, 32, 33, 34, 35, 36
};
int LEDlistRedToWKOSize = sizeof(LEDlistRedToWKO) /
    sizeof(LEDlistRedToWKO[0]);

int LEDlistRedFromWKO[80] = {
  36, 35, 34, 33, 32, 31, 30, 29, 28, 27,
  37, 38, 39, 40, 41, 42, 43, 44, 45, 46,
  47, 48, 49, 50, 51, 52, 53, 54, 55, 56,
  57, 58, 59, 60, 61, 62, 63, 64, 65, 66,
  67, 68, 69, 70, 71, 72, 73, 74, 75, 76,
  77, 78, 79, 80, 81, 82, 83, 84, 85, 86,
  87, 88, 89, 90, 91, 92, 93, 94, 95, 96,
  97, 98, 99, 100, 101, 102, 103, 104, 105, 106
};
int LEDlistRedFromWKOSize = sizeof(LEDlistRedFromWKO) /
    sizeof(LEDlistRedFromWKO[0]);
```

```
int LEDlistBlueFromWKO[75] = {
  74, 73, 72, 71, 70, 69, 68,
  67, 66, 65, 64, 63, 62, 61, 60, 59, 58,
  57, 56, 55, 54, 53, 52, 51, 50, 49, 48,
  47, 46, 45, 44, 43, 42, 41, 40, 39, 38,
  37, 36, 35, 34, 33, 32, 31, 30, 29, 28,
  27, 26, 25, 24, 23, 22, 21, 20, 19, 18,
  17, 16, 15, 14, 13, 12, 11, 10, 9, 8,
  7, 6, 5, 4, 3, 2, 1, 0
};
int LEDlistBlueFromWKOSize = sizeof(LEDlistBlueFromWKO) /
    sizeof(LEDlistBlueFromWKO[0]);

int LEDlistBlueToWKO[40] = {
  110, 109, 108, 107, 106, 105, 104, 103, 102, 101,
  100, 99, 98, 97, 96, 95, 94, 93, 92, 91,
  90, 89, 88, 87, 86, 85, 84, 83, 82, 81,
  80, 79, 78, 77, 76, 75, 71, 72, 73, 74
};
int LEDlistBlueToWKOSize = sizeof(LEDlistBlueToWKO) /
    sizeof(LEDlistBlueToWKO[0]);


//WKO PART

// Define the pattern parameters
int patternIndexRedWKO = 0;                  // Current pattern index
int patternIndexBlueWKO = 0;

unsigned long previousMillis = 0;       // Previous time in milliseconds
const unsigned long patternInterval = 500; // Interval between pattern
    changes in milliseconds

const int pattern1[] = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 20, 21, 30, 31,
    40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50};
const int pattern2[] = {12, 13, 14, 15, 16, 17, 18, 19, 22, 29, 32, 33, 34,
    35, 36, 37, 38, 39};
const int pattern3[] = {23, 24, 25, 26, 27, 28};

const int pattern1Size = sizeof(pattern1) / sizeof(pattern1[0]);
const int pattern2Size = sizeof(pattern2) / sizeof(pattern2[0]);
```

```
const int pattern3Size = sizeof(pattern3) / sizeof(pattern3[0]);

int currentStep = 0; // Tracks the current step

boolean summer = true;
bool itBlows = false;


void setup() {
  stripRedFlow.begin();
  stripBlueFlow.begin();
  stripRedWKO.begin();
  stripBlueWKO.begin();

  // Initialize all pixels to "off"
  stripRedFlow.show();
  stripBlueFlow.show();
  stripRedWKO.show();
  stripBlueWKO.show();

  // Set the LED pins as output
  pinMode(SummerButtonLEDpin, OUTPUT);
  pinMode(WinterButtonLEDpin, OUTPUT);

  pinMode(Wind1ButtonLEDpin, OUTPUT);
  pinMode(Wind2ButtonLEDpin, OUTPUT);

  // Set the button pins as input
  pinMode(SummerButtonSwitchPin, INPUT);
  pinMode(WinterButtonSwitchPin, INPUT);

  pinMode(Wind1ButtonSwitchPin, INPUT);
  pinMode(Wind2ButtonSwitchPin, INPUT);
}

void loop() {
  // Reset the ESP every week (this is only here because the millis()
     function will break after running for 50 days
  if (millis() > 7 * 24 * 60 * 60 * 1000) {
    reset();
  }
```

```
determineButtonPressed();
LightLEDcolorButtons();

//FLOW PART
if (summer) {
  Flow(&stripRedFlow, LEDlistRedToWKO, LEDlistRedToWKOSize,
      TOTAL_NUM_LEDS_RED, SUMMER_LED_PIN, 1);
  Flow(&stripBlueFlow, LEDlistBlueFromWKO, LEDlistBlueFromWKOSize,
      TOTAL_NUM_LEDS_BLUE, WINTER_LED_PIN, 3);
} else {
  Flow(&stripRedFlow, LEDlistRedFromWKO, LEDlistRedFromWKOSize,
      TOTAL_NUM_LEDS_RED, SUMMER_LED_PIN, 3);
  Flow(&stripBlueFlow, LEDlistBlueToWKO, LEDlistBlueToWKOSize,
      TOTAL_NUM_LEDS_BLUE, WINTER_LED_PIN, 1);
}


unsigned long currentMillis = millis(); // Current time in milliseconds
// Check if it's time to change the pattern
if (currentMillis - previousMillis >= patternInterval) {

  //WKO PART
  previousMillis = currentMillis; // Update previous time
  wkoMovement(&stripRedWKO, &patternIndexRedWKO, 10, 0, 0, summer);
  wkoMovement(&stripBlueWKO, &patternIndexBlueWKO, 0, 0, 10, !summer);


  //FACTORY PART
  currentStep = (currentStep + 1) % 4;
  if (itBlows) {
    setLEDsFactoryWind();
  } else {
    setLEDsFactoryNoWind();
  }
}

//SERVO PART
if (itBlows) {
  myservo.write(servoPin1, 92);     // set the servo position (degrees)
  myservo.write(servoPin2, 91);     // set the servo position (degrees)

} else {
```

```
    myservo.write(servoPin1, 94);     // set the servo position (degrees)
    myservo.write(servoPin2, 93);     // set the servo position (degrees)
  }
}

void Flow(Adafruit_NeoPixel* stripPtr, int LEDlist[], int numLEDs, int
    TotalNumLEDs, int ledPin, int numFlows) {
  // Clear the strip
  stripPtr->clear();

  // Depending on the color, make all the light a default color of
      brightness 10 in that specific color
  for (int i = 0; i < TotalNumLEDs; i++) {
    //The color is determenid by the ledPin
    if (ledPin == SUMMER_LED_PIN) {
      stripPtr->setPixelColor(i, stripPtr->Color(10, 0, 0));
    } else if (ledPin == WINTER_LED_PIN) {
      stripPtr->setPixelColor(i, stripPtr->Color(0, 0, 10));
    }
  }

  //Determine the spacing between flows by dividing the numOfLEDs in the
      flow part by the number of flows
  int spacing = numLEDs / numFlows;

  // Update the flows
  for (int flow = 0; flow < numFlows; flow++) {
    int startIndex = (millis() / flowDelay + flow * spacing);

    // Draw the flow from the lowest brightness on the left, to the highest
        brightness on the right
    for (int i = 0; i < flowLength; i++) {
      int pixelIndex = (startIndex + i) % numLEDs;

      //As it was to much work to send the color specifics as parameters, we
          just look at the ledPin
      //To see which color value neds to have a brightness change
      if (ledPin == SUMMER_LED_PIN) {
        stripPtr->setPixelColor(LEDlist[pixelIndex], stripPtr->Color(10 + i
            * 240 / flowLength, 0, 0));
      } else if (ledPin == WINTER_LED_PIN) {
```

```
        stripPtr->setPixelColor(LEDlist[pixelIndex], stripPtr->Color(0, 0,
            10 + i * 240 / flowLength));
      }
    }
  }
  // Show the updated strip
  stripPtr->show();
}

void wkoMovement(Adafruit_NeoPixel* stripPtr, int* patternIndex, int r, int
    g, int b, boolean reverse) {
  // Clear the strip
  for (int i = 0; i < LED_COUNT_WKO; i++) {
    stripPtr->setPixelColor(i, r, g, b); // Set color to default state
  }

  // Determine the pattern and its size based on the patternIndex
  const int* pattern;
  int patternSize;
  if (*patternIndex == 0) {
    pattern = pattern1;
    patternSize = pattern1Size;
  } else if (*patternIndex == 1) {
    pattern = pattern2;
    patternSize = pattern2Size;
  } else {
    pattern = pattern3;
    patternSize = pattern3Size;
  }



  // Turn on the LEDs in the current pattern
  for (int i = 0; i < patternSize; i++) {
    int ledIndex = pattern[i] - 1; // Adjust pattern index to match array
        index
    stripPtr->setPixelColor(ledIndex, 25.50 * r, 25.50 * g, 25.50 * b); //
        Set color based on r g b parameters
  }

  stripPtr->show(); // Update the LED strip
```

```
  // Increment patternIndex and wrap around if necessary
  if (reverse) {
    *patternIndex = (*patternIndex - 1 + 3) % 3;
  } else {
    *patternIndex = (*patternIndex + 1) % 3;
  }
}

void determineButtonPressed() {
  if (digitalRead(SummerButtonSwitchPin) == HIGH) {
    summer = true;
  } else if (digitalRead(WinterButtonSwitchPin) == HIGH) {
    summer = false;
  }

  if (digitalRead(Wind1ButtonSwitchPin) == HIGH) {
    itBlows = true;
  } else if (digitalRead(Wind2ButtonSwitchPin) == HIGH) {
    itBlows = false;
  }
}

void LightLEDcolorButtons() {
  if (summer) {
    digitalWrite(SummerButtonLEDpin, HIGH);
    digitalWrite(WinterButtonLEDpin, LOW);
  }
  else {
    digitalWrite(WinterButtonLEDpin, HIGH);
    digitalWrite(SummerButtonLEDpin, LOW);
  }

  if (itBlows) {
    digitalWrite(Wind1ButtonLEDpin, HIGH);
    digitalWrite(Wind2ButtonLEDpin, LOW);
  }
  else {
    digitalWrite(Wind2ButtonLEDpin, HIGH);
    digitalWrite(Wind1ButtonLEDpin, LOW);
  }
}
```

```
void setLEDsFactoryWind() {
  stripFactory.clear(); // Turn off all LEDs

  // Set LEDs based on the current step
  switch (currentStep) {
    case 0: // LEDs 1 and 2 are green
      stripFactory.setPixelColor(0, 0, 255, 0);
      stripFactory.setPixelColor(1, 0, 255, 0);
      break;
    case 1: // LEDs 1, 2, 4, and 5 are green
      stripFactory.setPixelColor(0, 0, 255, 0);
      stripFactory.setPixelColor(1, 0, 255, 0);
      stripFactory.setPixelColor(3, 0, 255, 0);
      stripFactory.setPixelColor(4, 0, 255, 0);
      break;
    case 2: // LEDs 1, 2, 4, 5, 7, and 8 are green
      stripFactory.setPixelColor(0, 0, 255, 0);
      stripFactory.setPixelColor(1, 0, 255, 0);
      stripFactory.setPixelColor(3, 0, 255, 0);
      stripFactory.setPixelColor(4, 0, 255, 0);
      stripFactory.setPixelColor(6, 0, 255, 0);
      stripFactory.setPixelColor(7, 0, 255, 0);
      break;
    case 3: // LEDs 1, 2, 4, 5, 7, 8, 10, and 11 are green
      stripFactory.setPixelColor(0, 0, 255, 0);
      stripFactory.setPixelColor(1, 0, 255, 0);
      stripFactory.setPixelColor(3, 0, 255, 0);
      stripFactory.setPixelColor(4, 0, 255, 0);
      stripFactory.setPixelColor(6, 0, 255, 0);
      stripFactory.setPixelColor(7, 0, 255, 0);
      stripFactory.setPixelColor(9, 0, 255, 0);
      stripFactory.setPixelColor(10, 0, 255, 0);
      break;
  }

  stripFactory.show(); // Update the LED strip
}

void setLEDsFactoryNoWind() {
  stripFactory.clear(); // Turn off all LEDs

  // Set LEDs based on the current step
```

```
  switch (currentStep) {
    case 0: // LEDs 1, 2, 4, 5, 7, 8, 10, and 11 are red
      stripFactory.setPixelColor(0, 255, 0, 0);
      stripFactory.setPixelColor(1, 255, 0, 0);
      stripFactory.setPixelColor(3, 255, 0, 0);
      stripFactory.setPixelColor(4, 255, 0, 0);
      stripFactory.setPixelColor(6, 255, 0, 0);
      stripFactory.setPixelColor(7, 255, 0, 0);
      stripFactory.setPixelColor(9, 255, 0, 0);
      stripFactory.setPixelColor(10, 255, 0, 0);
      break;
    case 1: // LEDs 1, 2, 4, 5, 7, and 8 are red
      stripFactory.setPixelColor(0, 255, 0, 0);
      stripFactory.setPixelColor(1, 255, 0, 0);
      stripFactory.setPixelColor(3, 255, 0, 0);
      stripFactory.setPixelColor(4, 255, 0, 0);
      stripFactory.setPixelColor(6, 255, 0, 0);
      stripFactory.setPixelColor(7, 255, 0, 0);
      break;
    case 2: // LEDs 1, 2, 4, and 5 are red
      stripFactory.setPixelColor(0, 255, 0, 0);
      stripFactory.setPixelColor(1, 255, 0, 0);
      stripFactory.setPixelColor(3, 255, 0, 0);
      stripFactory.setPixelColor(4, 255, 0, 0);
      break;
    case 3: // LEDs 1 and 2 are red
      stripFactory.setPixelColor(0, 255, 0, 0);
      stripFactory.setPixelColor(1, 255, 0, 0);
      break;
  }

  stripFactory.show(); // Update the LED strip
}

void reset() {
  ESP.restart();
}
```

Appendix C

Informational texts

The following texts where displayed on the top of the installation. All of these texts are in Dutch, as the target audience was also defined as Dutch.

C.1 Energienet Urk

Het geplande energienet van Urk zal bijdragen aan de verduring van de gemeente. Het energienet bestaat uit verschillende onderdelen. Aan de linkerkant op de Port of Urk staat de visverwerkende bedrijven. Tijdens het verwerken van vis moet de temperatuur erg laag blijven. Om deze reden wordt de vis gekoeld bij een temperatuur van -30 graden. Bij het koelingsproces ontstaat restwarmte. Zonder het energienet zou deze restwarmte verloren gaan. Met het huidige systeem kunnen we echter de warmte gebruiken om de huizen van de zeeheldenwijk te verwarmen. Die zijn weer verbonden aan de rechterkant. De koude die geproduceerd wordt bij het verwarmen van de huizen kan dan weer gebruikt worden om de koelmachines van de visverwerkende bedrijven efficiënter te maken. Dit net creëert hierdoor een gesloten energiecyclus.

C.2 Warmte Koude Opslag (WKO)

In de winter hebben huishoudens een grotere behoefte aan verwarming vanwege de lage temperaturen, terwijl visverwerkingsbedrijven in de zomer juist meer koeling nodig hebben. Dit creëert een onevenwichtige balans, aangezien de vraag naar warmte of koeling plaatsvindt in een ander seizoen dan de productie ervan. Om dit probleem aan te pakken, maakt het energienetwerk gebruik van Warmte Koude Opslag (WKO). WKO is een duurzame methode waarbij energie in de vorm van warmte of koeling wordt opgeslagen in de grond, waardoor deze energie op een later moment kan worden gebruikt. Het aanvullen en onttrekken van warmte en koude aan WKO-systemen varieert dus per seizoen. De twee knoppen naast deze tekst laten het verschil zien in de energiestromen tussen de seizoenen.

C.3 Werking elektriciteitsnetwerk

Het elektriciteitsnetwerk in Nederland is verantwoordelijk voor de distributie van elektriciteit door het land. Aan de ene kant van het elektriciteitsnetwerk bevindt zich de productie van elektriciteit, zoals kolencentrales en kerncentrales. Tegenwoordig groeit het aandeel duurzame energiebronnen, zoals windenergie en zonne-energie, in de energieproductie. Aan de andere kant staat de consumptie van elektriciteit, zowel door huishoudens, kantoren als de gehele industrie. Het is van groot belang dat de productie en consumptie van elektriciteit in balans zijn. Op het huidige netwerk ontbreekt een efficiënte manier om energie op te slaan. De zojuist geproduceerde energie moet direct worden verbruikt. Wanneer er een onevenwicht ontstaat, spreekt men van netcongestie. Dit probleem wordt steeds vaker ervaren, vooral door de toenemende flexibiliteit van energieproductie door duurzame bronnen zoals wind- en zonne-energie.

C.4 Directe route

Het elektriciteitsnetwerk is oorspronkelijk ontworpen om de energieproductie gedurende de dag aan te passen. Dit was mogelijk omdat de meeste energie werd opgewekt door kolencentrales. Om elektriciteit te transporteren, werd de energie eerst omgezet naar hoogspanning, omdat hogere spanning zorgt voor efficiënter transport, en vervolgens naar een centraal punt geleid. Vanuit dat centrale punt werd de energie omgezet naar laagspanning en gedistribueerd. Dit ontwerp van het elektriciteitsnetwerk werkt echter niet meer vanwege de flexibele energieproductie van hernieuwbare energiebronnen. Bij een piekmoment, wanneer er veel energie wordt opgewekt door hernieuwbare bronnen, kan er congestie ontstaan op het centrale punt. De voorgestelde oplossing in Urk is om het centrale punt over te slaan en de energie niet om te zetten naar hoogspanning. De energie die wordt geproduceerd door de windmolens zou in eerste instantie naar Emmeloord worden getransporteerd en vervolgens terug worden gebracht naar de Port of Urk, een regio met een hoog energieverbruik. Deze nieuwe route bespaart een omweg van 42 km.

C.5 Flexibel energie verbruik

Aangezien de energie productie en consumptie gelijk moet zijn, en aangezien de energie productie flucueerd vanwege herniewbare energie bronnen, moeten consumenten steeds flexibeler worden met hun energie verbruik in de toekomst. Een van de oplossingen voorgesteld voor de Port of Urk, is om de koelmachines van de visindustrie te gebruiken. Op momenten van overvloedige energieproductie kunnen deze koelmachines intensiever worden ingezet, wat resulteert in een verlaging van de omgevingstemperatuur. Bij een beperkt energieaanbod kunnen ze daarentegen worden verminderd of uitgeschakeld, waardoor de temperatuur geleidelijk terugkeert naar het minimale niveau.

C.6 Warmtepomp

Om een goed begrip te krijgen van het energienetwerk in Urk, is het essentieel om de werking van een warmtepomp te begrijpen, aangezien alle huizen in de Zeeheldenwijk van een warmtepomp zullen worden voorzien. Ondanks de naam genereert een warmtepomp geen warmte, maar verplaatst het warmte. De bron van de warmte kan verschillen, afhankelijk van de configuratie. In dit geval wordt de warmte uit het energienet gehaald.

Hoewel de toegevoerde warmte vanuit het energienet een temperatuur heeft van 20 graden Celsius, kan een huis dankzij een warmtepomp worden verwarmd tot een hogere temperatuur. Dit wordt mogelijk gemaakt door het opnemen van warmte uit het energienet door middel van verdamping van een koelmiddel. Vervolgens wordt de druk van het koelmiddel verhoogd, waardoor het een hogere temperatuur bereikt dan de binnentemperatuur. Hierdoor kan het de warmte afgeven aan de binnenruimte. Vervolgens wordt de druk weer verlaagd, waardoor de temperatuur daalt en het proces van warmteopname van het energienet opnieuw kan beginnen.

Hetzelfde proces wordt volledig omgekeerd aan de andere kant van het energienet, waar de koelmachines van de visverwerkende bedrijven koude uit het energienet halen.

Appendix D

Summary of survey results

In total, 8 surveys where filled in at the evaluation location (n=8). All participants gave permission to use their answers for this research. One participant indicated that he/she did not want his/her answers used in the form of a quotation.

Question and answers survey:

Question 1: What is your age?

Answer: Answers range from 27 to 56, with an average 46.3, a median of 51 and a mode of 54 and 51 (each appeared 2 times).

Question 2: What is your gender?

Answer: Male: 4 (50%), Female: 4 (50%), Other 0 (0%).

Question 3: What is the reason your are currently in the city hall of Urk?

Answer: All answers indicated that the participant was in the city hall of Urk, because the city hall of Urk was there (current) work place.

Question 4: What is your profession?

Answer: In accordance with the participants' privacy, the specific occupations will not be disclosed. However, it can be noted that none of the participants currently held a technical profession.

Question 5: What caught your attention to look at the physicalization?

Answer: The physicalization as a whole: 5 (62.5 %); the aesthetics of the physicalization: 1 (12.5%); the lights of the physicalizations: 2 (25%).

Question 6: What was your first impression of the physicalization

Answer: 5 participants included in their answer that he physicalization is aesthetically pleasing (62.5 %); 4 answers included that the physicalization was very clear (50%); 2 particpants included in their answer the physicalization was fun (25%).

Question 7: Is it clear which region the physicalization represents?

Answer: 7 answers stated it was totally clear which region it represented (87.5%); 1 participant made a distinction between from a far, and having a closer look. Saying that the specific region in Urk can only be observed when you are standing next to the physicalization (12.5%).

Question 8: Did you think the physicalization was aesthetically pleasing?

Answer: 8 participants answered: yes (100%); 1 participant added that especially the lights that represented summer and winter added to this fact (12.5%).

Question 9: What was your prior knowledge about the subjects presented in the physicalization?

Answer: Some basic principles: 3 (42.9%); heard about the subjects in the news: 1 (14.3%); no prior knowledge: 1 (14.3%); knew about the heat network project: 1 (14.3%); not much: 1 (14.3%).

One participant answered 'yes' to this question. It is assumed this participant misread the question. Therefore, this questions answer will be excluded.

Question 10: What did the physicalization taught you about net congestion?

Answer: Nothing: 2 (25%); How Urk will be connected to the electricity network: 1 (12.5%); that the use of new renewable energy sources leads to net congestion: 1 (12.5%); Which route the electricity will take with a lot and no wind: 1 (12.5%); More detailed information: 1 (12.5%); That it can be solved partially: 1 (12.5%); How it can be used on Urk with help of heat: 1 (12.5%).

Question 11: Can you explain to me what the solution for net congestion is for Urk?

Answer: Locally storing and using the produced electricity: 1 (16,7%); Using the fish companies: 1 (16,7%); A closed system without transport on high-voltage lines: 1 (16,7%); Shortening the route the electricity makes: 1 (16,7%); No/less taxes: 1 (16,7%); The use of heat pumps, storing electricity thermally and shortening the electricity route: 1 (16,7%).

Two responses stated that they indeed can explain it, but gave no explanation. As there is no way of checking if there statement is correct, these answers were excluded.

Question 12: Can you explain to me how the heat network (Dutch: Energienet) of Urk works?

Answer: Energy is stored into the ground: 1 (20%); There will be closed system where the port of Urks left-over heat (from cooling) can be used to heat the houses of the Zeeheldenwijk: 2 (40%); The fish companies produce heat and cold for the houses of the Zeeheldenwijk: 1 (20%); exchange of heat and cold: 1 (20%);

Three responses stated that they indeed can explain it, but gave no explanation. As there is no way of checking if there statement is correct, these answers were excluded.

Question 13: On a scale from 1 to 7, where 1 is completely clear and 7 is to much information, how would you rate this information?

Answer: Answers range from 1 to 7, with an average of 3.25, a median of 2.5 and a mode of 2 (appeared 3 times).

Question 13: Where there any part of the physicalization difficult to understand? If so, which one?

Answer: No: 6 (75%); the heat pump part: 2 (25%).