Tangible and Immersive Data Physicalisation using Sound and Temperature with Climate Change Data

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Bachelor thesis Creative Technology

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Abstract

Climate change reports indicate that the global average temperature is rising to alarming levels with devastating consequences such as rising sea levels. Now drastic measures are needed or climate goals such as the Paris Agreement will not be accomplished by 2050. An important factor in models for global warming is the concentration of carbon dioxide (CO_2). The Intergovernmental Panel on Climate Change developed four models for the prediction of CO_2 and other greenhouse gasses emissions concentration and temperature rise, so called Representative Concentration Pathway's (RCPs), to make people more aware of the connection between growing concentrations of CO_2 and increasing global temperatures.

Human behaviour lowering the emissions CO_2 hardly changes. Apparently, the ways the climate change message is communicated, mainly text, tables, and graphs, have too little impact. The objective of this thesis is to explore ways to convey the message in a more impactful way. Data physicalisations can convert abstract data in a more tangible and concrete manner, making data more understandable and memorable. This could make the underlying message more impactful. Current data physicalisations focus on the direct interaction between the user and the data. However, approaches which enhance the immersion by incorporating factors, such as sound and temperature, to stimulate the user's senses while interacting with the data are largely unexplored.

Therefore, for this thesis a data physicalisation was developed that incorporates the factors sound and temperature to convey climate change data in an immersive manner. Sound to simulate the sea-level rise, and temperature to simulate global warming. This installation displays the average temperatures of nine countries between 1950 and 2050. Users can tangibly control the installation by selecting the year and countries of which the data is displayed, and the RCP used in the simulation. In total, 44 people participated, split up in four subgroups with each group being subjected to a different combination of the factors sound and temperature. Their accuracy, experience, and perceived level of immersion were evaluated. Most participants were very enthusiastic after their interaction. However, participants managed to extract the correct data for only half of the tasks. Although the results for immersion between the subgroups showed no statistically significant difference, the results for the sound factor seem promising. For conclusive results on the impact of the used immersive factors, larger user groups and an optimised installation are recommended.

Acknowledgement
I would like to thank my supervisors Champika Epa Ranasinghe and Auriol Degbelo for all their help during the whole process and guiding me when I was losing myself in way to ambitious ideas. I would also like to extend my gratitude towards my peer Sander Dullaert who always happily answered my questions. Geert Maan also deserves a thank you for practically dragging me to the university at times when my own motivation was lacking. A big shoutout to all the 44 participants who spend their free time participating on the short notice of one week, showing enthusiasm for the prototype and giving feedback. Finally, a big thank you to my parents who kept me going in the final stages.
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Chapter 1 – Introduction

Climate change can best be described as "*Long-term shifts in temperature and weather patterns*" [1]. These changes can be due to natural factors such as the solar activity but are nowadays mainly caused by humans. Every time we use fossil fuels for flying, driving, powering ship engines, cooking, or for anything else, we produce greenhouse gas (GHG) emissions. Due to the nature of these gasses, rising concentrations of GHC's have caused the average global temperature of the Earth to rise by 1.1 degrees Celsius as compared to the temperature during the late 1800's. Records [2] show that the previous decennium holds the current record of being the warmest decade since recording started in 1850. However, warmer temperatures are just the tip of the iceberg. The earth is an ecosystem where a shift in one area can cause changes in others since everything is linked. Current consequences of climate change include, but are not limited to, rising sea-levels, heavy downpours causing massive landslides destroying villages and infrastructure, devastating forest fires, severe draughts, decreased biodiversity, and irreversible melting of the polar ice. These developments already have an effect on people's lives. Forcing them to move because their land does not produce enough food anymore due to the draught, or because built-up areas become uninhabitable due to the rising sea-level.

The main contributor to the rising average global temperature is the growing concentration of greenhouse gasses such as water vapor, carbon dioxide, methane, nitrous oxide, and ozone. These gasses absorb and radiate back to earth its thermal radiation created by the energy received from the sun. To combat the current temperature rise, nations worldwide have signed agreements promising to try and reduce responsible factors. One of these is the Paris Agreement [3], in which the countries that signed it agree to try to keep the rise in global average temperature below 1.5 degrees Celsius measured from the pre-industrial era (~1900) up to 2050 if possible, and otherwise below 2.0 degrees Celsius. The latest report [4] on climate change has indicated that change must happen fast if the damages to the ecosystem want to be contained, and if climate goals such as the Paris Agreement want to be achieved by 2050. Without additional action, current policies lead to global warming of, on average, 2.8°C in the course of this century (see Table 2). To put the current concentration of greenhouse gasses into perspective and allow for predictions about the impact of different future volumes of this concentration on the global temperature, four possible Representative Concentration Pathways have been constructed by the Intergovernmental Panel on Climate Change (IPCC). These pathways are trajectories of greenhouse gas concentrations that the IPCC used for their fifth assessment report [5]. They describe different possible climate futures, depending on the volume of greenhouse gases in the future. In their assessment report the IPCC published a graph depicting all forcing agents' atmospheric CO_2-equivalent concentrations (in parts-per-million-by-volume (ppmv)) (see Figure 1) and a table (see Table 1) containing the predicted average temperatures per pathway (RCP), illustrating the enormous effect of greenhouse gasses such as CO_2 on our climate.

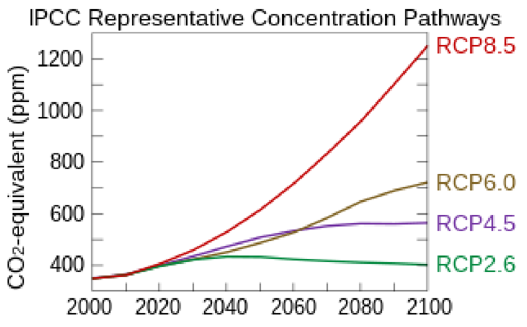

Figure 1 - All forcing agents' atmospheric CO2-equivalent concentrations (in parts-per-million-by-volume (ppmv)) according to the four RCPs used by the fifth IPCC Assessment Report [5] to make predictions

Scenario	2046–2065	2081–2100
	Mean (*likely range*)	Mean (*likely range*)
RCP2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)
RCP4.5	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)
RCP6	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)
RCP8.5	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)

Table 1 - PCC Assessment Report 5 global warming increase (°C) projections [7]

Scenario	Range of Global Mean Temperature Increase (Celsius) – 2100 from pre-Industrial baseline
RCP 1.9	~1 to ~1.5
RCP 2.6	~1.5 to ~2
RCP 3.4	~2 to ~2.4
RCP 4.5	~2.5 to ~3
RCP 6.0	~3 to ~3.5
RCP 7.5	~4
RCP 8.5	~5

Table 2 - Temperature change projections [8]

This data and these reports are available to the public. However, experts conclude that the changes made in personal lifestyle and government policies are highly inadequate [4]. Even though the UN has published an overview of six sectors [6] in which drastic emission cuts can be made in the short term, decisive actions and adequate progress keeps lacking, failing to reduce the emission gap that needs to be cut in half by 2050. Awareness of the current problematic course seems to be lacking among politicians and a large part of their voters. To raise the level of awareness among society and increase its current general understanding of the data, new methods must be used to present this data. Current methods of communicating data such as plain texts, large tables, and complicated graphs, lack effectivity it seems. A new method must be used that aims to increase the current understanding of climate change data and the social scientific issues emerging from that data. A method such as Data physicalisation.

Data physicalisations are installations that represent data not just visually, but also physically. Data physicalisation itself can be defined as *the process of an interactive installation that provides a tangible experience which has the aim to enhance the understanding of data insights and any social scientific issues that lie within that data.* Data physicalisation installations have the potential to deliver an experience that conveys abstract data in a more graspable manner and thereby makes data more memorable and understandable. Several data physicalisations [9], [10] have already been developed to present climate change data to the public in a more accessible way, either to create awareness or to test new ways of encoding climate change related data in data physicalisations. Where these installations focus on just the direct and tangible interaction between a user and the data it represents, installations with a focus on enhancing the experience of the user while interacting with the data are still largely unexplored. Enhancing the experience by triggering senses such as hearing and thermal sensation, besides just basic touch and sight, could increase the immersion of the user during the interaction. This then could add to its memorability and increase the awareness of the user of the impact of the data even more; Therefore, this thesis aims to explore which (combination of) factor(s) sound and temperature can attribute to a higher level of experienced immersion when these factors are incorporated within a tangible data physicalisation installation.

1.1 Research question

To discover if sound and/or temperature could potentially be used as a factor to increase the perceived level if immersion, a data physicalisation installation shall be constructed to test these factors in different study groups. Therefore, the research question this study will aim to answer is:

Which factor(s), sound and/or temperature, contribute to a higher level of immersion during the interaction with a data physicalisation installation on climate change?

1.2 Outline, approach & expected outcome

Outline

The documentation of this research has the following structure: The second chapter will include a literature review on the background and backbone of data physicalisation and immersive experiences, and a state-of-the-art reconnaissance establishing the current landscape of data physicalisation. The third chapter introduces the design process used, which is then step by step applied in the fourth, fifth, and sixth chapter. Chapter seven describes the process of the user tests that have been performed and their results. The eighth chapter is dedicated to the discussion, including the limitations encountered, the insights gained that could improve the design, and the possibilities for future research. Chapter nine wraps up the report with conclusions drawn based on the results and the performed statistical analysis of these results. The appendixes containing supportive material can be found at the end.

Approach

To achieve our goal and answer the research question, an immersive and tangible installation will be built in which users can interact with data on climate change. Users can to a certain extend control their experience via sensors such as touch capacitors, reed switches, encoders, and buttons. By connecting the user to the data via those sensors the experience could add to a more immersive experience. Collected datasets on the topic of climate change provide data over time and include temperature, sea level and CO2 emissions. The design allows manipulation of the time variable, giving the user the opportunity to explore the data and interact with it at points in time of their own choosing and experience the consequence with use of the immersion factors sound and/or temperature. Literature research will provide a basis for different ways on how to design and implement such an immersive and memorable experience.

The level of immersion will also be evaluated as part of the memorability of the experience. Four groups, 7-10 people each, will test different combinations of the different immersion factors: sound and temperature. One with both elements incorporated, two with one element either temperature or sound, and one without these elements.

Expected outcome

The expected outcome is a tangible and enjoyable to use data physicalizing installation on climate change that will provide inside on which (combination of) immersive factors(s) can attribute to the level of immersion when interaction with such an installation. This insight will be achieved by performed statistical analysis to determine which subgroup yields the highest perceived immersion score.

Chapter 2 – Background Research

This chapter entails an introduction to the terms data physicalisation and immersion, as well as some foundational guidelines on how to design an experience that is also tangible. State-of-the-art research on data physicalisation in general will be presented, after which a focus is being made on the factors sound and temperature. From analysing these studies, an unexplored sector in the field of data physicalisation emerged related to those factors influencing perceived levels of immersion.

2.1 Data Physicalisation, immersion, and the experience provided

2.1.1 Terminology

First, a clear definition of the term data physicalisation must be presented that can be used uniform throughout this thesis. At the start of our century, the term data sculpture was coined by Zhao & Vande Moere [11] and described as "a data-based physical artifact, possessing both artistic and functional qualities, that aims to augment a nearby audience's understanding of data insights and any socially relevant issues that underlie it."(par. 2), suggesting the idea of a tangible experience with which a user can interact with the conveyance of knowledge as one of the underlying goals. A more concise definition was later presented by Jansen et al. in 2015 [12], phrasing it as "a physical artifact whose geometry or material properties encode data" (par. 5). This definition is nowadays widely used in papers relevant to the data physicalisation field. For this thesis a definition will be formulated that includes the physicalizing installation aspect of the aim of the thesis, therefore combining the two previously mentioned definitions resulting in data physicalisation to be *the process of an interactive installation that provides a tangible experience which has the aim to enhance the understanding of data insights and any social scientific issues that lie within that data.*

Furthermore, the term "immersion" should also be defined beforehand. The term "Immersive", the adjective of the noun "immersion", is generally used to *describe the degree to which a participant is focussed on the environment created by the subject of interaction instead of being aware of its environment outside the subject of interaction* [13], [14]. This can be focussed down to a more comprehensible formulation where Immersion can be defined as "becoming physically (or virtually) a part of the experience itself" [15].

2.1.2 Designing an interactive experience

In order to encounter this tangible experience, a user must interact with the installation. A data physicalisation installation can be considered a system, and there are several types of interactions [16] to interact with a system. They distinct Instructing (where the user issues instructions to the system and selects options), Conversing (the user interacts with the system as if they are having a conversation), Manipulating (the user interacts with objects in a virtual or physical space by manipulating them), Exploring (the user moves through a virtual environment or a physical space), and Responding (here the system initiates the interaction, and the user chooses whether to respond). Related to, and formed out of, Interaction types are Interaction Models. "*Interaction models describe and group the things that a person can do with a system (rather than the result of the action i.e., system's response or reaction (perspective of an interacting person)"* [17]. After the classic Interaction model WIMP (Windows, Icons, Menus, Pointer), two other models emerged. Direct Manipulation and Natural User Interfaces (NUI). In 1983, Shneiderman [18] formulated the definition of Direct Manipulation as the name suggests, the direct manipulation of an object of interest. Shneiderman also formulated three design principles with which, when implemented correctly, systems can be designed with beneficial attributes. These principles (p. 64) are the following:

1. Continuous representation of the objects and actions of interest
2. Physical actions or presses of labelled buttons instead of complex syntax
3. Rapid incremental reversible operations whose effect on the object of interest is immediately visible

These design principles are since then wildly used and sometimes even extended [17], [19].

Having established some prime elements for interaction to be able to receive a tangible experience, attention must be paid to the abstract design of this experience. To design an experience that the user will remember for some time and with it, its message, a few key aspects as described by Pine & Gilmore [20] must be considered: 1) theme the experience, 2) harmonize impressions with positive cues, 3) eliminate negative cues, 4) mix in memorabilia, and 5) engage all five senses. Since the aim of this paper is focussed on a data physicalisation installation, aspect 1,2 and 5 will be of higher relevance than the other two. In order to captivate the user, the design of the installation should be a coherent, themed, experience. And in order to fully immerse the user, the user needs to feel part of the installation [14], [15], [21]. Possible aspects to consider are the theme of the installation and the setting in which it is being presented. If an experience would be implemented in an educational setting, the presence of supervising staff would not have a negative impact on the level of immersion, as long as the user's feelings of autonomy or ownership are not disrupted by interference of the staff too early or too late. The guidance of an immersive experience appears a delicate task [22]. Further enhancement the feeling of autonomy, ownership and thereby the immersive experience could be achieved by using technological support [23], [24]. Using devices that trigger the human senses via video, smell or audio adds even more to an immersive experience [20].

2.1.3 State-of-the-art

2.1.3.1 The everchanging landscape

Nowadays, there isa plethora of data physicalisations, each being built to explore this concept in their own way with their own data. From the early 1900s (see figure 2) to the present century (see figure 3), the technology may have evolved over time, but the general idea has stayed the same: making data more accessible to understand.

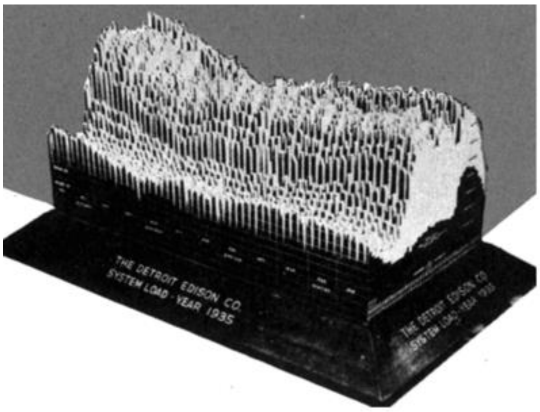

Figure 3 - Data physicalisation by the Detroit Edison Company showing electricity consumption for the year 1935 with a slice per day [25]

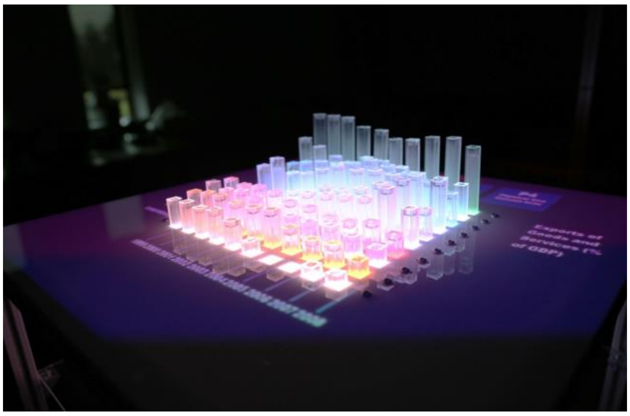

Figure 2 - The EMERGE shape display [26]

When for instance designing an interaction with regional data, an interactive map could be made that shows data about a region of the user's choice. This region can be as large as a world map, or as selective as a city divided up in different neighbourhoods. Dulleart utilised in his thesis [27] friction and resistance as factors for physicalizing data about income throughout different neighbourhoods in a city to see which one was more effective. No statistical significance was found, but promising results for classifying and rating such factors in the field of data physicalisation and positive a user experience did show.

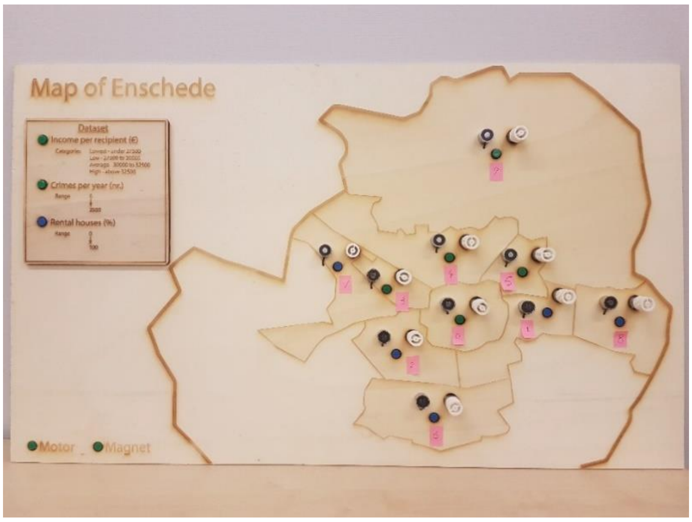

Figure 4 - Data physicalisation where data was mapped to level of friction and resistance [27]

2.1.3.2 Physicalisation using sound or temperature

Two interesting factors that can be incorporated into a Data Physicalisation are sound and temperature.

In April 2022, Van Loenhout, Ranasinghe, Degbelo, & Bouali described a data physicalisation in which temperature and vibration were used as modalities to encode SDG7 data on a discrete scale. There was chosen for a discrete approach instead of a continuous scale so the difference between the different values was more distinguishable [10]. After performing user tests with 16 participants, a small, but not statistically large enough, difference was detected when comparing the two modalities on the topic of enjoyability. However, the collective results from the quantitative and qualitative feedback do indicate a promising use for vibration and temperature to communicate data, in this case SDG7 data.

Figure 5 - (A) The physicalisation that uses temperature (T) and vibration (V) to represent Affordable and Clean Energy data of five countries: Sweden, Estonia, The Netherlands, Ukraine and Spain; (B) Laser cut wooden buttons (representing the geometric shape of the country) wrapped in metal to enable heat conductance; (C) Internal organization (using Sweden as example) of electronics and sensors to enable vibration and temperature output [10].

In 2015, Wilson, Davidson & Brewster subjected 15 participants to user tests tested subjective interpretations of thermal stimuli in three different scenarios (social media activity, a colleague's presence, and the extent of use of digital content) to, among other things, determine optimal levels of temperature for different meanings of presented data and to create guidelines for effective design of thermal feedback interfaces. The results of these user tests showed strong agreement among participants concerning their interpretation of warmth (presence, activity, quality) and cool (absence, lack of activity, poor quality). Two relevant guidelines for data physicalisations that followed from the results were that "*the quality or rating of content can be conveyed through temperature, with cool (~22-25°C) indicating the lowest quality and warmth (~35-38°C) indicating the highest."* and that "*While unique identification of thermal stimuli is challenging, users are able to appraise and make use of multiple (in our case up to 7) different feedback temperatures. Feedback designs can therefore reliably utilize different temperatures but should do so in an ambient or supportive manner."* [28].

Figure 6 - Experimental setup of Wilson, Davidson & Brewster with Peltier elements under the palm and the padded armrest for comfort [27]

Incorporating sound in data physicalisations has also been done before. A paper from august 1999 by Kaper. H.G., Tipei. S., & Wiebel. E. [29] describes a project where they use *data sonification* to encode data into visual and audio representations, where for the sound they used components such as amplitude, frequency, duration, and decay rate. Krygier [30] discusses several of these abstract variables for sound in his book on visualization. Explaining that "*There is, (…), evidence to support the claim that sound is a viable means of representing and communicating information and can serve as a valuable addition to visual displays.".* A difference is made between realistic sounds and abstract sounds, where realistic sounds consist of voice narration and so called earcons, sounds which resemble experiential sound [31], [32], [33]. Think of the sound of pressing keys on a physical keyboard when typing on a smartphone keyboard user interface. Abstract sounds are sounds that cannot be associated with an identifiable source [34]. Krygier further elaborates on how to successfully utilise such abstract sounds to encode data by changing various variables.

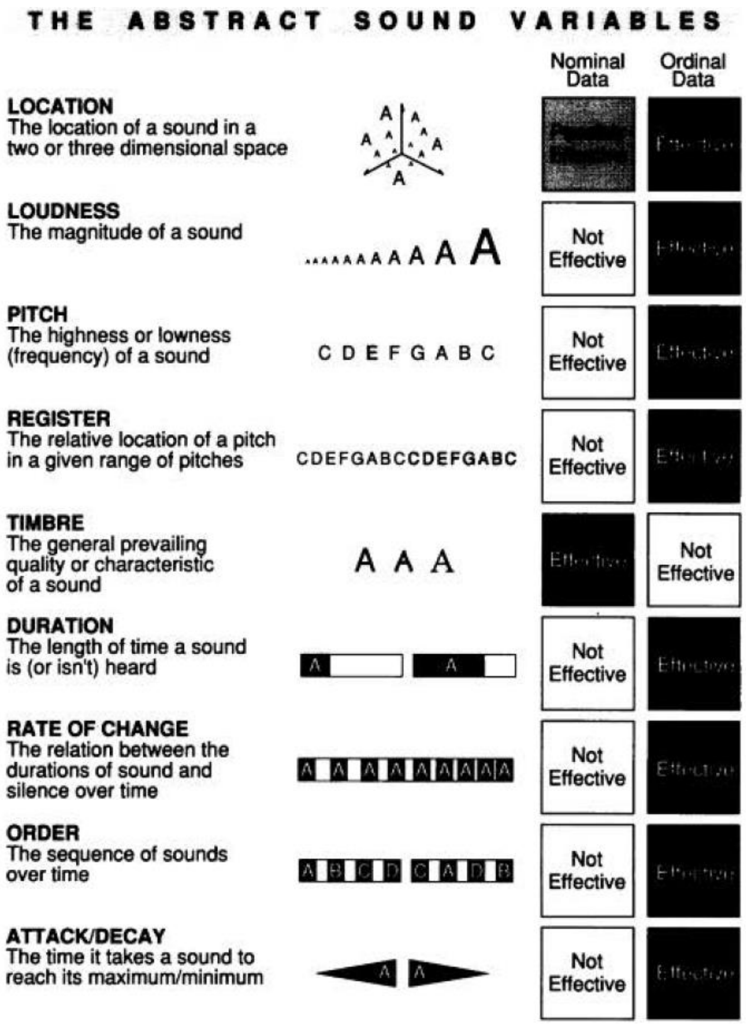

Figure 7 - Abstract sound variables as described by Krygier [30].

Since average temperature is not ordinal by nature, applying this approach would not seem possible at first glance. However, if the data is processed to an ordinal format, these variables can be adjusted to convey the data in an audible matter.

Also, this does not only apply to sound. Temperature can also be manipulated in some of the ways sound can. For instance, by changing the Attack/decay variable, changing how fast the heater is at its maximum and back. Or the Duration variable, changing how long the heater is on/off. Or the Loudness, in the case of the temperature factor the temperature the heater is set at.

2.2 Conclusion

In this chapter definitions of data physicalisation and immersion were set for this thesis to establish a clear starting point. Previous research on incorporating the factors temperature and sound in either data physicalisations or other forms of data communication have been examined and although there is some attention to the user experience, no clear study on the impact of factors such as sound and temperature on the perceived level of immersion exists. Data physicalisation has been here for a while and based on its rapid development it is here to stay since the limits have not yet been reached.

Chapter 3 – Method

This chapter briefly explains the chosen design process and how this process shapes the method used for this research.

The study Creative Technology provides its students with a design process [35] to guide them along the different phases of the research. This process is not linear but contains several feedback loops in order to finetune every step by evaluating every phase. This process consists of four phases once the first design question arises: Ideation, Specification, Realisation, and Evaluation (see figure 8).

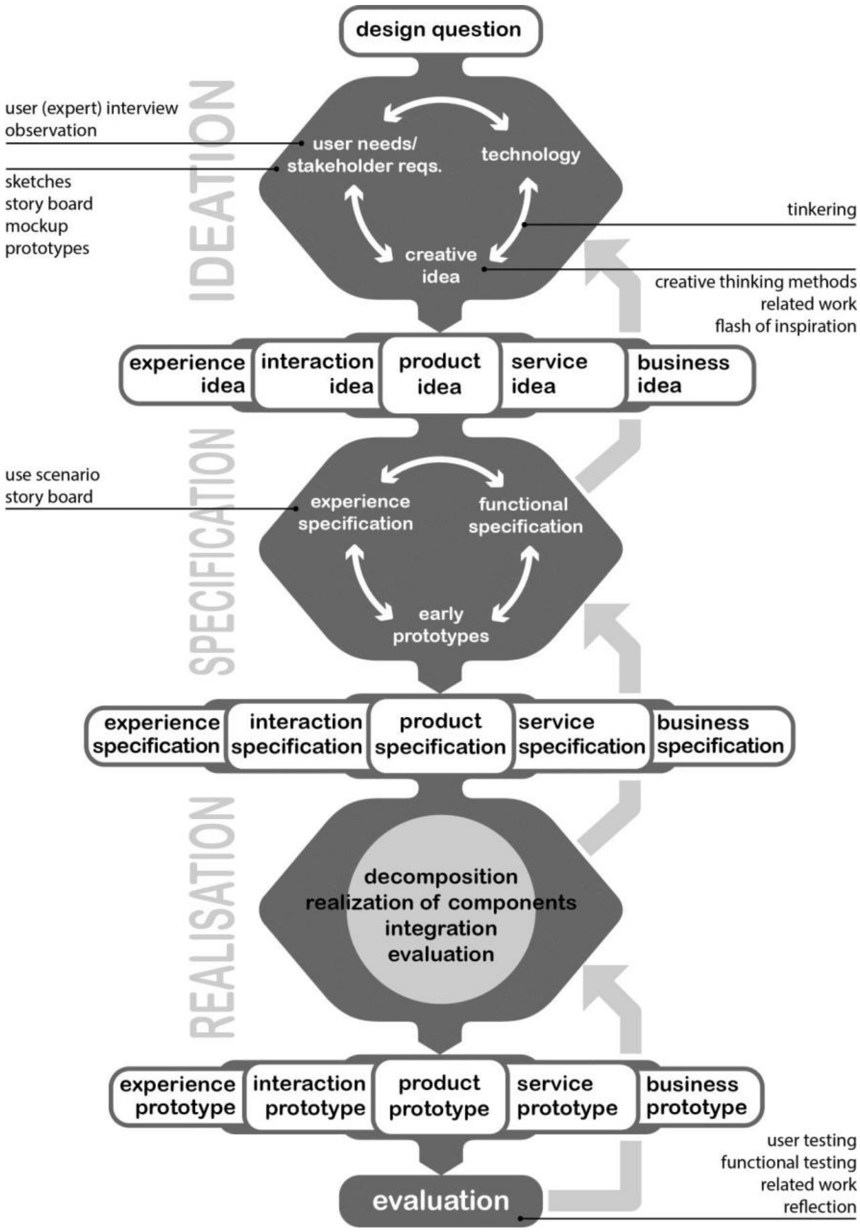

Figure 8 - Creative Technology design process [35].

3.1 Ideation

For this phase a starting point is chosen, in the case of this research: physicalizing climate change data. Inspiration is being drawn by studying the state-of-the-art research and the concept of Data Physicalisation in general, as well as taking into account aspects that intrigue on a personal level. Brainstorming with the supervisors and stakeholders can often generate a clearer insight into the possible directions the project could go. These discoveries result in a clearer and more elaborate picture of the prospective project and with that a more specific list of initial requirements.

3.2 Specification

This phase weighs different possible facets by comparing different lo-fi prototypes. These often express only parts of the potential final prototype in order to test the functionality and experience of these different aspects. Depending on the different requirements originally stated, different approaches are tested to satisfy those requirements on the sides of functionality, effectivity, and user experience. Quick testing is therefore an essential part of this phase, as the researcher should be open to new routes and not afraid to abandon the current approach. The Specification phase results in a clear design on paper consisting of different aspects that have been tested out in a lo-fi setup beforehand, are based on theoretical substantiation and/or experience of the researcher.

3.3 Realisation

The Realisation phase is characterised by the continuous process of realizing the individual components to fulfil the specifications and user requirements as determined in the earlier phases. If the implementation of certain components does not quite work out as expected, for instance in combination with other components, workarounds are devised. For this part of the process, the methods from the Engineering Design process can be fruitfully utilized.

3.4 Evaluation

Although a lot of evaluation has been performed in previous phases, it needs its own phase at the end of the process. Most functionality tests have already been done in the realisation phase, but usually only by the hands of the researcher who designed the installation. The researcher however has experience with the prototype and therefore will have an easier time interacting with the prototype. This can lead to a biased opinion regarding for instance the efficiency and functionality. Hence user tests should be conducted to gain more insight in the aspects of efficiency, functionality, accuracy, and effectivity. The reflective aspect of this phase should look at the (instinctive) design decisions made and allow the researchers to critically review the steps they took and learn from the mistakes discovered.

Chapter 4 – Ideation

This chapter explains the data chosen for this research and describes the various concepts considered before finalizing the prototype installation.

4.1 Data

There is a lot of data available on a plethora of topics that could be used for a data physicalisation installation. The direction of this project came from personal interest on the topic of climate change, since change must happen soon if we want to reach the goals stated in the Paris Agreement [3]. The Paris Agreement is a deal that was made between world leaders with the goal to keep the global temperature rise between the preindustrial era and 2050 below 2 degrees Celsius Therefore, to create more awareness on this topic, global temperature was chosen as variable. Monthly recorded data from nine countries evenly spread across the world was collected from the Climate Change Knowledge Forum [36] in the form of average temperature from 1900 up till 2020. Datapoints of future moments from 2021 up till 2100 were collected from the same source by selecting the Coupled Model Intercomparison Project Phase 5 (CMIP5) model that allowed for future predictions based on four different Representative Concentration Pathway's (RCP's). CMIP5 promotes a standard set of model simulations in order to, among others, provide projections of future climate change on two time-based scales, near term (out to about 2035) and long term (out to 2100 and beyond) [37]. Related to the rise in temperature are the rise of the sea-level, and data for these was also collected. Sea-level data was collected from this source [38] from 1993 up till 2022 with roughly 37 datapoints per year, and CO_2-level data was collected [39] from 1958 up till 2022 with 12 datapoints per year.

4.2 Physicalisation

The first iteration of the design was as follows:

To surround the user with the installation to add to the immersive experience, a hexagonal shape has been chosen. This way the users can easily access a control panel to interact with the installation in front of them while still being surrounded by the installation. The installation will be roughly 2.4 meters high and 2x2.4 meters in surface space.

When it comes to simulating the rise of the sea-level, sound was chosen as a data physicalisation factor. To simulate the sound of the rising water, 8 speakers will be installed behind the user on 4 different levels. Ground level, at 70 cm high, at 140 cm high, and at 210 cm high. The volume will be normal, meaning that the speakers will not produce deafening sounds. The speakers will be individually connected to output stages. These will be connected to one self-build single class A amplifier. Between the amplifier and the output stages, relays will be connected to control which speakers are on and which are off. This way the sea level can be simulated by only turning on the two speakers on the bottom level, and then when the sea level rises, turn on the two speakers one level higher level on, and so forth. To enhance the experience of rising water, two blue LED strips will be placed behind the user behind a diffuser which will also rise and lower, depending on the sea level.

To simulate the rise of the global temperature, temperature was chosen as second factor and therefore a heater will be placed out of sight underneath the control panel which will recreate the potential temperatures that could occur. A temperature sensor close by will monitor the temperature so the heater can be turned on and off at the desired moments. To aid this experience, a flat spiral made a of yellow-orange LED strip will be placed behind a diffuser which will shrink or grow in size, depending on the temperature.

The control panel will consist of three panels. One in the centre to select different countries (Iceland, USA, Netherlands, Greenland, Brazil, Australia, China, Russia, South Africa), on the left of the user, several parameters can be altered such as time by turning a wheel to the right or left (a LED strip will change its illuminated length corresponding to which time is currently displayed) and options to alter the level of CO_2 emission. The right panel is designed as a log-in terminal. Before the simulation can start, the user has to "connect" to the installation by placing a hand on the scanner, which is merely a capacitive touch sensor, and entering their name. This to create a psychological "connection" between the user and the installation by giving the feeling like part of the installation itself. A screen above the centre panel will display the results of the simulation as it progresses.

The simulation program will run on a laptop, which communicates via serial connection to an Arduino, which will handle the sensor input and actuator output. An alternative would be to use a Raspberry Pi 3B instead of a laptop and Arduino, but to accommodate quick handling of the large datasets and taking into account the familiarity of the engineer with programming in C on Arduino and programming in java-based Processing on Windows the design consists of the laptop + Arduino combination. The program will consist of a quick visualization of the data of the past, after the user has selected a country of interest. After this the program will continue to roll forwards in time though the data projections generated by the CMIP5 model, which allows for data modification based on different RCP's including CO_2 emissions. The user can change the current time by turning the wheel to the left or right and alter factors that influence the level of CO_2 emissions. These actions will be reflected on the screen and in the installation by changing the speaker level and/or triggering the infrared heater and their corresponding LED strips. Carton sheets painted black and silver will cover the outside, while black cloth will cover the inside.

Figure 9 shows design sketches without the outside cover to illustrate the design.

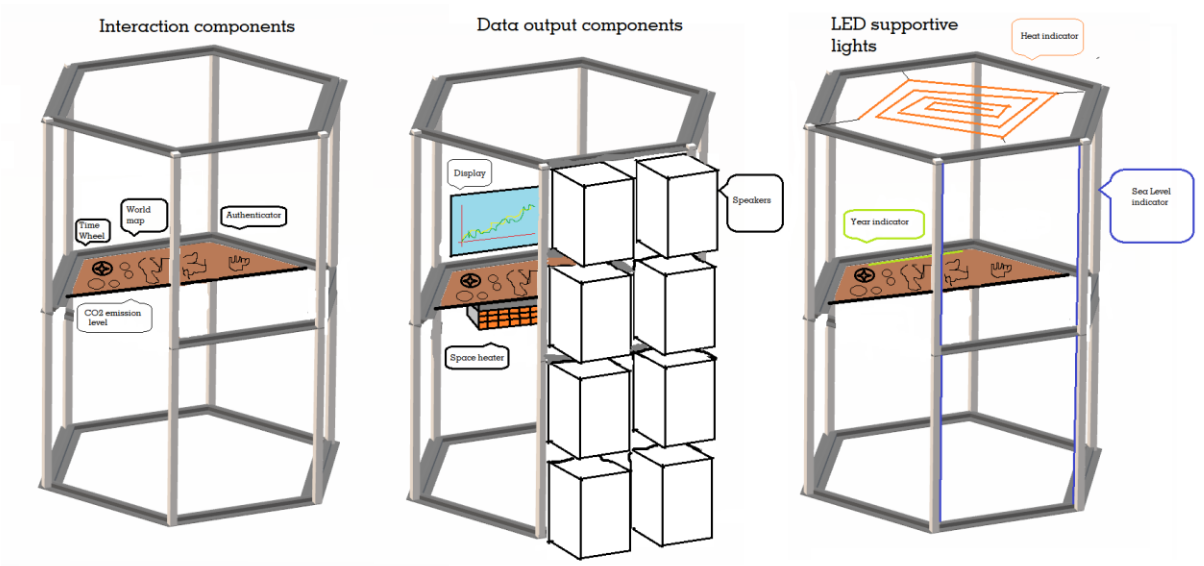

Figure 9 - Proposed design without the outside covers

The consecutive versions of the design involve changes implemented after rotating a few times between the ideation, specification, and realisation phase:

After discussing the design for the audio part of the system with an Electrical Engineer Masters' student, it became clear that it would be a challenge to manage the self-build amplifier and maintaining a constant gain independent of the amount of output stages turned on or off. If not carefully addressed, the volume would drop if more speaker sets would be turned on. To avoid this, two solutions were possible: either permanently connect all output stages and relocate the relays to the connection wire between the output stage and the physical speaker, or only turn on only two speaker sets at a time. Since this last option would require only one output stage instead of four, this option was chosen. At a later stage, when it became clear that there was no budget available and when there was less time available to build the amplifier from scratch, a complete surround sound amplifier was borrowed to replace the DIY class A amplifier and output stage.

As for the temperature factor, the heater that was the quickest to acquire and available for free was the garden heater owned by the neighbours which were so kind to lend their piece of equipment for the sake of this research. Since the heating elements of this heater were placed on top of a pole and proved to be irremovable, the design was changed to one where the heating elements were above the user's head level and beaming their heat with an angle down on the user. It also proved hard to control the temperature accurately with the temperature sensor since it would take some time for the heater to warm up and cool down its elements. Thus, an approach was chosen where the temperature data for the heater would be mapped the same as the sound data: in quadrants. Therefore, the need for a temperature sensor would be redundant and the heaters would have some time to warm up and cool down and allow for bigger time increments between the heaters being turned on.

After another meeting with the supervisors, the design was transformed into one that would focus only on the experience and immersion the factors would provide, extra elements that would also add to this could bring bias onto the results. Therefore, the hand scanner and LED strips aiding the heat- and sea-level were removed. This also resulted into a more specific data selection. The choice was made to only utilize the data on average temperature and drop the data on sea-level and CO_2 emissions. This way the two factors would both use the same dataset which would simplify drawing conclusions at a later stage. To change between future predictions, the user can switch between different RCPs. To simplify the interaction for the user, the often unknown term RCP (representing the concentration of greenhouse gasses, including CO_2, emitted in the future) has been replaced on the interface with the term "CO_2 emission" since this will speak better to the understanding of the user.

The wooden frame and black cloth covers were also removed due to time and cost restrictions, and instead a room would be chosen that would fulfil the same functionality of removing as many forms of distraction from the user as possible.

Chapter 5 – Specification

In this chapter the final requirements distilled from this phase and the other phases are presented, as well as intended interaction flows for different scenarios.

5.1 Requirements

The following requirement were gathered from the Ideation phase and through brainstorm sessions with the supervisors.

5.1.1 Functional

Users should be able to:

- Select and deselect data from the following countries:
  - Greenland
  - Iceland
  - Russia
  - United States of America
  - The Netherlands
  - China
  - Brazil
  - South Africa
  - Australia
- Switch between different Representative Concentration Pathway's / CO_2 emission concentrations
- Navigate through the years 1950 till 2050
- Read the visual data from a screen, including selected RCP/CO_2 level, average temperature of the countries selected, and the value of the absolute difference in temperature between the warmest and coolest country selected to remove the necessity for a separate calculator
- Adjust the range of the Y axis indicating the temperature according to the maximum and minimum value of the data selected to display the data as detailed as possible by optimally using the area in which the data is displayed
- Distinguish different levels of sound and temperature
- Notice the correlation between the data they selected and the level of sound and/or temperature they are exposed to

Other requirements:

- The system should allow for:
  - a quick switch between datasets
  - easy enabling and disabling of the immersive factors sound and temperature to facilitate easy selection of the desired immersion mode.
- Emitted sound level should range between barely audible and clearly audible and should not exceed basic conversation volume.
- Emitted temperature level should range between none and clearly experienceable; and should not cause harm to the user.
- The installation should provide the user with a certain level of immersion by using one or both factors.

5.1.2 Non-functional

Users should have:

- Embodied control by being able to physically interact with the tangible elements of the installation

The system should be:

- Easy, intuitive in use so no extensive instructions are necessary
- Suitable for user testing to determine which (combination of) factor(s) attribute to a higher level of perceived immersion by the user

5.2 User interaction

There are four different tangible elements with which the user can interact to change the data that is being displayed.

Navigating back in time

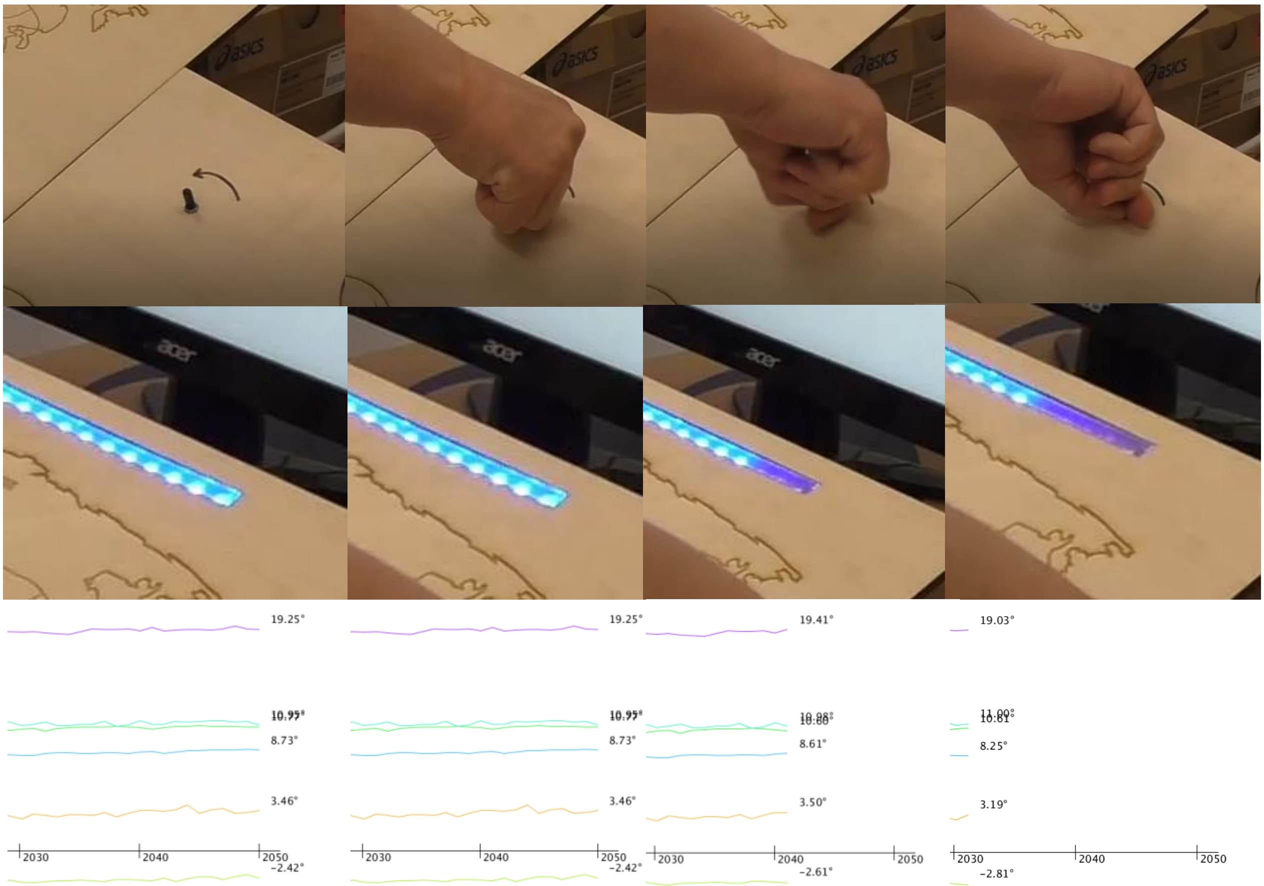

Figure 10 - Step-by-step illustration of a user scrolling back the time

To navigate backwards through the years, the user can turn the indicated knob on the dashboard. The LED strip on top of the board indicating the progress in time would change accordingly, and the graph on the screen would shift to the desired year. Figure 10 - Step-by-step illustration of a user scrolling back the time

Navigating forward in time

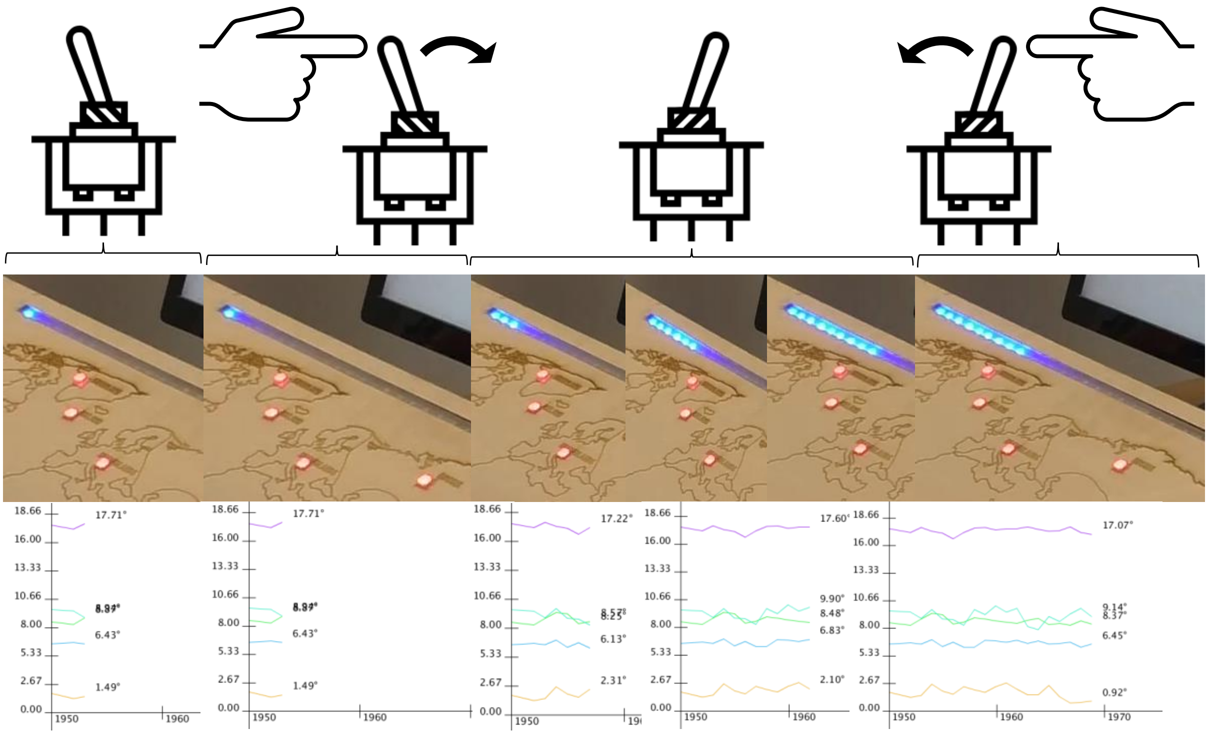

Figure 11 – Step-by-step illustration of navigating forward in time

The user can navigate forward through the years by flipping a designated switch on the dashboard. The system keeps incrementing the years until either the user manually flips the switch back, or when the system reaches the year 2050. In case of the latter, to ease the interaction, the user does not need to flip the switch before scrolling back in time. Figure 11 – Step-by-step illustration of navigating forward in time illustrates step-by-step the action of navigating forward in time.

Switching between different RCP levels

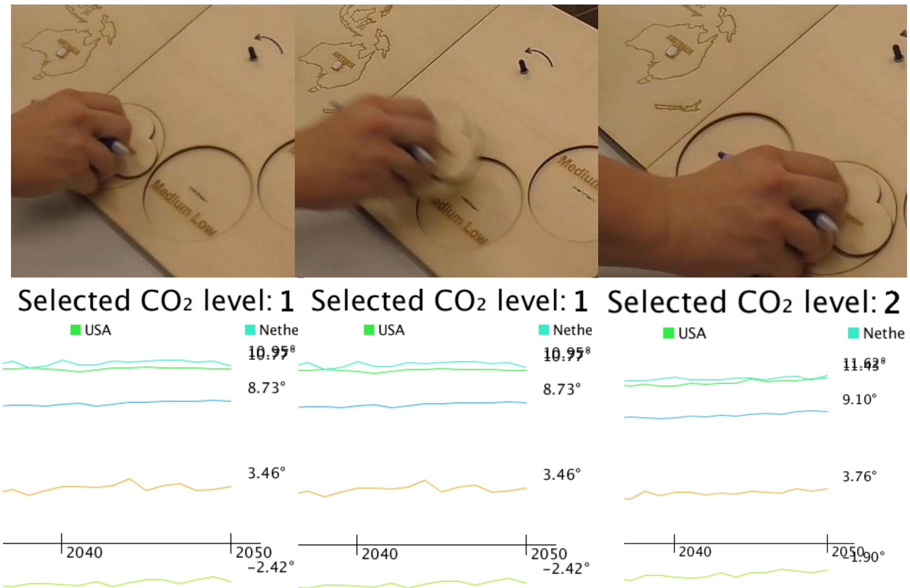

Figure 12 - Step-by-step illustration of selecting a different RCP level

To switch between different predicted trajectories that display different average temperature values for the same year, the user can move a disc to different slots. FFigure 12 - Step-by-step illustration of selecting a different RCP levelswitches from RCP 2.4, for the user indicated as CO_2 emission concentration Low and CO_2 level 1, to RCP 4.0 which is indicated for the user as CO_2 emission concentration Medium Low and CO_2 level 2. This results directly in a change of data on the screen, which now displays higher average temperatures for the year 2050 as opposed to when the user had the Low emission concentration selected.

Selecting and deselecting countries

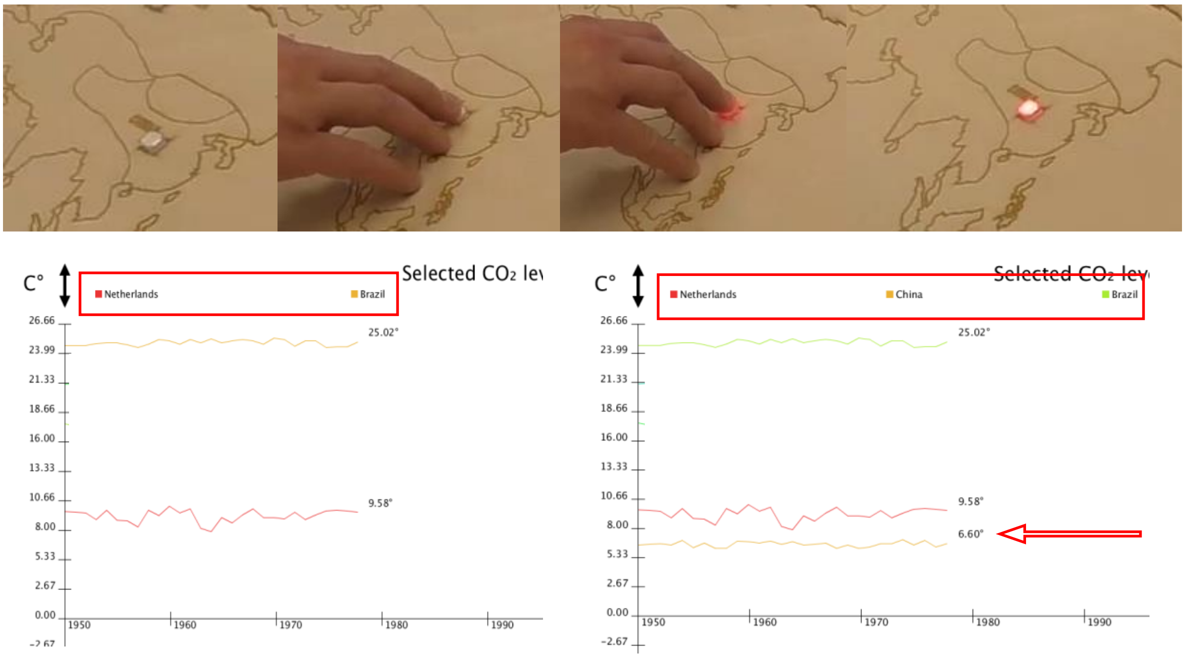

Figure 13 - Step-by-step illustration of a user selecting the country China

A user can select and deselect a country by pressing the corresponding button. If a country is selected, the LED in the button will turn on. In the example illustrated in Figure 13 - Step-by-step illustration of a user selecting the country Chinauser selects China as well. The graph of China is then added to the display, as well as its legenda will corresponding colour at the top of the screen. The user can now compare the average temperatures of China with those of the other selected countries. To deselect a country, simply press its button again. Its LED will turn off, and its graph and legenda will disappear from the screen.

Envisioned use scenario

The following scenario, as depicted in Figure 14 – Envisioned use scenariois imagined for when a user would interact with the installation. In this scenario the user wants to see the data of all nine countries up until the year 2030 based on the Low emission pathway. By controlling the tangible sensors, the desired parameters are easily adjusted. With the desired data displayed, the user can compare the selected countries with each other, as well as examine which country or countries would or would not complete the preliminary global climate goals by 2030. Having examined all the average temperatures of the year 2030, the user changes the year to 2040 by toggling the switch to positively increment the years until the year 2040 has been reached. After the user toggle's the switch again, the displayed temperatures can be compared with their predecessors one decade prior. The sound and temperature the user is exposed to while examining the data displayed add to the experience by increasing the perceived level of immersion of the user during its interaction with the data.

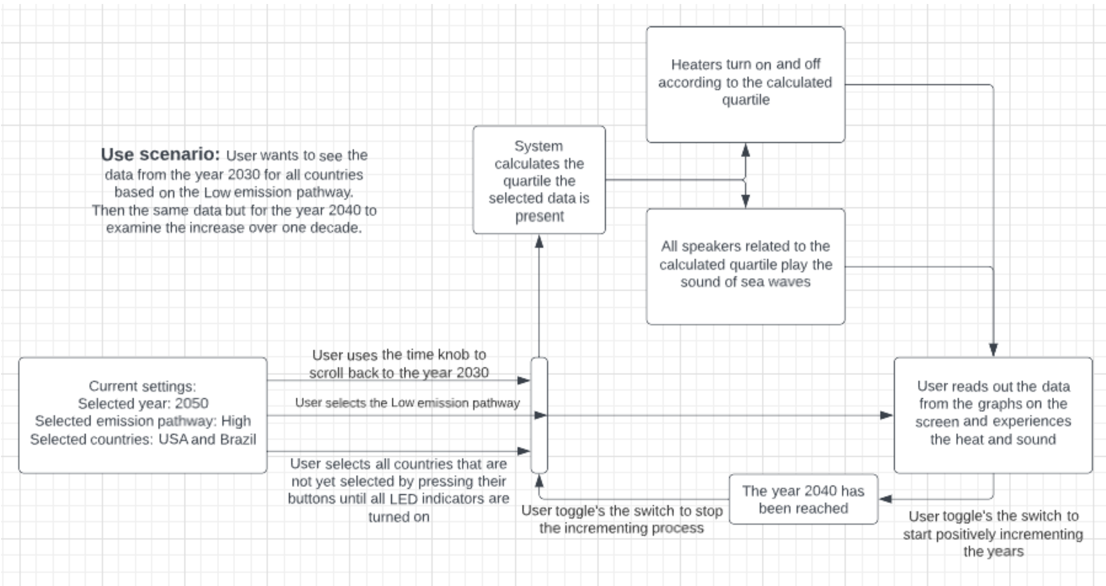

Figure 14 – Envisioned use scenario

Chapter 6 – Realisation

This chapter presents the details of the technical implementation of the system.

6.1 Hardware

The following components have been chosen to physicalize the refined design as outlined in the previous section:

6.1.1 Arduino

An Arduino Mega 2560 was chosen over other options such as a Raspberry Pi because of the extended experience of the researcher with working Arduino and the sensors suitable for this project. This microcontroller will be used to collect input from the sensors and to send this to the laptop, as well as receive data from the laptop to address the relays used for controlling the sound and temperature factors.

6.1.2 Laptop

An ASUS laptop running a Core I5 7^{th} generation was used since it would be more than enough capable to run the Processing software used for creating the visual representation of the data and play the sound required for the experience. It also stores the .txt file containing the average temperature data.

6.1.3 Actuators

For realising the physicalisation, the following actuators were used:

6.1.3.1 LEDs

An individually addressable LED strip, the WS 2812B was used to visually support the year selected by the user. The strip needed to be individually addressable to be able to specify which LEDs needed to be turned on and which turned off over a distance of half a meter. There were also LEDs inside the buttons to signal which countries were selected. This strip is used to indicate the process of the user on the timeline between 1950 and 2050.

6.1.3.2 Relays

Five relays were used to turn off and on the eight different speakers and the heater depending on the data selected.

6.1.3.3 Audio

Eight speakers divided in four sets of two were used to simulate the rise of the sea level. These were connected to an amplifier which would play the sound of sea waves crashing on the shore and depending on the data selected more or less speakers would be turned on. The speakers were stacked on top of each other to simulate the rise of the sea level.

6.1.3.4 Temperature

A garden heater with two electric coil heating elements was used to bring the heat to the experience and simulate the rise of global temperature. Depending on the data selected, the heater would be turned on or off for different periods of time.

6.1.3.5 Monitor

A monitor was used to display the visual representation of the data.

6.1.4 Sensors

List of sensors used:

6.1.4.1 Switches

- Buttons to select different countries.

- Reed switches to select different levels of CO_2 emission.
- Toggle switches to switch between data sets and to start/stop the automatic increment of time.

6.1.4.2 Rotary encoder

A rotary encoder was used for scrolling back in time. This sensor was chosen over a potentiometer since the rotating range would be infinitely larger, allowing for a higher level of accuracy when changing years.

6.2 Software

The following software was run on the Arduino Mega and laptop respectively. See Figure 15 - Code diagram below for a full diagram.

6.2.1 Arduino IDE

The Arduino code (*C++*) regulates the reading of the sensors and the actuators after it declared its global variables and established a connection between the Arduino and the laptop via serial communication. The input that is read from the sensors is sent to the Processing code running on the laptop and depending on the input the Arduino receives from the Processing code the relays and LED strip are addressed.

6.2.2 Processing

To run the digital visualizing aspects of the installation, Processing was chosen because of the long-term experience of the researcher with it and its excellent features when it comes to displaying adaptive visualisations and its possibility to directly connect to Arduino. The code (*Java based*) regulates the data handling and the visual output. Depending on what the code receives over the serial connection from the Arduino, different data is being selected from the dataset and shown on screen. Furthermore, based on what datapoint(s) is/are selected, the program calculates based on the data mapping in which quartile the average of that/those datapoint(s) belongs called the Quartile ID. The Quartile ID is then communicated back to the Arduino. It also sends the current year of which the data is being displayed, so the LED strip that visually aids the progress on the timeline can be adjusted.

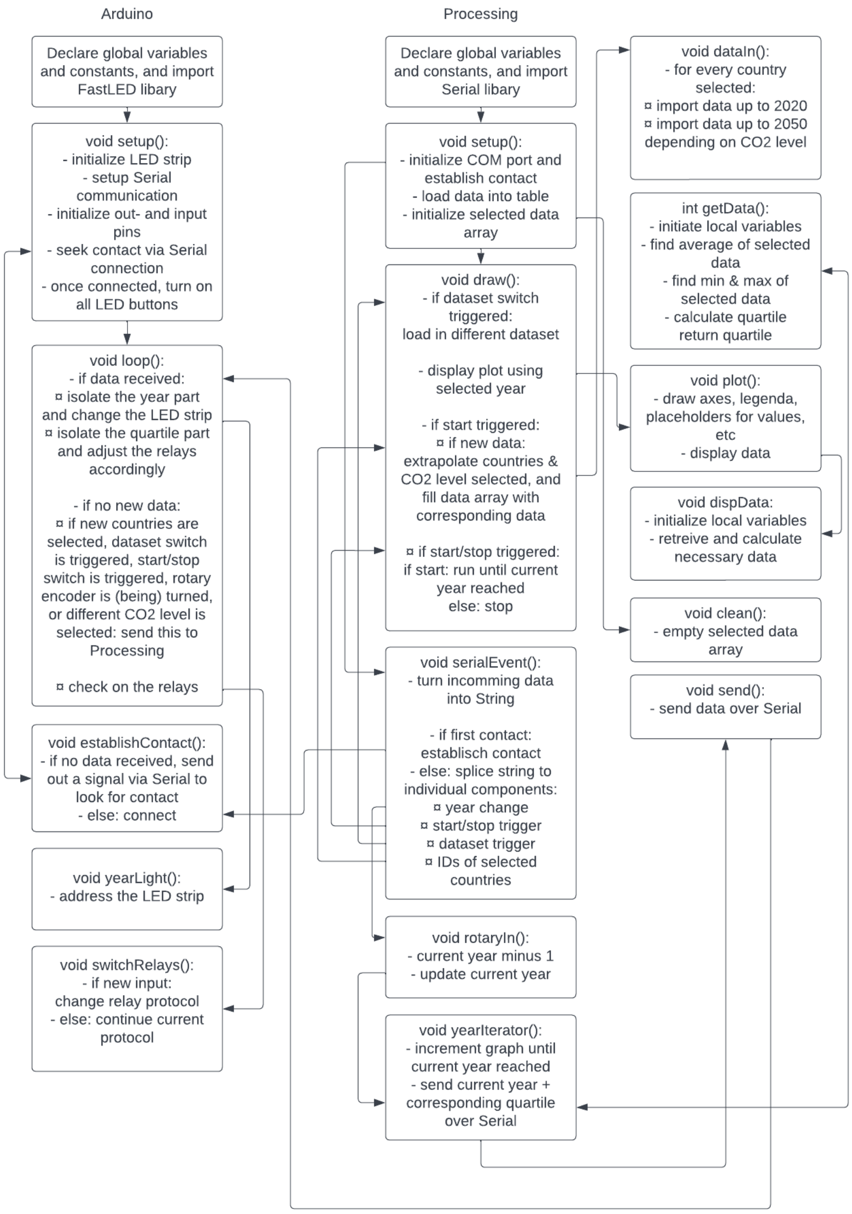

Figure 15 - Code diagram

6.3 Final setup

Figure 16 - A: heater; B: monitor for displaying the data; C: dashboard to select countries, different CO2 emission levels; and scroll through time D: laptop; E: speakers

The final setup (see Figure 16) consists of:

- a monitor for displaying the graph with the data
- an Arduino integrated behind a wooden dashboard
- sensors allowing for tangible interaction with the data by selecting different countries, changing the year of the displayed data, and changing the level of CO_2 emission
- a laptop which contains the data and runs the processing code
- a heater
- a set of eight speakers set up behind the user.

The Arduino receives the input from the user and communicates this to the processing code on the laptop. This displays the data on the monitor and sends back the current year the data is displaying as well as the quartile in which that data belongs. The Arduino then controls the relays based on the quartile and changes the LED strip to correspond to the data shown on screen. If the Arduino does not send new data to the laptop, but the year changes due to the automatic increment in time when the start/stop switch is triggered, Processing will keep sending updates on the year until the process is paused by the user or the end of the dataset is reached. Figure 17 shows a schematic overview of the system.

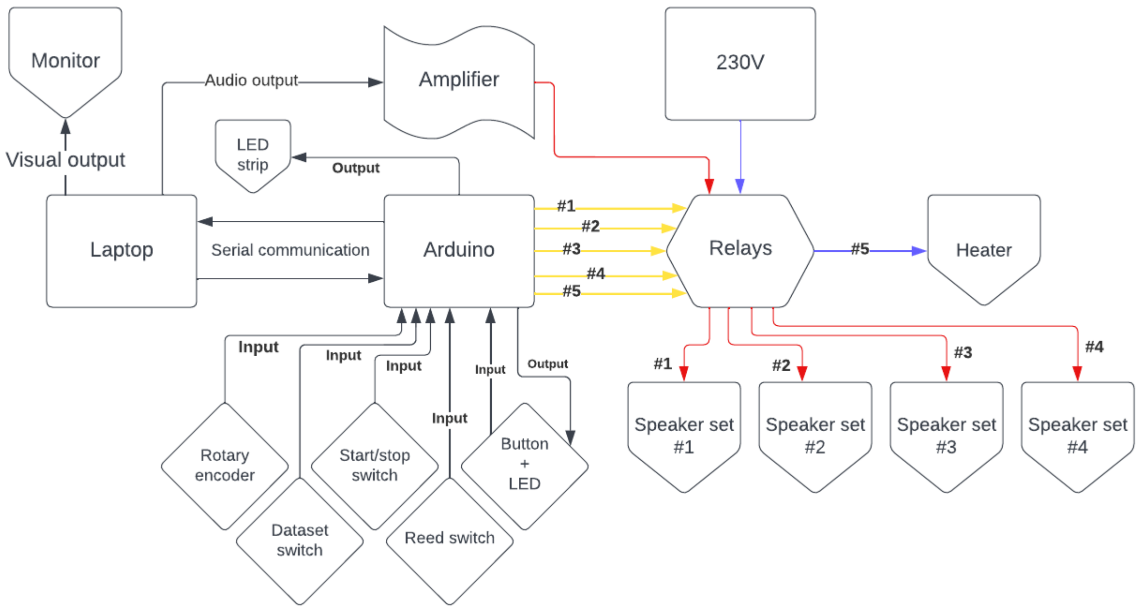

Figure 17 - Schematic overview of the system

6.4 Data mapping

The data consisted of the average temperature of nine different countries roughly spread evenly across the globe: Greenland, Iceland, Russia, USA, The Netherlands, China, Brazil, South Africa, and Australia. These counties have been chosen because they form a three-by-three grid, resulting in a global representation of the situation across the globe. Real data from the year 1950 till 2020 has been used, as well as predicted values based on four levels of CO_2 emission concentration from the year 2020 till 2050. This data can be found at Climate Change Knowledge Portal [34] as well as in Appendix H – Raw average temperature data. Table 3 - Categorizing the variables usedTable 3 specifies all prime in- and output variables by name, function, data format, and range.

Variable	I/O	Data format	Range
Country	Input	Categorical	Greenland, Iceland, Russia, USA, The Netherlands, China, Brazil, South Africa, and Australia.
Year	Input	Discrete	1950 - 2050 (with a one-year increment)
Average Temperature	Output	Continuous	Minimum and maximum value for each country
CO_2 emission concentration	Input	Ordinal	1 - 4 (Low, Medium Low, Medium High, High)

Table 3 - Categorizing the variables used

6.4.1 Visual representation

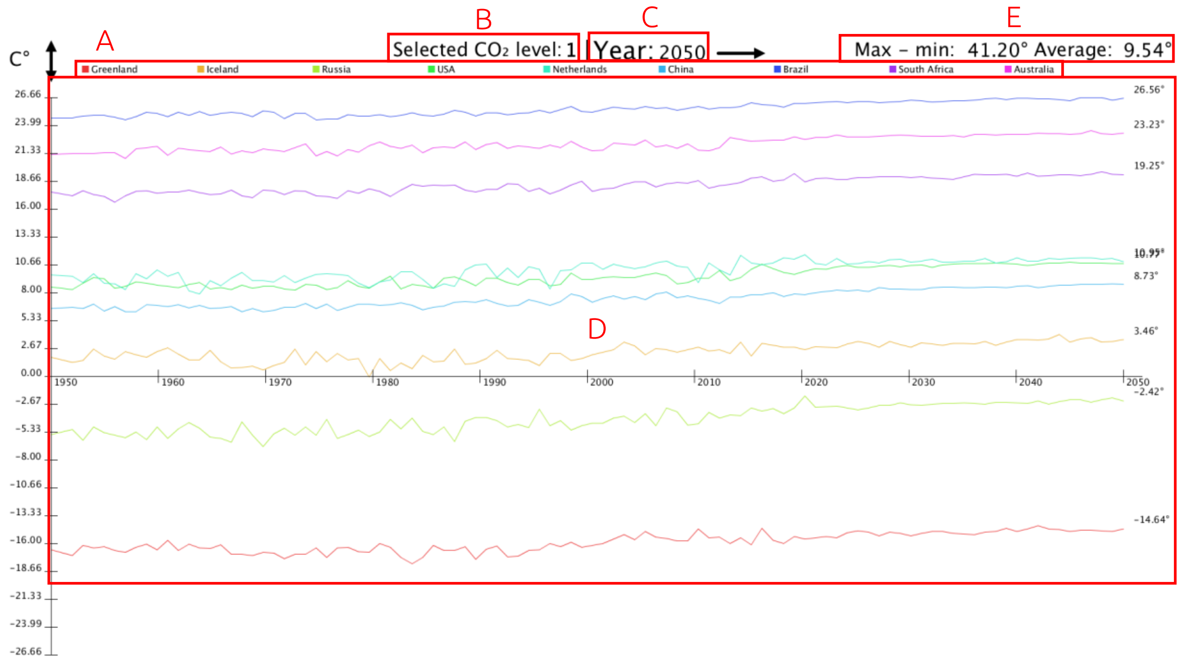

Figure 18 - Visual element of the UI displaying the main variables via a legenda (A), selected CO_2 level (B) indicator, year indicator (C), and the lines (D) in the graph

The variables are visually displayed on the monitor. The countries are colour coded to indicate which line belongs to which country. If a country is not selected, it is removed from the legenda (A) on top of the screen. The range of the Y axis dynamically adjust itself based on the selected data. It evaluates the largest value of the data selected, either positive or negative, and changes its range accordingly. The selected level of CO_2 emission (B) is indicated at the top. Level 1 indicating the selection of the Low concentration, increasing up till level 4 indicating the selection of the High concentration. The year indicator (C) specified of which year data is being displayed. The lines (D) in the graph area depict the average temperatures of the countries selected.

The values of Max – min and Average (E) are calculated based on the selected data and eased the comparison of either different countries or different years respectively. The Max – min value is the absolute value of the difference between the highest and lowest average temperature of the selected countries and year. The Average value is the average of the data for the selected countries and year.

6.4.2 Physical representation

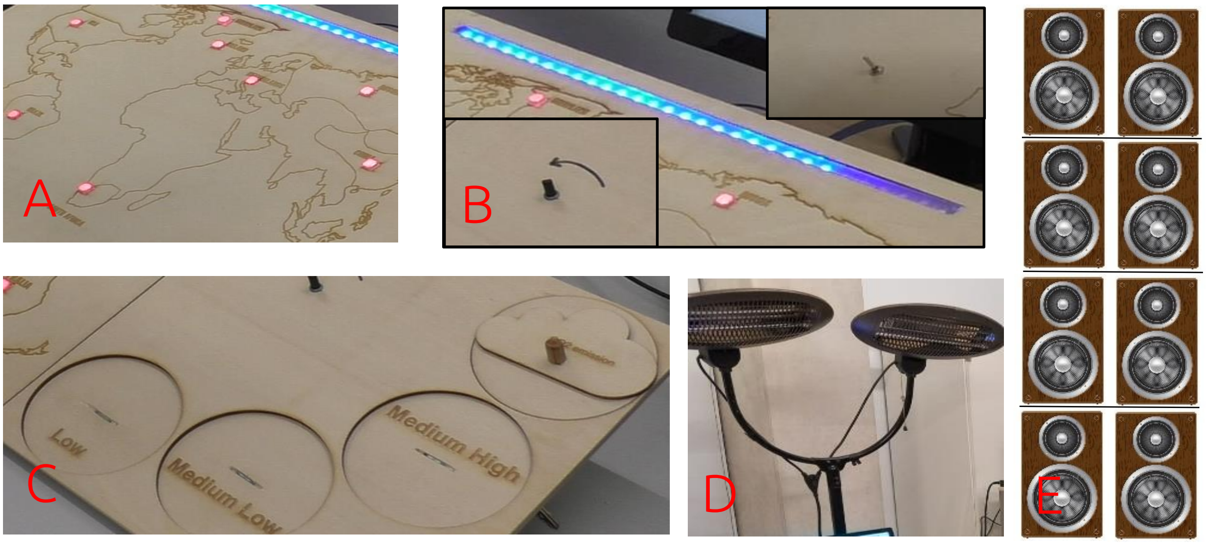

Figure 19 - Physical representation of the variables. Buttons with LEDs to select and deselect countries (A), turning knob and toggle swich to increment through the years with the LED strip indicating the progress (B), side panel to switch between different concentrations of CO_2 emissions (C), two heaters to use temperature as an immersive factor (D), four levels of two speakers to use sound as an immersive factor (E)

The input variables can be tangibly controlled by interacting with the components available on the wooden dashboard. To select or deselect countries, the user can press their corresponding buttons (A). If a country is selected, the corresponding LED will turn on. If the button is pressed again, the country will be deselected, and the LED will turn off. The data and the legenda corresponding to that county also appear and disappear from the visual UI accordingly. To navigate through the years, the user can control the designated knob and switch (B). By turning the knob to the left the user can navigate back in time, while toggling the switch allows the user to navigate forward in time. The blue LED strip on top of the dashboard indicates the progress through time. By moving the disc indicated by a lasercutted cloud and the text "CO_2 Emission" to different pre-cut slots (C), the user can select different levels of CO_2 emission concentrations for different future predictions. Heaters (D) above the dashboard and monitor provides the temperature factor based on the input from the user. A set of eight speakers (E) provide the sound factor based on the user's input.

6.4.3 Method

Encoding continuous data in sound and temperature factors is possible, but it is very hard for human senses to distinguish slightly different values. However, encoding ordinal data in abstract sounds has been proven to be effective [28]. Therefore, the choice was made to convert the data to an ordinal scale before encoding it in sound and temperature levels. Too many small increments within the allotted sound and temperature range would become indistinguishable for the user, while too large of an increment would make it too hard for

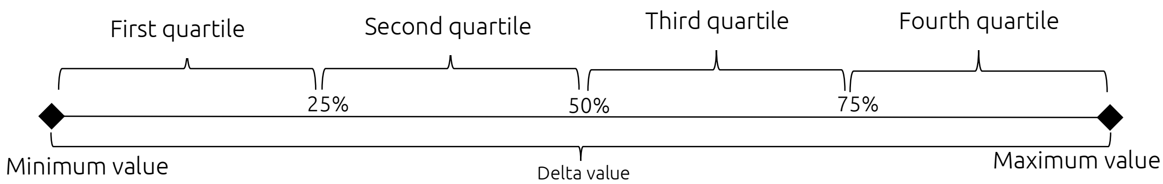

Figure 20 - Range division when data is selected

the user to note a correlation between the sound and temperature level and the data displayed. Furthermore, it would also weaken the immersion of the interaction since the changes would be too abrupt. Thus, based on similar studies [5], [23] encoding continuous data in physicalisation factors, the choice was made to split the sound and temperature range into four quartiles.

When a user selects countries and a specific year, the system will calculate the mean temperature per year from 1950 up till 2050 by summing all the average temperatures of the selected countries per year and dividing that value by the number of countries selected. This results in a range of 100 mean temperatures from 1950 up to 2050. This range has a minimum and a maximum value, and if the user selects a specific year, the mean of that year will be between these two values. The absolute difference between the maximum and the minimum value is the delta value. When subtracting the minimum value from the mean of the selected year, and dividing this value by the delta value, a fraction with a value between 0 and 1 is calculated. To create more precise cut-off points at the 25%, 50%, and 75% borders, this value is multiplied by eight. This decimal number is then being rounded up or down to the nearest integer. This integer has a value between and including 0 and 8 and functions as a Quartile ID since it determines in which Quartile the selected data is present, which the Arduino uses to regulate the heat and sound. Each quartile consists of two or three possible IDs: 0,1 & 2 means the first quartile, 3 & 4 the second quartile, 5 & 6 the third quartile, and 7 & 8 the fourth quartile. This full equation is compiled into equation 1. The value of the Quartile determines the regulation of heat and sound as described in the section below. If no data is selected, the sound and temperature factors will be turned off.

$$Quartile\ ID = \ int\left(\left|\frac{average\ value - min}{|\max - min|}\right|\right) * 8$$

Equation 1 - Quartile calculation

6.4.4 Sound and heat mapping

If the ID would be within the first quartile, only the first two bottom speakers will turn on. If the ID would be within the second quartile, the two bottom speakers and the two speakers one level higher will turn on. This routine repeats itself for the third and fourth quartile. This method combines the approach of encoding abstract sounds (see chapter 2.1.3.2 Physicalisation using sound or temperature) based on location and loudness with the use of the realistic sound of sea waves crashing on the shore [40]. This is noticeable every time the data shifts to a different quartile, where a different number of speakers will produce sound, resulting in the sound coming from a different location behind the user at a different volume.

Because temperature cannot be changed quick when using an electric coil heater, the mapping of the heat was also quartile based instead of having a linear correlation to the average temperature displayed. This results in an ordinal structure of the output, which allows for a similar approach utilised when encoding the sound factor. Possible variables are the Attack/Decay variable, Duration variable, and “Loudness”, which in the case of the temperature factor will be the temperature-setting of the heater. Since the heater available for use could merely be controlled by tuning it on and off, the Duration variable was chosen. If the ID would be within the first quartile, the heating system will turn off. If the ID would be within the second quartile, it will turn on for two seconds and off for six seconds. If the ID would be within the third quartile, it will turn on for four seconds and off for four seconds. And if the ID would be within the fourth quartile, it will turn on for six seconds and off for two seconds.

Chapter 7 – Evaluation

This chapter presents the evaluation of the prototype and the results.

7.1 User study plan

The experiment design consisted of the following components.

7.1.1 Goal, hypothesis, and variables

From the start, the goal of the experiment was to study *Which factor(s) attribute to better levels of immersion?* The design included both sound and temperature as a factor, and thus, the hypothesis was stated as: *The combination of the sound and temperature factor will yield the highest perceived levels of immersion (when compared to only one of the two or using none).*

To validate this hypothesis, the following dependent and independent variables were selected:

Independent:

- Different tasks in which the user must retrieve climate change data
- Different system configurations:
  - 1: Using Sound & Temperature
  - 2: Only sound
  - 3: Only temperature
  - 4: Using neither

Dependent variables:

- Time of completion per task
- Accuracy of task answers
- User experience
- Perceived level of immersion

7.1.2 Study design

7.1.2.1 Design

The study had a between-group study comparing four separate participant groups. One group was exposed to both factors, sound and temperature. Two groups were only be exposed to one factor, one group just temperature and the other group just sound. One group functioned as a control group and was exposed to neither factor. To measure the accuracy of the system and make users interact with all the tangible elements incorporated, the user was presented with two sets of tasks, see Table 4. These tasks required the user to find specific datapoints in the dataset by interacting with the installation. The first set consisted of tasks regarding random generated data to familiarize the user with the UI before commencing the actual user test, but without exposing the user to the actual data and therefore minimizing bias of the learning effect regarding the contents of the data. The tasks within the task set about the real data collected from the Climate Change Knowledge Portal [29] was presented to the user in a randomized order. Therefore, minimizing the learning effect bias on the results of the task completion time.

The evaluation was done by comparing the perceived levels of immersion rated by the users in a post-test questionnaire (Appendix C – Questionnaire) between the four different groups, each having interacted with a different system configuration. These evaluation questions about the perceived level of immersion during the interaction provided insight in the effectivity of the temperature and sound factors, and applicable standard USE questions

[41] were used to evaluate the user experience. To measure task performance time accurately, a video recorder was used to tape the interactions of the users with the installation. Combined with the accuracy with which the users completed the tasks, the performance of the installation was evaluated. The users were not identifiably visible on the recordings.

7.1.2.2 Materials

The following materials were used to perform the user tests:

- Questionnaire (see Appendix C – Questionnaire) divided into the following subsections:
    - Ease of use
    - Ease of learning
    - Satisfaction
    - Perceived level of Immersion
    - Increased awareness about climate change
    - Previous experience regarding Human Computer Interaction and Data Physicalisation
- Consent form (see Appendix D – Consent form)
- Informational brochure (Appendix E – Informational brochure)
- Video camera
- Random generated data from Mockaroo [41]
- Recorded live data from Climate Change Knowledge Portal [35]
- Task list as described in Table 4

7.1.3 Participants

44 participants were recruited of the study. There were no specific participant requirements regarding experience or demographic, except for a basic understanding of the English language. Recruitment took place among peers and other close contacts via Whatsapp and forum messages to reach the number of 44 participants as quickly as possible. During recruitment there was no mention of a reward, but afterwards they received a little bag of candy as a small thank you.

7.1.4 Task listing

The following task sets were presented to the participant. As stated earlier, the second set, set 1, was presented to the participants in different order to minimize potential bias. These tasks were designed to make the participant interact with all the tangible components, changing the parameters for every task. The tasks in set 0, to familiarize the participant with the system, were designed as easy tasks, asking the participant to retrieve only one datapoint or value from the system. If the tasks from set 0 were performed correctly, the participant had by the end of the set interacted at least two times with each tangible component. Two tasks from set 1 were designed to make the participant compare clusters of data points at two different moments in time. The other two tasks from set 1 were designed to make the participant find the difference between two data points at a singular moment in time. Cluster questions required the participant to compare more datapoints to able to complete the tasks, therefore taking a longer time to complete as compared to the Difference tasks where the tasks required the participant to compare data from different countries under different prospected circumstances.

Kind of question	Question
	Set 0 (randomised data)
Average	1. What is the average global temperature of the year 1980?
Average	2. What is the average global temperature of the year 2050 according to the high emission prediction model?
Average	3. What is the average temperature of Greenland in the year 2030 according to the medium low emission prediction model?
	Set 1 (real data)
Difference	4. What is the difference in average temperature between Australia and Greenland in the year 2040 when selecting the low emission prediction model?
Cluster	5. Which country or countries will fail the Paris Agreement (a raise of maximum 2.0 degrees as opposed to the temperature in 1950) by 2050 when using the low CO_2 emission model?
Difference	6. Select two different countries of your own choice and note down the difference in average temperature of the year 2030 for each CO_2 prediction model.
Cluster	7. *Find the first year for each CO_2 model in which the global temperature is above the target of the Paris Agreement (a raise of maximum 2.0 degrees as opposed to the temperature in 1950).*

Table 4 - Task list arranged in one of the possible orders

7.1.5 Procedure

Each study session consisted of one participant and one researcher. Most sessions took no longer than thirty minutes. First, the moderator would provide an explanation of the objective and the procedure of the study to the participant. Secondly, the participant would be asked to read the informational brochure and fill in the consent form. Thirdly, the participant would be verbally instructed on how to interact with the installation and would then perform practice tasks using task set 0 with the dataset containing randomized data. When participants were done with set 0, the recording of the actions of the participant would start. Fourthly, the participants would perform the tasks from task set 1 while using real climate change data. Fifthly, at the end of the study to get general feedback and attitudes about the intuitiveness and success of the interaction, a questionnaire was given to every participant to collect general feedback and the experience of the participant. This questionnaire consisted of applicable standard USE questionnaire questions, questions about the perceived level of immersion, and questions about the impact of the installation on the user. Here they could also rate their perceived level of immersion and user experience. Finally, the moderator would wrap up the session, asking participants if they had any further comments to share, and give them their reward.

7.1.5.1 Example introduction dialogue

Researcher: Welcome and thank you for participating in this user test. This study takes a closer look at the interaction between users and Data Physicalisation installations. During this session you will interact with the installation (points to installation) by executing tasks where you have to extract data from a dataset containing average temperature values from different countries from 1950 up till 2050. To select a country, simply press the corresponding button. The graph displaying the temperature will increment automatically, you can use this switch (points to pause/play switch) to pause or continue the increment. In order to scroll back in time, turn this knob to the left. A prediction model based on four different levels of CO_2 emission was used to determine the values of future average temperatures. To change between different levels, move this disc (point to CO_2 emission disc) to the designated spot. On the top of the screen, you can see which CO_2 level you selected, as well as which year the current data displayed is from. In the top right corner of the screen, you can see the average temperature of the selected countries, as well as the difference between the maximum and the minimum value of the selected countries. When you are done performing the tasks, you will be asked to fill in a questionnaire about the tasks and the installation. The first three tasks are for you to get familiar with the interface, therefore you will be using a dummy dataset filled with randomized data. The other four tasks will be using real average temperature data.

Here are the informational brochure and the informed consent. If you have any questions, please do not hesitate to ask.

7.1.6 Pilot study

The first four participants also served as pilot sessions, possibly identifying crucial elements that needed to be adjusted about the user study design or user test procedure. No problematic issues were observed during these pilot sessions. Therefore, their results could be included into the main study. However, two tasks were not described clearly enough and needed verbal elaboration before participants could complete the task due to poor phrasing. These tasks were rephrased by removing excessive words that made the task confusing.

7.2 User study data processing

All questionnaire and task list data was digitalized and processed into Excel. The time of completion per task was extracted from the video recordings made of the experiment sessions and also stored in Excel. The video recordings also provided context to why tasks were not executed correctly and if this was due to human errors or system errors. Statistical analysis was performed using SPSS 28.

7.3 Results

In the end, 44 users (27 M, 16 F, 1 Non-Binary) participated in the user study, with an even distribution of 11 participants per study group. Two of the participants studied Sustainable Energy Technology, their already high awareness beforehand resulted in them rating low on the questions about increased awareness. Three of the participants were Creative Technology students with more than average experience in the field of Human Computer Interaction and interacting with Data Physicalisation installations, skewing the results of the experience of the user a little bit to the righthand side (Strongly Agree, having experience). Outliers did occur, but the choice has been made to include these in the analyses since the sample sets per subgroups only have 11 participants. The results of the questionnaires and the task lists can be found in Appendix F – Questionnaire and task list results.

Conclusions and insights regarding the results can be found in Chapter 9 – Conclusion.

7.3.1 Task completion time

On average, participants spend 13 minutes and 41 seconds interacting with the installation. As stated earlier, in order to measure efficiency, a video recording was made of the users performing the tasks. Video was chosen over other time recording devices such as a stopwatch or a function within the code because video can provide context on why a specific task took as long as it did. For instance, if the device was not responding correctly or if the user made a mistake and takes the time to rectify this. This information is important to, among other things, investigate possible outliers. In total 43 recordings were analysed, since one recording turned out to be corrupted and therefore unusable.

Despite the instruction on the visual interface beforehand, quite a few of participants calculated the difference between two countries by hand instead of looking at the top righthand corner of the screen where the Max – min value showed the already calculated difference between two selected countries. This resulted in slightly longer completion times than neccerery. Table 5 contains the completion time in seconds per task per subgroup and the average over all subgroups.

Task completion time		Both		Sound*		Temp.		Neither		**Average**	
		Time (s)	SD	Time (s)	SD	Time (s)	SD	Time (s)	SD	**Time (s)**	**SD**
T4	*What is the difference in average temperature between Australia and Greenland in the year 2040 when selecting the low emission prediction model?*	56.82	15.43	70.30	37.90	77.82	33.88	72.64	21.66	**69.40**	**27.28**
T5	*Which country or countries will fail the Paris Agreement (a raise of maximum 2.0 degrees as opposed to the temperature in 1950) by 2050 when using the low CO2 emission model?*	303.18	74.46	310.90	106.55	292.36	86.50	319.82	73.68	**306.57**	**85.30**
T6	*Select two different countries of your own choice and note down the difference in average temperature of the year 2030 for each CO2 prediction model.*	146.36	44.79	165.00	68.92	127.55	44.42	164.73	63.80	**150.91**	**55.48**
T7	*Find the first year for each CO2 model in which the global temperature is above the target of the Paris Agreement (a raise of maximum 2.0 degrees as opposed to the temperature in 1950).*	258.82	112.40	349.50	151.25	278.82	100.18	297.36	110.41	**296.13**	**118.56**
Summed Task Completion Time		***765.18***		***895.70***		***776.55***		***854.55***		***823.01***	

***N=10 instead of 11 due to one corrupted recording**

Table 5 - Task completion time per task per subgroup

A One-way ANOVA test was performed to test for significant difference between the means of the four different subgroups across the four tasks. The H0 hypothesis "There is no

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
TimeT4	Between Groups	2644.128	3	881.376	1.092	.364
	Within Groups	31481.918	39	807.229		
	Total	34126.047	42			
TimeT5	Between Groups	4463.979	3	1487.993	.202	.894
	Within Groups	286728.718	39	7352.018		
	Total	291192.698	42			
TimeT6	Between Groups	10313.011	3	3437.670	1.088	.366
	Within Groups	123239.455	39	3159.986		
	Total	133552.465	42			
TimeT7	Between Groups	47044.100	3	15681.367	1.103	.360
	Within Groups	554490.318	39	14217.700		
	Total	601534.419	42			
TotalTime	Between Groups	124185.879	3	41395.293	.990	.407
	Within Groups	1630101.191	39	41797.466		
	Total	1754287.070	42			

Table 6 - Result of the One-way ANOVA test performed to determine a statistical significance in difference between the means of the different study groups. TimeT4 – TimeT7 being the task completion time variable of task 4 till 7.

statistically significant difference between the means of the four subgroups per task" on a 95% confidence interval was proven true since the Sig. value for none of the tasks was below 0.05, see Table 6 - Result of the One-way ANOVA test performed to determine a statistical significance in difference between the means of the different study groups.

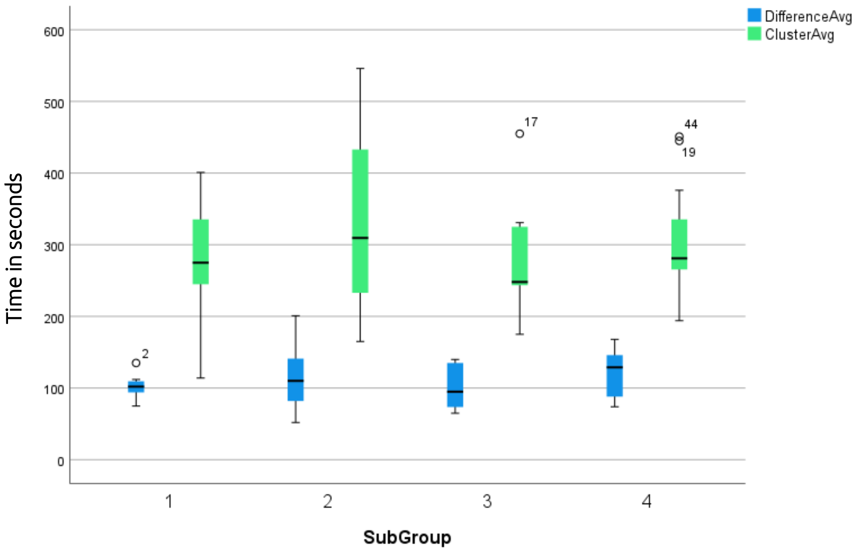

Figure 21 – Task time per subgroup (1: Both; 2: Sound; 3: Temperature; 4: Neither) sorted by kind of question

TimeT4 – TimeT7 being the task completion time variable of task 4 till 7.. This was as expected since the aim of including the factors sound and temperature into the physicalisation were merely to improve the perceived level of immersion, and not to influence the performance of the participant.

As can be seen in Figure 21, there is however a clear difference between the Difference and Cluster type tasks. This is expected since the Cluster questions required the user to compare a lot more data than the Difference questions. A paired sample T-test (Table 7) on a 95% confidence interval where the null hypothesis is "that there is no statistical difference" confirms that the two kinds of question statistically significant differ since p = <,001 < 0,05.

The fasted participant finished in 6 minutes and 16 seconds, and the slowest participant in 22 minutes and 52 seconds. The notion must be made that the fastest participant completed the cluster tasks only partially, missing several steps. The fastest participant who did complete all tasks spend 8 minutes and 54 minutes interacting with the installation.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	DifferenceAvg	110.23	43	33.089	5.046
	ClusterAvg	300.86	43	89.930	13.714

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	DifferenceAvg - ClusterAvg	-190.628	88.973	13.568	-218.010	-163.246	-14.050	42	<,001	<,001

Table 7 - Paired sample t-test to test for a significant difference between the means of the two kinds of question

7.3.2 Accuracy of task answers

The results from the tasks have been analysed in order to determine the effectiveness of the system to convey data and to interact with data. Overall, only half of the tasks were executed correctly. However, the notion must be made that due to a coding error, when selecting the year 1950, no data would be visible in the graph. The Average and Max – min value on the other hand would still be computed and visible for the year 1950. Therefore, the only way to collect any data from that year was to select only one country at a time and look at the top right corner where the variable "Average" would display the value of the average of all countries selected, in that case only one and thus just the average temperature of the selected country in 1950, a value the participants would need for completing the task correctly. As the system engineer, this workaround was easier to spot then for a lot of the users, most of whom would just use the values of the year 1951 instead. Also, the question "*Which country or countries will fail the Paris Agreement (a raise of maximum 2.0 degrees as opposed to the temperature in 1950) by 2050 when using the low CO_2 emission model?*" turned out to be subject to interpretation. The intention of the question was to make users compare the values of 1950 and 2050 and if the difference would be larger than two degrees, they would have to note down the name of the countries. However, for some countries the value of 2049 would be higher than the value of 2050, where the value of 2049 would cause the country to fail, but the value of 2050 not. This resulted in the unintended inclusion of these countries by participants when completing the task.

After review of the footage, task 5 "*Which country or countries will fail the Paris Agreement (a raise of maximum 2.0 degrees as opposed to the temperature in 1950) by 2050 when using the low CO2 emission model?"* turned out to suffer from confusing phrasing of the task, as well as from incorrect behaviour from the system such as mentioned above. Some participants would start calculating from the year1951 instead of 1950, others would include countries that would fail the conditions of the Paris Agreement (no increase larger than 2 degrees Celsius as opposed to the temperature in 1950) *before* 2050 but *would* satisfy the conditions *in* the year 2050. On other occasions, the disc denoting the level of CO_2 emission concentration would not be registered correctly by the Arduino, and thus displaying data from a different level than which the participant had correctly selected. Also, the rotary encoder would sometimes not register a step when being turned, resulting in incrementing into the wrong direction, making it harder for users to select the year 1950.

Therefore, the choice has been made to remove this task from the statistical analysis on task completion correctness. The values of the correct answers to verify the answers given by the participants have been acquired by both interaction with the installation and via analysis of the data in Excel.

For task 6 and 7, since the coding error mentioned previously and the imprecise working of the rotary encoder both often prompted users to measure using the data from the year 1951 instead of 1950, the choice has been made to include the results of those tasks separately. These tasks were executed correctly by the user but yielded the wrong data because the system malfunctioned. These separate statistics can be found under *Measured from 1951.* For task 7 additional statistics have been added for clarification. Questions that were only answered partially correct, were classified as incorrect. They are however, included in the table below for context.

All 176 tasks from set have been executed of which all results for task 5 were removed, resulting in a total of 132 tasks, 33 tasks per subgroup. Task 4 was completed the most accurate by a big margin. One reason for this difference could be that task 4 required less steps since it required the least steps, leaving less margin for system errors to occur. Another reason could be that the other tasks were less well defined, which resulted in participants interpreting the intention of the task differently.

		Accuracy of task answers	Both	Sound	Temp.	Neither	**Total**
Difference	*T4*	*What is the difference in average temperature between Australia and Greenland in the year 2040 when selecting the low emission prediction model?*	82%	82%	100%	100%	**91%**
Difference	*T6*	*Select two different countries of your own choice and note down the difference in average temperature of the year 2030 for each CO_2 prediction model.*	36%	82%	36%	18%	**43%**
		- *Measured from 1951**	*18%*	*0%*	*18%*	*0%*	***9%***
Cluster	*T7*	*Find the first year for each CO_2 model in which the global temperature is above the target of the Paris Agreement (a raise of maximum 2.0 degrees as opposed to the temperature in 1950).*	18%	18%	18%	0%	**14%**
		- *Measured from 1951**	*9%*	*0%*	*18%*	*0%*	***7%***
		- *Wrong but partially correct answers***	*52%*	*50%*	*59%*	*34%*	*49%*
	Summed Accuracy of task answers		***45%***	***61%***	***39%***	***52%***	***49%***
		- ***Including Measured from 1951****	***55%***	***61%***	***39%***	***64%***	***55%***

***** Tasks executed correctly by the user but wrongly answered due to system malfunction***
*****Includes answers from both measured from 1950 and 1951***

Table 8 - Results of the dependent variable Accuracy of task answers. T4, T6, and T7 denoting task 4, 6, and 7 respectively.

A Kruskal Wallis test could be performed to determine if a subgroup performed significantly different. To do this, for every participant the variable Task Completed Successfully would be added to the results, ranging from 0 to 3 depending on how many tasks they completed successfully. However, since these results just contain 11 values per subgroup with every datapoint ranging from 0 to 3, the occurrence of a type I error would be very likely if the hypothesis should be rejected.

7.3.3 Questionnaire

7.3.3.1 User Experience

The first questions of the questionnaire were to measure the User Experience, how the user experienced its interaction with the installation regarding Ease of use, Ease of learning, and Satisfaction.

	User Experience	Both		Sound		Temperature		Neither		**Average**	
		Score	SD	Score	SD	Score	SD	Score	SD	**Score**	**SD**
	Ease of use									***5.33***	***1.142***
Q1	*It is easy to use*	5.36	1.027	5.50	.707	5.64	.809	5.36	1.027	5.48	.876
Q2	*The tasks (4-7) were easy to complete*	5.27	1.009	5.40	.966	5.55	.934	5.64	.809	5.50	.928
Q3	*It is user friendly*	5.00	1.483	5.70	1.567	5.45	1.128	5.55	.820	5.43	1.246
Q4	*Using it is effortless**	4.36	1.206	5.30	1.767	4.82	1.168	4.64	1.206	4.77	1.342
Q5	*I can use it without written instructions*	5.64	1.286	6.00	.943	5.45	1.753	4.91	1.136	5.48	1.320
	Ease of learning									***6.44***	***.725***
Q6	*It is easy to learn how to use it*	6.55	.688	6.70	.675	6.73	.467	6.82	.405	6.70	.553
Q7	*I quickly became skilful with it.*	5.73	1.104	6.30	.949	6.27	.647	6.36	.809	6.18	.896
	Satisfaction									***6.00***	***1.078***
Q8	*It is fun to use*	5.73	1.348	6.00	.816	6.18	.603	6.00	1.414	6.00	1.078
	User Experience	***5.46***	***1.144***	***6.58***	***1.049***	***5.76***	***0,939***	***5.66***	***0,953***	***5.92***	***0,982***

** N = 43 instead of 44 due to a participant forgetting to fill in the question*

Table 9 - Questionnaire results from Q1-Q8 about User Experience

Since these questions are about the interaction the user has with the console and the screen, components that were equal for all four of the study groups, we expect there to be no significance between the groups. To confirm this, a nonparametric Kruskal Wallis test with a 95% confidence interval was performed since the data set contains ordinal data of which the four independent groups needed to be compared.

Test Statistics[a,b]

	QU1	QU2	QU3	QU4	QU5	QL6	QL7	QS8
Kruskal-Wallis H	.641	.877	2.586	3.005	4.055	1.314	3.284	.959
df	3	3	3	3	3	3	3	3
Asymp. Sig.	.887	.831	.460	.391	.256	.726	.350	.811

a. Kruskal Wallis Test

b. Grouping Variable: Subgroup Both/Sound/Temperature/ Neither

Table 10 - Kruskal Wallis test with a 95% confidence interval used to determine if there is a significance difference between the answers of the four groups regarding the questions about User Experience

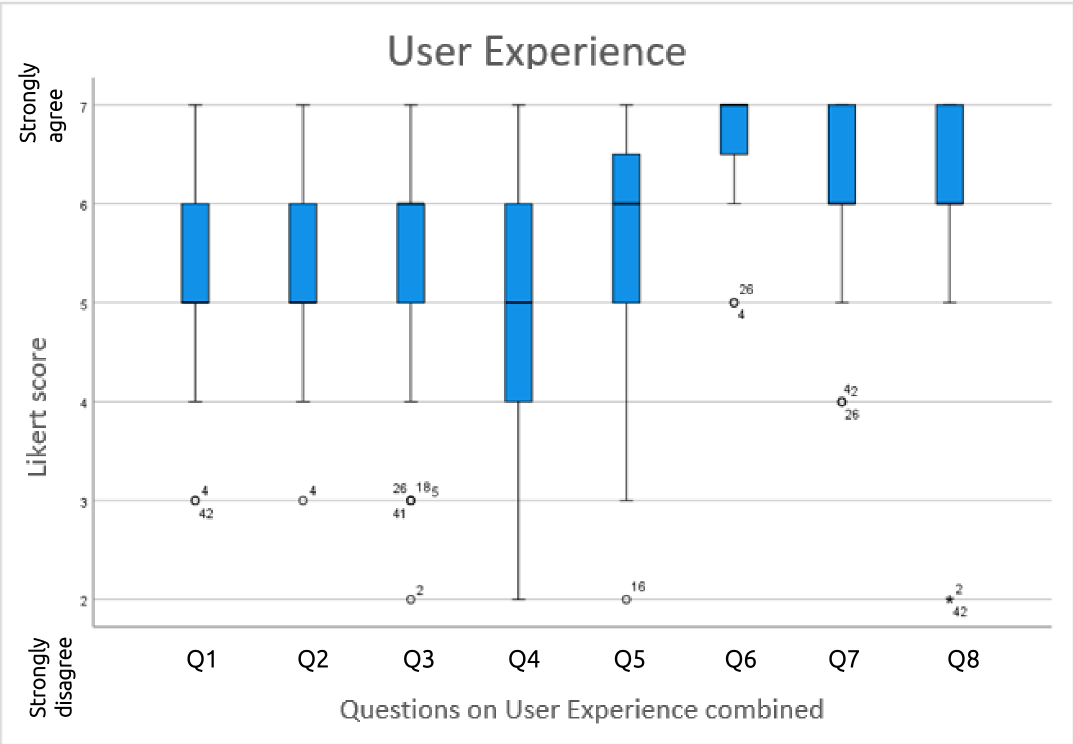

Figure 22 - Results per User Experience question combined. Q1 meaning question 1 up to Q8 meaning question 8

Because for all questions $p < 0.05$ is not met, we can assume that there is no statistical difference between the given answers when comparing the different study groups and therefore an average was computed for all questions. Interestingly, although the difference is not significantly large enough, the study groups with only one factor (sound or temperature) yielded higher average means as opposed to the study groups that had both or neither factor in 5 out of 8 cases (see Table 9).

A Likert scale ranging from 1 till 7 has been used for the questionnaire, and from that an overall score of 5.92 emerged. The lowest average recorded was 4.77 regarding question 4 “Using it is effortless”. One explanation for this could be found in the comments participants were able to provide if they felt necessary, where 13 out of 17 general comments addressed the knob that can be used to scroll back in time in ways such as "*button is hard to get the exact year*" and "*button for rewinding time is a little tricky to use".*

7.3.3.2 Immersion

The second set of questions of the questionnaire probed the users for their perceived level of immersion. Table 11 shows the results of the questionnaire questions Q9-Q13 about immersion. The score was measure via a Likert scale ranging from 1 (Strongly disagree) to 7 (Strongly agree).

	Perceived level of Immersion	Both		Sound		Temp.		Neither		**Average**	
		Score	SD	Score	SD	Score	SD	Score	SD	**Score**	**SD**
Q9	*I felt immersed when interacting with the system*	5.09	1.375	5.64	.924	5.27	1.009	5.18	1.537	**5.30**	**1.212**
Q10	*I felt **strongly** immersed when interacting with the system*	3.91	1.446	4.45	1.635	4.18	1.601	3.73	.905	**4.07**	**1.404**
Q11	*I felt **barely** immersed when interacting with the system**	5.09	1.300	5.91	.701	5.45	1.214	5.55	1.864	**5.50**	**1.321**
Q12	*I could distinguish a correlation between the data shown on screen, and the **sound** that I was exposed to***	4.45	1.440	4.00	2.449	-	-	-	-	**4.23**	**1.974**
Q13	*I could distinguish a correlation between the data shown on screen, and the **temperature** that I was exposed to***	3.82	1.779	-	-	3.45	1.635	-	-	**3.64**	**1.677**
	Perceived levels of Immersion									***4.55***	***1.518***

** Since this was presented as a negative question, the inversed values were used for better statistical analysis*
*** N = 22 since only 11 participants of the group Both and 11 participants from the group of that specific factor had to answer this question*

Table 11 - Questionnaire results from Q9-Q13 about Perceived level of Immersion

To provide context for the answers given at question 9, question 10 and 11 were added as sub questions. They should not be used for direct conclusions on the level of immersion, but to provide more insight on what the users intention was when answering question 9. If they felt immersed, how strong or weak was that perceived immersion. The first attempt to map the relation between Q9, Q10, and Q11 resulted in a 3D scatterplot where also study group and amount of duplicate data points (data points that are on the same coordinates and therefore not clearly visible if left untreated) was taken into account. Unfortunately, this made it a hard to interpret graph when placed into a 2D environment such as a bachelor thesis. After consulting with the supervisors, the 3D graph was split up into two different graphs (Figure 23 & Figure 24) to illustrate the results more clearly.

Test Statistics[a,b]

	QI9	QI10	InvQI11
Kruskal-Wallis H	1.279	2.913	2.326
df	3	3	3
Asymp. Sig.	.734	.405	.508

a. Kruskal Wallis Test
b. Grouping Variable: Subgroup Both/Sound/Temperature/ Neither

Table 12 - Kruskal Wallis test to determine a significance in difference between the groups regarding question 9, 10, and 11

To test if there was any significant difference between the groups regarding the immersion questions, a nonparametric Kruskal Wallis test with a 95% confidence interval was performed. Since for none of the questions a p value of < 0.05 was found, there was no significant difference between the different study groups regarding question 9, 10, and 11 under these conditions.

Figure 24 shows the relation between question 9 and both question 10 and 11. The size of the datapoints correlate to the number of duplicate points on that coordinate, ranging from the largest circles containing 6 data points and the smallest ones only 1. The boxplot in Figure 24 displays the variety of the answers given per user study group. Trendlines were added to Figure 24 to showcase the direction and the parallel spread of the datapoints, clearly showing a strong relation between high values for question 10, inverted values for question 11, and question 9.

Figure 24 shows study group 1 (both factors) containing 4 outliers as well as the lowest mean of 5.09. Since there was no significant difference was proven, subgroup results were grouped in the far-right boxplot.

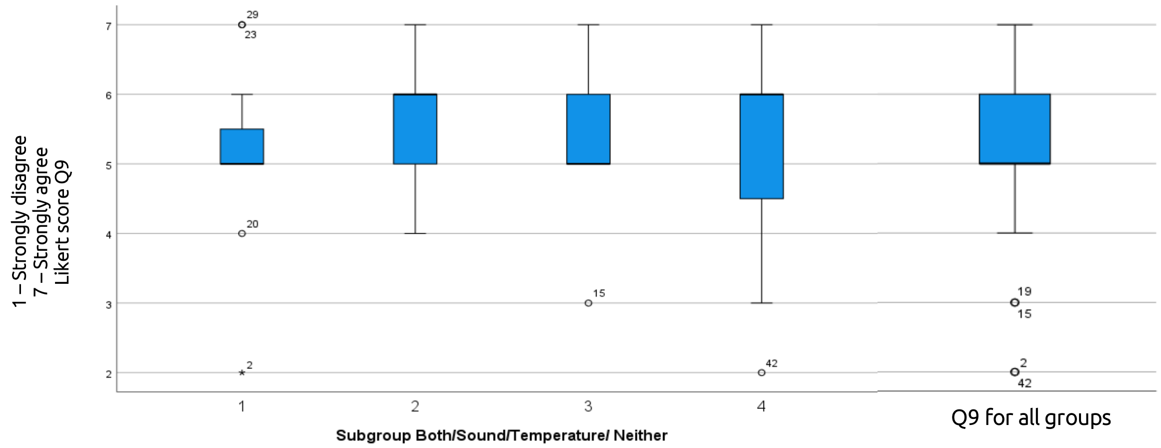

Figure 23 - Boxplot on question 9 depicting the spread of datapoints per group. The Y axis contains the Likert score ranging from 1: Strongly disagree to 7: Strongly agree

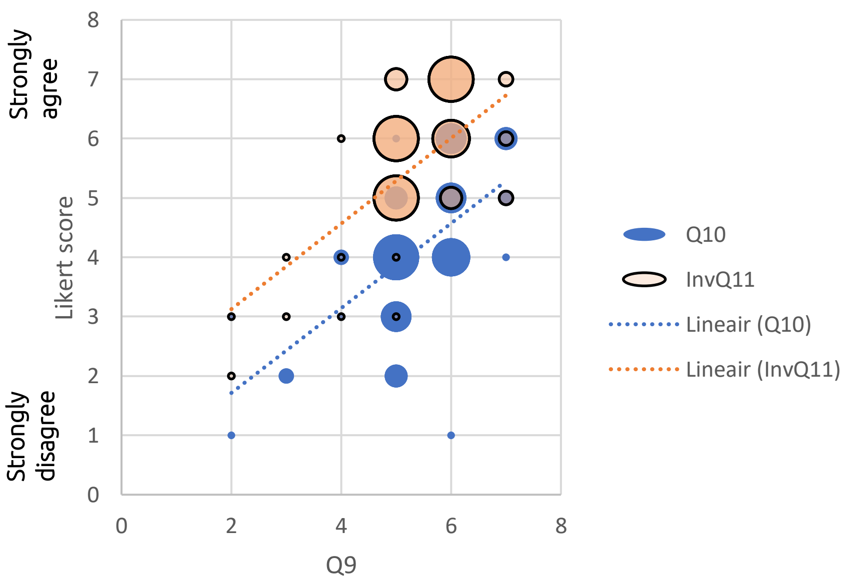

Figure 24 - Graph displaying the correlation between question 9, 10, and 11

Interesting is to see how, even though there is no statistical significance, user study group 2 (Sound) yielded the highest mean for question 9, 10, and 11 alike.

Comparing the ability to perceive any form of correlation between the data and the factor participants were exposed to is a little complicated due to this part of the data set containing both independent and dependent answers since group 1 (Both) answered both questions as opposed to group 2 and 3 (one factor each). Therefore there has been chosen to split this part of the dataset in two parts, a dependent part, and an independent part. For the dependent part a nonparametric Sign test will be performed to compare the answers from group 1 on both questions, and for the independent part a Mann-Whitney test will be performed to compare the answers from group 2 at question 12 and group 3 at question 13.

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Q12andQ13	22	3.73	2.051	1	7
SandT	22	2.50	.512	2	3

Ranks

	SandT	N	Mean Rank	Sum of Ranks
Q12andQ13	2	11	12.18	134.00
	3	11	10.82	119.00
	Total	22		

Test Statistics[a]

	Q12andQ13
Mann-Whitney U	53.000
Wilcoxon W	119.000
Z	-.498
Asymp. Sig. (2-tailed)	.619
Exact Sig. [2*(1-tailed Sig.)]	.652[b]

a. Grouping Variable: SandT

b. Not corrected for ties.

Table 14 - Mann-Whitney test to determine significance in difference between the results of question 12 and 13

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum	Percentiles 25th	Percentiles 50th (Median)	Percentiles 75th
QI12	22	4.23	1.974	1	7	2.75	5.00	6.00
QI13	22	3.64	1.677	1	7	2.00	4.00	5.00

Frequencies

		N
QI13 - QI12	Negative Differences[a]	5
	Positive Differences[b]	3
	Ties[c]	3
	Total	11

a. QI13 < QI12

b. QI13 > QI12

c. QI13 = QI12

Test Statistics[a]

	QI13 - QI12
Exact Sig. (2-tailed)	.727[b]

a. Sign Test

b. Binomial distribution used.

Table 14 - Sign test to determine significance in difference between the results of question 12 and 13

Since both tests (see Table 14 & Table 14) do not yield a $p < 0,05$ there can be assumed that there is **no** statistical significance between the answers given at question 12 and 13 under the given circumstances. Nevertheless, a difference of **0.59** in favour of group 2 can be observed in Table 11 when looking at these two questions.

You may expect that both (or at least one of the) factors yield a positive correlation between the corresponding question and question 9. However, when plotting trendlines for Figure 25 this does not seem the case, on the contrary even. The more participants got

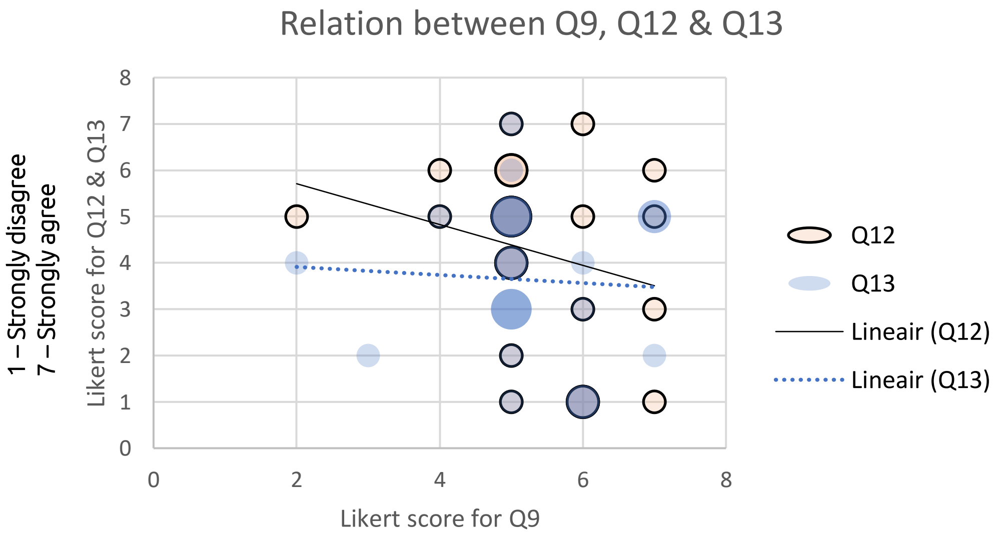

Figure 25 - Scatterplot displaying the relation between Q9, Q12 & Q13

immersed, the less they were able to distinguish a correlation between the data shown on screen and the factor(s) they were exposed to.

Even though there was no statistical difference between the groups on the questions regarding perceived levels of immersion, all questions except Q13 yielded an average mean of 4+ on a Likert scale where 4 is the average. Even the system configuration with no factors included (group 4) still yielded a mean of 5.18 which could suggest that the board and monitor alone provided the user with an offset regarding the perceived level of immersion.

7.3.3.3 Climate Change

The third set of questions of the questionnaire were regarding the user's possible shift of view on the topic of climate change.

	Climate Change	Both		Sound		Temp.		Neither		**Average**	
		Score	SD	Score	SD	Score	SD	Score	SD	**Score**	**SD**
Q14	*I am more aware of the climate change problem than before interacting with the installation*	4.55	.934	3.73	1.794	4.91	.944	3.64	1.120	**4.20**	**1.322**
Q15	*I perceive the climate change problem more urgent than before interacting with the installation*	4.55	1.214	3.45	1.809	4.18	.874	3.36	1.286	**3.89**	**1.385**
Q16	*I feel more like I can have a positive impact on the climate change problem than before*	3.09	1.446	2.55	1.440	3.45	1.368	2.82	1.328	**2.98**	**1.389**
	Climate Change									***3.69***	***1.365***

Table 15 - Questionnaire results from Q14-Q16 about Climate Change

These questions were not related to a specific dependent variable; however, these were included to offer the researcher a little more insight on the possible effect the installation could have on participants in future versions. A Kruskal Wallis test with a 95% confidence interval was performed to test for significance between the groups. Since a p value of < 0.05 was required, all questions failed to show a significant difference between the answers given by the different groups. On average, participants rated their awareness to be increased. A score of 4.20 where the neutral lies at 4 indicates a very small increase. Afterwards, participants did not seem to think that the climate crisis was a more urgent problem or that they could have a more positive impact on climate change than before interacting with the installation.

Test Statistics[a,b]

	QC14	QC15	QC16
Kruskal-Wallis H	7.817	5.327	2.714
df	3	3	3
Asymp. Sig.	.050	.149	.438

a. Kruskal Wallis Test

b. Grouping Variable: Subgroup Both/Sound/Temperature/ Neither

Table 16 - Kruskal-Wallis test for determining a significant difference between the study groups

7.3.3.4 Prior Experience

The final set of questions of the questionnaire were to evaluate prior experience of the participants in order to explain possible outliers due to there being a lot of difference of experience between the participants. Three of the participants were Creative Technology students with more than average experience in the field of Human Computer Interaction and interacting with Data Physicalisation installations, skewing the results of the experience of the user a little bit to the righthand side of the Likert scale (Strongly Agree).

	Prior Experience	Both		Sound		Temp.		Neither		**Average**	
		Score	SD	Score	SD	Score	SD	Score	SD	**Score**	**SD**
Q17	*I have experience in the field of Human Computer Interaction*	1.82	1.662	2.73	2.240	2.18	1.779	3.09	1.700	**2.45**	**1.861**
Q18	*I have experience with interacting with Data Physicalisation installations*	1.91	1.814	2.55	2.018	2.27	1.555	2.64	1.859	**2.34**	**1.778**
	Prior Experience									***2.40***	***1.820***

Table 17 - Questionnaire results from Q17-Q18 on Prior Experience

A Kruskal Wallis test with a 95% confidence interval was performed to test for significance between the groups. Since a p value of < 0.05 was required, all questions failed to show a significant difference between the answers given by the different groups. The one outlier at question 18 can be explained since this person was a Creative Technology student who also wrote a bachelor thesis on the topic of data physicalisation. The "tail" of the two questions reaching 7 and 6 respectively can be explained by the fact that there were a few Creative Technology students among the participants and these students encounter these topics during their study.

Test Statistics[a,b]

	QE17	QE18
Kruskal-Wallis H	6.193	2.053
df	3	3
Asymp. Sig.	.103	.562

a. Kruskal Wallis Test

b. Grouping Variable: Subgroup Both/Sound/Temperature/ Neither

Table 18 - Kruskal-Wallis test to determine statistical significance in means between question 17 and question 18

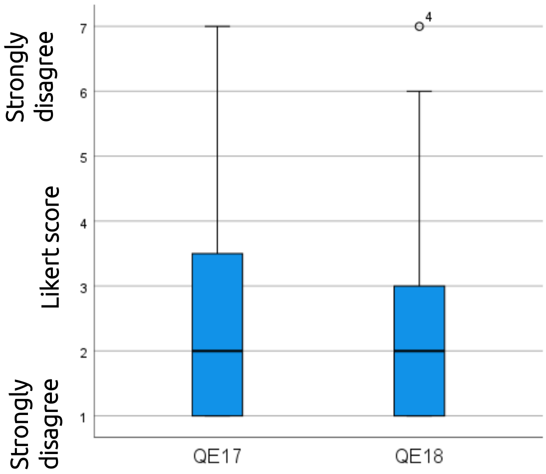

Figure 26 – Boxplot of the Likert score regarding Q17 and Q18 with combined groups

7.3.4 Feedback

Almost everybody really liked the installation and was very enthusiastic after interacting with it. Most of the critical feedback was regarding the poor functioning of the time scroll knob. Some typical reactions were: "*It was quite an eye opener to see the changes on screen and all the differences. Cool interactions.*" and "*I'm already concerned about the climate before using the installation. Using the installation confirmed this feeling but did not point a doomsday scenario either. I understand the specifies of it better.*". When it comes to the factors Sound and Temperature, not everybody seemed to be able to detect a clear causation between the factors enabled and the data displayed. One person mentioned to really noticing it when interacting with solely Greenland, which can be explained by the fact that a few of the tasks require the participant to have Greenland selected for a while at the end of the year selection to perform some calculations, which gives the heaters the time to heat up. A few people mentioned to only notice the sound and/or temperature when they were done, being so focussed on performing the tasks that they would filter out other stimuli.

One of the highlights participants mentioned afterwards were the LEDs incorporated in the dashboard displaying which countries were selected and where the participant was on the timeline. They were described as fancy and very satisfying,

"It was quite an eye opener to see the changes on screen and all the differences. Cool interactions."

Figure 27 - Quote from one of the participants on the system

Chapter 8 – Discussion

The aim of this research was to develop a tangible and immersive data physicalisation on climate change. We researched whether sound and/or temperature contribute to a higher level of immersion. Firstly, the limitations encountered during the design process and the analysis of the results will be discussed. Secondly, recommendations will be provided on how to improve the current design. Lastly, future research possibilities will be discussed.

8.1 Limitations and complications

Several limitations arose during the transition from a theoretical design to a physical prototype. The design had to be stripped down a minimal viable prototype. Apparently, there was no budget available. Workarounds needed to be found including alternative components that would fulfil the same function but still deliver the same experience while being lower in cost.

A bug would occur during some of the first sessions of the day. Starting the laptop from hibernation state would result in the connection between the laptop and Arduino being severed after a while without feedback. Seemingly, the only way to resume testing was to restart the laptop completely which took a few minutes. The restart procedure may have disrupted the immersive state of the user since the interaction had to be paused while influences outside of the intended experience restarted the system.

A coding error made it difficult for participants to read out the values of the year 1950. Therefore, a lot of participants used the year 1951 for the tasks that required values of 1950. Also, the phrasing of task 5 and 7 turned out to be multi-interpretable. These situations occasionally created confusion which could have disrupted the level of immersion, as well as influencing the accuracy results in a negative way by resulting in wrong answers.

The magnets attached to the disc with which the participants could select the different RCPs needed to be right above the reed switches for them to register the presence of the disc. If the participant would rotate the disc too much, the magnets would not be aligned well enough for the switch to trigger. Although text had been engraved on the disc to convey the intended orientation, during the user testing it would occur a few times that the disc was not properly placed. This oversight in the design resulted in skewed results regarding the accuracy of the answers.

Based on feedback such as "*Was not nice that I could not turn right to go to the correct year but had to hope that I could pause the simulation on time*" and by analysing the video footage, some of the outliers seemed to occur because that it was not always easy to quickly select the correct year.

Since the experiment design required four study groups to measure the different factors, a large group of participants was needed. The aim was to have 44 people in total, thus 11 per group, in order to find a balance between a realistic result in the total amount of participants that could be recruited and the ability to potentially yield a statistical difference without having a sample size that would be too small. However, using four categories with eleven participants per group does require a clear difference in score to be statistically significant, which the results from the user study did not show. Since the sample size is small and the results do show signs of some form of difference, it is not clear if the lack of significance is due to the small sample size or there is no significant difference, regardless of the sample size. These results therefore need to be interpreted with caution to avoid the occurrence of a type I or II error. Due to the small sample size per group, no distinction has been made between the male and female participants when analysing the results.

The target group that would potentially use an installation such as one constructed for this research contains people on a diverse demographic spectrum. The target group for the user tests was based on availability of responding students, resulting in a group of people that mainly contained students from the UT or Saxion between the ages of roughly 18 and 26 of which a few also study Creative Technology and have experience with Data Physicalisations and Human Computer Interaction. This can could influence the results when it comes to how users interact with the system since to these people it could come more easily than other participants.

8.2 Recommendations

In order to logistically manage the user test appointments, a Datumprikker was used where people could choose their own timeslot. However, a potentially small oversight regarding the privacy of the users became apparent since people who filled in the Datumprikker could see who also filled in the form. Although this does not prove that those people actually participated, it should be avoided in the future.

As discussed in 8.1, larger sample sizes would give more definite answers to the research question.

Since the table the control panel was installed on was rather low and not optimal for everybody's size, a few comments were made on the ergonomics of the test situation. There was a chair present, but since the hight of the heaters was not adjustable and configured for situations where people would stand instead of sit, people who would sit would experience the change in temperature less well since the design relied on close contact so it would be distinguishable when de heaters are active and when not. Future iterations of the design should include a chair by default and incorporate Infrared heating plates instead of heaters. These plates generate concentrated beams of Far Infrared Radiation instead of the more traditional electrical heater this design used that rely on convection by heating a specific element of the heater that transfers this heat to its environment. Infrared panel heating is energy efficient with proven savings as much as 50% compared to other conventional heating systems and it being on or off is far better distinguishable since the IR beam is either shining on the skin of the user or not, which is more accurate than a heating element that also needs time to warm up and cool down after being turned on or off.

Of the nine countries selected, six are situated in the northern hemisphere and thee in the southern hemisphere. A more accurate representation of the current and prospected situations could have been made by creating a more even spread across the globe by choosing an even amount of countries above and below the equator.

Future versions of this installation should rework the functioning of the RCP disc. A quick fix would be to alter the software, so it does not default back to the Low setting but shows the data of the last registered level. This will solve the issue if the disc would be placed roughly in the correct rotation. Another way would be to redesign the disc so it can only be placed easily in one configuration. Recommended is to apply both options to ensure proper functioning.

Tasks should be well specified, with highlighted key words such as "Higher than" and "Low model" as missing these specifications was a regular mistake made by the participants. To ease analysis of wrong answers, instruct users to note down observed in between values such as the average of countries at the start and end of the timeline.

Another improvement could be made by addressing the hardware issue regarding the knob that was used to scroll back in time, since a lot of feedback from the participants were regarding the occasionally annoying handling of this knob. It should be made functional as it was intended during the design phase where it was intended to scroll backwards as well as forwards in time. Also, the visual aspect of the UI on screen could be aesthetically improved as well as the readability.

> *"Switching between years unintuitive and inconvenient. Other than that, things worked but the graphs on screen weren't particularly visually appealing. Good prototype, could use some UI improvements before final product :p"*

Figure 28 - General comment from one of the participants on the installation

Surprisingly, since the subgroup with neither factor enabled during testing scored higher than the group with both factors enabled and by being skewed to the right of the Likert scale (Strongly Agree), it could be possible that the installation itself provides an offset regarding the perceived level of immersion. This observation seems to be supported by Emri & Mäyrä [43] who identify three different dimensions of immersion regarding gameplay: sensory based, challenge based, and imaginary based. The latter refers to the impact of the storyline of the experience could have on the level of immersion and is not relevant for the results of this study since this was absent from the design. Challenge based and sensory based however were present in the form of tasks and visuals, audio, and temperature respectively. This is an important issue for future research to further investigate all the specific factors of a data physicalisation that can enhance the level of immersion of users.

Immersion is a complex and intricate construct which this study tried to measure directly using a Likert scale. However, measuring immersion and analysing the results proved more difficult than anticipated beforehand. Judging by the results, a Likert scale may not have been the best tool for measuring immersion. This since a person cannot be "negatively immersed, only either immersed to a certain degree or not at all. Emri & Mäyrä [43] for instance used for their research on different dimensions of immersion in gameplay a Likert scale with statements related to immersion, instead of asking participants directly to which degree they felt immersed, validating the results reliability with a Cronbach Alpha test.

8.3 Future research possibilities

This research could be used to further explore the use of the factors sound and temperature in the field of data physicalisation. To take a better look at which factor is better distinguishable a new study could use a participant group of similar size and either perform a within or between group study to measure if there is a statistically significant difference on how well people can perceive change in data.

Furthermore, there is still a lot to discover on how to effectively incorporate temperature in a data physicalisation installation for either on how to convey data better or on how to make it contribute to the level of immersion the user perceives. The skin's thermal receptors are generally weaker in distinguishing change as opposed to the ear, and this could be considered when implementing these factors. Humans have five main senses and incorporating factors that trigger other senses than just the sight is crucial for data physicalisations.

When improved, this installation could also be placed for instance at a Natural History Museum or science fair, utilizing data relevant theme wise or for an ongoing exposition. Users could be either reminded of the current situation, their knowledge refreshed, or gain new insights in what it is they are exposed to.

Chapter 9 – Conclusion

A tangible data physicalisation installation has been built to gain insight in the incorporation of the factors sound and temperature into such installation, and the effect of these factors on the user's level of immersion. A research question has been formulated, and conclusions based on the statistical analyses performed on the user testing results have been drawn. The research question was formulated as:

Which factor(s), sound and/or temperature, contribute to a higher level of immersion during the interaction with a data physicalisation installation on climate change?

The hypothesis for this question was formulated as:

The combination of the sound and temperature factor will yield the highest perceived levels of immersion (when compared to only one of the two or using none).

To validate this hypothesis, an installation with four different system configurations was constructed, and a task list was drawn up to facilitate the measurement of the dependent variables:

Accuracy

On average, only 49% of the tasks were executed correctly. This was partly due to some minor hardware and software issues, for which upgrades have been presented in the previous chapter. Also, the tasks themselves were not clearly enough described, resulting in cases of mis interpretation or mis reading. Overall, taken these issues and their proposed solutions into account in combination with the reviewed footage of the test sessions, the installation performed adequately enough on delivering the data requested by the user.

User experience

Based on the feedback from the user as presented in the questionnaire results, yielding an average score of 5.92 out of 7, the conclusion can be drawn that the installation was well received by the participants. This was also noticeable in conversations with the participants after their session, where they expressed their joy of interacting with the system and seeing the LEDs change based on their input and having that feeling of being able to control the data that was presented to them. There were a few low ratings, accompanied by feedback on the ergonomics for which in return recommendations for improvement of the design have been presented in the previous chapter. There was no statistical difference determined regarding the measured user experience between the four subgroups, however, the sound group scored the highest with an average of 6.58 out of 7 where the rest would only score a 5.76, 5.66, and 5.46 for the groups temperature, neither, and both respectfully. The installation was overall greatly received by the participants, which is a positive argument for continuing research on this design and its incorporated factors sound and temperature.

Perceived level of immersion

All groups felt immersed in various degrees. On average, participants rated their perceived level of immersion a 5.30 out of 7 on a Likert scale, skewing towards "Strongly agree" when asked if they felt immersed. Analysing and cross-referencing questions on the perceived level of immersion and if they felt either strong or barely immersed showed that on average the participants did feel immersed, albeit lightly. A statistical test indicated no statistical difference between the subgroups, but concluding this being so could be a type II error since the subgroup size was small and the sound subgroup did show a score of 5.64 out of 7 whereas the other groups only scored a 5.27, 5.18, and 5.09 for the groups temperature, Neither, and Both respectfully. Interestingly, the subgroup with neither factor scored better than the group with both factors, indicating that the installation itself also offers a certain base level of immersion.

General conclusion

Since there was no statistical difference found when comparing the different subgroups, the hypothesis must be rejected until more research is performed. Therefore, the answer to the research question is inconclusive. Although the sound factor scored the highest on both User Experience and Perceived level of Immersion, more user tests must be performed to answer the research question since the results were not conclusive. Improvements for the UI and task formulation have been presented to increase the accuracy. Overall, promising steps have been taken to fill the void in the academic field regarding the perceived level of immersion from users when interacting with a tangible and immersive data physicalisation installation. This yielded an installation that users enjoyed interacting with and that can function to support further research in this field while generating awareness and new insight for users on the data it presents.

Appendixes

Appendix A – Arduino Code

```
/* Arduino code for the bachelor graduation project of Stijn Teekens
s2133350.

 Once connected to a device running a processing sketch it can be used
to select different countries using the buttons connected,
 different levels of CO2 emission by moving a disk with a magnet onto
different reed switches,
 scroll back in time using a rotary encoder,
 advance forward in time by flipping a switch,
 switching between datasets using a switch.
 Based on the input received via Serial from the laptop, the LED strip
on the top of the screen will change its position,
 relays will be turned on or off.

*/
#include <FastLED.h> //LED strip library

#define LED_PIN     13
#define NUM_LEDS    30
CRGB LEDs[NUM_LEDS];

// these constants won't change. They're used here to set pin numbers:

const int inputA = 2;
const int inputB = 4;

const int buttonPins[] = {47, 51, 52, 50, 53, 46, 44, 48, 49};
const int LEDpins[] = {38, 39, 43, 45,  37, 42, 36, 41, 40, 37};

const int coButtons[] = {3, 5, 6, 7};

const int toggleSwitch = 22;
const int datasetSwitch = 24;

// these variables will change:
boolean ledState = LOW;
char val; // Data received from the serial port
String msg;
String ids = "11;21;31;41;51;61;71;81;91";
String prevIds = "00;";

// Relay related var's
int quad = 0;
int relaySound[] = {8, 9, 11, 12};
int relayHeat = 10;
int quadSum = 0;
long relayTime = 0;
boolean heat = false;

// rotary encoder var's
int counter = 0;
long prevTime = 0;
long rotaryCount = 0;
long lastRotaryCount = 1;
int aState;
```

```
int aLastState;

int year = 0;

// country button var's
boolean LEDstates[] = {true, true, true, true, true, true, true, true,
true};
boolean pressed = false;
int pin = 0;
int buttonState = 0;

long kTime = 0;

String coTwo = "1";

String leds = "";

int prevToggle = 0;
int prevDataset = 1;

void setup() {
  // initializing LED strip
  FastLED.addLeds<WS2812, LED_PIN, GRB>(LEDs, NUM_LEDS);
  FastLED.setBrightness(80);


  // initialize the relay pins as an output:
  for (int i = 0; i < sizeof(relaySound) / 2; i++) {
    pinMode(relaySound[i], OUTPUT);
  }
  Serial.begin(9600);

  pinMode(LED_BUILTIN, OUTPUT);
  // initialize the country buttons as input and the attached LED as
output:
  for (int i = 0; i < sizeof(buttonPins) / 2; i++) {
    pinMode(buttonPins[i], INPUT);
    pinMode(LEDpins[i], OUTPUT);
  }

  // initializing rotary encoder
  pinMode (inputA, INPUT);
  pinMode (inputB, INPUT);
  digitalWrite(inputA, HIGH);
  digitalWrite(inputB, HIGH);
  aLastState = digitalRead(inputA);


  establishContact();
  for (int j = 0; j < sizeof(relaySound) / 2; j++) {
    digitalWrite(relaySound[j], HIGH);
  }
  delay(1000);
  for (int j = 0; j < sizeof(relaySound) / 2; j++) {
    digitalWrite(relaySound[j], LOW);
  }
  pinMode(relayHeat, OUTPUT);
  digitalWrite(relayHeat, HIGH);
```

```
  for (int k; k < sizeof(LEDpins) / 2; k++) {
    digitalWrite(LEDpins[k], HIGH);
  }

  //CO2 buttons as input
  for (int l; l < sizeof(coButtons) / 2; l++) {
    pinMode(coButtons[l], INPUT);
  }


  for (int m = 0; m < NUM_LEDS; m++) {
    LEDs[m] = CRGB(0, 0, 0); // turn off all LEDs
  }

  FastLED.show();

  pinMode(toggleSwitch,INPUT);
  pinMode(datasetSwitch,INPUT);


}

void loop() {
  //changeInput();
  if (Serial.available() > 0) { // If data is available to read,
    val = Serial.read(); // read it and store it in val
    if (val != 'A') {
      if (val != ';') {
        msg = msg + val;
      } else {
        //Serial.println(msg);
        if (msg.charAt(0) == 'Q') {
          msg.replace("Q", "");
          quad = msg.toInt();

          switchRelays(quad);

        } else if (msg.charAt(0) == 'Y') {
          msg.replace("Y", "");
          year = msg.toInt();
          yearLight(year);

        }
        msg = "";
      }
    }


  }
  else {
    if (ids.equals(prevIds)) {
      //nothing
    } else {
      if (!ids.equals("")) {
        Serial.println(ids);
      }
      prevIds = ids;
```

```
    }

    if (digitalRead(toggleSwitch) != prevToggle) {
      Serial.println("T1");
      prevToggle = digitalRead(toggleSwitch);
    }

    if (digitalRead(datasetSwitch) != prevDataset) {
      Serial.println("D1");
      prevDataset = digitalRead(datasetSwitch);
    }


    switchRelays(quad);

    if (millis() > kTime + 5000) {
      String K = "K + quad";

      kTime = millis();
    }

    aState = digitalRead(inputA); // Reads the "current" state of the
outputA
    // If the previous and the current state of the outputA are
different, that means a Pulse has occured
    if (aState != aLastState && aState == 1) {


      // If the outputB state is different to the outputA state, that
means the encoder is rotating clockwise
      if (digitalRead(inputB) != aState) {
        Serial.println("R1");
      } else {
        Serial.println("R0");
      }
    }
    aLastState = aState;

    // check if the pushbutton is pressed. If it is, the buttonState is
HIGH:
    for (int i = 0; i < 9; i++) {
      buttonState = digitalRead(buttonPins[i]);
      if (buttonState == 1) {
        pin = i;
        break;
      }
    }

    if (buttonState == HIGH) {
      if (!pressed) {
        if (!LEDstates[pin]) {
          // turn LED on:
          digitalWrite(LED_BUILTIN, HIGH);
          digitalWrite(LEDpins[pin], HIGH);
          LEDstates[pin] = true;
        } else if (LEDstates[pin]) {
          digitalWrite(LED_BUILTIN, LOW);
          digitalWrite(LEDpins[pin], LOW);
```

```
          LEDstates[pin] = false;
        }
        pressed = true;
      }
    } else {
      pressed = false;
    }

    leds = "";

    for (int l = 0; l < 4; l++) {
      int co = 4 + l;
      int coState = digitalRead(co);
      if (coState > 0) {
        coTwo = String(l + 1);
      }
    }
    for (int j = 0; j < 9; j++) {
      if (LEDstates[j]) {
        leds = leds + (j + 1) + coTwo + ";";
      }
    }
    if (!leds.equals("")) {
      ids = leds;
    } else {
      ids = "00";
      //      digitalWrite(relayHeat, LOW);
      for (int m = 0; m < sizeof(relaySound) / 2; m++) {
        digitalWrite(relaySound[m], LOW);
      }
    }
  }
}

void establishContact() {
  while (Serial.available() <= 0) {
    Serial.println("A");   // send a capital A
    delay(300);
  }
}


void yearLight(int yr) {
  int yearLED = NUM_LEDS / 100.00 * (yr - 1950) + 1;

  for (int j = 0; j < yearLED; j++) {
    LEDs[j] = CRGB(0, 0, 255);
  }

  for (int m = yearLED; m < NUM_LEDS; m++) {
    LEDs[m] = CRGB(0, 0, 0);
  }

  FastLED.show();
}

void switchRelays(int rls) {
  if (!leds.equals("")) {
```

```
    int sound = rls / 2.0;

    for (int i = 0; i < sound; i++) {
      digitalWrite(relaySound[i], HIGH); // turn on all relay's up to
and including  the quartile given
    }

    for (int j = sound; j < sizeof(relaySound) / 2; j++) {
      digitalWrite(relaySound[j], LOW); // turn off the rest
    }

    if (rls <= 2) {
      digitalWrite(relayHeat, LOW);
      // turn off the heaters indefinetly
    } else if (rls <= 4) {
      if (millis() > relayTime + 8000) { // on for 2 seconds, off for 8
- 2 = 6 seconds
        digitalWrite(relayHeat, HIGH);
        relayTime = millis();
      }
      if (millis() > relayTime + 2000) {
        digitalWrite(relayHeat, LOW);
      }
    } else if (rls <= 6) {
      if (millis() > relayTime + 8000) { // on for 4 seconds, off for 8
- 4 = 4 seconds
        digitalWrite(relayHeat, HIGH);
        relayTime = millis();
      }
      if (millis() > relayTime + 4000) {
        digitalWrite(relayHeat, LOW);
      }
    } else if (rls >= 7) {
      if (millis() > relayTime + 8000) { // on for 6 seconds, off for 8
- 6 = 2 seconds
        digitalWrite(relayHeat, HIGH);
        relayTime = millis();
      }
      if (millis() > relayTime + 6000) {
        digitalWrite(relayHeat, LOW);
      }
    } else { // turn off everything
      digitalWrite(relayHeat, LOW);
      for (int l = 0; l < sizeof(relaySound) / 2; l++) {
        digitalWrite(relaySound[l], LOW);
      }
    }
  }
}
```

Appendix B – Processing code

```
/* This Processing sketch is part of the bachelor graduation project of
Stijn Teekens s2133350
  After connected to an Arduino via Serial, it displays data on the
screen based on the input provided by the arduino.
  It display's graphs containing the average temperature of nine
different countries from across the globe

*/
import processing.serial.*; //import the Serial library
Serial myPort;  //the Serial port object
String val;

// initializing variables
Table dataTable;
int cols;
int rows;
float[][] dataSet;

String ids = "";
String prevIds = "";
int countries = 0;
String msg = "";
String rec = "";

int lastTime = 0, prevTime = 0;
boolean start = false;
int currYear = 1950;
boolean sameInput = false;
int spacer = 100;
int boxX = spacer;
int boxY = spacer;
boolean isPause = false;
color colors[] = {color(235, 52, 52), color(235, 177, 52), color(168,
235, 52), color(52, 235, 70), color(52, 235, 195), color(52, 177, 235),
color(52, 79, 235), color(159, 52, 235), color(235, 52, 235)};
boolean realData = true;
boolean prevData = false;


// since we're doing serial handshaking,
// we need to check if we've heard from the microcontroller
boolean firstContact = false;

void setup() {
  fullScreen();
  background(255);
  //  initialize your serial port and set the baud rate to 9600
  println(Serial.list());
  myPort = new Serial(this, Serial.list()[0], 9600);
  myPort.bufferUntil('\n');

// importing data
  dataTable = loadTable("GPdata.txt", "header,tsv");
  //dataTable = loadTable("GPdummyData.txt", "header,tsv");
  println(dataTable.getRowCount() + " total rows in table");
```

```
  println(dataTable.getColumnCount() + " total columns in table");
  rows = dataTable.getRowCount();
  cols = dataTable.getColumnCount();
  dataSet = new float[cols][rows];

  clean();
}

void draw() {

  // if new dataset selected, load that one in
  if (realData != prevData && realData == true) {
    dataTable = loadTable("GPdata.txt", "header,tsv");
    rows = dataTable.getRowCount();
    cols = dataTable.getColumnCount();
    dataSet = new float[cols][rows];
    clean();
    prevData = realData;
    println("dataset change 1");
  } else if (realData != prevData && realData == false) {
    dataTable = loadTable("GPdummyData.txt", "header,tsv");
    rows = dataTable.getRowCount();
    cols = dataTable.getColumnCount();
    dataSet = new float[cols][rows];
    clean();
    prevData = realData;
    println("dataset change 2");
  }

  plot(currYear);  //print UI based on current selected year

  // if new input received, load corresponding data into display array
  if (start && firstContact) {
    if (ids.equals(prevIds)) {
      sameInput = true;
    } else {
      sameInput = false;
      clean();
      String[] inputIds = split(ids, ';');
      countries = inputIds.length;
      prevIds = ids;
      for (int k = 0; k < countries; k ++) {
        dataIn(int(inputIds[k]), k);
      }
    }

    if (!isPause) {
      yearIterator();  //if not paused, increment year automaticly
    }
  }
}


void serialEvent( Serial myPort) {
  //put the incoming data into a String -
  //the '\n' is our end delimiter indicating the end of a complete
packet
  val = myPort.readStringUntil('\n');
```

```
  //make sure our data isn't empty before continuing
  if (val != null) {
    //trim whitespace and formatting characters (like carriage return)
    val = trim(val);


    //look for our 'A' string to start the handshake
    //if it's there, clear the buffer, and send a request for data
    if (firstContact == false) {
      if (val.equals("A")) {
        myPort.clear();
        firstContact = true;
        myPort.write("A");
        println("contact");
      }
    } else { //if we've already established contact, keep getting and
parsing data
      println(val);
      if (val.charAt(0) == 'R') {
        rotaryIn(val);
        val = "";
      } else if (val.charAt(0) == 'K') {
        println("K   check");
      } else if (val.charAt(0) == 'L') {
        println("LED check");
      } else if (val.charAt(0) == 'T') {
        println("Toggle check");
        isPause = !isPause;
        val = "";
      } else if (val.charAt(0) == 'D') {
        println("Dataset check");
        val = "";
        realData = !realData;
      } else {
        if (val.charAt(val.length()-1) == ';') {
          val = val.substring(0, val.length()-1);
        }
        ids = val;
      }
    }
  }
}

void rotaryIn(String phase) {  // change the year if rotary encoder
turned
  int state = int(phase.replace("R", ""));
  if (state == 1 && currYear < 2050) {
    currYear++;
  } else if (state ==  0 && currYear > 1950) {
    currYear--;
  }
  yearIterator();
}


void dataIn(int id, int countCount) {  // load in the data asked for
based on the provided county id's
  int rowNr = 0;
```

```
  for (TableRow row : dataTable.rows()) {

    int year = row.getInt("year");
    float data = 999;

    if (year < 2021) {  //first part of the ID indicates which country
      if (id < 20) {
        data = row.getFloat("Greenland");
      } else if (id < 30) {
        data = row.getFloat("Iceland");
      } else if (id < 40) {
        data = row.getFloat("Russia");
      } else if (id < 50) {
        data = row.getFloat("USA");
      } else if (id < 60) {
        data = row.getFloat("Netherlands");
      } else if (id < 70) {
        data = row.getFloat("China");
      } else if (id < 80) {
        data = row.getFloat("Brazil");
      } else if (id < 90) {
        data = row.getFloat("SouthAfrica");
      } else if (id < 100) {
        data = row.getFloat("Australia");
      }
    } else {   // second part of the ID indicates which CO2 level is
selected
      if ( id == 11) {
        data = row.getFloat("GreenlandL");
      } else if ( id == 12) {
        data = row.getFloat("GreenlandML");
      } else if ( id == 13) {
        data = row.getFloat("GreenlandMH");
      } else if ( id == 14) {
        data = row.getFloat("GreenlandH");
      } else if ( id == 21) {
        data = row.getFloat("IcelandL");
      } else if ( id == 22) {
        data = row.getFloat("IcelandML");
      } else if ( id == 23) {
        data = row.getFloat("IcelandMH");
      } else if ( id == 24) {
        data = row.getFloat("IcelandH");
      } else if ( id == 31) {
        data = row.getFloat("RussiaL");
      } else if ( id == 32) {
        data = row.getFloat("RussiaML");
      } else if ( id == 33) {
        data = row.getFloat("RussiaMH");
      } else if ( id == 34) {
        data = row.getFloat("RussiaH");
      } else if ( id == 41) {
        data = row.getFloat("USAL");
      } else if ( id == 42) {
        data = row.getFloat("USAML");
      } else if ( id == 43) {
        data = row.getFloat("USAMH");
```

```
      } else if ( id == 44) {
        data = row.getFloat("USAH");
      } else if ( id == 51) {
        data = row.getFloat("NetherlandsL");
      } else if ( id == 52) {
        data = row.getFloat("NetherlandsML");
      } else if ( id == 53) {
        data = row.getFloat("NetherlandsMH");
      } else if ( id == 54) {
        data = row.getFloat("NetherlandsH");
      } else if ( id == 61) {
        data = row.getFloat("ChinaL");
      } else if ( id == 62) {
        data = row.getFloat("ChinaML");
      } else if ( id == 63) {
        data = row.getFloat("ChinaMH");
      } else if ( id == 64) {
        data = row.getFloat("ChinaH");
      } else if ( id == 71) {
        data = row.getFloat("BrazilL");
      } else if ( id == 72) {
        data = row.getFloat("BrazilML");
      } else if ( id == 73) {
        data = row.getFloat("BrazilMH");
      } else if ( id == 74) {
        data = row.getFloat("BrazilH");
      } else if ( id == 81) {
        data = row.getFloat("SouthAfricaL");
      } else if ( id == 82) {
        data = row.getFloat("SouthAfricaML");
      } else if ( id == 83) {
        data = row.getFloat("SouthAfricaMH");
      } else if ( id == 84) {
        data = row.getFloat("SouthAfricaH");
      } else if ( id == 91) {
        data = row.getFloat("AustraliaL");
      } else if ( id == 92) {
        data = row.getFloat("AustraliaML");
      } else if ( id == 93) {
        data = row.getFloat("AustraliaMH");
      } else if ( id == 94) {
        data = row.getFloat("AustraliaH");
      }
    }

    //add the year
    dataSet[0][rowNr] = year;
    dataSet[countCount+1][rowNr] = data;
    rowNr++;
  }
}

String receiveData() {
  String input = ids;
  return input;
}

void printTable() {  //for debugging, prints the data selected
```

```
  if (dataSet[0][0] != 0) {
    for (int i = 0; i < rows; i ++) {
      for (int j = 0; j < cols; j++) {
        if (dataSet[j][i] != 0) {
          if (dataSet[j][i] > 1900) {
            print(int(dataSet[j][i]));
            print(" ");
          } else {
            print(dataSet[j][i]);
            print(" ");
          }
        } else {
          println("");
          break;
        }
      }
    }
  }
}

void yearIterator() {  //increments the year and sends an update
message to the arduino
  if (millis() > prevTime + 66) {
    if (currYear<2050) {
      int quad = getData(currYear);
      msg = "Y" + currYear + ";" + "Q" + quad + ";";
      //msg ="Q" + quad + ";";
      send();
      prevTime = millis();
      currYear = currYear + 1;
    } else {
      isPause = true;
    }
  }
}

int getData(int yr) {  //calculates in which quartile the data is
present
  float quad = 0;
  float min = 999;
  float max = -999;
  float avg = 0;
  float delta = 0;
  float AVG[] = new float[rows];

  for (int k = 0; k<rows; k++) {
    float localAvg = 0;
    for (int j = 0; j<countries; j++) {
      localAvg = localAvg + dataSet[j+1][k];
    }
    localAvg = localAvg/countries;
    AVG[k] = localAvg;
  }
  min = min(AVG);
  max = max(AVG);
  delta = max - min;

  avg = AVG[yr-1950]-min;
```

```
  quad = abs(avg/delta)*8;

  return (int(quad)+1);
}

void plot(int yr) {  //builds the UI
  pushStyle();
  textAlign(LEFT);
  background(255);
  int offset = spacer;
  int xStart = offset;
  int yStart = int(height/2);

  dispData(yr, xStart, yStart, offset);

  if (boxX<(width-offset)) {
    fill(255);
    noStroke();
    stroke(0);

    if (start) {
      boxX = boxX + 4;
    }
  }
  line(xStart, yStart, width-offset+30, yStart); //horizontal axis
  int yrLabel = 1950;
  for (int i = 0; i < 11; i++) {
    fill(0);
    text(str(yrLabel), xStart + 5 + (width-2*offset)/10*i, yStart+15);
    line(xStart + (width-2*offset)/10*i, yStart-10, xStart + (width-
2*offset)/10*i, yStart+10);
    yrLabel = yrLabel + 10;
  }
  line(xStart, 2*yStart-offset, xStart, xStart); //vertical axis
  textAlign(LEFT);
  textSize(40);
  text("Year:", width/2 + 10, 40);
  textSize(30);
  if (start) {
    text(currYear, width/2 + 115, 40);
  } else {
    text("1950", width/2 + 115, 40);
  }
//my mother is amazing, she is my academic hero
  strokeWeight(5);
  line(width/2 + 110+ 100, 30, width/2 + 110 + 60+ 100, 30);    //arrow
arm
  triangle(width/2+120+50+ 100, 30-5, width/2+120+50+ 100, 30+5,
width/2+120+50+10+ 100, 30);    //arrow head
  textAlign(CENTER);
  text("C°", 50, 50);
  line(50 + 50, 20, 50 + 50, 20 + 50);    //arrow arm
  triangle(50 + 50 - 5, 20 + 50 - 10, 50 + 50 + 5, 20 + 50 - 10, 50 +
50, 20 + 50);    //arrow head
  triangle(50 + 50 - 5, 20 + 5, 50 + 50 + 5, 20 + 5, 50 + 50, 20 - 5);
//arrow head
  strokeWeight(3);
  line(width/2, 10, width/2, 40);
```

```
  textSize(30);
  text("Selected CO₂ level:", width/2-175, 35);
  text("Average:", width-180, 35);
  text("Max - min:", width-450, 35);
  textSize(15);

  popStyle();
}

void dispData(int yr, int xO, int yO, int margin) {
  pushMatrix();
  pushStyle();
  float interval = (width-2.0*margin)/(rows-1);

  float max = -999;
  float min = 999;
  float scale  = 1;


  int maxRows = rows - (2050-currYear);
  if (maxRows > 102) {
    maxRows = 102;
  }

  //printTable();

  for (int k = 0; k<countries; k++) {          //finding max and min
value of dataSet[][]
    for (int l = 0; l<rows; l++) {
      float data = dataSet[k+1][l];

      if (data > max) {
        max = data;
      }
      if (data<min) {
        min = data;
      }
    }
  }

  max = abs(max);
  min = abs(min);
  max = max(max, min);
  scale = (height/2-margin)/max;
  textAlign(RIGHT);
  fill(0);
  for (int l = 0; l < 21; l++) {
    text(nf(max-(2.0*max/20*l), 0, 2), xO-15, (yO-(height-
2.0*margin)/2)+(height-2.0*margin)/20*l);
    line(xO-10, (yO-(height-2.0*margin)/2)+(height-2.0*margin)/20*l,
xO+10, (yO-(height-2.0*margin)/2)+(height-2.0*margin)/20*l);
  }

  translate(xO, yO);
  String[] nameTags = split(ids, ';');
  if (!nameTags[0].equals("00" )) {
    for (int i = 0; i < nameTags.length; i++) {
      color rdmClr = colors[i];
```

```
      stroke(rdmClr);
      float prevX = 0;
      float prevY = 0;
      for (int j = 0; j<maxRows; j++) {
        int year = int(dataSet[0][j]);
        if (year > 1950) {
          float dataPoint = -dataSet[i+1][j]*scale;
          line(prevX, prevY, interval*(j), dataPoint);
          fill(0);
          prevX = interval*(j);
          prevY = dataPoint;
        } else {
          prevX = 0;
          prevY = -dataSet[i+1][j]*scale;
        }
      }
      textAlign(LEFT);
      if (maxRows>2) {
        String txt = nf(dataSet[i+1][maxRows-1], 0, 2) + "°";
        text(txt, interval*(maxRows), -dataSet[i+1][maxRows-1]*scale-
10);
      }

      String tag = "";
      if (int(nameTags[i]) <10) {
        tag = " ";
      } else if (int(nameTags[i])<20) {          //legenda name tag
selection
        tag = "Greenland";
      } else if (int(nameTags[i])<30) {
        tag = "Iceland";
      } else if (int(nameTags[i]) <40) {
        tag = "Russia";
      } else if (int(nameTags[i])<50) {
        tag = "USA";
      } else if (int(nameTags[i])<60) {
        tag = "Netherlands";
      } else if (int(nameTags[i])<70) {
        tag = "China";
      } else if (int(nameTags[i])<80) {
        tag = "Brazil";
      } else if (int(nameTags[i])<90) {
        tag = "South Africa";
      } else if (int(nameTags[i])<100) {
        tag = "Australia";
      }

      fill(0);
      textAlign(LEFT);
      if (start && !tag.equals(" ")) {
        fill(rdmClr);
        rect(50 + ((width-margin*2-55)/nameTags.length)*i, 50-height/2,
10, 10);
        fill(0);
        text(tag, 70 + ((width-margin*2-55)/nameTags.length)*i - 5, 50-
height/2+10);
        char coLvl = 1;
        if (nameTags[0].length()>1) {
```

```
          coLvl = nameTags[0].charAt(1);
        }
        textSize(30);
        fill(0);
        text(str(coLvl), (width-margin*2)/2-35, -height/2+35);

        textSize(15);
      }
    }
    float avgTemp = 0;
    float minMax = 0;
    float minMin = 99;
    float maxMax = -99;

    for (int m = 0; m<nameTags.length; m++) {
      avgTemp = avgTemp + dataSet[m+1][maxRows-1];
      if (dataSet[m+1][maxRows-1]<minMin) {
        minMin = dataSet[m+1][maxRows-1];
      }
      if (dataSet[m+1][maxRows-1]>maxMax) {
        maxMax = dataSet[m+1][maxRows-1];
      }
    }
    minMax = maxMax - minMin;
    String minMaxText = nf(minMax, 0, 2) + "°";
    avgTemp = avgTemp/nameTags.length;
    String avgTempText = nf(avgTemp, 0, 2) + "°";
    textSize(30);
    text(avgTempText, (width-margin*2), -height/2+35);      // displays
average temperature of the countries selected
    text(minMaxText, (width-margin*2)-250, -height/2+35);   // displays
the delta between the warmest and coldes country selected
  }
  popStyle();
  popMatrix();
}

void clean() {  //clears the data array
  for (int i = 0; i < cols; i++) {
    for (int j = 0; j< rows; j++) {
      dataSet[i][j] = 0;
    }
  }
}

void send() {  //sends the variable msg via serial to the arduino
  myPort.write(msg);
  println(msg);
  msg = "";
}

void mouseClicked() {                             //if we click in the
window, start the program
  if (ids.length()>0) {
    start = true;
  }
  isPause = !isPause;
}
```

Appendix C – Questionnaire

Questionnaire Participant #:

EASE OF USE		1	2	3	4	5	6	7		NA
It is easy to use.	strongly disagree								strongly agree	
The tasks (nr 4-7) were easy to complete	strongly disagree								strongly agree	
It is user friendly	strongly disagree								strongly agree	
Using it is effortless.	strongly disagree								strongly agree	
I can use it without written instructions.	strongly disagree								strongly agree	
EASE OF LEARNING		**1**	**2**	**3**	**4**	**5**	**6**	**7**		**NA**
It is easy to learn how to use it.	strongly disagree								strongly agree	
I quickly became skilful with it.	strongly disagree								strongly agree	
SATISFACTION		**1**	**2**	**3**	**4**	**5**	**6**	**7**		**NA**
It is fun to use.	strongly disagree								strongly agree	
IMMERSION (when performing task 4-7)		**1**	**2**	**3**	**4**	**5**	**6**	**7**		**NA**
I felt immersed when interacting with the system	strongly disagree								strongly agree	
I felt **strongly** immersed when interacting with the system	strongly disagree								strongly agree	
I felt **barely** immersed when interacting with the system	strongly disagree								strongly agree	
I could distinguish a correlation between the data shown on screen, and the sound that I was exposed to	strongly disagree								strongly agree	

Room for elaboration regarding the question above:

I could distinguish a correlation between the data shown on screen, and the temperature that I was exposed to	strongly disagree								strongly agree	

Room for elaboration regarding the question above:

CLIMATE CHANGE										
I am more aware of the climate change problem than before interacting with the installation	strongly disagree								strongly agree	
I perceive the climate change problem more urgent than before interacting with the installation	strongly disagree								strongly agree	
I feel more like I can have a positive impact on the climate change problem than before interacting with the installation	strongly disagree								strongly agree	

EXPERIENCE		1	2	3	4	5	6	7		NA
I have experience in the field of Human Computer Interaction	strongly disagree								strongly agree	
I have experience with interacting with Data Physicalisation installations	strongly disagree								strongly agree	

Room for optional additional comments:

Appendix D – Consent form

Consent form for “Physicalizing Dynamic Climate Change Data”

You will receive a copy of this informed consent form

Please tick the appropriate boxes	Yes	No
Taking part in the study		
- I have read and understood the study information dated 15/09/2022, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
- I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
- I understand that taking part in the study involves a video-recorded experiment consisting of me interacting with a physical installation and completing task, of which the recording will be destroyed after the completion of the bachelor’s assignment. I understand that afterwards I will complete a survey questionnaire relating to this interaction.	○	○
Risks associated with participating in the study		
- I understand that taking part in the study I will be interacting with sound and temperature. The temperature and the amount of sound changes according to the average temperature, but they are within the safe levels for humans and thus are non-risky. However, if I feel uncomfortable, I can stop my participation at any given time.	○	○
Use of the information in the study		
- I understand that information I provide will be anonymized and used for scientific publication or made public in any other manner.	○	○
- I understand that personal information collected about me that can identify me, such as recorded footage and identification code, will not be shared beyond the study team.	○	○
- I agree to be audio/video recorded.	○	○

Signatures

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Stijn Teekens
Researcher name Signature Date

Study contact details for further information:

Researcher:
Stijn Teekens – s.teekens@student.utwente.nl - +31 619428238
Ethics Committee Computer and Information Science:
DRS. P. de Willigen - ethicscommittee-cis@utwente.nl - +31 534892085
Graduation project supervisor:
dr. C. Epa Ranasinghe - c.m.eparanasinghe@utwente.nl - +31 534899189

Appendix E – Informational brochure

Informative brochure

Dear reader,

This brochure aims to provide you all the necessary information about this research before you may partake in the user study. The data that this Data Physicalisation presents is the Climate change data. This data consists of average temperatures of different countries over the past 72 years and the upcoming 28 years. The data will be displayed in a visual and physical manner, hence the term "physicalisation". Do not hesitate to ask any questions that you may have prior, during, or after the interaction. Before the actual test starts you will be allowed to interact with the installation to familiarize yourself with the system by performing some tutorial like tasks. After this you will asked to perform several main tasks with the installation to answer some questions. Following the tasks, you will be asked to fill in a questionnaire containing questions about the installation and the tasks you performed.

This experiment has been reviewed by the Ethics Committee Information and Computer Science and should not cause you any harm. It is possible that you might feel uncomfortable during the experiment and therefore you should know that you are free to leave and stop the experiment at any given time and withdraw without any consequences.

Your interaction with the installation will be videorecorded and linked to your anonymous participant ID. Recorded footage will be stored securely and according to General Data Protection Regulation (GDPR), it will only be accessible to the researcher and, upon request, to the participant. You have the right to access, rectify or erase your personal data, please contact the researcher if you wish to do so. Statistical analysis and coding will be performed on the collected data from the sessions and anonymously presented during the discussion of the research and results. No data will be published separate from this research and will be erased after this research is done.

For any questions after the session or if you want to withdraw your participation and erase the data collected on you, please contact the researcher:

S. Teekens

s.teekens@student.utwente.nl

+31 619428238

For complaints about the research or researcher, please contact the Ethics committee via:

Drs. P. Willigen

Ethicscommittee-cis@utwente.nl

+31 534892085

In any case, the research supervisor can be contacted via:

Dr. C. Epa Ranasinghe

c.m.eparanasinghe@utwente.nl

+31 534899189

Appendix F – Questionnaire and task list results

parti	Su	QU1	QU2	QU3	QU4	QU5	QL6	QL7	QS8	QI9	QI10	InvQI11	QI11	QI12	QI12 comments	QI13	QI13 comments	QC14	QC15	QC16	QE17	QE18	General comments
1	B	5	5	6	4	7	7	6	6	5	3	5	3	4	In my opinion, the volume difference could have been higher	3	Always felt hot, exept for selecting cols countries	4	3	3	1	1	I study SET
2	B	5	5	2	4	7	6	4	2	2	1	3	5	5	discomfort for sure	4	After a while I noticed the heat, but idk if that has to do with the timeline shown on screen	3	6	3	1	1	
3	B	6	5	5	7	6	7	7	6	5	4	3	5	5	nfi	6	nfi	5	5	2	1	1	
4	B	3	3	4	4	5	5	4	5	5	4	6	2	6	sound clearly mapped to data	2	did not perceive quick changes in temperature, when cursor was static for long I did feel the heat	5	5	3	6	7	
5	S	5	4	3	2	6	6	6	7	5	5	7	1	7	the sound increase of the waves feels intuitively when the temperature increases	NA	nfi	3	3	2	2	1	
6	S	6	6	6	7	5	7	6	5	4	4	6	2	5	nfi	NA	nfi	2	1	2	2	4	
7	S	7	6	7	6	6	7	7	7	6	6	6	2	1	nfi	NA	nfi	3	6	4	1	1	
8	S	6	7	6	nfi	5	7	7	7	7	6	6	2	1	I think the sound definetly gelped with the immersion, but I did not consciously notice a correlation between the sound and the data. I also did not pay a lot of attention to the sound so may be that's why.	NA	nfi	5	5	4	5	5	
9	N	5	6	6	4	6	7	7	6	6	4	5	3	NA	nfi	NA	nfi	2	2	1	2	2	
10	N	6	7	6	4	4	7	6	6	5	3	5	3	NA	nfi	NA	nfi	3	5	5	2	2	
11	N	5	6	5	3	4	7	7	6	6	4	7	1	NA	the progress dial had some issues and could be difficult to use, but it became easier the more I used it	NA	nfi	3	2	1	4	2	
12	N	5	6	5	6	3	7	7	6	6	4	7	1	NA	nfi	NA	nfi	3	3	2	2	1	
13	N	7	6	7	7	5	7	7	7	4	3	3	5	NA	nfi	NA	Only switch and turn button were unclear without instruction. - Was not nice that I could not turn right to go to the coreect gear but had to hope that I could pause the simulation on time - Q143 hace sound/temperature immersion - I really liked the physical sound interaction	3	3	2	6	6	I think the climate change question is unfair as I study sustainable technology and thus I'm exposed to the problem on a almost daily bases
14	T	6	7	6	6	7	7	7	6	5	4	4	4	NA	nfi	4	In noticed a difference in temperature. But I didn't really feel like it was because of the change of data shown	4	5	3	3	3	
15	T	6	5	6	3	6	7	7	6	3	2	3	5	NA	Sommige aspecten waren wel vervelend om te bedienen zoals landen [symbol voor button?] en de tijdterugknop	2	Ik vond het gewoon vervelend warm	6	4	5	1	1	
16	T	6	5	6	4	2	6	7	6	5	4	6	2	NA	I had no sound	3	I could feel more warmth at later years (I assume since the average was higher). But I was given a seat so was further from the heaters	3	3	2	5	4	
17	T	4	7	5	4	6	7	6	7	5	6	7	1	NA	nfi	5	nfi	4	5	3	2	2	
18	B	6	6	3	3	5	7	6	6	6	4	6	2	1	totaal niet op het geluid gelet	1	LOL niet op gelet	5	4	5	1	1	
19	N	6	5	6	3	6	6	6	6	3	2	4	4	NA	nfi	NA	nfi	3	4	4	4	4	Op zich prima ding, prima interactie, maar ik had me waarschijnlijk meer immersed gevoeld als die hoger had gestaan. Ergonomisch was dit niet fijn. Fijn dat die snel naar de toekomst kon. Miste wel langzaam naar de toekomst en snel naar het verleden, bvb beide knoppen twee kanten op laten werken, knopjes voelen klein
20	B	5	5	6	5	6	7	7	6	4	NA	NA	NA	6	nfi	5	Het zou makkelijker zijn als de draaiknop voor en achetruit in de tijd zou kunnen.	6	4	4	1	1	

Part = participant ID

Su = Subgroup

B = Both

S = Sound

T = Temperature

N = Neither

NA = Not Applicable

Nfi = not filled in

part	Su	QU1	QU2	QU3	QU4	QU5	QL6	QL7	QS8	QI9	QI10	InvQI11	QI11	QI12	QI12 comments	QI13	QI13 comments	QC14	QC15	QC16	QE17	QE18	General comments
20	B	5	5	6	5	6	7	7	6	4	NA	NA	NA	6	nfi	5	Het zou makkelijker zijn als de draaiknop voor en achetruit in de tijd zou kunnen.	6	4	4	1	1	
21	N	6	6	5	5	5	7	7	7	6	5	7	1	NA	nfi	NA	nfi	4	5	3	2	1	
22	S	6	5	7	7	6	7	7	7	6	5	5	3	7	nfi	NA	to have better ease of use, please make the turning knob for going back in years better	2	1	1	7	5	[concerning question 14:] I already am quite aware that earth is going to shit
23	B	6	6	5	4	7	7	6	7	7	6	7	1	3	Ease of use-forward switch is a bit difficult to use if you want to move slowly. I noticed differnces in sound and temperature, but did not notice the correlation.	5	I noticed the differences in temperature, but did not notice the correlation explicitely. Now that I read the question, I do notice it. It became hotter when the temperature on the screen increased.	3	2	1	1	1	
24	B	5	5	5	3	3	6	6	6	5	5	6	2	5	didn't really [hear] noise during, but do notice in	5	see above	5	5	6	1	1	
25	T	5	6	5	4	6	7	6	6	5	4	6	2	NA	did not notice any sound effects	7	nfi	6	4	2	1	2	
26	S	5	5	3	3	4	5	4	5	5	2	6	2	1	nfi	NA	nfi	2	2	2	1	1	
27	T	6	5	6	6	4	7	6	6	5	2	6	2	NA	nfi	3	I noticed different temperatures, and that the temperature increaeses when the year increases. But I did not feel a correlation between countries and	6	6	4	1	1	I think it would be logical that if you turn the otherway around with the time turning thing you can go forward in time
28	S	5	5	7	6	7	7	7	6	7	5	5	3	6	differences between going back and forward in time were not really connected. The fast forard switch was useful but not precise	NA	nfi	5	4	4	6	6	I'm already concerned about the climate before using the installation. Using the installation confirmed this feeling but did not point a doomdsay scenarion either. I understand the
29	B	7	7	7	6	6	7	7	7	7	6	6	2	5	nfi	5	nfi	5	6	2	4	2	
30	S	5	4	6	4	6	7	6	6	6	6	6	2	3	not being able to use the radio button to forward in time , was a bit annoying, other than that the machine worked great and was easy to use	NA	nfi	2	2	2	3	1	
31	T	6	5	6	5	7	7	6	6	5	2	5	3	NA	nfi	4	I didn't really pay attention to a correlation. I could feel the heat at times, but didn't realise and also con't say anymore if it is related to the temperatures	5	3	2	1	2	
32	N	6	5	6	5	4	6	6	7	6	5	7	1	NA	I didn't really notice the sounds	NA	Felt a slight difference maybe, didn't really notice it in the moment [kan niet was groep N -> placebo	5	4	3	6	6	It was quite an eye opener to see the changes on screen and all the differences. Cool interactions.
33	T	6	5	6	5	7	7	6	7	6	6	6	2	NA	nfi	3	nfi	5	4	5	2	2	
34	T	7	6	7	7	7	7	7	7	6	6	7	1	NA	nfi	4	nfi	5	4	5	1	1	
35	S	5	6	6	5	7	7	6	6	5	4	7	1	2	fun to explore	NA	nfi	6	4	1	1	1	button is hard to get the exact year
36	B	6	5	6	4	6	7	5	6	5	3	5	3	5	the further in years the louder the sound	1	nfi	5	5	3	1	3	
37	B	5	6	6	4	4	6	5	6	5	3	5	3	4	upon the selected button, ocean sound started to play	5	Temp. increase similar to model	4	5	2	2	2	button for rewinding time is a little tricky to use
38	S	5	7	5	6	7	7	7	5	6	1	6	2	5	higher temp = more sound? Unsure wasn't very consistent.	NA	nfi	4	4	1	1	2	switching between years unintuitive and inconvenient. Other than that things worked but the graphs on screen weren't partcularly visually appealing. Good prototype, could use some UI improvements before final product :p
39	T	5	4	4	5	3	6	5	6	6	5	5	3	NA	~~geen geluid gehoord~~ [klopt was groep T]	1	nfi	5	4	5	1	1	
40	S	6	6	7	7	6	7	7	6	5	5	5	2	6	nfi	NA	nfi	7	6	5	1	1	
41	T	5	6	3	4	5	6	6	5	7	5	5	3	NA	nfi	2	I noticed the heaters the most with Greenland selected. Makes me wonder what it is corelated to	5	4	2	6	6	
42	N	3	5	4	4	5	7	5	2	2	3	2	6	NA	nfi	NA	Strange that at higher CO2 scenario's temperatures were lower. Starting temperatures weren't mentioned for individual countries	4	2	2	2	2	
43	N	5	6	6	5	5	7	7	7	6	4	7	1	NA	nfi	NA	nfi	6	5	4	3	2	
44	N	5	4	5	5	7	7	5	6	7	4	7	1	NA	~~I didn't really hear anyting influecing me. Other than some clicking.~~ [klopt was van de N group]	NA	nfi	4	2	4	1	1	

parti	T1:	T1:W	T2	T2:W	T3	T3:W	T4	T4:W	T5	T:5Wrong Ans	T6:Selected countrie	T:6 Ans: L-H	T7:L	T7:Wrong Ans	Notes
1	1		1		1		1		0	Greenland, Iceland, South Africa	NL - USA	0.34/0.34/0.23/0.31	0	L-/2042/2042/2035	
2	1		1		1		1		0	Greenland, Iceland, South Africa	NL- Australia	12.11/11.79/12.27/12.03	1		
3	0	7.52	0	8.23	1		0	38.08	0	Brazil,SA, NL, Greenland, Iceland, all lands	NL - AUStralie	11.79	0	2038	
4	1		1		1		1		0	SA,Iceland,Greenland	China - Brazil	18.11/18.02/17.95/18.11	0	L2037/2031/2038/2032	
5	1		1		1		1		0	Greenland, Austria MIS: Australia	USA - NL	0.34/0.58/0.23/0.31	1		
6	1		1		1		1		0	Greenland	nfi	34.30/34.1/34.26/33.81	0	L2041/-/-/2035	
7	1		1		1		1		0	Greenland, Iceland MIS: China, Australie	Russia -Brazil	29.14/29.07/29.30/29.36	0		
8	1		1		0	14,8	1		0	Greenland	USA - Russia	13.69/13.43/13.37/13.33	1		
9	1		0	9,72	1		1		1		China -Iceland	6.43/5.90/5.49/9.18	0	L-/2042/-/-	
10	1		1		1		1		1		USA -China	9.40/9.44/9.24/9.57	0	1950 2033	
11	1		1		1		1		0	Greenland, Iceland, SA	Greenland - Iceland	17.84/18.71/18.56/18.05	0	L2038/3031/2043/2042	
12	1		1		1		1		0	Greenland, Iceland, SA MIS Australia	Greenland - SA	34.3/34.43/34.1/33.81	0	L2041/2037/2043/2033	
13	1		1		1		1		1		USA -NL	10.72/10.89/10.40/10.89	0	L2041/2036/2042/2034	
14	1		1		1		1		0	Greenland, SA MIS Australia	nfi	8.13/8.12/7.95/8.12	0	L2032/2038/2031/2037	
15	1		1		1		1		0	Greenland, Iceland, MIS Australia	NL- Greenland	26.18/26.31/25.55/25.68	1		
16	1		0	10.50	0	-15,13	1		0	Greenland, Iceland, SA, Brazil NL MIS all the correct countries	SA -Greenland	34.30/34.26/34.10/33.81	0	L2041/-/-/2035	
17	1		1		1		1		1		Iceland - Brazil	23.20/22.48/22.87/23.6	0	L2043/-/-/-	
18	1		1		1		1		0	MIS Australia	Brasil-Australia	3.36	0	L2032/2040/2035/-	
19	1		0	8.73	1		1		1		NL- Australia	12.11/11.79/12.27/12.03	0	L2003/2003/2003/2003	
20	1		1		0	-14,60	1		1		Australia- SA	3.98/4.08/3.6/3.86	0	L2041/-/-/2034	
21	1		1		1		1		1		nfi	19.87/19.11/19.54/21.24	0	L2041/-/-/2034	
22	1		1		1		1		0	Greenland, Brasil	nfi	25.84/25.73/25.32/25.37	0	L2041	T6: [aan de berekeingen te zien elke keer twee andere landen gekozen]
23	1		1		1		1		1		USA -Brazil	15.81/15.7/15.87/15.67	0	L-/-/-/2035	
24	1		1		1		0	8.19	0	Greenland	NL-SA	8.12	0	L2041/-/2042/2035	
25	1		1		1		1		1		NL-Russia	13.67/13.95/13.66/13.67	0	L2041/-/-/2041	
26	1		1		1		1		1		USA-Rus	13.33/13.37/13.43/13.69	0	L2041/-/-/-	
27	1		1		1		1		1		USA-Rus	3.89/3.92/3.56/3.88	0	L2041/-/-/-	
28	1		1		1		1		0	Greenland, Iceland	NL-Brazil	15.97/15.12/15.64/15.36	0	L2043/-/-/2035	
29	1		0	9.78	1		1		1		nfi	25.84/25.73/25.32/25.37	0	L2041/2038/-/2035	
30	1		1		1		0	37.74	1		Greenland -SA	34.3/39.26/34.1/33.81	0	L-/-/-/2035	
31	1		1		1		1		0	NL	nfi	18.62/18.74/18.33/18.72	0	L2041/2036/2043/2034	
32	1		1		1		1		0	Greenland, Iceland, SA MIS Australia	NL- Australia	12.11	0	L2041/-/-/2035	
33	0	3.50	0	5.78	0	2.90	1		0	Iceland MIS USA, Russia	Iceland-Russia	5.54/20/6.82/6.16	0	L2041/-/-/2034	
34	1		1		1		1		1		USA -China	2,30/2.32/2.08/2,31	1		
35	1		1		1		1		1		Aus-China	14,75/14.69/14,58/14,65	0	2041	
36	0	3.50	0	5.78	1		1		0	Greenland, Iceland, SA MIS Australia	Aus - Brazil	6.36/3.33/3.37/3.33	0	L2048/-/2045/-	
37	1		1		1		1		1		Russia-China	11.03/11.05/11.35/11.38	1		
38	1		1		1		1		1		Iceland- China	5.49/4.85/4.53/5.22	0	L-/2036/2043/2035	
39	1		1		1		1		0	Greenland, Iceland, SA MIS Australia	NL-Aus	16.94/17.08/16.65/17.06	0	L2037/2031/2038/2032	
40	1		0	8.85	1		0	38.19	0	Greenland MIS USA, Russia, Australie	China - Iceland	0.30	0	L2038/3033/2040/2032	
41	0	9.44	0	11.12	1		1		1		USA - China	9.40/9.44/9.23/9.57	0	L2041/2036/2042/2034	
42	1		0	9.72	1		1		0	Greenland, Iceland, SA	NL- ?	10.89/11.18/10.51/10.84	0	L2041/-/-/-	
43	1		1		1		1		0	Iceland	Iceland-Australia	20.43/19.54/19.11/19.87	0	L2043/-/-/2035	
44	1		1		1		1		0	Greenland	SA-Australie	3.99/3.84/3.72/3.94	0	Australia: 2029, USA: 2016: China: 2032, Russia 1995, Greenland 2010 (exact) 2016 is higher [participant calculated for each of the countries in Q de year]	

Appendix G – Recorded Task completion time

P	Total time	T4: What is…	T5: Which country…	T6: Select two…	T7: Find the…
p1	00:10:42	00:01:03	00:04:20	00:02:09	00:03:10
p2	00:15:51	00:00:32	00:05:51	00:03:57	00:05:31
p3	00:06:16	00:01:26	00:03:40	00:01:03	00:00:07
p4	00:11:58	00:01:03	00:04:31	00:01:45	00:04:39
p5	00:17:41	00:01:15	00:05:51	00:02:00	00:08:35
p6	00:14:12	00:00:58	00:06:32	00:01:46	00:04:56
p7	00:13:38	00:01:29	00:03:49	00:02:32	00:05:48
p8	00:21:06	00:00:54	00:07:13	00:05:00	00:07:59
p9	00:14:15	00:00:52	00:04:13	00:04:28	00:04:42
p10	00:12:17	00:00:43	00:06:16	00:02:20	00:02:58
p11	00:14:08	00:01:50	00:04:55	00:02:28	00:04:55
p12	00:13:20	00:01:13	00:04:54	00:03:21	00:03:52
p13	00:08:54	00:01:17	00:03:58	00:01:10	00:02:29
p14	00:11:40	00:02:03	00:04:11	00:01:46	00:03:40
p15	00:11:20	00:01:06	00:04:45	00:01:59	00:03:30
p16	00:10:26	00:00:45	00:05:00	00:01:25	00:03:16
p17	00:19:46	00:01:21	00:06:57	00:03:16	00:08:12
p18	00:09:00	00:01:17	00:03:20	00:02:06	00:02:17
p19	00:20:25	00:01:38	00:06:02	00:03:57	00:08:48
p20	00:16:57	00:00:56	00:07:22	00:02:40	00:05:59
p21	00:14:17	00:01:18	00:03:55	00:03:37	00:05:27
p22	00:12:02	00:00:29	00:04:13	00:02:09	00:05:11
p23	00:12:22	00:00:40	00:03:58	00:02:52	00:04:52
p24	00:16:13	00:00:56	00:06:15	00:02:08	00:06:54
p25	00:15:06	00:01:08	00:06:20	00:03:31	00:04:07
p27	00:12:56	00:00:34	00:04:21	00:01:42	00:06:19
p28	00:22:52	00:01:05	00:07:49	00:03:36	00:10:22
p29	00:14:41	00:00:47	00:05:51	00:02:55	00:05:08
p30	00:15:18	00:01:48	00:04:59	00:02:30	00:06:01
p31	00:11:14	00:01:22	00:03:47	00:01:48	00:04:17
p32	00:14:14	00:01:24	00:05:13	00:03:24	00:04:13
p33	00:13:18	00:00:54	00:04:15	00:01:22	00:06:47
p34	00:10:48	00:00:54	00:04:03	00:01:44	00:04:07
p35	00:10:47	00:00:53	00:05:16	00:02:24	00:02:14
p36	00:13:52	00:00:55	00:05:41	00:02:48	00:04:28
p37	00:12:25	00:00:50	00:04:46	00:02:27	00:04:22
p38	00:09:30	00:00:22	00:04:19	00:01:22	00:03:27
p39	00:15:37	00:01:46	00:07:21	00:02:52	00:03:38
p40	00:12:11	00:02:30	00:01:48	00:04:11	00:03:42
p41	00:10:11	00:02:23	00:02:36	00:01:58	00:03:14
p42	00:11:53	00:01:23	00:04:41	00:01:44	00:04:05
p43	00:15:18	00:00:57	00:06:49	00:01:50	00:05:42
p44	00:17:39	00:00:44	00:07:42	00:01:53	00:07:20
Average	00:13:41	00:01:09	00:05:06	00:02:31	00:04:55
Minimum	00:06:16	00:00:22	00:01:48	00:01:03	00:00:07
Maximum	00:22:52	00:02:30	00:07:49	00:05:00	00:10:22

Appendix H – Raw average temperature data

Indicators L, ML, MH, and H indicate the predicted values according to the Low, Medium Low, Medium High, and High model.

year	Greenland	Year	Greenland	GreenlandL	GreenlandML	GreenlandMH	GreenlandH
1901	-16,76	2000	-16,23				
1950	-16,64	2001	-16				
1951	-17,17	2002	-15,61				
1952	-16,22	2003	-15,16				
1953	-16,44	2004	-15,68				
1954	-16,34	2005	-14,9				
1955	-16,72	2006	-15,45				
1956	-16,89	2007	-15,53				
1957	-16,37	2008	-15,77				
1958	-16,08	2009	-15,77				
1959	-16,63	2010	-14,64				
1960	-15,73	2011	-15,49				
1961	-16,71	2012	-15,41				
1962	-16,09	2013	-16,05				
1963	-16,43	2014	-15,47				
1964	-16,54	2015	-16,16				
1965	-16,14	2016	-14,55				
1966	-17,07	2017	-15,74				
1967	-17,04	2018	-16				
1968	-17,17	2019	-15,37				
1969	-16,88	2020	-15,63				
1970	-16,94	2021		-15,5	-15,3	-15,65	-15,36
1971	-17,49	2022		-15,34	-15,32	-15,47	-15,41
1972	-17,06	2023		-15,5	-15,32	-15,4	-15,51
1973	-17,08	2024		-14,99	-15,19	-15,29	-15,35
1974	-16,46	2025		-14,84	-15,28	-15,41	-15,24
1975	-17,38	2026		-14,94	-15,24	-15,42	-14,99
1976	-16,44	2027		-15,27	-15,12	-15,34	-14,9
1977	-16,41	2028		-14,95	-15,08	-14,89	-15,07
1978	-16,83	2029		-15,04	-15,08	-15,36	-15,1
1979	-16,86	2030		-15,29	-15,13	-15,04	-14,64
1980	-16	2031		-15,03	-14,83	-15,3	-14,85
1981	-16,42	2032		-14,86	-14,83	-15,29	-14,96
1982	-17,33	2033		-14,86	-14,97	-15,55	-14,82
1983	-17,97	2034		-15,06	-14,85	-14,89	-14,82
1984	-17,36	2035		-15,13	-14,75	-15,23	-14,64
1985	-16,2	2036		-15,17	-14,9	-15,08	-14,49
1986	-16,67	2037		-14,95	-14,59	-15,27	-14,63
1987	-16,7	2038		-14,87	-14,74	-14,78	-14,33
1988	-16,34	2039		-14,56	-14,68	-14,85	-14,47
1989	-17,56	2040		-14,9	-14,73	-14,74	-14,21
1990	-16,56	2041		-14,61	-14,66	-15,22	-14,3
1991	-16,29	2042		-14,36	-14,37	-14,92	-14,2
1992	-17,27	2043		-14,66	-14,34	-15,48	-14,09
1993	-17,23	2044		-14,7	-14,45	-14,96	-13,88
1994	-16,68	2045		-14,85	-14,31	-14,57	-13,99
1995	-16,62	2046		-14,77	-14,53	-14,84	-13,88
1996	-16	2047		-14,74	-14,37	-14,69	-13,73
1997	-16,33	2048		-14,84	-14,17	-14,6	-13,81
1998	-15,89	2049		-14,89	-14,01	-14,66	-13,69
1999	-16,37	2050		-14,64	-14,11	-14,35	-13,33

year	USA	Year	USA	USAL	USAML	USAMH	USAH
1901	8,58	2000	9,44				
1950	8,49	2001	9,46				
1951	8,27	2002	9,43				
1952	8,87	2003	9,42				
1953	9,43	2004	9,68				
1954	9,28	2005	9,83				
1955	8,39	2006	9,63				
1956	8,57	2007	8,83				
1957	8,99	2008	8,96				
1958	8,86	2009	9,36				
1959	8,69	2010	9,37				
1960	8,58	2011	10,11				
1961	8,48	2012	9,09				
1962	8,77	2013	9,42				
1963	8,92	2014	10,22				
1964	8,35	2015	10,68				
1965	8,47	2016	10,25				
1966	8,29	2017	9,89				
1967	8,71	2018	9,74				
1968	8,37	2019	10,05				
1969	8,59	2020		10,29	10,16	10,06	10,24
1970	8,56	2021		10,18	10,19	9,92	10,23
1971	8,31	2022		10,44	10,34	10,02	10,44
1972	8,24	2023		10,55	10,29	10,06	10,41
1973	8,77	2024		10,38	10,45	10,09	10,45
1974	8,68	2025		10,39	10,6	10,01	10,48
1975	8,26	2026		10,49	10,47	10,2	10,46
1976	8,46	2027		10,57	10,56	10,23	10,71
1977	9,12	2028		10,46	10,49	10,26	10,56
1978	8,57	2029		10,55	10,6	10,28	10,73
1979	8,38	2030		10,61	10,6	10,07	10,53
1980	8,97	2031		10,42	10,62	10,37	10,63
1981	9,54	2032		10,61	10,7	10,34	10,9
1982	8,33	2033		10,71	10,81	10,6	10,81
1983	8,74	2034		10,73	10,9	10,3	10,91
1984	8,65	2035		10,73	11,03	10,44	10,91
1985	8,39	2036		10,76	10,88	10,4	11,03
1986	9,39	2037		10,79	11,03	10,56	11,09
1987	9,47	2038		10,74	10,88	10,56	11,04
1988	9,1	2039		10,68	10,9	10,67	11,06
1989	8,66	2040		10,6	11,06	10,65	11,19
1990	9,38	2041		10,68	11,01	10,66	11,42
1991	9,37	2042		10,82	11,07	10,88	11,32
1992	8,94	2043		10,83	11,1	10,82	11,41
1993	8,72	2044		10,86	11,36	10,86	11,37
1994	9,24	2045		10,8	11,19	10,99	11,53
1995	9,26	2046		10,83	11,27	10,9	11,63
1996	8,63	2047		10,82	11,28	11,05	11,79
1997	8,78	2048		10,74	11,37	11	11,94
1998	9,83	2049		10,77	11,43	10,76	11,92
1999	9,25	2050		-14,64	-14,11	-14,35	-13,33

year	Brazil
1901	25,49
1950	24,69
1951	24,7
1952	24,86
1953	24,95
1954	24,96
1955	24,74
1956	24,48
1957	24,81
1958	25,25
1959	25,1
1960	24,83
1961	25,26
1962	24,95
1963	25,3
1964	24,92
1965	25,11
1966	25,22
1967	25,14
1968	24,8
1969	25,38
1970	25,23
1971	24,61
1972	25,1
1973	25,14
1974	24,53
1975	24,59
1976	24,57
1977	25,02
1978	24,85
1979	24,85
1980	25,02
1981	24,81
1982	24,96
1983	25,15
1984	24,96
1985	24,9
1986	25,06
1987	25,44
1988	25,21
1989	24,86
1990	25,2
1991	25,15
1992	25,01
1993	25,09
1994	25,2
1995	25,39
1996	25,17
1997	25,49
1998	25,8
1999	25,28

Year	Brazil	BrazilL	BrazilML	BrazilMH	BrazilH
2000	25,24				
2001	25,5				
2002	25,75				
2003	25,59				
2004	25,56				
2005	25,78				
2006	25,59				
2007	25,68				
2008	25,39				
2009	25,57				
2010	25,79				
2011	25,51				
2012	25,69				
2013	25,66				
2014	25,8				
2015	26,12				
2016	25,98				
2017	25,88				
2018	25,72				
2019	26,07				
2020	26,06				
2021		26,16	26,07	26,08	26,29
2022		26,21	26	26,11	26,28
2023		26,27	26,14	26,15	26,09
2024		26,17	26,21	26,08	26,09
2025		26,26	26,27	25,92	26,32
2026		26,28	26,34	26,17	26,55
2027		26,12	26,31	26,2	26,41
2028		26,21	26,28	26,24	26,45
2029		26,29	26,21	26,15	26,46
2030		26,36	26,3	26,15	26,4
2031		26,32	26,47	26,22	26,43
2032		26,21	26,45	26,25	26,53
2033		26,28	26,51	26,16	26,61
2034		26,3	26,51	26,18	26,71
2035		26,34	26,48	26,35	26,62
2036		26,4	26,53	26,08	26,72
2037		26,49	26,79	26,26	26,71
2038		26,55	26,72	26,45	26,74
2039		26,46	26,65	26,54	26,92
2040		26,59	26,66	26,3	26,96
2041		26,56	26,65	26,29	26,91
2042		26,5	26,7	26,62	26,88
2043		26,52	26,81	26,61	27,18
2044		26,47	27	26,67	27,17
2045		26,35	26,79	26,62	27,07
2046		26,63	26,79	26,69	27,14
2047		26,66	26,94	26,63	27,45
2048		26,65	26,81	26,74	27,31
2049		26,38	27	26,78	27,43
2050		26,56	26,99	26,85	27,5

year	Iceland
1901	1,6
1950	1,76
1951	1,28
1952	1,49
1953	2,56
1954	1,91
1955	1,59
1956	2,31
1957	2,04
1958	1,77
1959	2,35
1960	2,7
1961	2,1
1962	1,56
1963	1,57
1964	2,46
1965	1,34
1966	0,78
1967	0,82
1968	0,92
1969	0,56
1970	0,97
1971	1,28
1972	2,57
1973	1,04
1974	2,34
1975	1,38
1976	2,16
1977	1,54
1978	1,67
1979	-0,09
1980	1,67
1981	0,49
1982	1,26
1983	0,72
1984	1,98
1985	1,36
1986	1,41
1987	2,58
1988	1,13
1989	1,27
1990	1,65
1991	2,46
1992	1,69
1993	1,6
1994	1,47
1995	0,99
1996	2,18
1997	2,13
1998	1,49
1999	1,69

Year	Iceland	IcelandL	IcelandML	IcelandMH	IcelandH
2000	2,03				
2001	2,26				
2002	2,51				
2003	3,22				
2004	2,87				
2005	2,06				
2006	2,64				
2007	2,52				
2008	2,29				
2009	2,54				
2010	2,73				
2011	2,38				
2012	2,49				
2013	2,16				
2014	3,25				
2015	1,91				
2016	3,15				
2017	2,95				
2018	2,74				
2019	2,78				
2020	2,51				
2021		2,81	2,82	3,13	3,18
2022		2,76	3,26	2,77	2,84
2023		2,7	2,93	2,47	2,88
2024		3,08	3,18	2,99	2,88
2025		3,28	3,03	2,94	2,9
2026		3,1	3,18	3,04	2,92
2027		2,77	3,18	3,32	2,87
2028		3,3	3,17	4,04	3,03
2029		3,02	3,43	3,35	2,99
2030		2,76	3,43	3,67	3,2
2031		3,19	3,54	2,98	3,19
2032		3,06	3,53	2,45	3,1
2033		2,92	3,16	3,34	3,14
2034		3,12	3,27	3,47	2,96
2035		3,1	3,05	3,19	3,18
2036		3,05	3,14	3	3,78
2037		3,31	3,06	3,09	3,11
2038		2,94	3,57	3,51	3,54
2039		3,24	3,27	3,53	3,58
2040		3,47	3,51	3,63	3,58
2041		3,5	3,51	3,17	3,63
2042		3,45	3,37	3,24	3,82
2043		3,57	3,47	3,76	3,7
2044		3,96	3,39	3,8	4,02
2045		3,27	3,57	3,49	3,84
2046		3,53	3,5	3,41	3,55
2047		3,67	3,46	3,03	4
2048		3,27	3,78	3,41	3,74
2049		3,33	3,61	3,32	4,1
2050		3,46	3,76	3,93	4,01

year	Netherlands
1901	8,78
1950	9,69
1951	9,57
1952	8,94
1953	9,76
1954	8,87
1955	8,79
1956	8,25
1957	9,77
1958	9,28
1959	10,16
1960	9,56
1961	9,9
1962	8,14
1963	7,82
1964	9,11
1965	8,65
1966	9,38
1967	9,91
1968	9,14
1969	9,13
1970	9,02
1971	9,59
1972	8,93
1973	9,39
1974	9,72
1975	9,79
1976	9,72
1977	9,58
1978	8,9
1979	8,43
1980	8,97
1981	9,19
1982	9,94
1983	9,99
1984	9,27
1985	8,39
1986	8,8
1987	8,58
1988	10,12
1989	10,62
1990	10,68
1991	9,42
1992	10,35
1993	9,41
1994	10,46
1995	10,21
1996	8,33
1997	10,06
1998	10,15
1999	10,79

Year	Netherlands	NetherlandsL	NetherlandsML	NetherlandsMH	NetherlandsH
2000	10,8				
2001	10,21				
2002	10,67				
2003	10,48				
2004	10,24				
2005	10,45				
2006	10,84				
2007	10,98				
2008	10,49				
2009	10,41				
2010	8,95				
2011	10,82				
2012	10,15				
2013	9,66				
2014	11,56				
2015	10,79				
2016	10,61				
2017	10,83				
2018	11,31				
2019	11,18				
2020	11,63				
2021		10,74	10,9	10,79	11,2
2022		10,64	10,75	10,81	11,12
2023		11,22	10,48	10,69	11,16
2024		10,7	10,97	10,63	11,11
2025		10,78	11,08	10,43	11,06
2026		10,96	11,1	10,71	10,9
2027		10,79	11,12	10,52	10,88
2028		11,09	11,02	10,63	11,14
2029		11,19	11,02	10,82	11,09
2030		10,89	11,18	10,51	11,04
2031		11	11,16	10,93	11,05
2032		11,19	11,17	10,83	11,31
2033		10,85	11,13	10,96	11,08
2034		10,88	11,39	10,78	10,86
2035		11,01	11,1	10,95	10,98
2036		11,02	11,19	10,87	11,27
2037		11,25	11,23	10,94	11,2
2038		10,81	11,25	10,74	11,54
2039		10,91	11,38	11,09	11,39
2040		11,28	11,48	11,22	11,34
2041		10,98	11,32	11,38	11,23
2042		10,99	11,33	11,27	11,64
2043		11,21	11,33	11,47	11,64
2044		11,2	11,42	11,13	11,57
2045		11,23	11,46	11,04	11,68
2046		11,32	11,33	10,82	11,49
2047		11,31	11,51	11,5	11,66
2048		11,16	11,54	11,22	11,8
2049		11,22	11,33	11,31	11,7
2050		10,95	11,62	11,36	11,85

year	SouthAfrica	Year	SouthAfrica	SouthAfricaL	SouthAfricaML	SouthAfricaMH	SouthAfricaH
1901	16,98	2000	17,64				
1950	17,6	2001	17,91				
1951	17,23	2002	17,95				
1952	17,71	2003	18,32				
1953	17,35	2004	18,58				
1954	17,17	2005	18,58				
1955	16,65	2006	18,07				
1956	17,22	2007	18,39				
1957	17,64	2008	18,49				
1958	17,7	2009	18,43				
1959	17,51	2010	18,68				
1960	17,6	2011	17,99				
1961	17,6	2012	18,22				
1962	17,76	2013	18,3				
1963	17,54	2014	18,51				
1964	17,33	2015	18,96				
1965	17,44	2016	19,07				
1966	17,81	2017	18,62				
1967	17,26	2018	18,75				
1968	17,07	2019	19,37				
1969	17,76	2020	18,55				
1970	17,73	2021		18,88	18,86	18,9	18,98
1971	17,33	2022		18,93	18,74	18,92	19,02
1972	17,7	2023		18,82	18,89	19,03	18,88
1973	17,66	2024		18,84	18,86	18,75	18,8
1974	17,21	2025		18,98	18,94	18,84	18,99
1975	17,2	2026		19	19,03	19,04	19,18
1976	17	2027		19,03	18,92	18,8	19,18
1977	17,71	2028		19,03	19,03	18,87	19,12
1978	17,5	2029		19,04	19,08	18,98	19,11
1979	17,89	2030		19,01	19,13	19,06	19,17
1980	17,68	2031		19,03	19,21	18,92	19,11
1981	17,2	2032		18,95	19,33	18,92	19,3
1982	17,81	2033		18,87	19,13	18,87	19,47
1983	18,32	2034		18,8	19,14	19,01	19,48
1984	18,15	2035		19,07	19,3	19,06	19,39
1985	18,24	2036		19,31	19,23	19,07	19,5
1986	18,18	2037		19,23	19,46	19,15	19,46
1987	18,26	2038		19,23	19,59	19,18	19,53
1988	17,76	2039		19,28	19,34	19,42	19,66
1989	17,58	2040		19,09	19,33	19,14	19,64
1990	17,82	2041		19,41	19,47	19,16	19,75
1991	17,86	2042		19,12	19,39	19,24	19,61
1992	18,41	2043		19,16	19,51	19,36	19,92
1993	18,35	2044		19,26	19,71	19,4	20,02
1994	17,68	2045		19,25	19,5	19,38	19,92
1995	17,99	2046		19,15	19,5	19,39	19,91
1996	17,41	2047		19,27	19,55	19,61	20,13
1997	17,78	2048		19,55	19,74	19,46	20,15
1998	18,26	2049		19,3	19,62	19,48	20,04
1999	18,61	2050		19,25	19,58	19,64	20,25

year	Russia	Year	Russia	RussiaL	RussiaML	RussiaMH	RussiaH
1901	-5,38	2000	-4,53				
1950	-5,59	2001	-4,51				
1951	-5,1	2002	-4,04				
1952	-6,17	2003	-3,87				
1953	-4,85	2004	-4,46				
1954	-5,4	2005	-3,63				
1955	-5,66	2006	-4,77				
1956	-5,93	2007	-3,07				
1957	-5,36	2008	-3,41				
1958	-6,08	2009	-4,69				
1959	-4,9	2010	-4,59				
1960	-5,95	2011	-3,5				
1961	-5,03	2012	-4,05				
1962	-4,44	2013	-3,71				
1963	-4,99	2014	-3,78				
1964	-5,82	2015	-3,08				
1965	-5,95	2016	-3,37				
1966	-6,33	2017	-3,1				
1967	-4,4	2018	-3,62				
1968	-5,64	2019	-3,06				
1969	-6,75	2020	-1,9				
1970	-5,53	2021		-3,02	-3,26	-3,25	-3,21
1971	-5,01	2022		-2,93	-3,31	-3,24	-3,13
1972	-5,69	2023		-2,86	-3,04	-3,22	-2,98
1973	-4,86	2024		-3,03	-2,99	-3,28	-3,02
1974	-5,67	2025		-3,23	-3,03	-3,12	-2,92
1975	-4,15	2026		-3,05	-2,85	-3,07	-2,84
1976	-5,98	2027		-2,82	-3,14	-2,98	-2,88
1977	-5,59	2028		-2,84	-2,86	-3,2	-2,66
1978	-5,21	2029		-2,59	-2,66	-2,84	-2,65
1979	-5,78	2030		-2,78	-2,77	-3,15	-2,96
1980	-5,39	2031		-2,81	-2,74	-2,7	-2,67
1981	-4,14	2032		-2,69	-2,6	-2,9	-2,54
1982	-5,08	2033		-2,61	-2,58	-2,96	-2,28
1983	-4	2034		-2,66	-2,6	-3,22	-2,48
1984	-5,31	2035		-2,58	-2,82	-2,88	-2,19
1985	-5,58	2036		-2,66	-2,45	-3,22	-2,32
1986	-4,86	2037		-2,72	-2,61	-2,76	-2,24
1987	-6,25	2038		-2,54	-2,27	-2,59	-2,31
1988	-4,34	2039		-2,54	-2,24	-2,68	-2,08
1989	-3,99	2040		-2,56	-2,35	-2,87	-2,18
1990	-3,98	2041		-2,61	-2,43	-2,75	-1,99
1991	-4,3	2042		-2,41	-2,34	-2,42	-1,73
1992	-4,9	2043		-2,72	-2,03	-2,31	-1,82
1993	-4,62	2044		-2,43	-2,37	-2,36	-1,82
1994	-4,93	2045		-2,29	-2,04	-2,64	-1,66
1995	-3,21	2046		-2,3	-2,06	-2,45	-1,56
1996	-4,77	2047		-2,51	-1,81	-2,18	-1,53
1997	-4,29	2048		-2,28	-1,92	-2,5	-1,4
1998	-5,17	2049		-2,11	-2,05	-2,46	-1,28
1999	-4,77	2050		-2,42	-1,9	-2,29	-1,39

year	China
1901	6,51
1950	6,48
1951	6,55
1952	6,43
1953	6,89
1954	6,23
1955	6,61
1956	6,13
1957	6,15
1958	6,82
1959	6,77
1960	6,64
1961	6,83
1962	6,51
1963	6,76
1964	6,44
1965	6,49
1966	6,65
1967	6,17
1968	6,45
1969	6,16
1970	6,3
1971	6,6
1972	6,56
1973	6,91
1974	6,43
1975	6,89
1976	6,26
1977	6,6
1978	6,85
1979	6,89
1980	6,76
1981	6,8
1982	6,98
1983	6,74
1984	6,36
1985	6,57
1986	6,68
1987	7,03
1988	7,1
1989	7,05
1990	7,32
1991	6,92
1992	6,68
1993	6,74
1994	7,32
1995	7,08
1996	6,75
1997	7,12
1998	7,83
1999	7,63

Year	China	ChinaL	ChinaML	ChinaMH	ChinaH
2000	7,08				
2001	7,44				
2002	7,66				
2003	7,36				
2004	7,61				
2005	7,3				
2006	7,83				
2007	8,03				
2008	7,47				
2009	7,65				
2010	7,41				
2011	7,23				
2012	6,94				
2013	7,57				
2014	7,55				
2015	7,81				
2016	7,79				
2017	7,95				
2018	7,59				
2019	7,85				
2020	7,77				
2021		7,98	8,02	7,86	8,04
2022		8,08	8,14	7,87	8,18
2023		8,24	7,97	8,09	8,14
2024		8,13	8,15	8,07	8,12
2025		8,18	8,26	8,17	8,24
2026		8,11	8,06	8,12	8,26
2027		8,44	8,35	8,19	8,37
2028		8,32	8,28	8,26	8,47
2029		8,35	8,35	8,14	8,47
2030		8,25	8,28	8,2	8,42
2031		8,25	8,43	8,04	8,46
2032		8,46	8,36	8,18	8,52
2033		8,53	8,48	8,29	8,59
2034		8,5	8,6	8,24	8,71
2035		8,48	8,52	8,36	8,67
2036		8,44	8,69	8,42	8,79
2037		8,49	8,76	8,29	8,76
2038		8,54	8,67	8,52	8,83
2039		8,48	8,65	8,39	8,9
2040		8,59	8,7	8,38	8,98
2041		8,61	8,8	8,4	9,14
2042		8,48	8,73	8,55	9,12
2043		8,58	8,88	8,59	9,34
2044		8,72	8,83	8,8	9,26
2045		8,69	8,93	8,55	9,17
2046		8,77	8,97	8,65	9,35
2047		8,78	8,94	8,55	9,46
2048		8,73	9,11	8,75	9,47
2049		8,81	9,16	8,69	9,46
2050		8,73	9,1	8,68	9,61

year	Australia
1901	21,62
1950	21,15
1951	21,32
1952	21,29
1953	21,28
1954	21,34
1955	21,33
1956	20,8
1957	21,72
1958	21,82
1959	21,95
1960	21,09
1961	21,79
1962	21,67
1963	21,57
1964	21,49
1965	21,93
1966	21,21
1967	21,53
1968	21,33
1969	21,71
1970	21,58
1971	21,45
1972	21,86
1973	22,18
1974	21,05
1975	21,49
1976	21,04
1977	21,68
1978	21,44
1979	22,04
1980	22,4
1981	21,96
1982	21,77
1983	22,07
1984	21,33
1985	21,87
1986	21,88
1987	21,83
1988	22,4
1989	21,64
1990	22,13
1991	22,3
1992	21,76
1993	22,01
1994	21,93
1995	21,78
1996	22,11
1997	21,82
1998	22,43
1999	21,9

Year	Australia	AustraliaL	AustraliaML	AustraliaMH	AustraliaH
2000	21,53				
2001	21,58				
2002	22,26				
2003	22,22				
2004	22,08				
2005	22,57				
2006	21,93				
2007	22,09				
2008	21,78				
2009	22,22				
2010	21,59				
2011	21,54				
2012	21,83				
2013	22,81				
2014	22,63				
2015	22,43				
2016	22,5				
2017	22,58				
2018	22,59				
2019	22,88				
2020	22,66				
2021		22,81	22,77	22,81	22,89
2022		22,8	22,79	22,64	22,92
2023		23,07	22,89	22,78	22,76
2024		22,86	22,89	22,67	22,72
2025		22,89	23,09	22,57	22,86
2026		22,85	23,13	23,11	23,06
2027		22,92	23,03	22,9	22,96
2028		22,99	22,98	22,92	22,95
2029		23,07	22,89	22,87	23,22
2030		23	22,97	22,78	23,07
2031		22,94	23,05	23,23	23,21
2032		22,96	23,1	22,91	23,09
2033		22,91	23,19	22,93	23,26
2034		22,99	23,15	22,93	23,26
2035		22,89	23,02	22,84	23,23
2036		23,12	23,07	22,74	23,37
2037		23,14	23,37	22,84	23,32
2038		23,08	23,31	23,09	23,29
2039		23,09	23,33	23,08	23,52
2040		23,09	23,35	23,06	23,53
2041		23,13	23,42	23,01	23,59
2042		23,23	23,37	23,18	23,55
2043		23,16	23,35	23,23	23,71
2044		23,18	23,53	23,24	23,72
2045		23,13	23,42	23,41	23,74
2046		23,15	23,29	23,31	23,73
2047		23,46	23,45	23,41	23,86
2048		23,2	23,48	23,52	23,96
2049		23,1	23,53	23,48	23,68
2050		23,23	23,66	23,24	24,11

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