(Spirit of Create)
Exploration of illusory feedback

Bachelor Thesis for Creative Technology

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Abstract

The Spirit of Create is a project that aims to create interactive artefacts that showcase the multidisciplinary nature of Creative Technology. This specific project aimed to produce can an installation exploring movement and illusive feedback as this has yet to be done within this context. The goal was to produce an installation that users interact with using movement and interacts with the user using movement as well.

Through literature research the question “What are interesting concepts for a SoC module that incorporates illusory feedback?” was answered. An interesting concept must maintain the attention of the user but not trigger the user to think about how it works and means that the technical implementation must be non-obvious to the user. This requirement resulted in not allowing touch and focusing on proxemic interaction because it triggers the user to think and answer about what the installation is subconsciously. All interaction must try to build a rapport with the user, with the correct proxemic interaction, creating an illusion that the installation has an emotional presence. All with the goal of maintaining an illusory emotional presence without using traditional anthropomorphic features, using only movement, emphasised by colour.

This research let to the second research question “What are the requirements for a SoC module that incorporates illusory feedback?” and the third “How to design a SoC module that incorporates illusory feedback?. These questions have been answered using the iterative Creative Technology Design Process. The process iterates within and through the phases of ideation, specification, realisation and evaluation.

In the ideation phase, many concepts and interaction types were explored using a stakeholder analysis, brainstorm sessions and scenario-based ideation. These resulted in two concepts, a table with a moving surface and a wall with moving rods in it, the latter of which was selected to continue.

The specific requirements were determined in the specification phase, where the interaction was specified using a UML interaction model, and the systems and subsystems were specified. This, combined with the scenario’s resulted in a list of requirements that could be used as guides during the realisation and evaluation phase.

The next step was to create a series of prototypes to explore various technical challenges in the realisation phase. These then resulted in the creation of the final installation, through various iterations, making first morphological decisions and then detailed designs using CAD. The emotional framework underlying the scenarios was also translated into software to run then interaction and determine how the installation should respond to the user. The result is a small wall segment with 16 rods placed in a 4x4 grid that can move and change colour individually while responding to movement in front of them.

This installation has been evaluated in the evaluation phase using a rundown of the technical requirements and by using the installation in a user test consisting of 10 people, all students, some first years, others 2nd-year master not all of which were creative technologists. The installation was well received by these participants, as they enjoyed their interaction and took a while to explore the range of behaviour. The technical function and behaviour were not instantly apparent; the behaviours were correctly interpreted when asked but not always acted upon due to the effect being too weak, the installation not building enough rapport with the participants to adequately convey the emotions. The technical aspect was obscured to most of the users during their interaction.

Future works should focus on creating more depth to interactions with the installation by adding more detail to the emotional states displayed by the installation to improve the perception of them, possibly the model should also be fleshed out more to allow for more states in the installation. The range of the proxemic detection should also be increased to allow more interaction that users seemed to expect. The installation should also be rebuilt so it can move faster and more reliably for longer periods of time. The addition of multi-rod patterns would also be advisable to improve the expressiveness of the installation.

Acknowledgement

I got a lot of help during this project from many people, whom I would like to thank here.

First, of I would like to thank Richard Bults. Primary supervisor for this project, who offered a lot of feedback, input and guidance during the project as well as having the patience and time to keep helping me when I was having issues with myself, causing a significant delay in the project.

Second I would like to thank my critical observer Erik Faber, for providing a different perspective on the work as well as taking the time to be the critical observer.

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1 Introduction

1.1 The Spirit of Create

Early 2014, Creative Technology initiated an independent promotion project named “Spirit of Create” (SoC). The goal is to showcase artefacts, a module, project or installation, produced by students that achieve high-quality user experience by seamless merging knowledge of multiple disciplines. These artefacts are all results of *Imagineering*[1] type graduation projects.
All these modules combine in a geographically dispersed installation that collectively represents the spirit of the CreaTe program. The installation's setup is a star network, with one core module and several peripheral modules connected by internet communication technology. Each artefact is a module in this network and supports a form of (local) user interaction as well as (remote) interaction with the core module. The aim of the CreaTe program regarding the Spirit of CreaTe is to add at least one peripheral module with an innovative interaction form to the SoC installation every graduation semester.

1.2 The Research

The goal of the current project is to develop a SoC (peripheral) module that uses illusory feedback, which is to say a user perceives feedback through a sense which is not stimulated. The illusion, in this case, is touch which is used to create an intriguing user experience for, the geographically dispersed, SoC installation. An essential element is the proxemic interaction with the user's hand, physical touch of any part of this module is not permitted as this breaks the illusion. This restriction makes the movement and touch-based interaction with the installation illusory, stimulation being implied as opposed to real. This non-touch based interaction makes "proxemic", the study of distance people keep between themselves and others during an interaction, a better word though usually it is used in the context of distance between people in a room.

This area of interaction leads to the challenge; What are interesting concepts for a SoC module that incorporates illusory feedback. Now this rather broad so to be specific the challenge lies in which factors play a role in illusory feedback and create an intriguing user experience, what does the proxemic interaction look like and which factors can translate into a concept for a SoC module?

This challenge results in the research questions of this project:
RQ1: What are interesting concepts for a SoC module that incorporates illusory feedback?
1a: Which factors play a role in illusory feedback to create an intriguing user experience?
1b: What does the proxemic interaction look like with an object?
1c: Which factors can be translated into a concept for a SoC module?
RQ2: What are the requirements for a SoC module that incorporates illusory feedback?
RQ3: How to design a SoC module that incorporates illusory feedback?

1.3 Report structure

This report follows the structure of the Creative Technology Design Process which starts with a design question, then iterates through ideation, specification, realisation ending with an evaluation and a conclusion.

Each of these phases has its own chapter in this report, starting with chapter 2 which provides background from literature to clarify the theoretical framework within which the RQ’s should be answered.

Chapter 3 contains the ideation phase, where concepts for interaction have been generated using brainstorms, explored using scenario-based design and selected, and some preliminary requirements have been formulated.

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[1] “Imagineering is letting your imagination soar, and then engineering it down to earth”, Time Magazine 1942, http://graphic-design.tjs-labs.com/show-picture?id=1118935951&size=FULL

Chapter 4 contains the specification phase, where the concept is broken down into UML interaction flows, and specific requirements are formulated from the scenarios.

Chapter 5 contains the realisation phase, in which the morphological decisions of the installation are described, and the installation architecture and details are designed.

Chapter 6 contains the evaluation phase, where both technical requirements are evaluated, and interaction is tested with users, the results of which are also discussed.

Finally, chapter 7 contains the conclusion of the project and recommendations for future development based on the evaluation of the installation.

2 State of the Art review

To make a current and relevant design, it is crucial to know what the current state of affairs or 'State of the Art' in the world is. To this end, literature research has been done to make an inventory of what is known in the field about illusory feedback and close proxemic interaction. Below are the results of the analysis done before and during the ideation process divided into several sections. This chapter describes the results of the preliminary research done before, and some during, the design process of the Installation

2.1 Factors of illusory feedback

Many human-computer interfaces partly rely on illusions to enrich the experience of a user by using feedback of different modalities or senses. For instance, a small single vibration based tactile feedback (as adopted by most current smartphones), when combined with other modalities of input, can induce illusory directional haptic feedback and a rich user experience.

According to Kim et al. [1] using feedback on multiple senses to imply more information or context than there actually is, is called illusory feedback (described in psychology and neuroscience as illusory perception). It can also be understood as the tendency of the brain to complete an image or sensory perception based on partial information. This effect influences some senses stronger than others. Aglioti et al. [2, 2, 3] show that using this it is easier to fool the eyes than it is to fool the hands.

When it comes to motion, many things can be done with illusory feedback to create responses and thoughts in people. Parkes et al. [3] say that people possess a deeply rooted response to motion, recognising innately in it a quality of ‘being alive' provoking a significantly more profound and emotional response from users.

Fujita [4] suggests that imperfections in motion and mistakes, as well as new non-repetitive reactions, will lead to users perceiving emotion and feeling empathy for robots. Once these behaviours have been established, he continues that, people will start attributing other ‘neutral' or accidental behaviours to emotion even though the robot is actively trying to express them. This perception could make the difference between a friendly, ‘gentle giant' and an ominous ‘scary' machine when it comes to robots or moving installations in general.

It is widely accepted that certain emotions can be associated with particular colours, red for instance is linked to anger and blue to sadness, the transition between these emotions and a colour association is described by Plutchik's emotional wheel model [5].

Figure 2-1: Plutchik's emotion colour wheel model

A practical Implementation by Angelini et al. [6] shows when combined with a simple, relatable model these colours actively help to reinforce the conveyed emotion. Plutchik does not say that the colours and the emotions are hard linked to one another; however, it is a reasonable starting point that corresponds reasonably well to the western understanding of colour. The way emotions transition from one to another is also similar with the

notable exception that emotions can invert or cross over to the other side of the wheel. For instance from fear straight to anger, without having to transition through trust, joy and anticipation or surprise, sadness and disgust first.
Sound can also help with this perception but tends to not be practical in public spaces with much noise and so has not been investigated further at this time.
The conclusion here that to achieve illusory feedback an illusion need to be simple and well defined with no factors to break the illusion. Where imperfect movements can be used, the functions of a machine need to be consistently functioning yet can be unclear on how it works. Since touch tends to trigger people to perceive more and think about things the installation should avoid it.

2.2 Proxemics

The study of distance people keep between themselves and others during interaction is called proxemics and can also be seen as personal space. [7] This interaction distance is dependent on quite a few factors, including culture, place and purpose [8] of the interaction. In a subway people consider their personal space to be a lot smaller than in a park. One essential condition for this is that the person in question perceives the other as an equal social being and not an object (which by its nature cannot think), in which case there are no proxemic effects [9] [10]. This perception is something which for robots and especially machines is not always a given. When people do not register a robot as an equal social being but see it as a machine without a complicated will, they will allow it to come closer than they would otherwise [11]. For example, people will let a robot vacuum cleaner pass by very close to them but will move out of the way of a person doing the same job. Whether or not a robot (or person for that matter) acknowledges (looks at) a person around it also changes its perceived social position for the person in question being looked at [12]. Another influence is the experience of a person with lower social actors, such as pets and children, as well as experience with robots [13].
As can be seen, proxemics tends to focus on the distance between people and other people, and these distances tend to be between 15cm and 3,5m [8] [11]however, the interaction for this SoC module these theories will only be used for the ranges closer than 1 meter.

2.3 Haptic interaction

Though haptic interaction will not be used in the sense that there is no touch in the installation, a lot can be learned from it about how movement and near-touch interfaces can be used to convey emotion and create illusory feedback. Since haptic interaction focuses on touch and near-touch movements, it can help fill the gap between touch and 15 cm at the lower end of proxemics research.
Traditionally haptic interaction is used to create feedback and depth to visual experiences. This effect is found commonly in video games and phones to simulate/enhance on-screen movement and recently in laptops [14] to replace moving parts. These are from a haptic point of view pretty crude tools to create feedback. As Kim et al. [1] show using a technique called "funnelling" an illusory haptic interaction can be established between two input devices on the skin by simultaneously stimulating them with different amplitudes. Hachisu et al. [15] note that this effect can also be used to create stiffness, texture or mass for a virtual object. Renkimoto [16] even shows that using vibrations directional force can be implied.
Touch, or the perception of it, can be used to convey emotion as well. Tsalamlal et al. [17] show that using air jets blown to make patterns users can distinguish different emotions quite accurately. Additionally, Hertsein et al. [18] [19] show that different types of touch, such as a stroke or a squeeze are quickly recognised as a specific emotion by most people.
A different type of haptic interaction device like the inFORM interactive table [20] which uses shape change to restrict and change the affordances, which are the perceived interactions or uses an object has based on appearance; it has available to a user. It can facilitate interaction by creating buttons, for instance, or restrict interaction by trapping object's in gulleys and manipulating objects by moving the surface supporting them. These different aspects could be combined to imply facilitation or restriction without direct touch. These types of interactions might be used by the SoC module to suggest openness/happiness (‘come closer') or closed-ness/fear (‘don't come closer') and communicate these emotions more efficiently.

2.4 Factors for a SoC module

For humans to interact with one another, they use much non-verbal communication though it has not been proven that all humans respond the same way Brooks & Arkin [21] state that people will socially react to sociable robots. In other words, when a behaviour or emotions are recognised, they will be responded to as such by people, this also counts for body language. Space inhabited or perceived to be one's own by a person or the installation for that matter can also help to express emotion to the other participant. When one is ‘happy' the personal space, the distance that is considered to be too close for comfort, is a lot smaller than when one is ‘scared'. Practically this means that when the SoC module (or a person for that matter) is ‘scared’ it will retreat from incoming objects at a greater distance ‘in fear' than when it is happy and come closer ‘to explore'. This behaviour can be superimposed on top of the usual functional behaviour to express an emotional state or rapport [22] as it is called in Neuro-Linguistic Programming. This rapport can be used to connect to another, in this case, the user, to create more empathy and better express/project emotion. The SoC module maintaining rapport can help to get people to empathise with it.

2.5 Other related work.

Some related products use haptic and movement-based interaction.
The Myo (illusory) [23] is a device that uses muscle activity and accelerometers as input to interact with a computer, using this movement the user can have the illusion of grasping pieces of the interface or directly controlling on-screen items without the need to physically grasp controls, which improves immersion and illusion.
The Leap (illusory) [24] scans hand movement above the sensor and translates them to a virtual representation of a hand on the screen. This representation can be used to manipulate virtual items using natural hand movements giving the user the illusion that they can reach into the screen to manipulate items.
The Wii controller (illusory and haptic) [25] can be used to translate movement to games on a screen. It is used to move tools in a game which have handles like the controller; e.g. swinging a golf club by swinging the controller. These devices all have one thing in common; they work relatively well until they do not work naturally. Which then breaks the illusion and makes them worse than just having buttons to interface with a game which might not have broken the illusion.

2.6 Conclusion

To create exciting concepts for a SoC module using illusory feedback, it is necessary to understand the illusion it is attempting to create. In the case of this module, the illusion is designed to create an intriguing user interaction by creating an experience of the module having emotion (or personality) and the illusion of touching the installation. The module can employ proxemic feedback, This illusion will create the response of having touched the installation, and the movement will, in turn, facilitate the personality or emotional expression of the installation.
Using the knowledge about how and why haptic feedback and proxemics work, movement will be coordinated to create visual output in the module to represent the touch interaction that would otherwise have been made. Proxemic interaction will create an installation with a personality that appears to have a presence or rapport (if not perceived sentience) of its own.
One of the most important things is that the implemented functions of the installation work well. If they do not work well, then the illusion gets shattered.

In relation to the research questions that have been stated in chapter 1, the conclusion of the literature study can be stated as follows.

1) What are interesting concepts for a SoC module that incorporates illusory feedback?
    a. *Which factors play a role in illusory feedback to create an intriguing user experience?*
    For an illusion to survive, the user must not be aware of how the module works, and they must not be prompted to think about how it works. When a user expects something to work and it does not they start thinking about why not and this thinking breaks the illusion. Also when

people touch objects, they gain an understanding of how it functions and subconsciously start breaking the illusion. Therefore to maintain the illusion they must not touch the module.

b. *What does the proxemic interaction look like?*
The proxemic interaction needs to be based on rules that have been established with human interaction. All movements need to be based on near touch and when users move the module should react to these movements. To place some behavioural rules on the type of movement the module uses an emotional framework. The emotional framework will help sustain the illusion by supplying a vague yet straightforward answer to why the module moves the way it does.

c. *Which factors can be translated into a concept for a SoC module?*
By having colour and movement correspond to an emotion the user will be supplied with an illusion as to what's going on in the installation. By not touching, but seeing and moving, the user will have an interaction with the installation that is interesting/meaningful. By the way the installation moves and responds, users will get a sense of how the object moves and feels without touching it.

2) *What are the requirements for a SoC module that incorporates illusory feedback?*
It is imperative that whatever happens the installation must not break the illusion of being a semi-social/sentient actor. Emotional state and movement patterns will be used to achieve this, and by moving a certain way the installation will seem to have been touched without the user having to do so; this would endanger the illusion. The installation must build a rapport with the user to maintain a functioning illusion and avoid being seen as just a machine playing a fixed 'track'.

3) *How to design a SoC module that incorporates illusory feedback?*
Keeping all these non-functional requirements in mind, the installation will have many moving parts to create an illusion moving in such a way not to be touched by the user. Colour will be used to represent the emotional state of the installation and movement will need to corresponding to- and supporting the states the installation is. These movements will be used to engage the user and depending on distance and response of the user the installation will change its output.

2.7 Preliminary Requirements

The answers to the questions also lead to some preliminary requirements, which were used in the Ideation phase as guides lines as to which direction to proceed in. Table 2-1 lists these requirements as distilled from the research and conclusion above.

Req. ID	Description
P1	The system shall detect users in front of it.
P2	The system shall interact with and respond to the user.
P3	The parts of the system shall move individually
P4	The interaction shall be based on proximity
P5	The operational mechanics of the system must be non-obvious.
P6	The system shall change colour based on user interaction
P7	The system should be/feel responsive
P8	The exterior of the system must be clean and straightforward and aesthetically pleasing. (form all sides of the installation)

Table 2-1 Preliminary requirements for the installation

3 Ideation Phase

The ideation process for this project has gone through several stages, often in parallel as well as in many iterations. The initial approach was to brainstorm on concept develop one into a useful idea and then with a final concept test response with some fellow student. This approach was selected because the concept was initially somewhat vague so asking for opinions and feedback was not possible while it was unclear what the module was

3.1 Create Design Cycle

The project uses the Create Design Process developed by Mader and Eggink [26], the main diagram of which is also found in Appendix B.
This design process is characterised by its cyclical nature, in general, choosing to focus on prototypes and iteration as opposed to single waterfall-style progression. This process, or variations on it, is also the standard practice for Creative Technology so it will not be elaborated on further here.

3.2 Stakeholder analysis

To understand how the final concept will be decided upon is important to understand stakeholders are and the influence they have within the process.
Freeman [27] defines it as follows "A stakeholder in an organisation is (by definition) any group or individual who can affect or is affected by the achievement of the organisation's objectives."
Sharp [28] builds on this to state that there are four categories of stakeholder, listed below, who can be found by listing all parties involved and analysing how they interact with the project:

User: A User can be anyone who will interact with the system, this includes passers-by, but also the people installing and controlling the system or those purchasing it. For this project, the main user will be the people interacting with the installation, the passing students, when installed in a public space in the University. Also, the project owner and client Richard Bults is a user since the installation is commissioned as a module for the Spirit of CreaTe and so will be used by the client to promote CreaTe.

Developer: A Developer is anyone who has to do with the creation of the system both on the research and the technical development side of it. In the case of this project that is only the Developer is Abel Gerritse, the student graduating on this project. Some advice and questions have been asked of others but not to the point of them becoming a stakeholder.

Legislator: A Legislator is anyone, usually a formal entity, who makes rules or guidelines that can influence the outcome or operation of the installation. In the case of this project, the only legislator is the University of Twente or Faculty of Creative Technology who have made rules for the Graduation Project in general.

Decision maker: A Decision maker is a higher-up who is involved with all more substantial decisions; usually they are managers or financial directors. In the case of this project, they are the researcher, Abel, and the client, Richard who are the only ones directly involved in the development part of the project.

Once a party has been identified their role and key interest need to be identified. Next, their influence topic and level are analysed to see how and where they might influence the project.

Stakeholder	Role	Key Interests	Interest level	Influence Topic	Influence Level
Passerby ('user')	User	Interaction	Medium	Interaction	Low

CreaTe	Legislator	Organisation	Medium	Time	Medium
Richard Bults (client)	Decision maker, User	Development / Installation	High	R&D	Medium
Abel Gerritse (researcher)	Decision maker, Developer	Development / Graduation	High	Everything	High

Table 3-1: Stakeholders

As can be seen in the table every stakeholder with a high interest has a high influence. Mostly the influence of stakeholders, other than the researcher, is limited to a specific part of the project and so the demands are inventoried and manageable when it comes to making decisions, and the stakeholder's influence on them.

The Decision makers in some preliminary conversations expressed some non-functional desires regarding the installation to be produced. Fist, since this is a complicated and relatively expensive module, there is a desire from both parties to make the installation repurpose able for other research or projects or at the very least make it possible to reuse components. For Richard this has to do with the investment made for the installation and for Abel, this is a point of pride not to produce an installation that is used for a bit and then send to storage indefinitely. Also due to the nature of research and how work is done at The University it should, in general, be possible to reproduce work and if necessary and possible be easily repaired or replaced.

3.3 Exploration of tactile interaction

Though the project eventually focuses on illusory feedback, it did not start out that way.
Touch/haptic/movement based interaction was the starting point for the ideation of the installation.
This definition gradually evolved to non-touch, distance-based or proxemic interaction when the parallel literature study (previous chapter) showed that touch is such a primal sense for people it is hard to maintain an illusion when people can touch an object.

To start with an inventory of possible tactile and haptic interaction was made using a mind map as is seen in Figure 3-1 below.

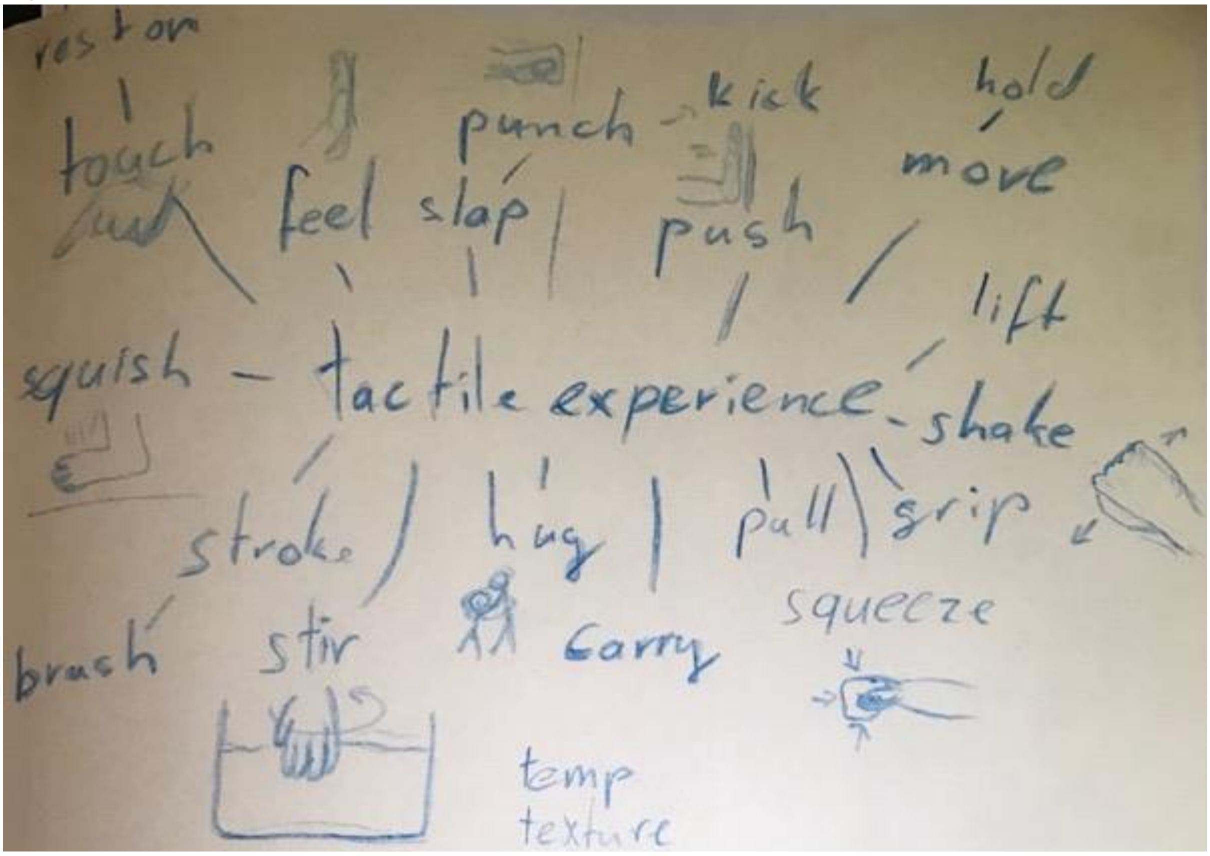

Figure 3-1 Mindmap of tactile interaction

When analysed some main categories can be roughly distinguished:

- Large movements, including; slap, kick punch, shake, hug
- Small movements, including; stroke, touch, squeeze, feel, stir
- Calm movements, including; hug, stroke, feel, touch
- Extra sense experience, including; temperature, texture
- Meta experience, including; carry, lift, hug

Due to the potentially destructive or dangerous nature of the Meta, Extra Sense and Large Experiences, it was decided to focus on the direction of Calm and mostly Small movements.

3.4 Brainstorming

The nature of this type of installation makes it hard for users to imagine or tell researchers or designers precisely what they want or expect from an installation design. Because of this, the design phase of the project is based on creative concepts that incorporate knowledge of how interaction works based on literature which has been discussed in chapter 2. The results of this phase have then been discussed with an expert and shown to people to gauge interest in the concept and decide how to continue.

This round was merely based on various types of interactions that could be distinguished from one another and sketching them so these concepts could be discussed. The idea's flow from each other and sketching them helps define some boundaries between them. This process then leads to new ideas and variations which are also fleshed out to simple concept sketches.

Figure 3-2 and Figure 3-3 show some of the interaction concepts that were explored. These concepts were then discussed with the client.

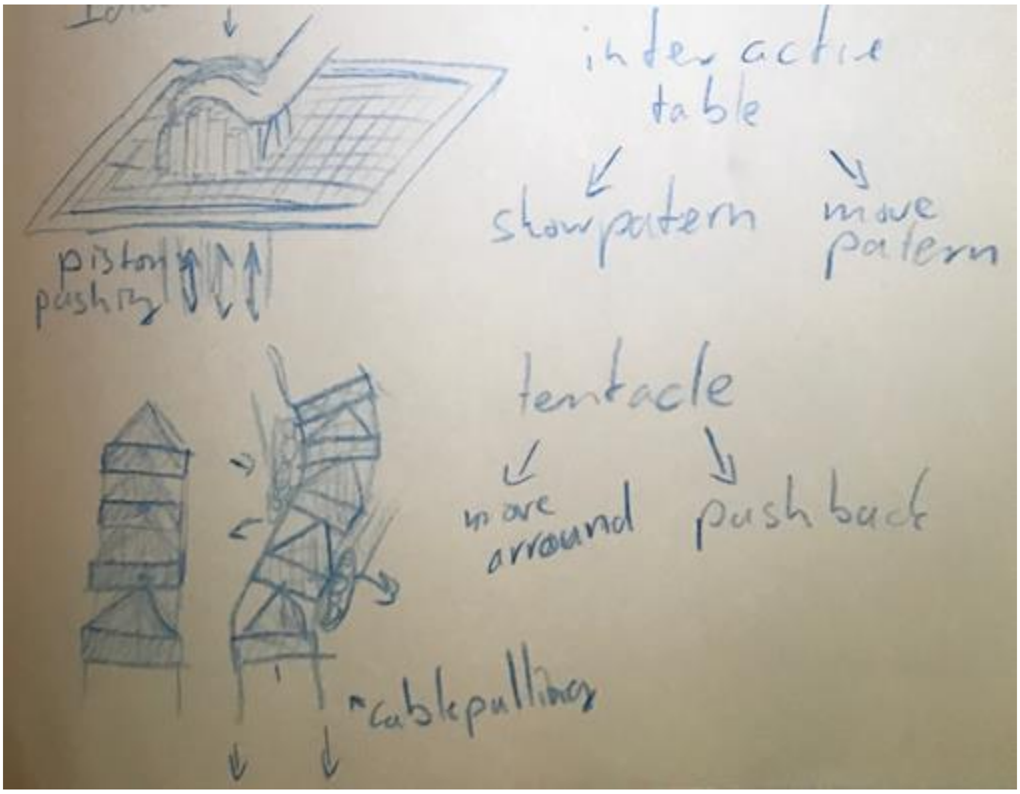

Figure 3-2 Exploration of tactile concepts I

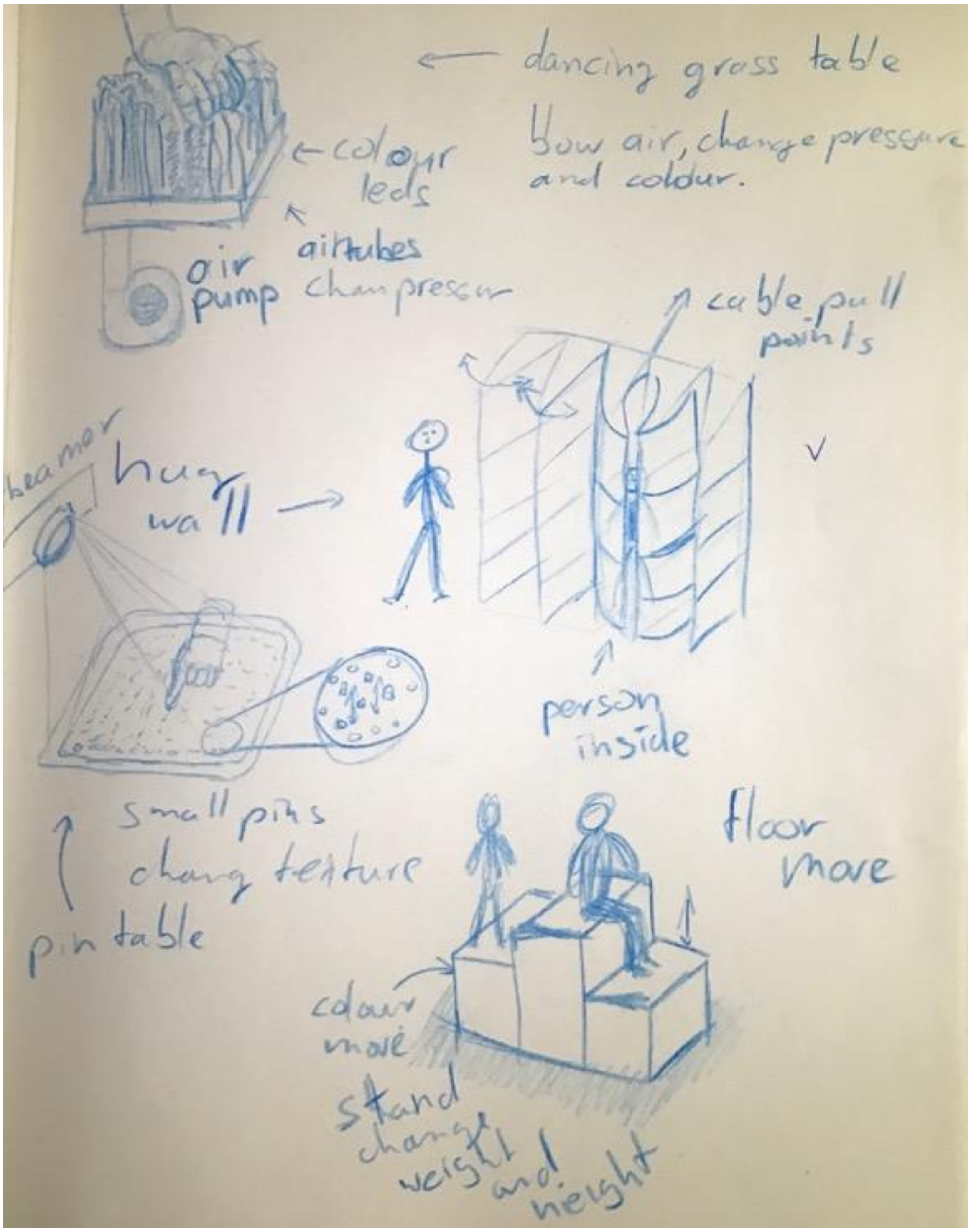

Figure 3-3: Exploration of tactile concepts II

It quickly became clear that within the context of a module for the SoC two base forms can be used for the kind of interaction desired; a large wall based installation or a table based installation. Depending on the scale of the movement some of the SoC concepts are better suited as a table or a wall. Although most concepts could be modified to be suited as either.

While developing the concept, it also became quite clear, by investigating how the interactions would work using simple scenario's, that using only touch the interaction would probably not remain interesting enough for long. Adding an illusory element, thereby making the interaction mechanics less visible, would also substantially increase interest as is also mentions in chapter 3.

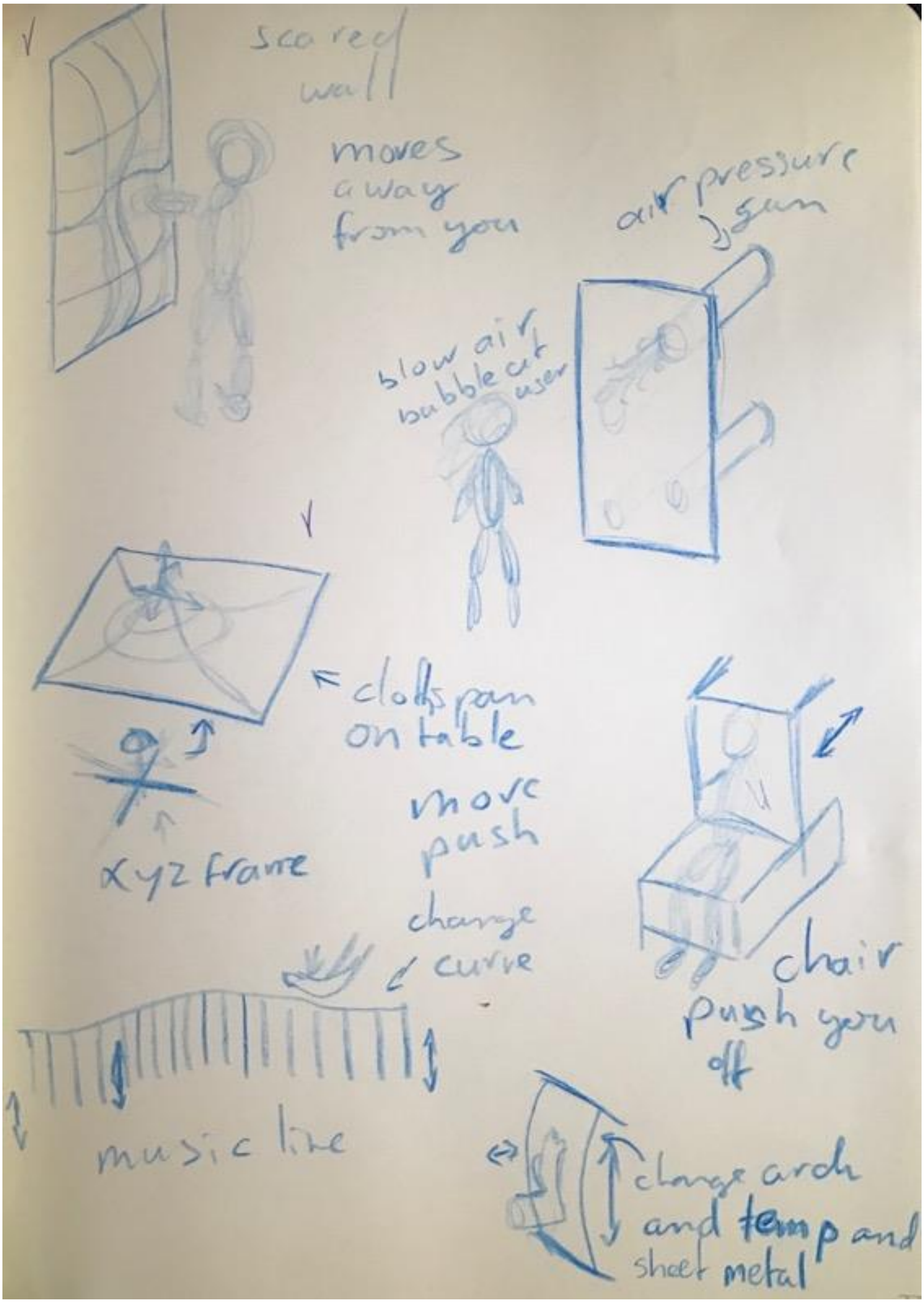

Figure 3-4: Exploration of tactile concepts III

Figure 3-4 and Figure 3-5 page show some non-standard interactions such as using water thermals, temperature and air blasts to interact with the user. Together with the client, it was decided not to investigate these interaction types any further as they were deemed to fickle to work within a public space, and visually attractive enough to continue with.

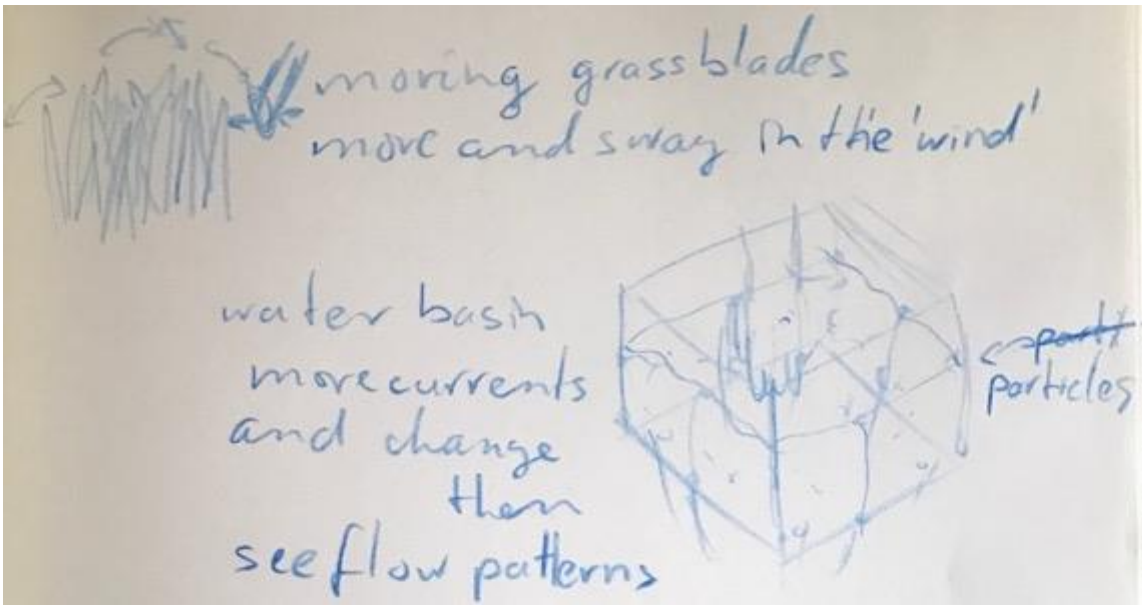

Figure 3-5: Exploration of tactile concepts IV

These concepts attempt to explore all the available interactions one can have in a tactile manner. The conclusions, based on conversations with the client, was to explore malleable surfaces in greater detail. The idea that it should not be apparent to the user how the installation works was also reiterated. Movement of part of the installation should occur but, in a manner and scale that does not instantaneously show how it is achieved or by which mechanic. (so, for instance, no gears showing)

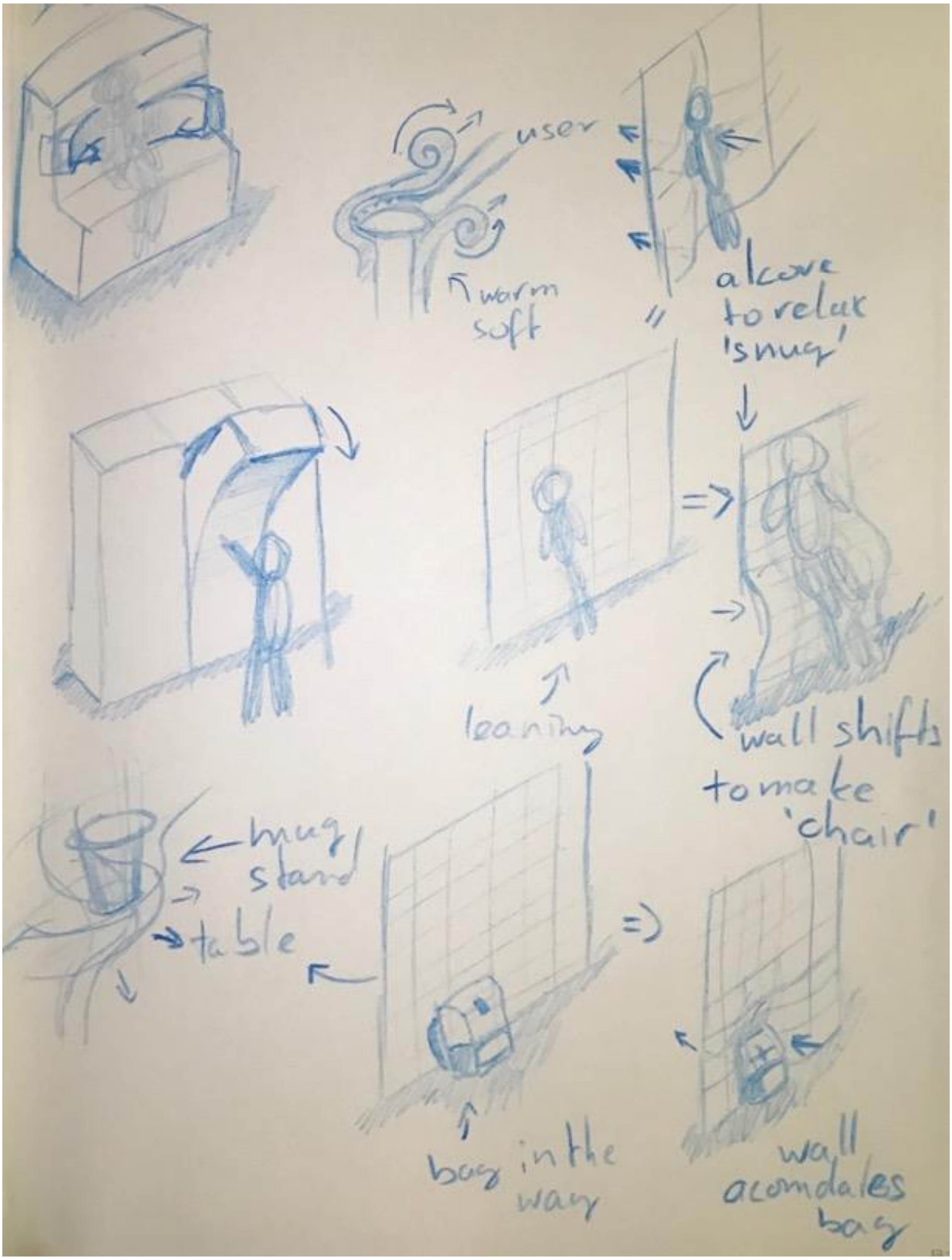

Figure 3-6: Exploration of tactile concepts V

The concepts in Figure 3-6 above explore the requirements that the installation should be placed in a public space as well as the desire for a ‘human scale' installation. The resulting concepts use a wall as a flexible surface. This direction was abandoned because, though appealing, the practical side of making and testing such an installation would have probably surpassed both the budget and the time set for the research.

3.5 Scenario-based Ideation

After just creating concepts by sketching, thinking them over and consulting with the client, two central concepts were selected and tweaked for further development: the wall that is ‘scared’ and the table that come up to greet the user both from Figure 3-4. Both were selected and developed alongside a usage scenario.
These scenarios are used to get an in-depth understanding of the interaction between the user and the module. These scenarios are used to communicate the interaction required to the client by describing the interaction from a user perspective in great detail. They also help to find limitations or flaws in the concepts and interaction with them. The accompanying sketches for these scenarios can be seen in Figure 3-7 and show the standalone concepts for the table using a flexible surface and a wall using movable rods.

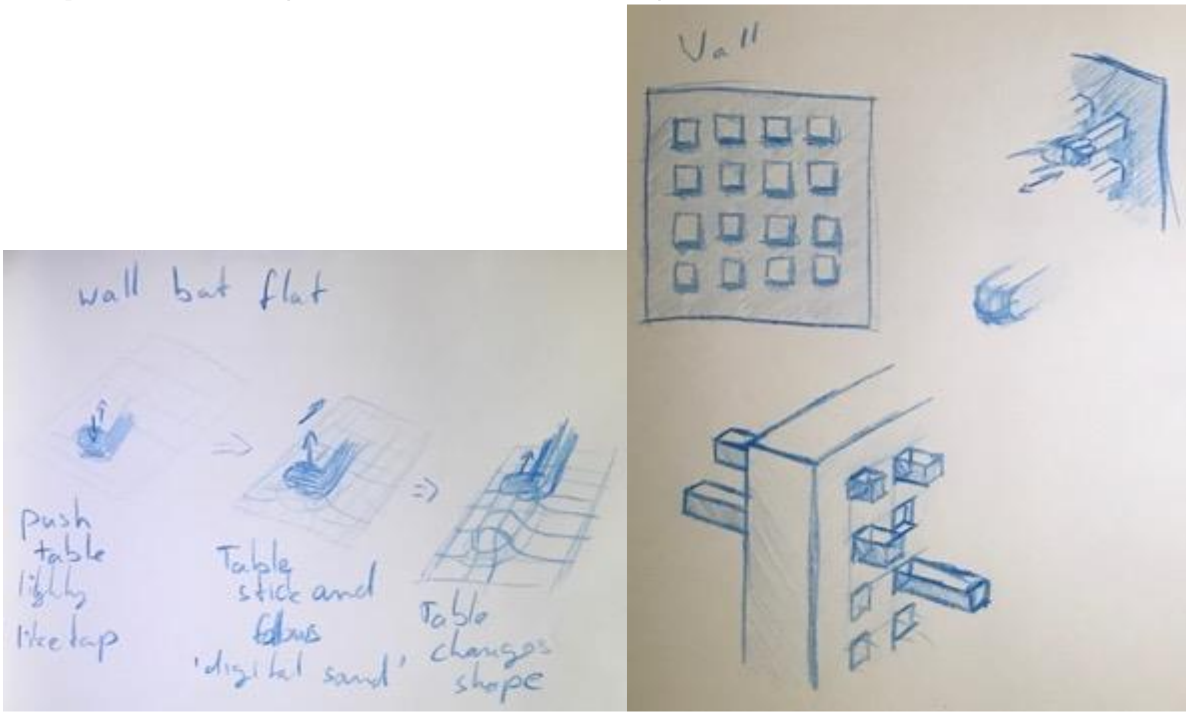

Figure 3-7: Scenario-based concept sketches; left) table based with a flexible surface, right) wall based with rods.

After several (5 primary) iterations together with the client, two scenarios have been developed, one based on a wall which can be found below and one based on a table which can be found in Appendix B. During the development of these concepts, it became apparent that the reactions of the installation might be classifiable with emotions and that they could be used as a framework to ground how the installation should react to a person.

3.5.1 Interactive Wall Scenario

Bob is a 20-year-old second-year Create student, as he often does he is walking to Proto to get a snack from the Omnomcom. He walks there in a break through the SmartXP with lots of other people moving about. While walking towards the stairs, he notices that there is a new thing on the wall. It has many coloured surfaces in a grid on the main surface, which seem to be moving slightly in the main surface. They come out slightly while no one is around and turn lighter green as they move forward and when others pass they turn a darker green and blue again. There seems to be a flow like jitter in their movements, the movement influencing its neighbours.

Bob is curious and stays in front of the surface. After a few seconds, the smaller coloured surfaces start to slowly come his way turning lighter green and almost yellow as they go. As the surfaces extend towards Bob, they turn out to be rods mounted in the main surface.

Rods are slowly extending towards Bob he reckons he should extend back a raises his hand towards them. As his hand comes closer, the rods start moving slower and more cautiously the colour switches to a more orange

and less yellow in colour as the rods get closer to his hand. The others are still happily moving and flowing in their yellow glory.
When he is almost touching the rod it stops staying a light orange colour, when bob come closer the colour gets slightly darker and when he retreats is turns more yellow.

This stays the same as he moves slowly sideways way to the next rod which is behaving the same as the first. Just less direct than the first. Now that Bob's hand is above it, it moves up slightly and starts to behave just like the first.

Bob then removes his hand but stays in front of the installation. All the rods settle at about the same height and dance around a bit, swinging in colour from light orange to yellow to light green and back.

Now Bob raises his hand again but apparently, he comes to close to fast as the colours of the rods turns bright orange and the rods closest to his hand flash red and turn dark green as they retract quickly, taking its neighbours with it. This effect dies out after a few rods and the ones at the other side of the grid barely change colour.

Thinking that maybe it was because he moved too quickly, he slowly moves to the rods that are slightly nervously dancing on the wall. As he draws close, they slowly turn more yellow and extend as the first rods did before. While interacting with the rods, which are shimmering between yellow and green, the other rods in the wall seem to respond in a sort of fading wave by also becoming more confident and coming back out in green that is slowly becoming lighter.

After having done this for a bit, Bob decides that it is time to get back to getting his snack and leaves the wall be. It is now a lot calmer in the XP, and the rods retract about halfway and start slowly dancing as is moving in the waves while shimmering in a yellowy greenish set of colours.

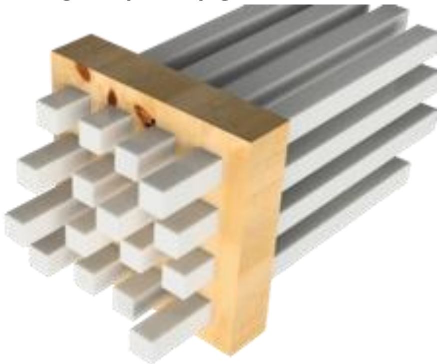

Figure 3-8 Render of concept included in the final scenario version

3.6 Scenario selection

Eventually, the base concept of the wall with rods was selected due to practical limitations and technical difficulties of using a flexible surface, as the one seen in the left image in Figure 3-7. Showing patterns to support emotion and reacting individually are easier to accomplish when parts are separate. Also due to the extra (technical) risk of the rods fall out of the module and break the scenario implementing a wall was selected over the scenario involving a table.
Literature research also pointed out that colour can be used to amplify the expression of emotion (though there can be cultural differences in interpretation of them) and having individual parts can help place colour more accurately.

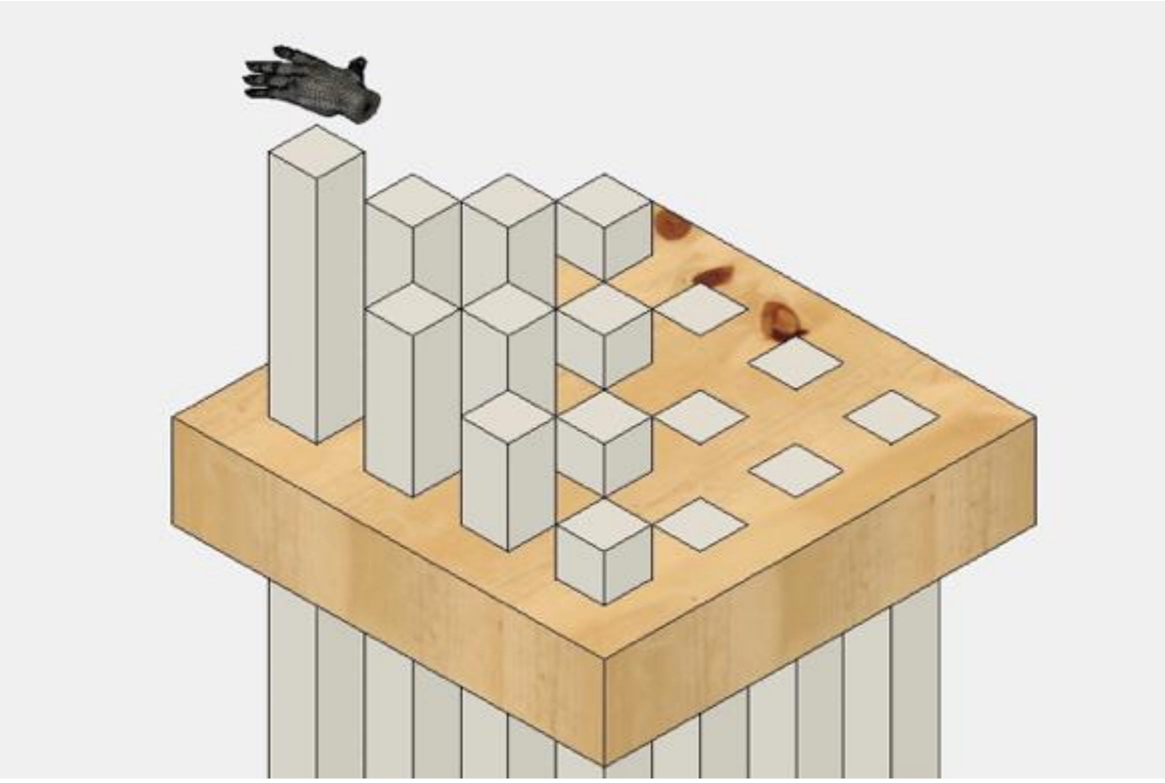

Figure 3-9: Still from the animation of final concept (in table form)

Figure 3-9 is a still from a concept animation (using a table incarnation of the rod concept) showing a user, represented by the hand interacting with the installation. When the user moves slowly, the rod extends to meet him, taking the surrounding rods part of the way up with it in the process. When the user moves quickly, the rod reacts skittishly and retracts back into the table as do the other rods. This interaction mimics the force user might have exerted by moving the rod down.

3.7 Requirements

By analysing the scenario mentioned in chapter 3.5 (which can also be found in Appendix B) requirements can be formulated to capture the capabilities of the installation. These requirements can be divided into two categories, functional requirements (FR) and non-functional requirements (NFR).

To form these requirements some guidelines form the project description, chapter 1.2, are reiterated:

- The installation should operate in a Public space
- The installation should incorporate an Illusory interaction
- The installation should tie into the Spirit of Create
- The installation should be made and interacted with on Human/single person scale

Using these guides actual requirements have been formulated in Table 3-2 as goals to strive for. During the Realisation phase, which heavily overlaps with design due to the prototyping development style, many of these requirements were tweaked due to real-world interferences such as the size of available parts. Detail below lists of Functional Requirements and Non-Functional Requirements.

Since not all requirements are not equally important, they need to be prioritised. The method used to determine the importance of the requirements is the MoSCoW [29] method. MoSCoW stands for 'Must have', 'Should have', 'Could have' and 'Would or Won't have' which are explained as follows:

Must have: These are the requirements that must be included in the project, without them it will not work.
Should have: These requirements are not critical for operation but will significantly improve the product when included. They are therefore still essential.
Could have: These requirements are nice to have but non-essential for the installation if resources become critical they can be skipped.
Would/Won't have: These requirements would be nice to incorporate but are most likely practically unfeasible to incorporate in this iteration. They might be implemented if there are many recourses left or in the next generation of the project.

Req. ID		**Description**	**Importance**	**Origin**
FR	1	The system must detect users in front of it.	Must	Section 1.2
FR	2	The system must interact with and respond to the user.	Must	Section 1.2
FR	3	The part of the system should move individually	Should	Section 3.5
FR	4	The operational mechanics of the system should be non-obvious.	Should	Section 2.1
FR	5	The installation must hide its drive mechanism	Must	Section 2.1
FR	6	The system must be/feel responsive	Must	Section 2.3
FR	7	The system should move at different speeds depending on user input	Should	Section 2.3
FR	8	The system must have 16 rods in a 4x4 grid.	Must	Section 3.5
FR	9	The system should have a movement range of ±40cm	Should	Section 3.5
FR	10	The system should detect a user within a range of ±100cm	Should	Section 3.5
FR	11	The system should be ±50-80x50-80cm wide and high	Should	Section 3.5
FR	12	The system must change colour based on user interaction	Must	Section 3.5
FR	13	The system must show four emotions/colours*	Must	Section 3.5
FR	14	The system could show more emotions	Could	Section 3.5
NFR	1	The exterior of the system should be clean and straightforward and aesthetically pleasing. (form all sides of the installation)	Should	Section 2.1
NFR	2	Installation should be reusable/repurpose-able	Should	Section 3.2
NFR	3	Installation components could be reclaimable	Could	Section 3.2
NFR	4	Installation rods must be removable and replaceable	Must	Section 3.2
NFR	5	The installation should be reproducible at a later date (by a different person)	Should	Section 3.2
NRF	6	Parts could be standardised (easily replaceable) when possible	Could	Section 3.2

Table 3-2: Requirements

Addition to FR-13: The emotion joy, trust, anticipation and fear with the corresponding colours yellow, green, orange and dark green corresponding with Plutchick's suggestions. In practice dark green wat changed over to dark blue to make the distinction clearer.

4 Specification and Design

This chapter contains the various design processes used to specify the final design of the installation. Starting at the abstract functional level and working down to the engineering level. The actual selection of part, though somewhat overlapping with the engineering design process, will be handled in the next chapter

4.1 Process overview

As is not uncommon within CreaTe, the Specification and Design phase of this project ran in parallel with small-scale testing and prototyping, influencing the design and scope of the end product.
Starting with a rough concept and working the way down to more specific design problems.
First with the functional system architecture of the installation using UML diagrams, then moving down to the morphological design method deeded to design the parts of the system. After that, the installation is created in CAD where many specific choices are made. Some of them are found in this chapter but most of the specific parts, as they involve testing, are in the next chapter

4.2 Functional Architectural Design

To start with a functional diagram of the installation is made. This shows what, where and, relatively, how functions are performed within the system. This description is done in two level, the Top layer, containing the entire system and the Sub Layer containing the subsystems within the system. Below that there is Physical Layer, this is where it is determined for each component how it should be implemented in the installation, be it hardware, software or both.

4.2.1 Top Layer

The Top layer of the system, in Figure 4-1, shows the system responding to input by the user by moving rods and changing their colour. To do this the system detects movement by the user with Proxemic Detector which provides the Movement Generator with input which in turn generates a movement response. The input from the Proxemic Detector is also used by the Emotion Engine to generate a colour for the rods which the Colour Driver outputs to the rods and behaviour and speed data witch the MG uses to modify the rod movement output generated.

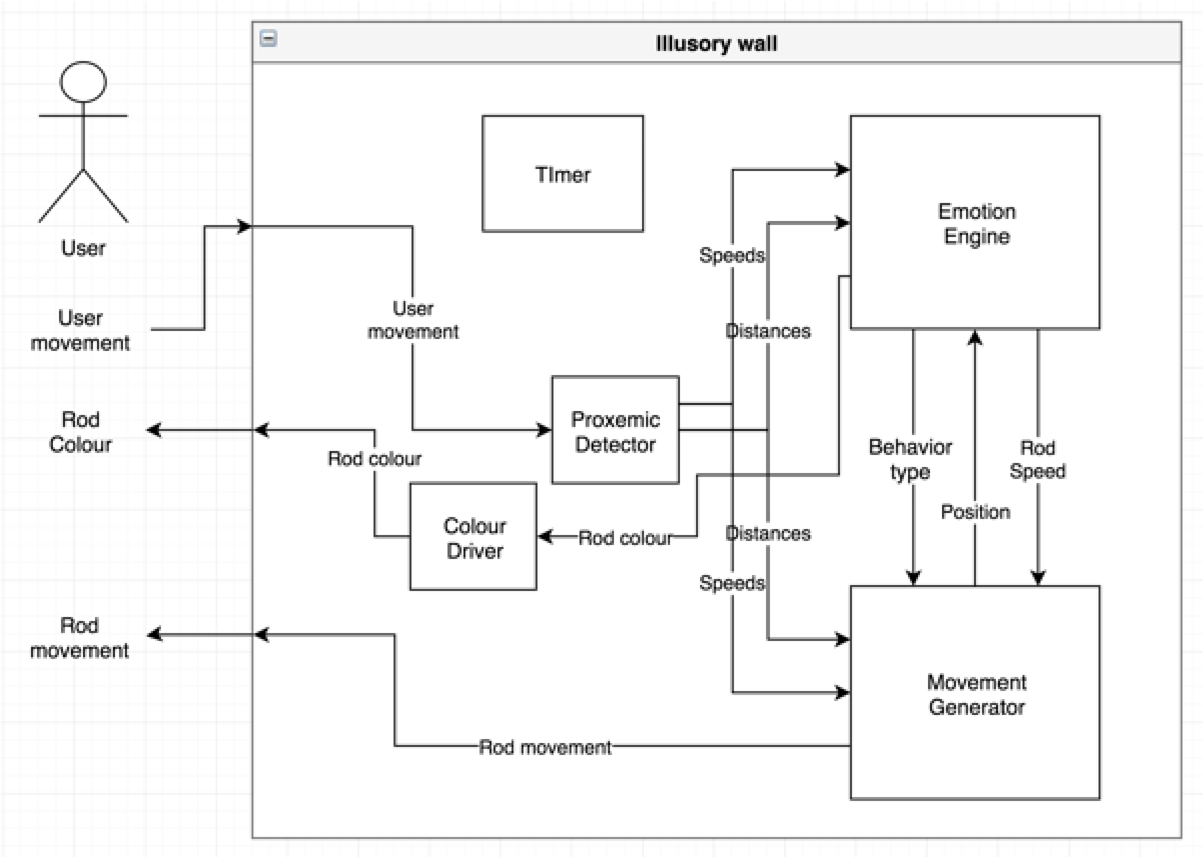

Figure 4-1: Top Layer functional system design

Contained in the Top Layer there is also a timer, which managed the timing of the movement of the rods in the Motion Generator. It also delegates the remaining time, in order, between; the Proxemic Detector, the Emotion Engine and the Colour Driver. All these functions are run as necessary when time permits.

4.2.2 Sub Layers

The Sub Layer contains three components; the Proxemic Detector, the Emotion Engine and the Motion Generator. The Timer and the Colour Generator are not included because they are already a single function that cannot be broken down any further. All these processes are run individually for each rod, shortening the time each process takes.

The Proxemic Detector first cleans-up the measurement data to remove the noise created by measurement errors. This clean current distance is compared to previous distances to determining how much movement has occurred and how fast that movement is.

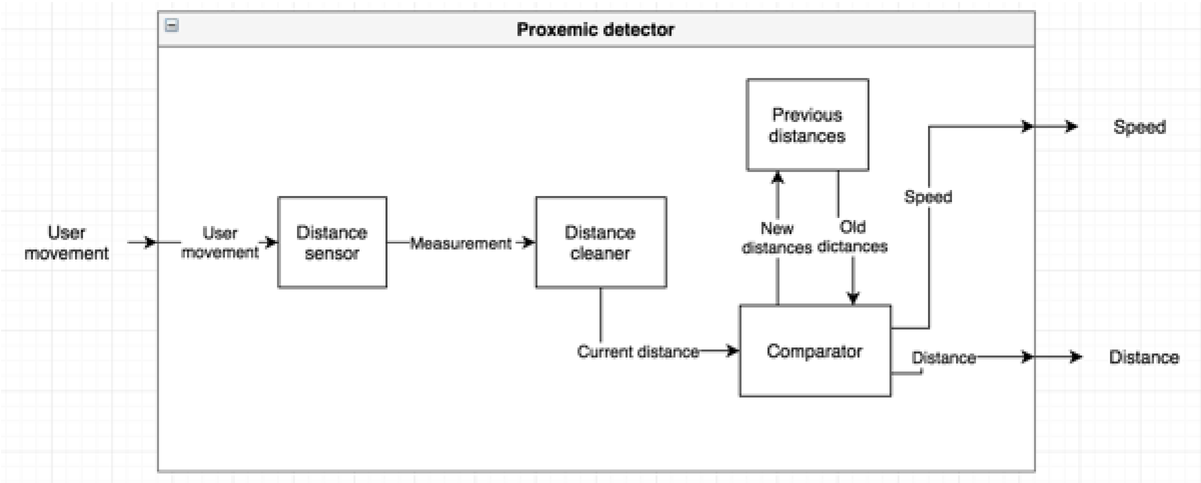

Figure 4-2: Sub Layer; Proxemic Detector

These distances and speeds are passed to both the Emotion Engine and the Motion Generator. The former combines this data with position data, provided by the latter, to determine what emotion should be displayed. The colour corresponding to this is then sent to be displayed on the rods.

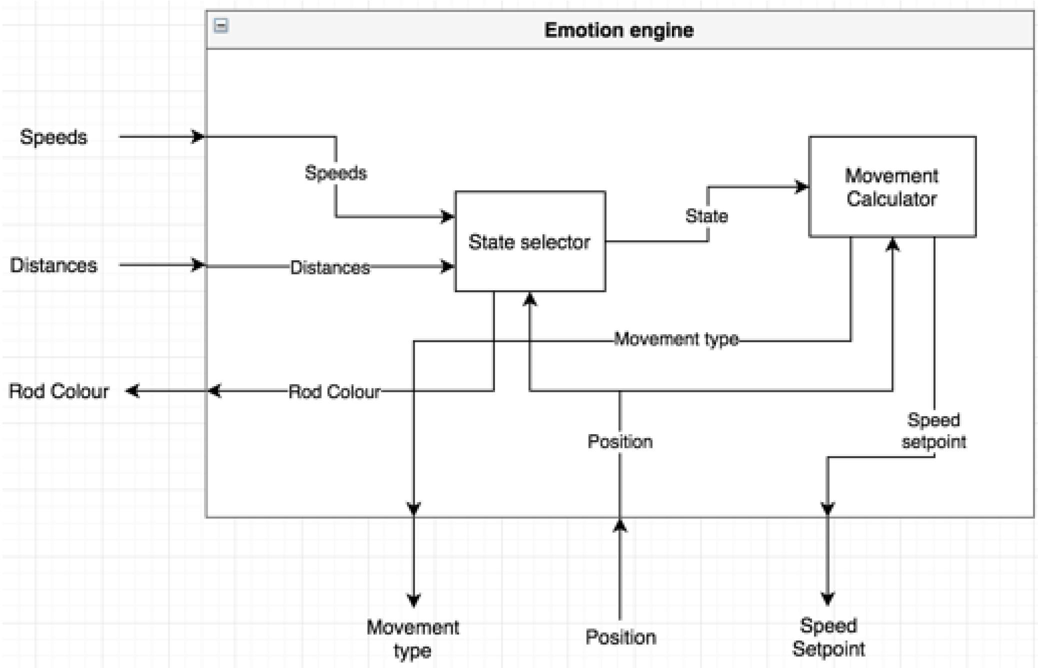

Figure 4-3: Sub Layer; Emotion Engine

Behavioural modifiers to movement type and speed are sent to the Movement generator with used this data to modify its response to the speed and distance input provided. The Response generator uses current measurements and emotional modifications to generate a new position set-point and speed for the rod. This set-point is checked versus the current position of the rod to see if the movement is allowed and then passed along to the actual output generator which takes care of actual movement.

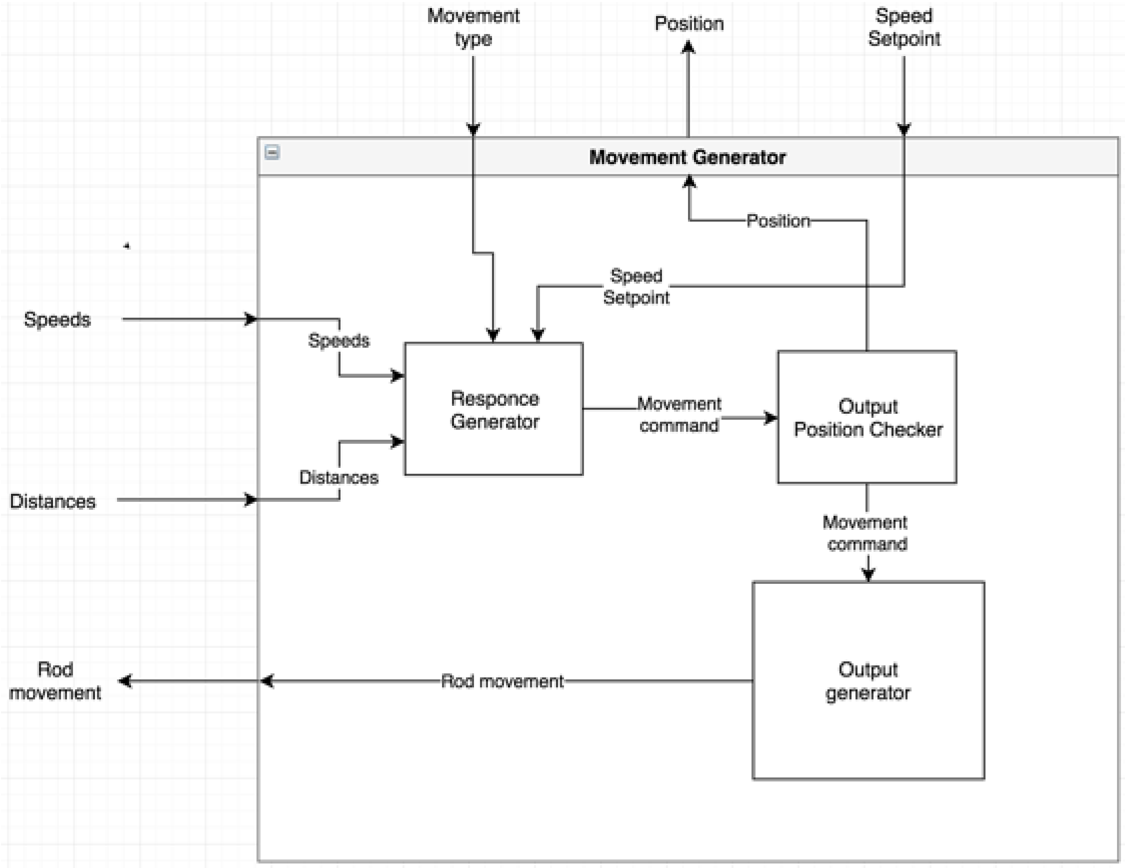

Figure 4-4: Sub Layer; Movement Generator

4.2.3 Physical Layer

For each function in the Sub Layer that physical state can be determined, so should the function be hardware or software based essentially. The Table below shows which solution has been selected per function, this, in turn, determines where in the physical hierarchy the function/component needs to be placed.

Top Layer	Sub Layer	Physical Layer
Timer		Software
Proxemic Detector		-
	Distance sensor	Physical sensor
	Distance cleaner	Software
	Comparator	Software
	Previous distances	Software
Emotion Engine		-
	State selector	Software
	Movement Calculator	Software
Motion Generator		-
	Response generator	Software
	Output position checker	Software
	Output generator	Driver board & physical motor
Colour Driver		Software & Physical light

Table 4-1: Physical layer placement

4.3 Installation part overview/breakdown

Following from the Function layer the components are reorganised into their engineering domains. This allows the various domains to have their own engineering and selection methods. These components are then places in a new hierarchy reflecting these domains. Figure 4-5 show this breakdown in a representation of the installation.

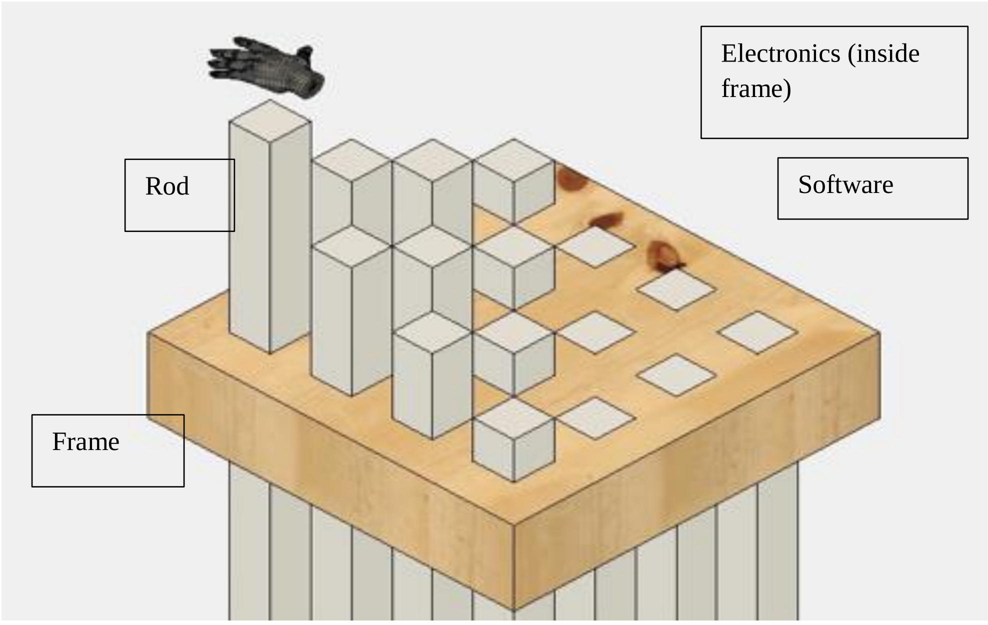

Figure 4-5: Physical, logical part breakdown

By analysing the concept design as it is at this point, some logical parts, which we will call sections, can be found in the design. To start with the moving bars in the table are obvious separate part of the design, they have been named Rods. The Rods move in a supporting structure which presumably can be placed in the world; this will be referred to as the Frame. Inside the frame, all the electronics can be housed. Because they are a different engineering domain, they are also separated out and referred to as the Electronics. This section contains one notable exception namely the power and data transferred system, which spans the rods is, the frame and the electronics.

Separate from this all is the control programming needed to run the installation and the hardware to run the software, all of this is collectively housed in the section Software.
Each of these main sections can be broken down further as can be seen in the table below; this breakdown contains the components named in section 4.2.3, as well as the supporting elements, needed to make the installation function.

Rod	Frame	Electronics	Software
Structure	Structure	Power supplies	Basic movement and driving LED’s
Emotion/colour feedback	Drive motor	Motor type	Measurements
Proximity sensing	Wiring	Driving boards	Timing
			Patterns/behaviours
Power/data transfer	Power/data transfer	Power/data transfer	Processor(Board)/Language

Table 4-2: Installation parts break down/Section overview

5 Realisation

This section of the report will roughly follow the design order of the steps taken to realise the installation. All major design decisions are discussed here, as well as some of the issues and the resolutions to them. First, the Morphological design choices will be discussed afterwards the detailed design and prototyping process will be handled. These last two processes ran in parallel and will be discussed that way. All final material selections can be found in Appendix D Materials list. The end result can be seen here in Figure 5-1.

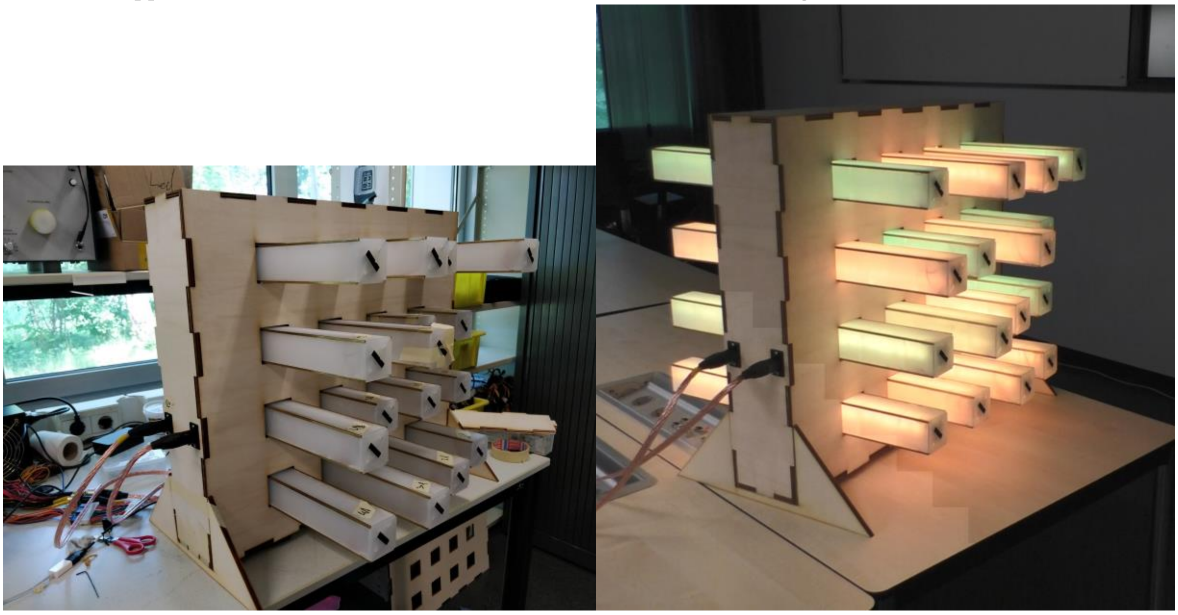

Figure 5-1: Installation in a completed state

5.1 Morphological design

Before starting on any of the actual design work the morphological design choices need to be made. That is to say, choices that have to do with the principle of the design, not the detailed design itself. This process was iterated throughout the design process of the individual parts, but for clarity, all the choices will be grouped here. Each part was treated individually (up to a certain point), with decisions starting at the rod design and working their way up through the design.

Figure 5-2 shows the hierarchical breakdown of the parts of the installation more clearly than Table 4-2 but contains the same information. The dotted lines showing the element that is present in multiple parts of (and so ignores the structure of) the hierarchy.

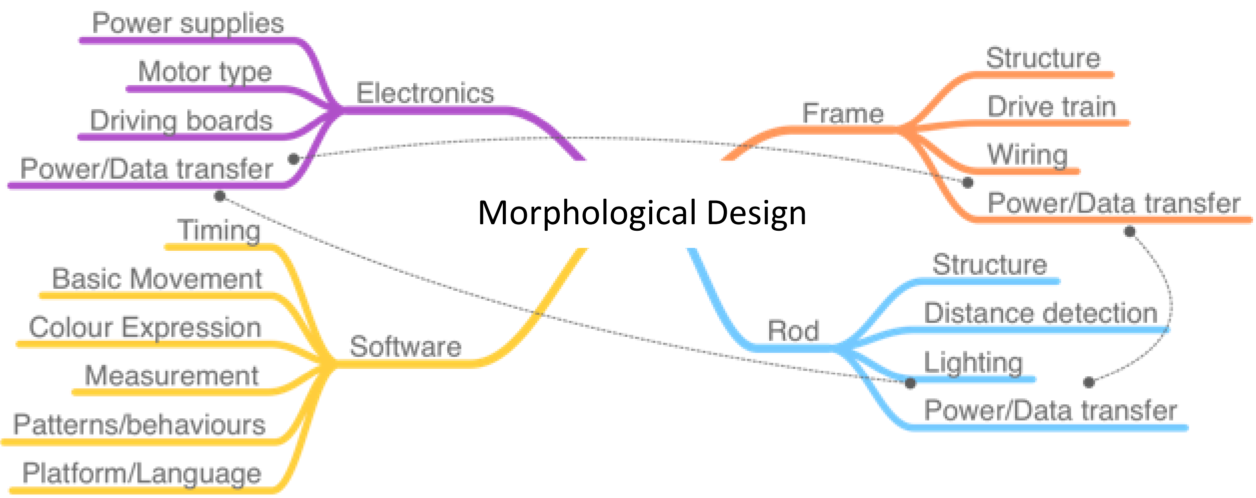

Figure 5-2: Part hierarchy breakdown

5.1.1 General geometry

The frame geometry follows merely from making contact spots on around the rod, with acrylic sliders gliding along the brass corners to create low friction guidance for the rods. Four contact points have been selected to compensate for torsion introduced by the drive wheel on the rod combined with the small gaps that will inevitably be present between the rods and the Frame. The proof of principle design is included in Figure 5-3.

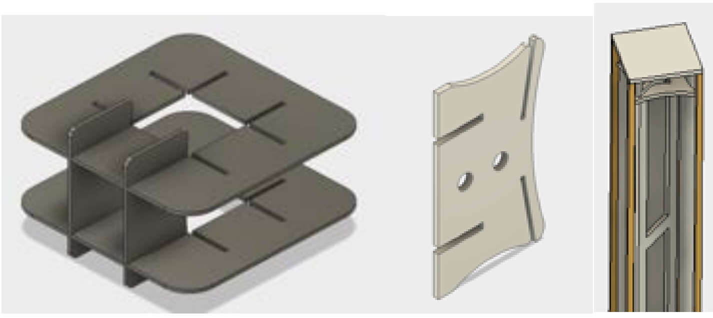

Figure 5-3: left and middle; Frame geometry test renders, right; the corresponding rod

5.1.2 Rod

The moving parts of the installation are, from the users perspective, the parts with which they are interacting. While selecting solutions for this section of the installation, an important requirement was the reproducibility of the solution since 16 parts needed to be produced and of them needed to be the same. Anything that could not be standardised or machine produced to a degree was seen as a non-viable solution due to work and required involved in the production of the parts.

5.1.2.1 Structure and assembly

Being able to use standard parts (using standard brass rods for the corners for instance) and reproducibility (being able to assemble the rods) combined with a desire for the driving mechanism to be invisible is the primary reason for making the rods square. It also allowed for a wider variety of plastic surface finishes to be considered since most plastic is made in flat sheet (or custom produced) . To keep the exterior of the rod's clean both above and well as below a sliding contact was settled on to use for both data and power transfer. Alternatives would have meant having wires going in and out of the rod which would not have maintained the minimalist aesthetics and the mess of wires would break the illusion of the rods just moving 'somehow'. This decision called for several strips of conductive material to be placed along the length of the rod, which strengthened the case for making the rods square. It also aids in the design for laser cutting which was selected due to the facility and skills being available within the CreaTe organisation. For the same reason, (square) conductive corners were used. This choice does however limit the number of connections to a rod to 4 since there are only four corners. Brass rods were selected as conductors because they are highly conductive, readily available and are straightforward to work with.

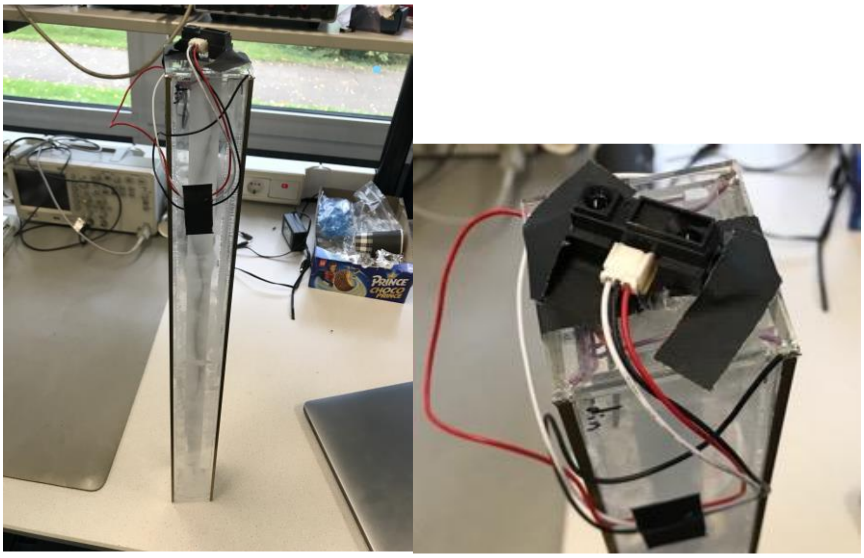

Figure 5-4: left; rod prototype with external wiring, right: zoom in on sensor placing

Figure 5-4 shows this concept as it was tested separately to test if a square rod with brass corners would slide in a frame, before a full version with electronics inside was produced. This prototype led to the conclusion that more diffuse plastic with an air gap in between was needed for the final version.

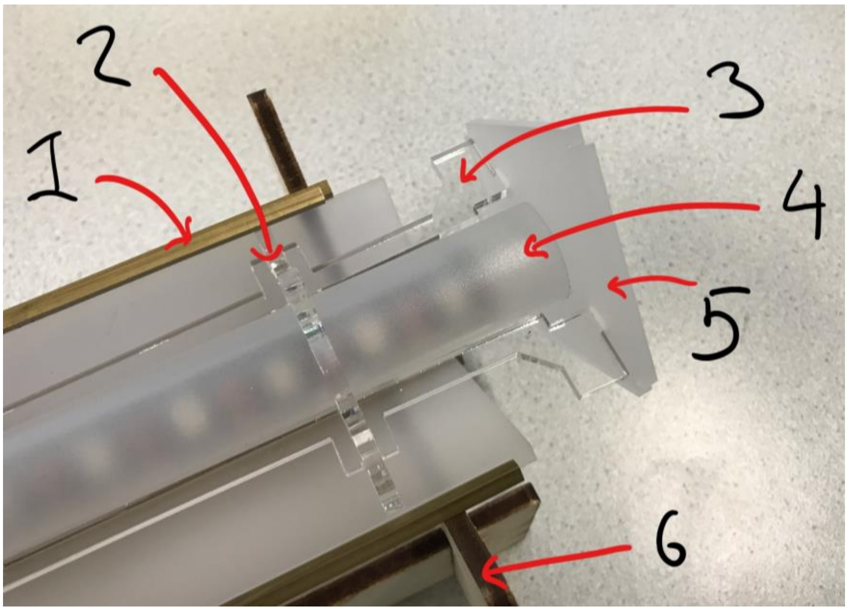

Figure 5-5: Rod frame parts. 1)brass corner, 2) frame ring, 3) frame rod-guide, 4)Inner tube, 5)outer casing, 6)assembly jig

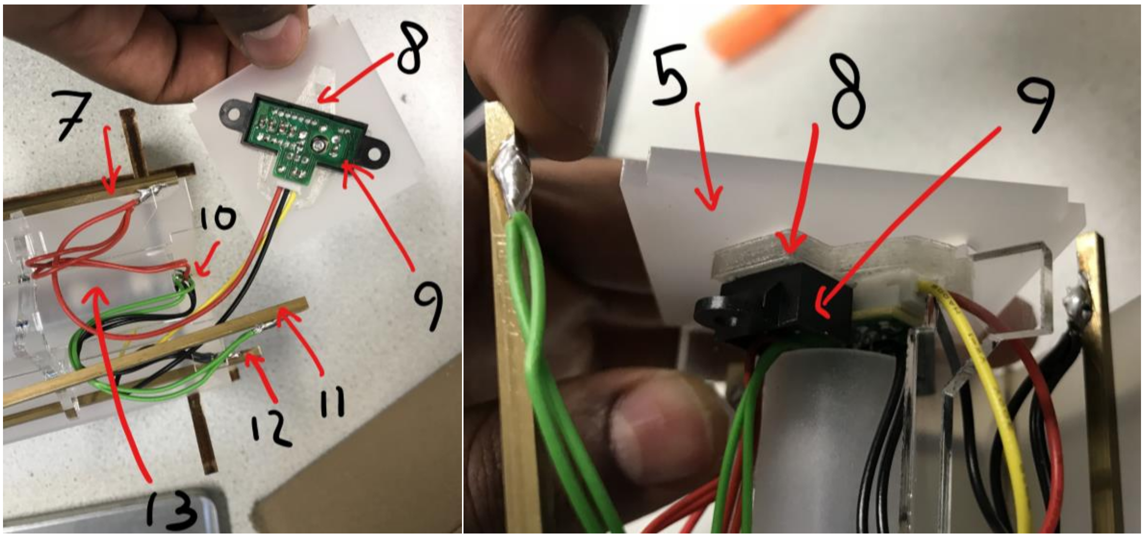

Figure 5-6: left; frame with component writing, right; components held together how they are assembled: 5)outer casing, , 7)5V(red) line, 8)sensor bracket, 9) proxemic sensor, 10)data-out(yellow) line (behind the inner tube), 11)data-in(green) line, 12) ground(black) line, 13) LED-strip inside inner tube

In Figure 5-5 and Figure 5-6 all the component in the rod as implemented can be seen. The inner tube (4 in Figure 5-6) holds the LED’s (13) and is the first stage diffuser, the tube is supported by the frame (2&3). The outer shell of the rod is made out of plastic sheets (5) and the brass corners (1). The frame is slotted together and the outer shell is glued to it.

Before the rods are glued shut the electronics are soldered together. The sensor (8) is supplied with power from the 5V and ground lines (7 & 12) and outputs data to the data-out line (10). The LED’s are also powered from the same power line and are driven from the data-in line (11). The sensor is kept under the correct position under an opening in the outer shell by the sensor bracket (8) which is clamps on to the sensor(9) and the frame (3) to fix the position, while the inner tube (4) keeps it from falling into the rod.

5.1.2.2 Proxemic Sensing

After considering the options, Sharp light-angle distance sensors were selected. Due to the rods being close together in the frame, ultrasonic and light time-of-flight sensor were eliminated as the physical signals they use to measure distance would interfere with each other. Passive light and capacitive sensors were excluded because the surroundings influence these sensors too much, which makes reading from them unreliable as they are in constant need of calibration. Finally, a Microsoft Kinect was considered, this solution was rejected due to a Kinect probably being more evident to ordinary people, thus instantly shattering the illusion of how it functions. As well as the requirement of a computer and many more complex systems. Some examples of these sensors are in Figure 5-7.

Figure 5-7: Distance sensor options, from left to right; Sharp IR, Ultrasonic, Microsoft Kinect, capacitive

The central questions for the distance sensor were how accurate can distance be determined and can they operate correctly in proximity to one another and close to de sides of other rods. To test this two sensors were wired to a testing setup and distance measure net to a sheet of plastic. The sensors do not interfere with each other or the wall because they measure the light angle which is not influenced by surroundings. This was suspected but needed to be verified, this unfortunately also made it impossible to hide the sensor behind a black

UV transparent filter, like in on the front of a television remote control, since they are not transparent enough to preserve the angle of the light. A schematic can be seen in Figure 5-8 below.

Figure 5-8: Sharp IR test setup schematic

Functional test of the measuring of a single rod in the installation resulted in good responses, however when using all rods together a lot of noise was introduced to the distance measurement signal and so in the movement of the installation resulting from it. To debug the problem the installation was debugged using the following setup.

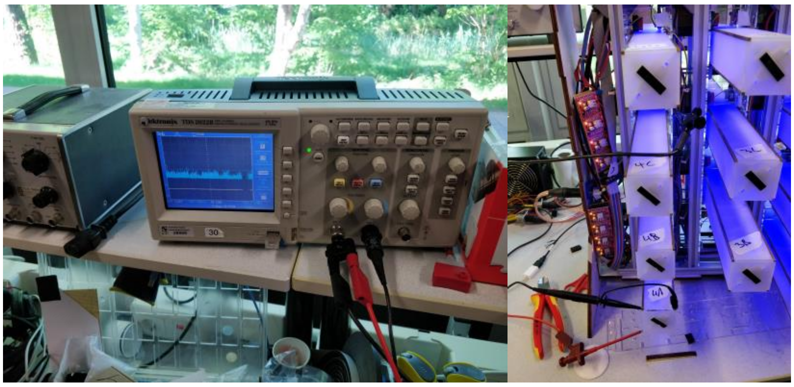

Figure 5-9:Measuring setup

The right image in **Error! Reference source not found.** shows high-frequency noise 'blocks' in the signal, the l ower bound of the of the top signal is what the measurement should be, as in the left image.

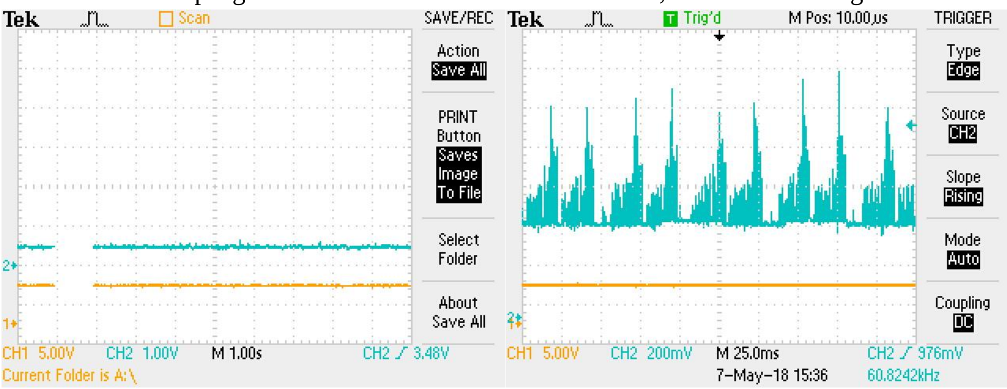

Figure 5-10: left; single rod measurement, right; full installation measurement.

The noise is timed in 25ms intervals, which corresponds with the measurement (resulting in new led values for the rods) of 4 rods at 10Hz, so it is most likely caused by the digital communication with the LED strips in the flat cables and may also be amplified by interference caused by the motors. The jittery movements may be interfering with the distance measurements even though they, in theory, happen sequentially and should not overlap with the measurement window. They are however very close together and so the noise is probably not yet dissipated when the measurements occur.

Neopixel timing is in the 1.25 microsecond (µs) range which translates to the roughly 800MHz range, so having a cut-off frequency just above the expected measuring speed will be more than enough. To suppress the noise, a low pass filter has been added as in Figure 5-11. This filter was added close to the Arduino because interference produced the noise in the signal somewhere between the distance sensor and AD converter and so to catch all the noise it should be removed close to the measurement side of the circuit.

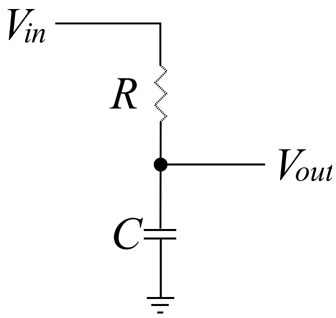

Figure 5-11: General low-pass filter

The maximum sample frequency used in the installation software is 10Hz, thus a cut off at 15Hz (so that it can be made to run faster) has been implemented. The actually measured movements should always be lower than 10Hzso in practice a cut off at 15Hz high enough by quite a margin.
Due to 10uf capacitors being easily available they were the ones selected. Using the following formula for the cut off frequency the result is a 1k Ohm resistance.

$$f_c = \frac{1}{2\pi RC} => \frac{1}{2\pi C f_c} = R$$

$$\frac{1}{2\pi \cdot 10.10^{-6}(F) \cdot 15(Hz)} = 1061(\Omega) \approx 1k\Omega \ => 15{,}9Hz$$

Equation 1: Filter calculations

The 1k resistors are actually ~1070 Ohm when measured, making f_c is about 14.9Hz, more than good enough due to the margin of selected f_c.

When hooked back up to scopes it resulted in the plots as seen in Figure 5-12. The left image shows a measurement of a stationary hand, the right while the tracking a moving hand.

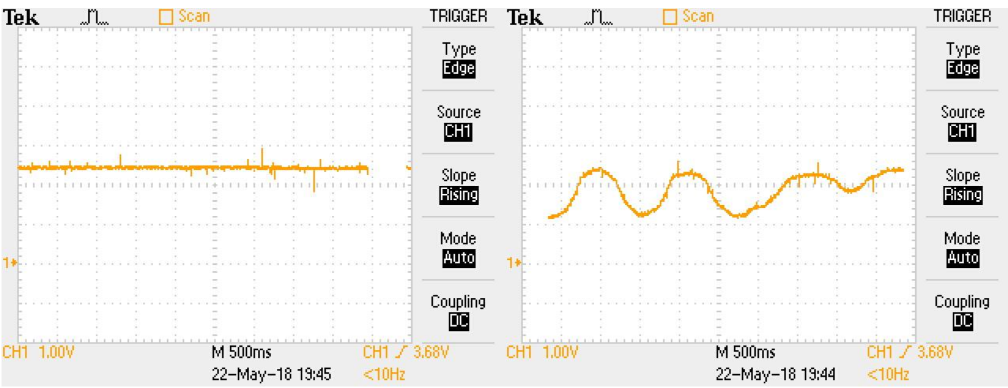

Figure 5-12: Measurement after filter installation, whole installation running. left; static distance, right; moving distance

5.1.2.3 Lighting

For lighting the rods, there are not that many solutions available. One can either use LEDs inside the rods or light project light into the rods from the frame as can be seen in Figure 5-13. Other lighting options need to much power produce to much heat and are too vulnerable. A beamer mounted above might have worked but would not have given a strong illusory result due to projection being visible. The LED's have also been installed in a satin coated tube which together with the semi-transparent white sides of the rods help hide the individual LED's inside the rods. The LEDstip in the rod was selected because they can be digitally controlled, the advantages being that they only need one data line to operate them. This single data line is a requirement since there are only four lines available into the rod. One is required to take the measurement data of out of the rod, and two more are needed for 5V and the ground only leaving only one available for the LEDs. The distance sensor also requires a constant 5V to provide an accurate measurement so in this case changing led colour or intensity by changing voltages is not an option.

Figure 5-13: Lighting options considered

To test Light diffusion various transparent and semi-transparent plastics were placed over a LEDstrip and various light intensities shone through them. After several layers and combinations of plastic, it was found that having semi-transparent (satin finish as it is called in the plastic world) layers with an air gap in between made the light appears the most diffuse. In the design, this was achieved by having a centre tube in the rod suspending the LED in the middle as in Figure 5-5. This was already envisioned, the only real design change here is that the centre tube would now also be semi-transparent.

5.1.3 Frame

The frame holds the rods in place and contains all the other elements of the installation. The individual elements of the frame also need to be reproducible and designed to be produced on a laser cutter.

5.1.3.1 Structure

For the frame it was decided to use laser cutting as a primary method of construction, as this is the prevalent technology within the study of CreaTe. However, upon testing, the plastics used (3 in Figure 5-14 and Figure 5-15 were found not be strong enough to hold the rods in place. To solve this aluminium extrusion profiles (1) were added, to make the structure of the frame more rigid.

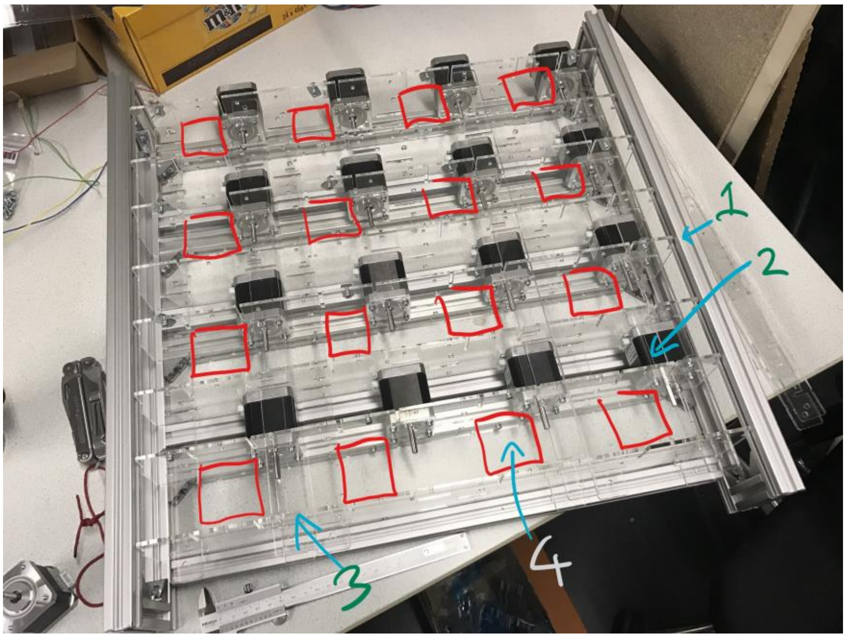

Figure 5-14: Bare frame with motors installed. 1) aluminium frame, 2)motors, 3) plastic frame, 4) red squares indicating rod placement opening

The drive motors (2) are connected to the frame with bolts. The drive wheel (6) is bolted directly to the shaft of the motor and the guide wheel (5) is across from it to push the rod on to it. Power lines (7 & 8) and data lines (10) connect to the rod using sliding contact (9).

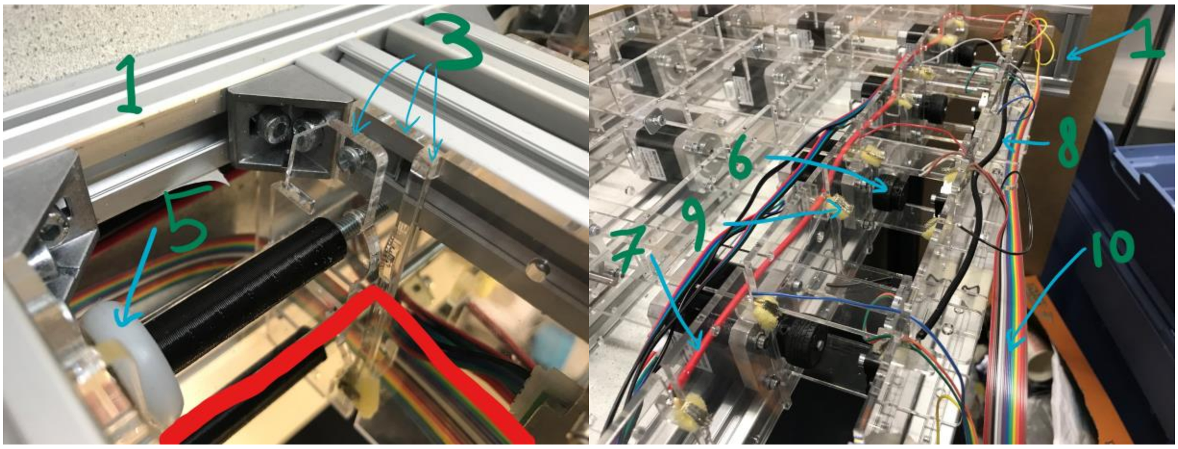

Figure 5-15: Frame closeups showing parts. 1) aluminium frame, 3) plastic frame parts, 5) rod guide wheel, 6) drive wheel, 7) 5V wire, 8) ground wire, 9) sliding contact, 10) data flat cable.

5.1.3.2 Drivetrain

Due to FR4, the mechanical function being non-obvious, all the usual drive options were excluded. The installation is viewable on all sides so using pistons below, or drive-racks on the side of the rods won't work. This leaves driving the rods from the outsides of the rods, concealed inside of the frame, which is done with a tire on a wheel directly driving the rods through the frame by rolling over the rods surface, creating a rack and pinion like mechanism

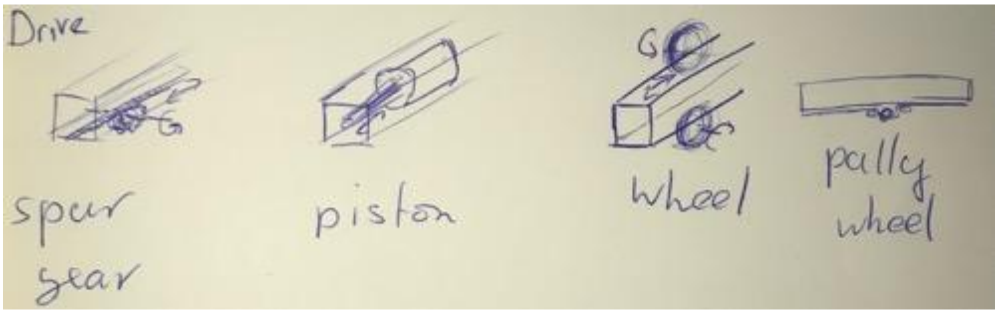

Figure 5-16: Drivetrain option sketches

5.1.3.3 Drive motor

For movement, stepper motors have been selected. AC or DC motors would have been more expensive and harder to control because they need encoders to know their position as well as expensive gearing to increase torque output. Combined with the decision to make the drivetrain direct drive this left stepper motors as the best choice

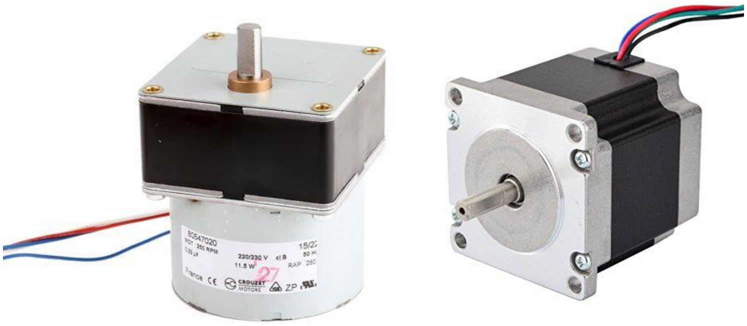

Figure 5-17: Motors; left; ac geared motor, right; stepper motor

5.1.3.4 Power wiring

For power wiring, not many alternatives have been explored. It was decided that power wiring should be as thick as possible and readily available, which are 4mm^2 for the motors and 1,5mm^2. Though the power (watt) is not extremely high, though they are not trivial at 19,2A (see Equation 2)and it is important that the voltage does not drop to ensure reliable measurements from the analogue proxemic sensor.

$$5[V] * 20\ [mA] * 60\ [led/rod] * 16\ [rods] = 19{,}6[A]$$

Equation 2: LED power draw

The motors can draw up to 2A per motor, so the theoretical max for them is 36A (see Equation 3) This is also not very high but does require amply thick wires.

$$12[V] * 2[A] * 16[rods] = 432[W]$$

Equation 3: Motor power draw

For data cables, after some testing with wiring, it was decided to use flat-cables instead of trying to construct a wiring loom for ease of conduction and wiring, Figure 5-15 show these wires in the frame. And section 5.1.4.3 shows the specific diagrams for the wiring.

5.1.4 Electronics

Most of the solutions selected here follow as a result of all the parts selected above. The main limitation being which parts were readily available, since having to resort to special parts would both have been expensive and conflicted with the demand for standardisation and replaceability within the installation.

5.1.4.1 Power supplies

Because the installation uses stepping motors and LEDs, it requires 12V (motors) and 5V (LED’s and other electronics) power sources. It was found that a standard (large) computer power supply could supply both of these voltages at a sufficient current (A). This made this solution both cheap and easily replaceable if necessary. Some quick maths (in section 5.1.3.4) showed that using thick audio cables available at a local electronics shop would suffice for the power transfer between supply and installation.

5.1.4.2 Motor powering/Driver boards

The one downside of using stepper motors is that they need to be precisely controlled with exact timing. Since doing this on one processor would simply be too resource intensive, separate driver boards are used for each stepper motor. Several different versions and makes have been tried in the testing phase, and the most capable version was selected. Unfortunately, these were expensive parts, the reliability and silence, however, made them worth the price. The selected parts can be seen in Figure 5-18.

The Adafruit "Big Easy Driver" was selected to be the driver for the stepper motors because they were the quietest driver when not implementing micro-stepping, which would slow down the installation by requiring more steps for any given movement, the considered alternative are shown below. Some drivers use fancy silent current curves which make motors very quiet but also remove most of the torque available to the motor (which would stop the installation from moving at all.)

Figure 5-18: Stepper driver options from left to right; Polulo, Stickstep, Trinamic, Adafruit Big Easy driver

5.1.4.3 Power/data transfer

For aesthetic reasons to do with maintaining the illusion of how the installation functions, the rods are entirely closed off from the outside, this makes them pleasing to the eye but also makes it hard to get power and data in and out of them since wires coming out of them would show users how the installation works. To overcome this in the design stage, it was decided to add conductive strips on the outside rods, as can be seen in section 5.1.2.1 with sliding contacts in the frame used to transfer power in.

This solution was tested separately before the build began to verify the idea. The concept was copied from toy race cars and trains. Since this works well at speed for power and for the low amount of data that gets transferred along with it, it was feasible that it might work for the high data transfer used for the LED strips. This was tested by simply connecting a LED strip to a brass corner rod and moving a contact slipper along it while changing colours, as long as some contact is maintained this works reasonably well. The various available contact shoes were tested. The options can be seen in Figure 5-19. Considering size and function the simple wire braid version was found to function best.

Figure 5-19: Contact shoe options: right; braided wire, middle; metal with spring, left; large suspended metal

Once the transfer method was selected the wiring plan was made, Figure 5-20 shows the diagram to connect one rod to the Arduino. For legibility the long data cables and the shield containing them, between the Arduino and the other connection, have been left our of this image. The shield is placed on top of the Arduino so the connections can be soldered to it instead of the Arduino.

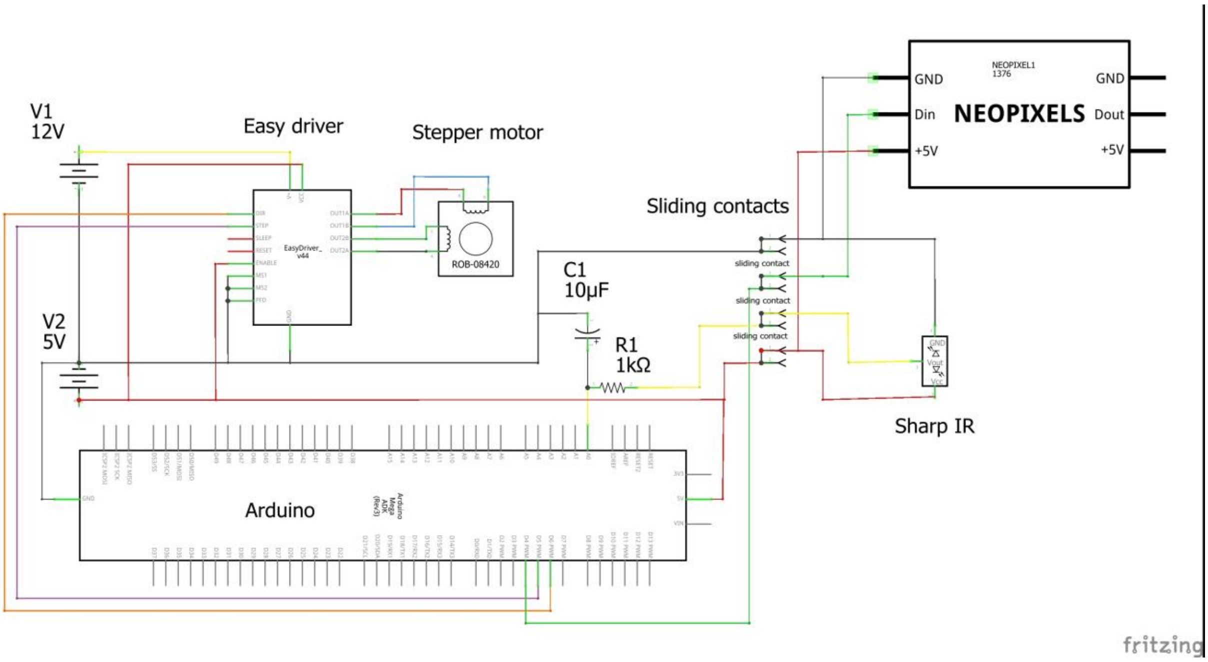

Figure 5-20: Single rod wiring plan

The complete wiring table of all parts can be found in the digital archive. The implantation overview can be seen in Figure 5-21.

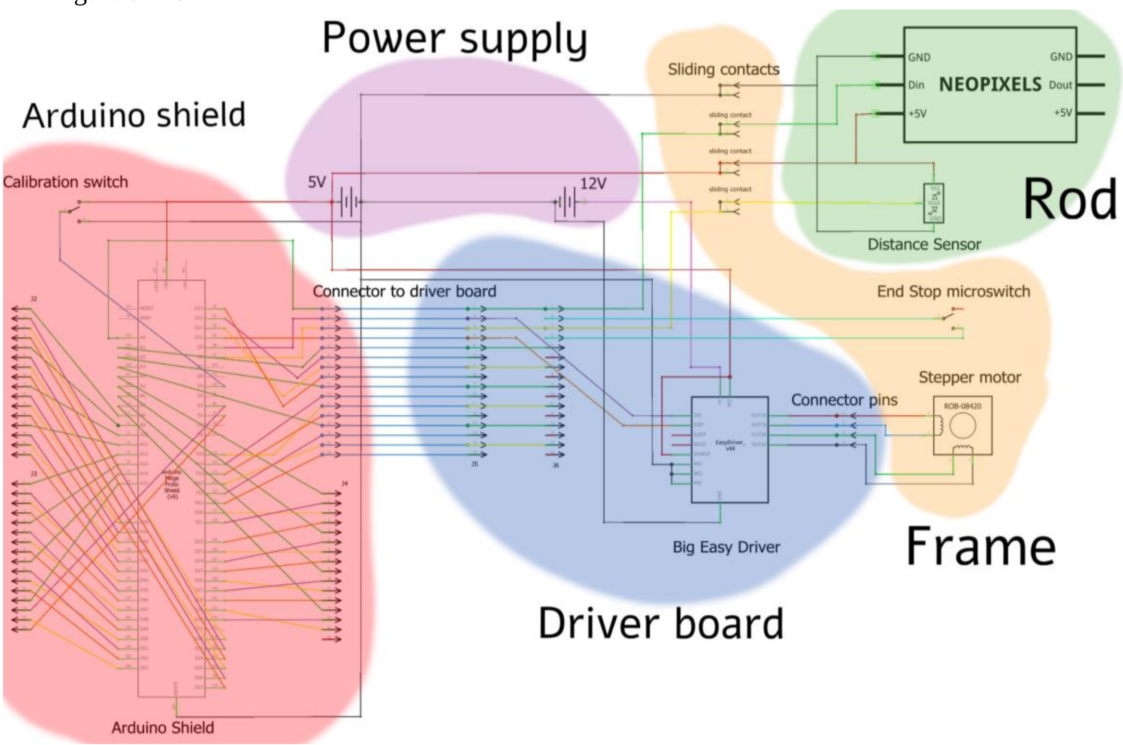

Figure 5-21: Wiring scheme of 1 rod, with thier location in the installation

The actual implementation can be seen in Figure 5-22.

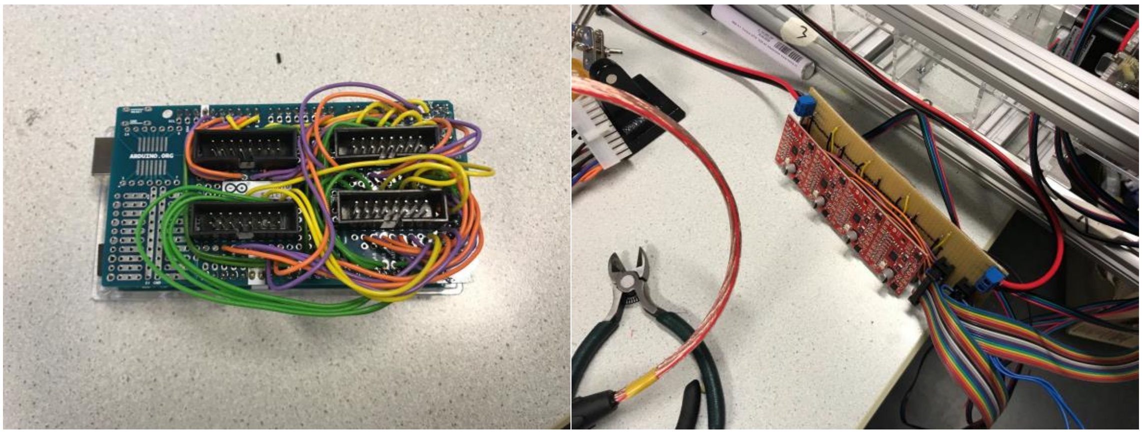

Figure 5-22: Left; Arduino shield implementation. Right; Driver board implementation

5.1.5 Control hardware/Software

The selection was primarily influenced by previous experience and preference of the researcher. For this reason, an Arduino based approach was selected above a full computer or Raspberry Pi based one.

5.1.5.1 Processor

This installation requires a lot of inputs and outputs, 16 analogue in and 54 digital out, and a fair bit of computation which limited the choices to an Arduino Mega or above. Unfortunately, it was discovered too late that the more powerful Arduino Due operates at 3.3 Volts making it incompatible with the analogue distance sensor without adding more electronics to the selected LED strips in the rods,
This made the Arduino Mega the only choice. Arduino's were the best choice since other processor boards tend to have fewer ports, and in tests it proved just capable of running the installation.
Unfortunately, the solution to hardware limitations would be to slow down the installation. During testing a measuring frequency of 10Hz was found to be stable. Because of the way the 'analogue read' function and hardware works it is physically quite slow, this is the main limiting factor regarding the speed of the installation.

5.1.5.2 Rod control

From a software point of view the most crucial part of this installation is multitasking, all 16 rods need to move independently of each other, at different speeds and patterns.
To implement these requirements, it was decided to make everything time based, using relative priority, the remaining time and whether a task has just been done to decide which task to do next.

Because the step motors move with discreet intervals, the speed is determined how often they take a step. This makes the timing of the steps the most crucial part of the installation since movement is the most crucial feature. Therefore before anything else is done in this software should check w this time to move one of the motors. After that user input, which is measured by the distance sensor, is the most important as it is used to determine which movement should occur next. After that movement and the measured distance can be used to calculate the state or colour of the installation expressed by the rods, and finally outputting the colour to the rods.
These four basic tasks combine to make up the base functionality of the installation can be seen in Figure 5-23.

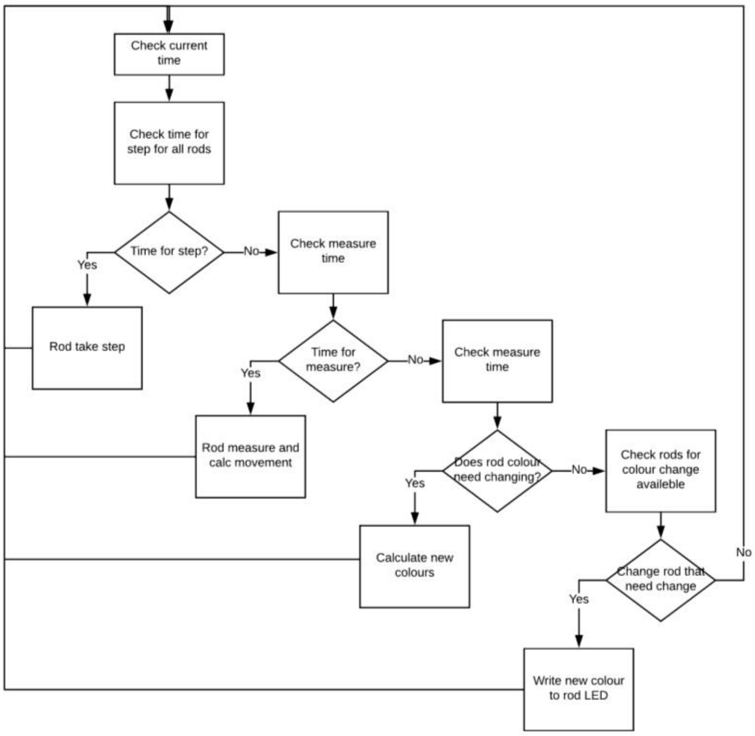

Figure 5-23: Software flow-chart

5.1.5.3 Patterns/behaviour

Though independent movement of all rods in necessary, it is also important that they combine or synchronise to make patterns. After consulting an experienced programmer, it was decided to make this into a separate primary task as opposed to combining it in with the individual tasks that control the rods. In this way the coordination of all patterns is centralised and the program runs faster. However the combined behaviour was not completed, it was however the reason for the current

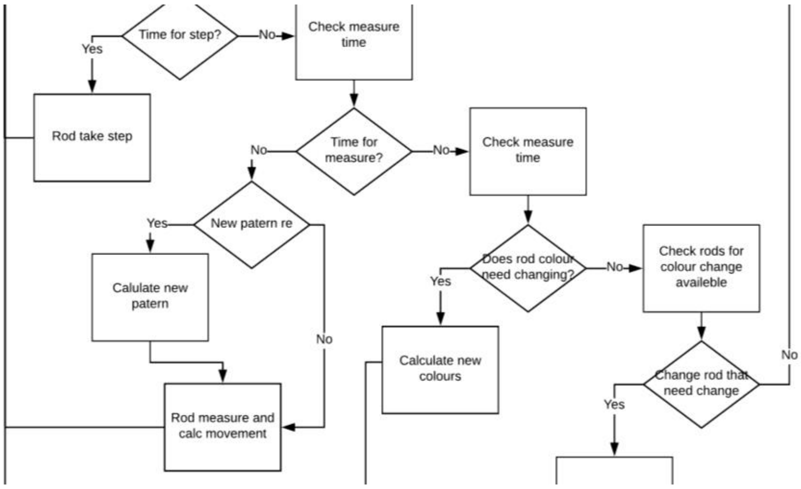

Figure 5-24: Software flow-chart plus pattern behaviour places in Figure 5-23.

5.2 Detailed Design stage

After the morphological choices, detailed designs needed to be made, mostly in CAD. Just as an iterative prototyping design process was used in this project design, the CAD drawings, though precise and production ready, were revised continuously during development. Below we describe the designs of both the tests and final prototypes.

5.2.1 CAD

To produce a product of this complexity it needs to be designed in a 3D CAD program. CreaTe as a study does not have its own recommended CAD software solution. The University does have licenses for Solidworks, it is a resource intensive program that only runs on Windows. The researcher has a Mac computer, and though it is possible to use Windows software with some workarounds it was decided to use the Autodesk alternative which is native on both; Fusion360 a still of which can be seen in Figure 5-25. It is also free software for non-professional use, which also aligns better with the values of CreaTe to share and/or open-source work where possible.
Some results of the CAD software and some models can be seen. Each design version went through several minor revision tweaks and was updated after the realisation to incorporate all the small alterations made during assembly.

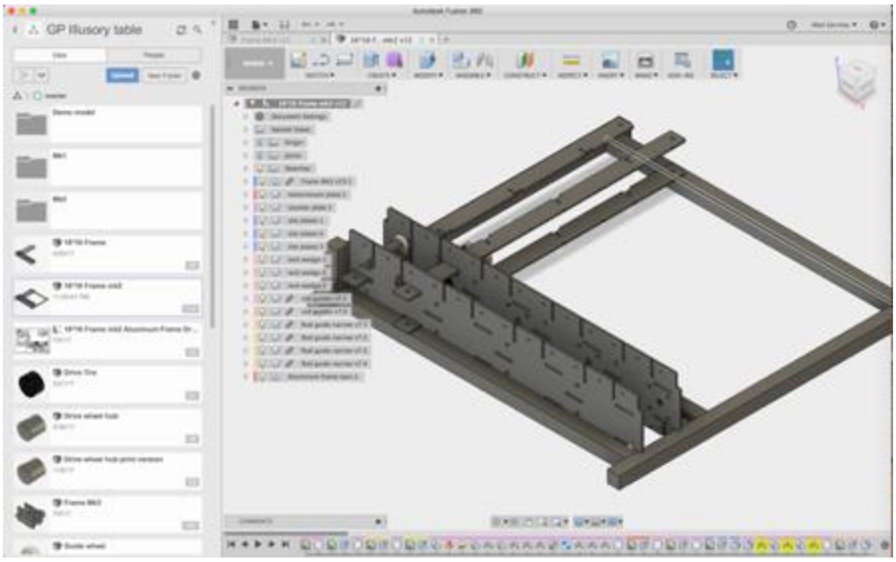

Figure 5-25: Screenshot of the Fusion360 interface

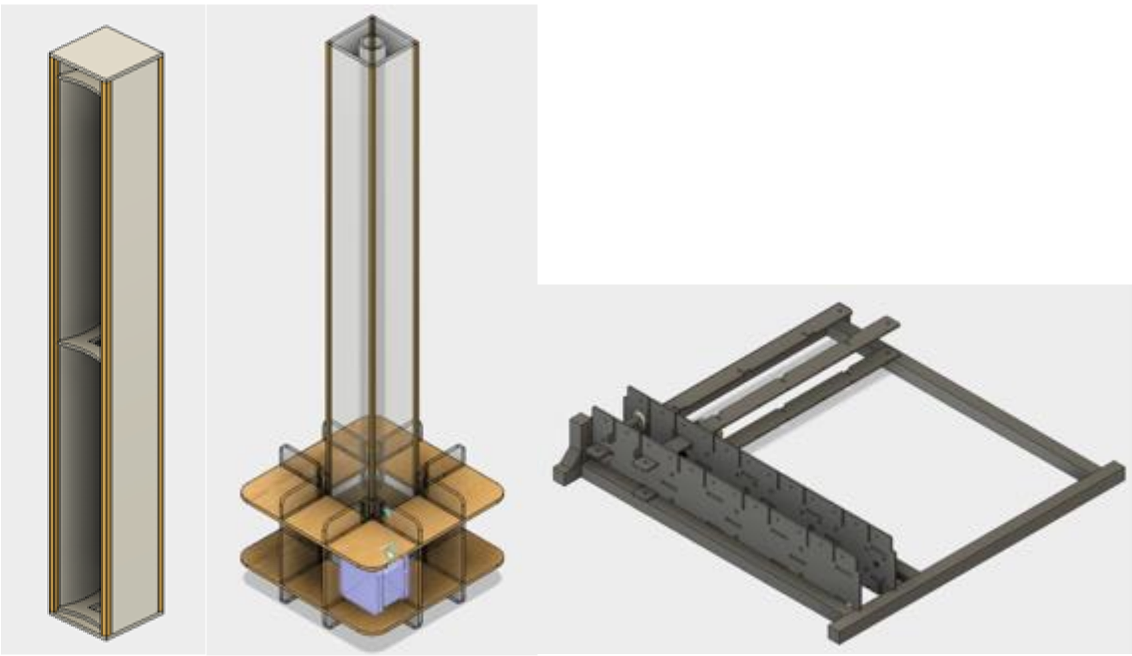

Figure 5-26: Various stages of design. Left; mk1 test rod. Middle; frame test 1. Right; the frame design as implemented.

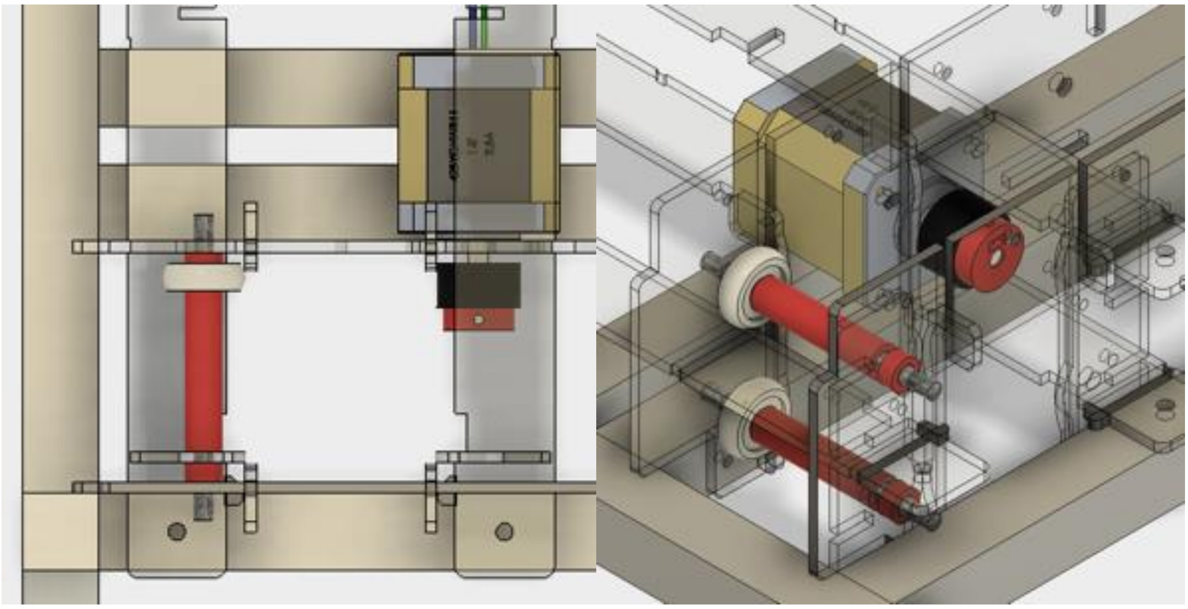

Figure 5-27: left; Top view of the frame, right;3d view

In Figure 5-27up a single instance of the frame can be seen. Black wheel is the drive tire, and the white wheels are the guides on the other side. The grey bars are the extrusion profile (very basically modelled) supporting the transparent laser cut plastic parts. All the red parts, the tyre hub on the right and the spacers on the left, are 3D printed. Figure 5-27

The full models can be found in the digital Appendix F.

5.2.2 Software tooling

Because this project is more complicated than the average Arduino project, all the coding was done in the Sublime Text and Atom. This IDE has more autocomplete and reference functionality than the original Arduino IDE.
For the LED strip and the distance sensor, there are good libraries available, so these were used. To deal with the fact that there are 16 rods a class-based solution was selected, where each rod is an instance of the class rod with each containing a sensor a led strip and a motor drive protocol. All of which are called, managed and timed from the main program containing a rod controller. Due to the speed requirements of this installation, it was decided to write a rod controller program from scratch since the available open source libraries proved not to be fast enough on an Arduino Mega.

The software structure based on the functional architecture diagram's in section 4.2 can be seen in Figure 5-28.

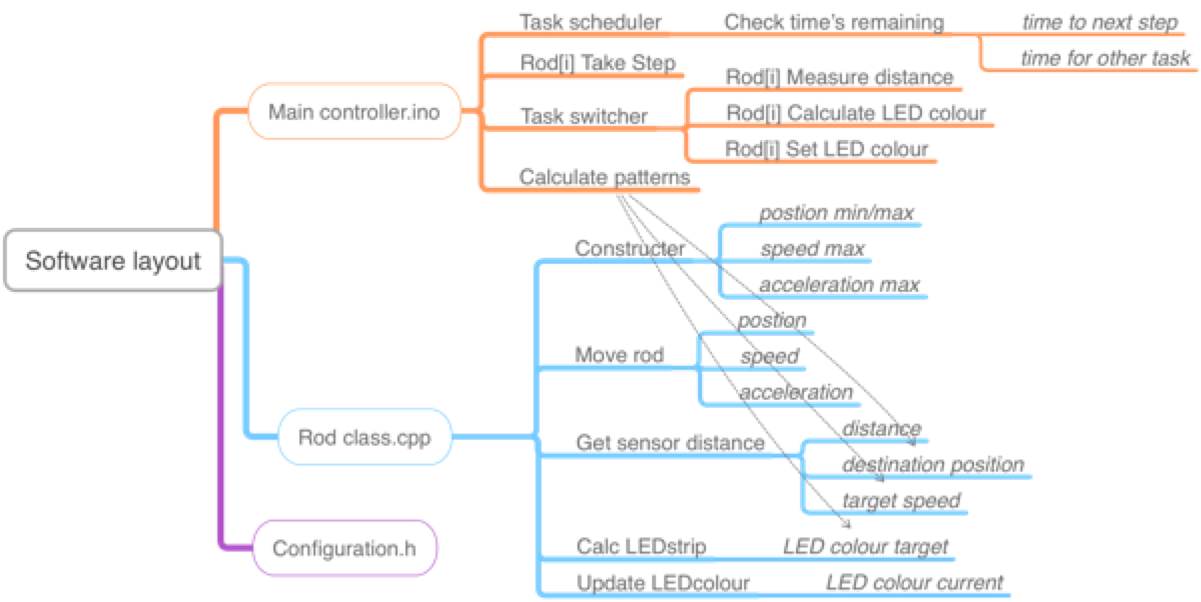

Figure 5-28: Software Structure

6 Evaluation

Chapters 4 Specification and Design and 5 Realisation aimed to answer RQ2 'What are the requirements for SoC module that incorporates illusory feedback?' and RQ3 'How to design a SoC module that incorporates illusory feedback?'. This chapter aims to evaluate how well the answers to these RQ's work, first by evaluation the functional requirement and then the user experience of illusory feedback.

6.1 User interaction evaluation

The Realisation phase describes an answer to the third part of the research question and document the solution built. This section deals with the user interaction evaluation of the design, centring on the 3rd part of the research question; How to design a SoC module that incorporates illusory feedback?

The specific goal of the user interaction evaluation centres on whether the installation effectively uses illusory feedback to convey a sense of emotional presence, as set out in paragraph 2.6 section 1)b in the user interacting with it. This question leads to a desire to evaluate whether the installation comes across as illusory and emotional, with the requirements as guidelines. To verify whether the goal is reached, a user test has been executed to evaluate the extent to which movement improves this illusory feedback experience and emotional presence and to test how the participants interpret the emotional framework . The design of this evaluation corresponds to the findings in the State of the Art review in chapter 2 of this report.

6.1.1 Test design

The installation as realised during the realisation stage that can move gently and change colour but only has basic movements, and responses available. The installation can display four main behaviours;

1) When there is no movement in the vicinity, the rods will move slowly back and forth and the colour is orange.
2) When high-speed movement is detected close the rods, they will retreat and turn dark green
3) When slow movement is detected the rods will slowly approach and follow the user while turning from orange to yellow to green.
4) When a user moves slowly, the installation will follow their movements, while remaining bright green.

The movement in all cases is linear and proportional and does not include acceleration or smoothing. These four simple behaviours can be expanded upon at a later date.

Due to the qualitative nature of the research and practical constraints, it has been decided to test within the one user group and to ask for their opinions on the states of the installation relative to one another.

To be able to rule out the influence of the physical design of the installation and the lighting used to make it more visually appealing the evaluation will be split into sections in which both factors will first be examined individually. After these two 'baseline' interactions, the user interacted with the installation whilst it moved.

This setup gives the interaction evaluation of three parts:

- First, the user will examine the installation to get a feel for its presence.
- Second, the user will interact with the stationary installation while it only responds to user proximity with colour changes.
- Last they interact with the installation in full operation, while it moves and responds the user proximity

Ten users have partaken in the evaluation test which was considered to be enough to start with within the scope of this research. However, during the interaction, some clear points of interest presented themselves which could also be seen in the questionnaires.

Participants were observed during their interaction and be asked to fill in a questionnaire at the end, this was expected to take them approximately 10 minutes.

Interesting observations during the tests would be noted and supplementary questions resulting from them might be asked after completion of the questionnaire.

Figure 6-1 depicts a map and a photo of the test setup used. During the first and second part of the test, the researcher was present in position 1 to answer questions and guide the participants if they got stuck. For the third part, the researcher was in position 2, behind a one-way window, allowing the participant to interact without being disturbed. For this reason, the experiments were executed in Zilverling A-124.

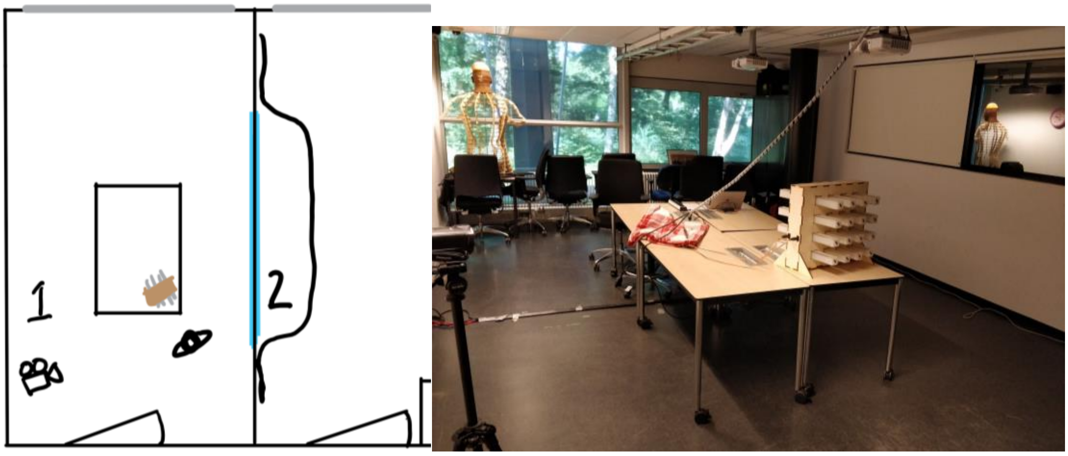

Figure 6-1: Left; Map of the testing setup. Right; Image of the actual setup

6.1.2 Test protocol

The tests of the installation were all executed in one day in Zilverling A-124 using the following protocol:

1. Ask user:
2. Will you help in my experiment for 20 minutes max? There is and OmNomCom cookie in it for you
3. Hello, welcome,
   I am conducting an experiment with interaction between this installation and users nearby.
4. Before we start, of course, I have a consent form I would like you to sign and know that you can quit the experiment at any time if it makes you feel uncomfortable.
5. Your results will be used anonymously in the analysis, and the videos will be deleted within six weeks after the completion of the project.
6. Minimal welcome talk:
   'The experiment is going to have three parts during the first two of which I will observe here and might take a few notes. For the third, I will not be in the room and will observe from outside. After these three parts, there will be a questionnaire that will take a maximum of 10 minutes, possibly followed by a few questions based on observations made during the interaction. I would like to film the second and third part.
7. During the first part I just want you to look at the installation and take a general impression of it.
8. For the second and third part, I would like you to approach and interact with the installation in any way you see fit. If you get stuck, you can ask me a question.
9. The explanation supplied with the consent form basically says what I have just said.'
10. Take participant to the installation.
11. Interaction 1, observe only, researcher present (position 1 in Figure 6-1)
12. Interaction 2, colour, researcher present
13. Interaction 3, movement and colour, researcher in the observatory (position 2 in Figure 6-1)
14. Questionnaire on computer
15. 'Thank you' and Cookie/Omnomcom

6.1.3 Questionnaire Design

The entire questionnaire can be found in Appendix E.
To avoid neutral answers due to lack of engagement many of the scales have been made to have six answers to force people to select a slightly positive or negative answer.

The general setup on the questionnaire is as follows;
Page 1; basic information, about participant
    To verify answers later
Page 2; relative observations, comparing the 3 phases
    To establish a baseline and relative strength of observed emotions in installation during movement versus stationary
Page 3; emotional association
    To evaluate which emotions of the installation the user believes to have observed and when.
Page 4; emotional strength
    To evaluate the intensity (and again presence) of emotions of the installation observed by the user
Page 5; perception of installation
    To evaluate the illusive presence of the installation
Page 6; open observations, feedback
    To leave people a place to comment so as to avoid having questionnaire related feedback in the results. As well as a place to articulate things not fitting with other questions
Page 7; thank you, cookie time!
    People should always be rewarded as well as served sandwiches of fun. (the assumption being that the test was fun and the cookie is also positive)

This approach was selected because there is interest in how the emotional framework is perceived and also how participants perceive the installation in general.

6.2 Results

This section is broken down into a questionnaire and an observation section. The first just provides a summary with the results from the questionnaire, the latter has observations on unexpected user interaction and puts some of the questionnaire results into perspective using these observations.

6.2.1 Questionnaire results

The full results of the questionnaire can be found in Appendix E. Some remarkable highlights and summaries will be covered here.

Some general impressions people got about the installation were queried about the three stages of the experiment. One of the goals was to use illusory feedback in the form of movement and coloured light to give the installation more presence than that of a mere object.

The 'Presence in general', 'Emotional presence' and to a degree the 'Interesting' metric in the figures below show that adding movement to the installation increases these aspects and so increase the illusory feedback provided by the installation. Green and purple, the two right most bars, are stronger presence values, and so indicate improvement in the figures below.

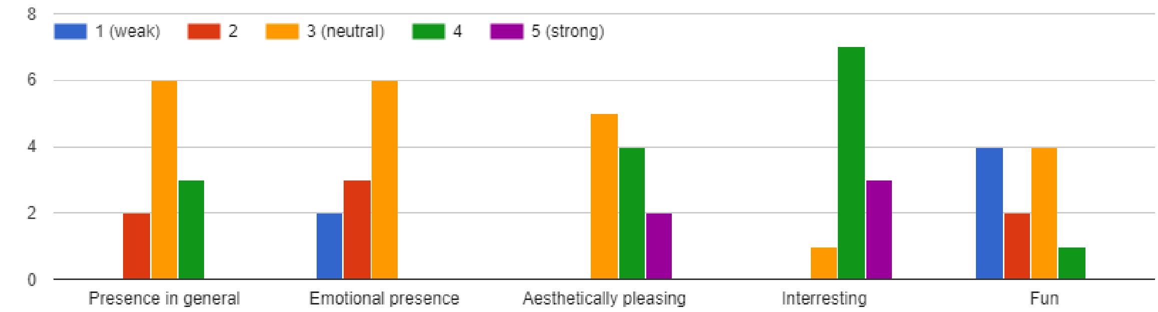

Figure 6-2: Presence of general features while installation is off

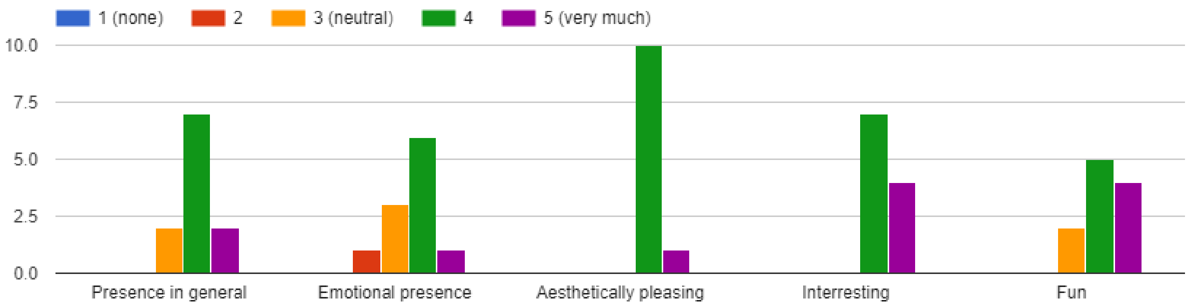

Figure 6-3: Presence of general features while installation is only using light

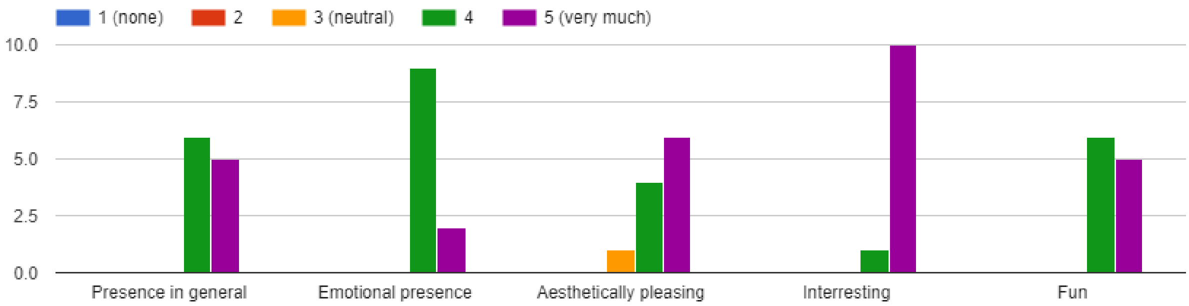

Figure 6-4: Presence of general features while installation is using movement and light

Using a decoloured emotional wheel of Pluchick participants were asked which emotion they associated with a particular behaviour of the installation. The following plots in Figure 6-5 show the difference in perceived emotions between stationary (grey in figures below) and moving (red) interaction per state of the installation, the headed per image states the colour state and the desired the emotion being displayed. The images below show that adding movement, for most behaviours, strengthens or emphasises the perceived emotions of the installation.

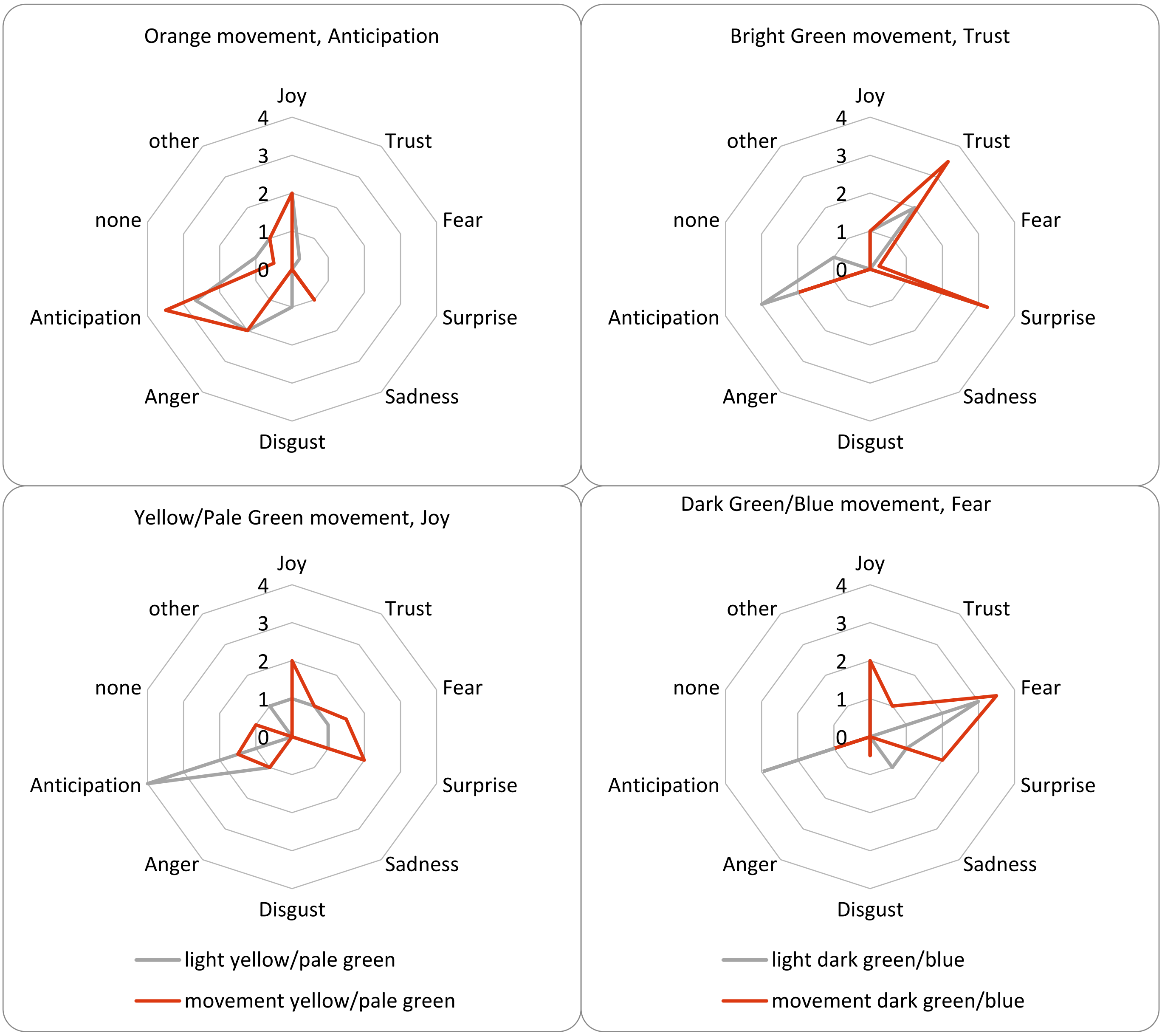

Figure 6-5: Emotions displayed by installation, grey for stationary, red for movement.
Top Left; while orange, Top Right; while yellow/pale green, Bottom Left; while bright green, Bottom Right; while dark blue

All the emotion seems to have 2 or 3 dominant interpretations, with a spike in the designed/desired emotion or a related emotion. However, with the small sample size results are not very conclusive. The pattern does, however, match the observation later on that people did not very strongly feel the emotional presence as emotions, maybe more as guidelines if even noticed during the interaction.

Users were also asked to indicate how strongly they felt specific emotions were displayed at all during the 3rd/movement phase of the experiment. This question pertained to the entire interaction. The blue segment indicated neutral.

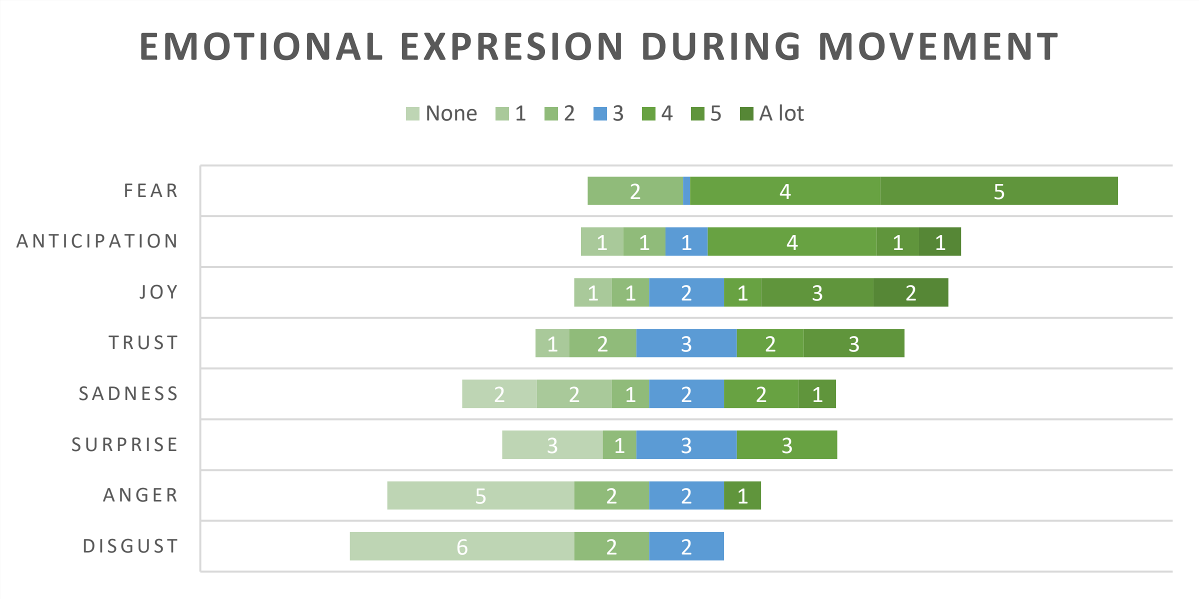

Figure 6-6: Emotional presence during interaction with movement, the numbers correspond to the response count, blue is neutral

What can be seen above is that fear, anticipation and joy were strongly displayed, trust and sadness were perceived to be about neutral and surprise, anger and disgust are not well represented. This spread roughly corresponds to the intended behaviours programmed into the installation defined FR-13.

Finally, the goal was to make an installation that was intriguing to the user and would provoke a user's interest. Figure 6-7 shows that most users found the installation exciting and fun enough to want to interact with it if they were to encounter it in a public space and had time.

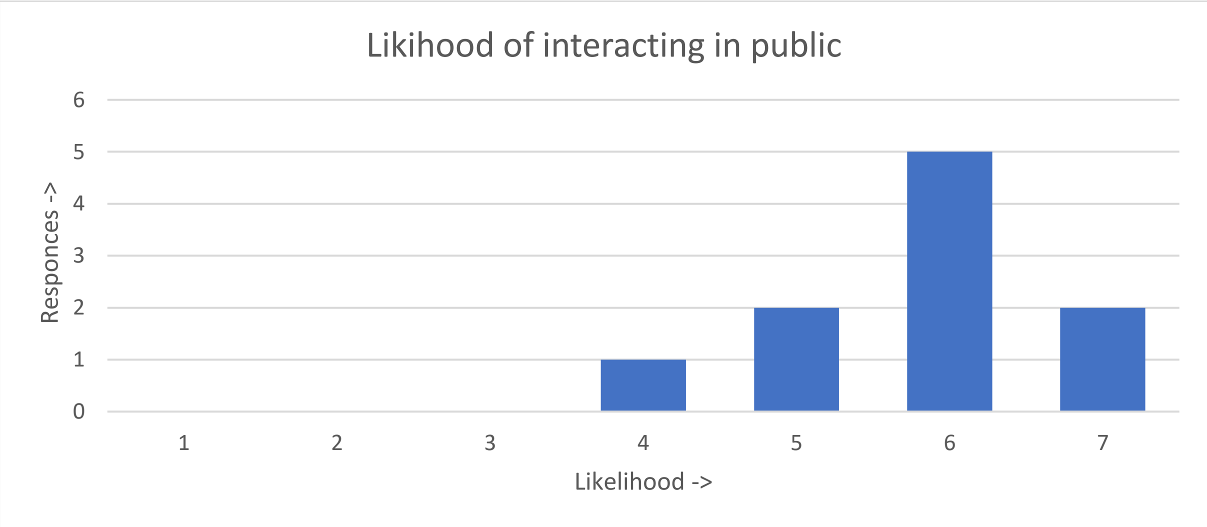

Figure 6-7: Likelihood of users wanting to interact with installation if encountered in a public space

Though this figure shows interest, it should be considered that users were framed to be positive in their response here because they just interacted with the installation already and were now aware of how and why to interact.

6.2.2 Other user observation

During the user interaction with the installation, the researcher filmed them and took notes. These observations showed that most users tried particular interactions, some of which the installation was able to deal with and some of which the installation should have responded to but did not, or not in a way the user expected.
Users also interacted in ways which were not expected or designed for during the realisation phase. One of these unexpected behaviours was that the instant change of the installation to dark blue, which was supposed to be fear, became one of the things users played with during their interaction. When asked afterwards most users reported seeing that the installation was trying to take more distance. But most participants at some point had a 'goal' of turning the entire installation blue by moving quickly past all the rods in an attempt to get the whole installation to turn blue, just for the fun or satisfaction of have the installation be one colour. An attempt at this can be seen in Figure 6-8.

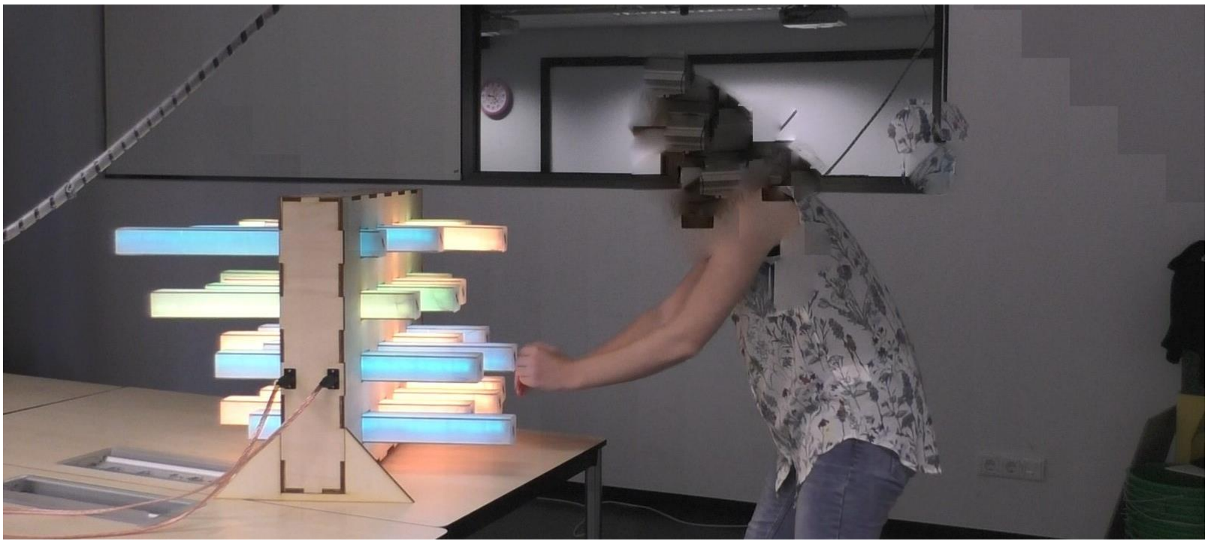

Figure 6-8: User turning installation blue

This interaction of trying to 'scare' the installation seems to imply that the user did not see the installation as a higher level entity or else they might have hesitated more about distressing it, this can be seen in the questionnaire in the question about what the participants thought of the level of emotional presence of the installation.
As can be seen in Figure 6-9 where 1 was labelled 'no like an object' and 6 was labelled 'yes, like an entity (such as a person or animal)' the answers were rather scattered with a skew to the negative as it is a 6 point scale.

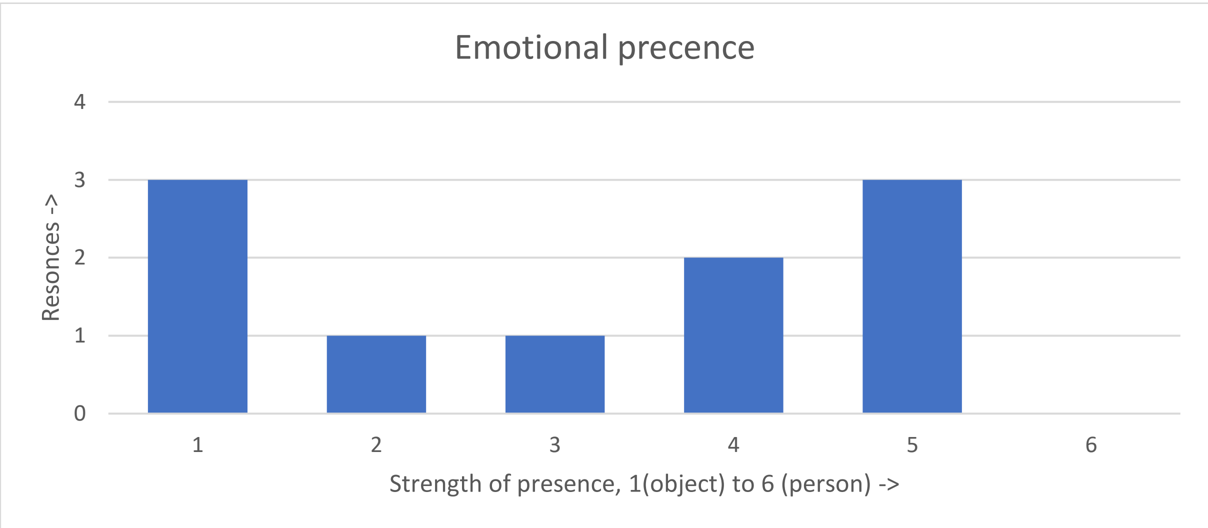

Figure 6-9: Emotional presence of the installation

The speed at which the installation responded to the users was high enough to convey difference however if it was faster it might have conveyed a stronger ‘sense of fear.’
When asked however, the participants mostly answered that they did think the installation had the potential to display emotions. 8 out of 10 respondents said ‘yes’ and two said ‘maybe’ (and one did not know). This seems to imply that with a slightly different technical implementation of this concept the goals should be more strongly achievable.

Almost all of the users tried interacting with the installation at very close range. The installation registers all interaction that is closer than 9cm as 9cm, so speed or relative approaches are not registered and so not responded to at all. Many tried to invoke a fear response by quickly moving at this range. They also seemed to expect that the installation would come, or allows users to come, much closer than it did. The observed interactions suggest that users were expecting the green trust behaviour at the 2 to 3cm range (as seen in Figure 6-10) instead of the implemented 9cm. As well as stronger or more response if they came within this range.

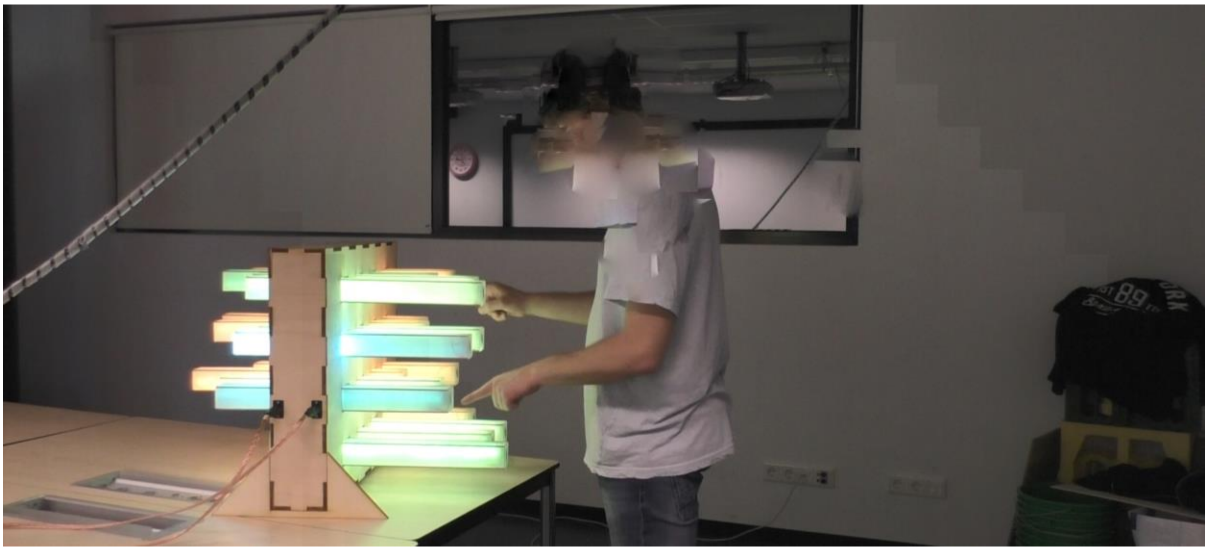

Figure 6-10: User interacting at very close (~3cm) range

Many of the participants looked at the installation form the front and behind and although the more technically inclined did have an idea of how it worked most did ask afterwards how the rods were powered and how the installation was actuated. During their interaction, they did not seem to take expected physical limitations of the system into account when testing, trying very high movement speeds to see if the system might be able to react more quickly. Had they thought about the inner workings of the machine they might have been more cautious.

Seeing as it took people several minutes to figure out the technical implementation and the behaviour of the installation is dan be said that the illusion of ‘magically working’ held for several minutes. The question of how the installation was responding to input though not random was unclear for a while even with the limited implementation of the installation.

6.2.3 Technical problems

The installation had some issues with sensor noise which lead to some random ‘fear’/blue flashes being displayed in rods, as shown in Figure 6-11. Meaning that while the installation was ‘anticipating’/orange, there would be small blue glitches. Although this was technically a bug, research also showed that some imperfection in behaviour would help with the perception of the installation having personality. This would help with the perceived behaviour and so the installation be more illusive.

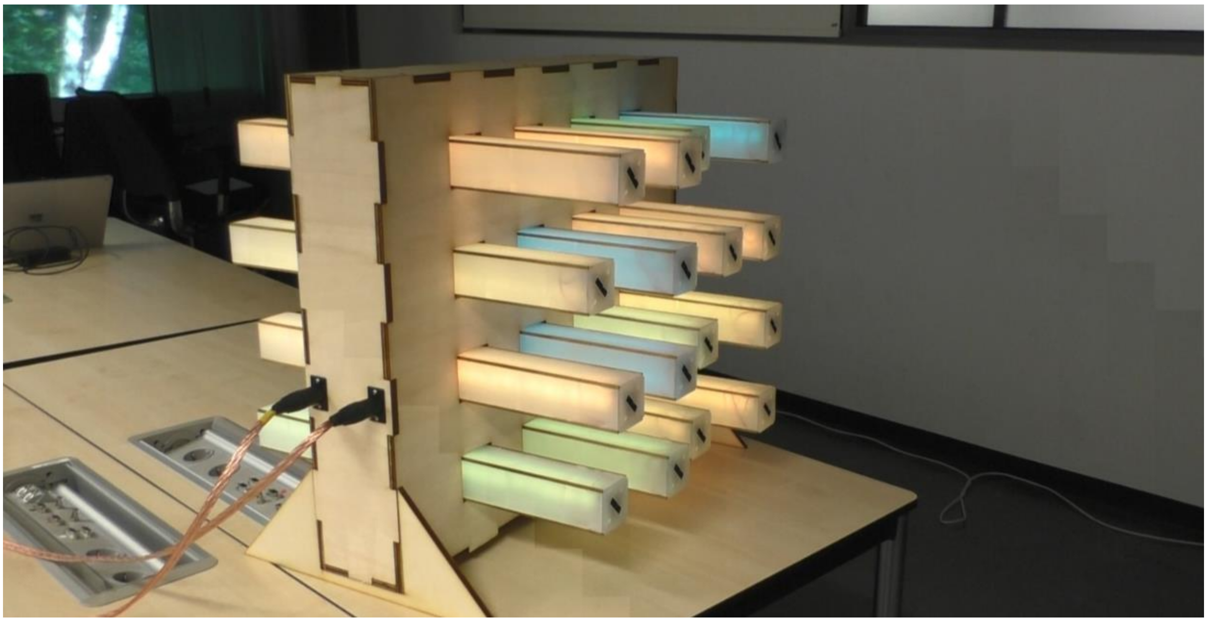

Figure 6-11: Installation displaying random blue flashes.

During the user tests, in some instances, a rod would get stuck in the installation. The rod stopped moving in or beyond its minimum or maximum distance and was no longer able to move. Once a rod even fell out of the installation during an interaction. After an initial period of confusion, this did not seem to further interfere with the user interaction or perception. After the test, they mostly reported that something seemed to have malfunctioned with the installation, which when confirmed effectively mitigated the problem for evaluation purposes.

6.3 Functional evaluation

Functional requirements have been evaluated to see if the installation performs on a functional level that is acceptable. Using the requirements set up in Table 3-2: Requirements using the MoSCoW format, this evaluation is ordered using the same priority format. All of the requirements have been functionally tested before the user testing; however some have been evaluated or reiterated upon using parts of the user evaluation.

6.3.1 Must have requirements.

FR1; The system must detect users in front of it from about 1 meter.

Sort of, the installation responses within about 1/10 of a second to a user in front of it at 40, making it feel practically instantaneous for the user, though a bit short.

FR2; The system must interact with and respond to the user.

Yes, depending on the user the installation will display different behaviour and actively respond to input towards the user

FR5; The installation must hide its drive mechanism

Using a wooden casing and no external drive(train) components beyond the surface of the rods the drive mechanism is non-obvious to most users. During the evaluation, many users walked and looked around the installation to find out where the motors were. Most figured out how it must be but it was not apparent to all users.

FR6; The system must be/feel responsive

As stated in FR1 reaction speed is within 1/10th of a second making almost instant in the eye of the beholder. The maximum movement speed of the installation has however been kept lower than planned at about, 2cm/s, for reliability considerations.

FR8; The system must have 16 rods in a 4x4 grid.

Yes, as can be seen in the images in Error! Reference source not found..

FR12; The system must change colour based on user interaction

The system changes colour depending on user distance (closer or further than 15 cm) and movement speed (slower or faster than 3cm/s)

During the evaluation phase, the system performed this functionality.

FR13; The system must show four emotions/colours

Yes, the installation has four colour states and four distinct phases to its movements, orange anticipation (idle), yellow-green joy (approach), bright green trust (follow at a distance) and dark blue fear (retreat at speed).

As seen in the survey results, this is not always clear to the user

NFR4 Installation rods must be removable and replaceable

Rods can be removed and replaced entirely, as well as moved around in the installation a can be seen in Figure 6-12

Figure 6-12: Rods out of frame for maintenance.

6.3.2 Should have requirements

FR3; The part of the system should move individually

Rods measure and move individually. Note that synchronised patterns of movement have not been implemented.

FR4; The operational mechanics of the system should be non-obvious.

Wooden casing hides all drive parts from all sides, the power transfer is not apparent instantly, only the sensors can be seen but are not instantly recognisable**.** Many users afterwards asked how the rods were lit and how the installation measures the proximity of the user. This reaffirms that the operational mechanics were sufficiently hidden.

FR7; The system should move with different speeds depending on user input

Yes, see FR13, Depending on speed and distance these separate behaviours were triggered

FR9; The system should have a movement range of ±40cm

Yes, the current system is limited to 35 cm for reliable operation.

User evaluation indicted the user expected more range, not understanding the end of the movement

FR10; The system should detect a user within a range of ±100cm

No. Due to noise and signal distortion on the measured signal of the sensor, larger distances that ±40cm cannot be measured reliably.

FR11; The system should be ±50-80x50-80cm wide and high

Yes, casing falls within these dimensions. The installation is 52x52cm this was done to create the highest density in rods.

NFR1; The exterior of the system should be clean and straightforward and aesthetically pleasing (form all sides of the installation).

Yes, few external parts can be made out, and the questionnaire result displayed in Figure 6-2 through Figure 6-4 shows that people found the installation aesthetically pleasing.

NFR2; Installation should be reusable/repurpose-able

The installation can be reprogrammed to run different software, and the basics for driving the rods is set-up in classes within the software. However, the installation is limited to intermittent use as opposed to continues operation.

NFR5; The installation should be reproducible at a later date (by a different person)

Technical drawings and are available, and all significant system choices and design decisions have been discussed in Chapter 5, Realisation

6.3.3 Could have requirements

FR14; The system could show more emotions

No, however software can be designed in such a way that speed, acceleration and colour can be easily modified pending new decision parameters.

NFR3; Installation components could be reclaimable

Yes, all significant component beyond plastic and wood can be removed and reused with relative ease.

NFR6; Parts could be standardised (easily replaceable) when possible

Yes, most components are off the shelf and otherwise using 3d printing, and laser cutting (both available in-house at the study of CreaTe) can be produced quite quickly. Most of the components can be removed if glue seals are broken, which will not destroy the part, only requiring cleaning and regluing.

6.4 Discussion

The results of this experiment show that users enjoyed and mostly understood the installation after some time. A lot of the users ended up interacting in ways different from those that the design of the installation was trying to guide them towards. The goal was to guide users to interact calmly with the installation by implementing an emotional framework to communicate to people what the installation ‘wanted’, in this case, calm interaction at a given distance. Many users did not perceive this during their interaction or ignored the cues from the installation during testing/playing with the installation with a higher intensity. For instance by changing all the rods to blue, which was not easy to do because the rods have a narrow field of view and don’t stay ‘scared’ for long. This behaviour was seen as a challenge and was possibly more interesting than all of the installation’s other reactions.

The illusion of ‘magically working’ was maintained for most user for quite some time, having to ask the researcher how it worked because they were not sure. The sensor was discovered by most participants quite quickly, though some did not recognise it. The technical aspect of the illusion would be stronger if the sensor were hidden and the motors would be more silent, this in turn facilitates a stronger base for the illusory feedback.

Users wanted to interact at close range with the installation; this implies that users were happy to allow the installation into their close personal space. There is probably a correlation between the size and movement speed of the parts of the installation and the range people allow. For most other moving objects that are not always entirely predictable, this range is usually larger. Some of this might be attributable to the fact that the installation actively retreats from the user when they are in close range.
This broke with the expectations of the users, which made them think of where the limitations of the system were, this actively broke the illusion established by longer range behaviour. Adding more depth and detail to the behaviours would most certainly strengthen the perception of the installation and the illusion of emotional presence would be strengthened.

Some other factors also need to be taken into account when looking at these results. One of the most important is the users themselves, though most could not be considered experts in interactive installations others were. For all the users involved in the testing, it could at least be said they had some experience with this type of installation because they were all students at the university where this type of installation, are regularly built.

Also because all the user were exposed to the same 3 tier test, all of them were influenced by the learning effect of examining the installation while off and while stationary. This familiarity probably made the interaction with the moving version more confident and more intuitive. Users were also told to interact with the installation, some displayed some confusion as to how to do this when they started their stationary interactions, issues which were thus solved before the moving interaction.

Some users also reported that they might not have known to interact with the installation if they had not been told to do so because the detection range was rather short, a technical limitation nevertheless influencing the tests. This has already been identified as a major point of improvement in the next version.
Similarly, the close range interaction might also have hindered the rapport forming of the installation because the closer ranges at which users were expecting responses were suddenly inactive breaking the established ‘fear as an entity’ rule

Other practical limitations include, as mentioned in the literature researched that colour is subjective to cultural background. In mostly western setups it is not much of an issue but could present problems with a user from a different background. Material choices were not thoroughly researched and selected due to technical functionality, availability and aesthetic values of researcher and client with some input of some people around them. These have been deemed sufficient for the project, but the individual choices fall outside of the scope of this GP and so may be improved in a future project.

7 Conclusion and Future work

To conclude this report, the research questions will be discussed again and answered using the results found with the project. Afterwards, the discovered potential for future work will be discussed.

7.1 Conclusion

The goal of this project was to design and create an interactive module for the Spirit of CreaTe, which after some initial brainstorming, was determined to explore illusive interaction and feedback. To achieve this the appropriate literature was researched in order to explore the field of illusory feedback and formulate the domains that should be used to achieve it. Following this a concept was created and used as the basis for a design, which was built and evaluated. To this end, research questions were asked and can now be answered.

The State of the Art literature was used to answer the first question. ‘What are interesting concepts for a SoC module that incorporates illusory feedback?’ To help with answering this question, it was broken down into smaller parts. The first ‘Which factors play a role in illusory feedback to create an intriguing user experience?’. To summarise’, an illusion needs to remain mysterious to survive, for a technical application this means that its working must be concealed and users must not be prompted to try to figure them out and so break the illusion. Touch is very visceral to understanding so denying this to the user keeps things inherently more illusive.

Having decided that touch would not be permitted and all interaction would be proxemic based the next logical question was ‘What does the proxemic interaction look like with an object?’. Proxemic interaction is heavily determined by how users perceive an object and to understand which rules to use the object needs to achieve a specific the perception level. To help users perceive the object as mildly ‘intelligent’, lifelike or more than merely a machine it was concluded it should build a semblance of rapport with a user and then follow a rule set the user understood, such as emotion, to govern its movements. This rapport would help users identify the installation as a (higher level) entity.

Using this information the final sub-question ‘Which factors can be translated into a concept for a SoC module?’ was answered. Following the conclusions above movement, accentuated by colour, in specific patterns can help create an intriguing and illusive interaction for a user. By having the installation move imperfectly and shy away from a user the illusive effect is strengthened. Personality and weight are conveyed in a way that is not hindered by the touch sensation of the user, which might override the illusion by supplying, conflicting, dominant information to the user.

The second research question ‘What are the requirements for the SoC module that incorporates illusory feedback?’ is answered partially by the results of the first question and by the next exploration into interaction. The amount of information to the user needs to be limited, which in an installation in a public space using movement can be achieved by not allowing the user to touch the installation (since sight, sound and smell cannot be easily limited in a public space). Also, the feedback should be understandable but not too consistent, to allow the user to relate, in this case, the emotional framework. Without completely understanding it to quickly, which would break the illusion and replace it with facts.

Using these results the final question ‘How to design a SoC module that incorporates illusory feedback?’ could be answers and the installation designed. In this project, an installation has been designed using proxemic interaction backed by an emotional frame expressed in movement and colour, implemented in an illusive manner. The installation is a table based ‘wall segment’ of about 50x50xm with a 4x4 grid of moving rods as can be seen in Figure 7-1 and Figure 5-1.

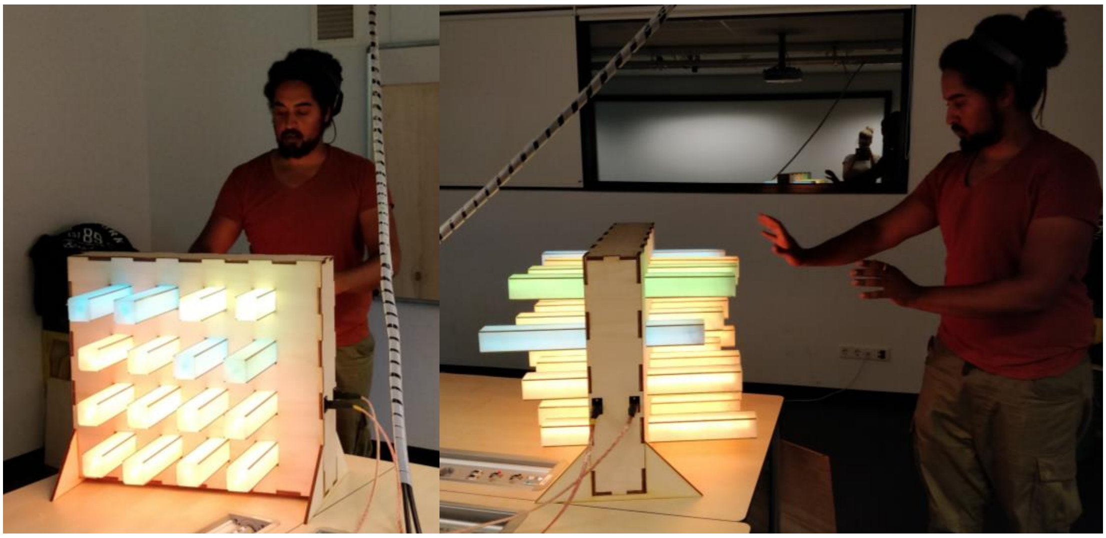

Figure 7-1: Final installation in use, left; back view, right; side view

The installation used user distance and movement speed to determine how to respond to the user. It will always try to maintain its optimal distance, and even though the users seemed to prefer a closer optimal distance than the machine could handle, the principle of the installation did seem to be sound.

The installation was tested using 11 user evaluations all of which resulted in positive evaluations by the users though they did not always interact in the way envisioned during the design process. Whether this was due to users not being able to see the installation as a higher level entity due to technical limitations or implementation or due to this principle not working within an installation\ requires more research. However, when asked the users all answered that they did think the installation had enough potential to have a stronger presence.

7.2 Future work

As mentioned in the conclusion and evaluation sections of this report there is quite a lot of room for improvement within the current concept as well as ample opportunity to explore other avenues in related concepts. The important ones are listed here as well as a list of technical improvements. Though for a full understanding and appreciation chapter 6 Evaluation should be referenced.

The concept of the interaction was understandable for most participants. However, it did not come across in a manner that they responded to. The first improvement that should be tested is to enhance the expression of the current emotions available. The installation now switches states but does not express many details within these states, such as more intense fear when the rods cannot retreat any further or a kind of longing for the closeness of trust when they can no longer move forward.

Building on this, the rapport building can be explored further by having the behaviour of the installation evolve during the interaction. For instance that when the installation trusts a user it can start to push back to steer their hand, so they follow it, instead of the installation simply following them. Another variation could be to switch from fear to anger if the user scares a rod for too long. Of course, adding more emotions as available states would help in this area as well.

To further increase the strength of expression the degrees of freedom of the installation could be improved not only by having the position, speed and colour per rod but by also adding some ‘herd’-behaviour to the installation. This behaviour would strengthen the intensity of an emotional expression since it is easier to interpret the change of movement patterns of many rods moving together as opposed to a small change in speed or colour of a single rod. Especially when all the rod surrounding the primary ‘scared’ one are doing something else.

Next interaction at very close range should be explored. This might improve the rapport people can build with the installation. Users wanted to interact at a sub 9cm distance which this installation did not allow. It seems that for the size of the rod the interpersonal distance people allow is very short. Therefore to convey personality and emotion the installation should respond to these short distances, this is similar to how people approach animals or plant, they also come very close, much closer generally than when people are speaking) Some more research on this theory might also be wise.

Beyond this, the installation and its interaction theories have only been tested in controlled circumstances. It is unclear how and if users will interact with the installation in public spaces. Some of the participants said that while they were observing, they at first did not realise they needed to get closer for the interaction to cause it to move or change colour based on their input.

A reduction of noise emanating from the motors in the installation could make a significant difference in the perception of and the interaction that users have with the installation. So a future iteration should aim to make less sound or maybe create sound on purpose to emphasise parts of the interaction.

Finally, a completely different array of interactions could also be explored. Participants seemed to enjoy the direct response of the installation to sudden movement, causing them to 'want to turn the hole installation blue'. Elements of direct change instead of smoother transitions could be used to create more direct games or more guided experiences

Alongside these research directions, there are also direct technical aspects which are listed below, starting with general changes that should be implemented and continuing with concrete details that should be taken into account in the next version of this installation.

Recommendation on principle implementation:

- Use a processor with more processing power to create more overhead for behavioural programming (such as an Arduino Due, Raspberry Pi or equivalent or a computer).
- Use a team of several people to catch design errors sooner
- Use glue with a longer drying time than contact glue, 5 minutes minimum to align the parts correctly.
- Uses alignment rings to assemble rods
- Use PCB's for electronics.
- Change fear reaction criteria to speed plus closer range to deal with sensor noise.
- Sliding contacts have a limited lifespan, redesign them to be replaceable in a future version.
- Take imperfections in the laser cutting work into account, check material thicknesses when using small tolerance slots
- Use bearing/low friction materials for sliders in frame

Specific recommendation on technical design:

- Add small slits just below the surface of the contact points of the frame with the rods to create some give/springiness to the contact point and to account for small size differences between the rods
- Add pass-through holes in the frame to allow for better wiring.
- Adjust plastic frame parts to allow for the aluminium corner supports of the frame on all sides.
- Place the distance sensor 7 cm deep in the rod to avoid the dead zone (closer than 5cm) in sensing.
- Physically separate digital and analogue data wires within the installation to avoid interference.
- Add cooling for stepper drivers to frame
- Make motor mountings more accessible for mounting in the frame.
- Add hole for stepper motor bump in the frame.
- Add rubber between motor and frame to dampen vibrations.
- Glue frame parts together to stop rattling.

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9 Index

9.1 List of Table's

9.2 List of Figure's

Appendix A Emotional model

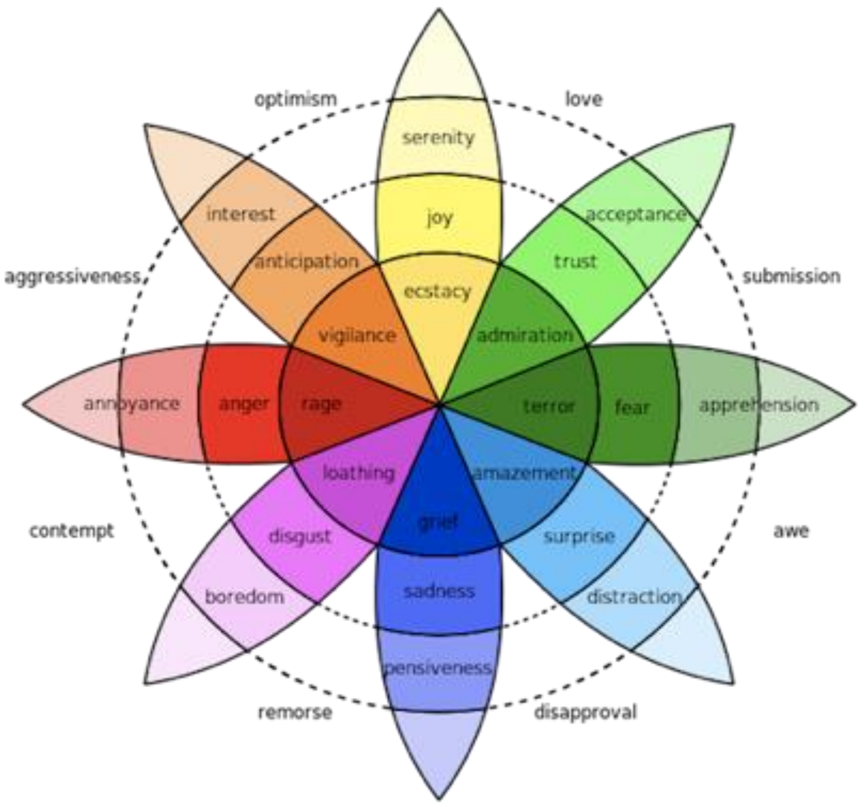
Illusory: Convey these emotions like states through colour and movement.
The way people 'touch' the installation is also illusory. The speed of approach is translated into force of contact, Giving users the sensation of having touched the wall/table

Emotional states
The movement conveys an overlaying state, that is linked to the actual states. This overlay determines the method of movement
Calm <---> Stresses
Expresses through movement speed and jitter

- When calm, the motions are slow and with intent, calm and collected as it were.
- When stressed movements are faster, and tend to be more jittery, twitchy and nervous.

This is inspired by what an animal might do in nature when exposed to these situations.

States:
The states are expressed as colours that flow on to one another according to the Wheel of Plutchik.
Curious/Interest <---> Surprise <---> Fearful <---> Trust <---> Joy <---> Interest <---> Anger

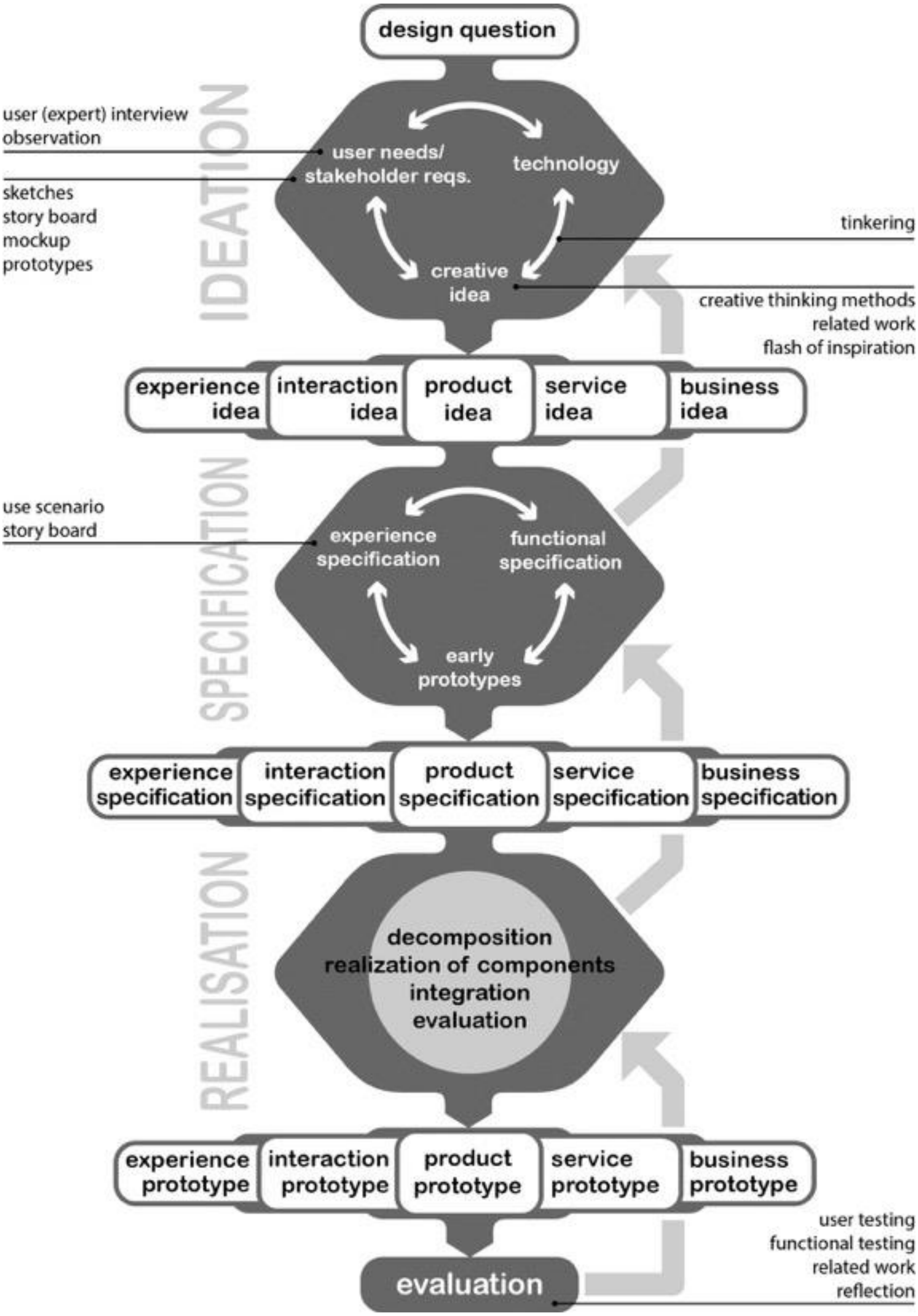


Curious: when a user is close and interacting calmly.
Surprise: when a user is suddenly close
Fearful: When a user moves to fast (thus pushing the installation)
Trust: When users wait at a distance for installation to calm
Joy: Happy when interacting for a while
Anger: When a user continues to move fast and doesn't go away

Illusory output resulting apparent underlying emotions of the system.
This makes users care, and curious what else the system may do.
The more the user inputs, the more awake and apparently intelligent the system must become.

Appendix B Creative Technology Design Process

This diagram shows the iterative nature of the Creative technology design process



Appendix C Scenario Interactive Table

Claire is on her way to Alfred in the SmartXP, she is a first-year and has not discovered the ‘is Alfred there?' website so now finds herself in front of a closed door under the black cloth in the XP. Bummed out and looking around she sees a glowing table in the corner. Most of it has rods in it moving up and down in a kind of sway like pattern, shimmering a golden orange colour.

As she walks over Claire sees that there is a paper on the table and under it, there are some rods trying to move up while glowing red. They poke the paper and then retract again when it does not move out of the way. When they touch the paper, they turn a darker red and the other rods also pulse a darker orange.

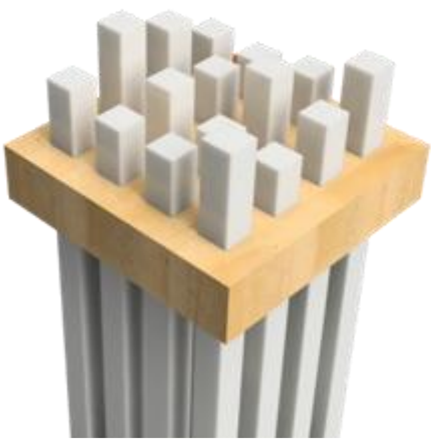
Having looked at this Claire decides to move paper out of the way, and the rods under the paper stop dead, waiting. Then after a second or so the move up in bright orange, as the reach up higher than the others they turn a bright yellow, almost gold and start happily dancing in some kind of invisible wave.

Since the table seems to react to a thing being close or not, Claire reaches out her hand to the table. The rods closed to her hand respond by turning slightly more orange and extending towards her. They stop short of touching her hand but seem to follow at a fixed distance. As she moves her hand around the ‘highpoint' in the table follows her across the rods to follow her hand, and the rods glow with yellow, green and orange.

Since the rods seem to be following she tries moving faster sideways, the rods follow and seem to become more excited and start to overshoot the movement Claire inputs. The rods respond as is Claire’s hand is making waves in a field that the rods are following.
Then she lifts her hand and it down fast as is smashing the water. The rods respond by turning green and retracting to the table. The ones in the centre shoot down and seem to make a wave that propagates through the others to the end of the table. The rods stay down and tremble in the table.

Being sorry for them Claire tries to coax them out by slowly waving above them. This is to work out the colour become slightly lighter green and then move up a little. Continuing to move slowly Claire gains the rod's ‘trust', and the green slowly turns to yellow as they slowly start moving again.

That is when Alfred reappears, and Claire is off to ask her question.



Appendix D Materials list

Part	**Amount**	**Comment**
Sharp IR gp2y0a41sk0f	16 pc	
3-WAY CABLE WITH JST CONNECTOR	16 pc	To connect Sharp sensor
Adafruit NeoPixel RGB 60 leds/m led strip	16 m	1 meter per rod in 2x50cm
Nema 17 stepper motor (1,8 deg/step, 50N/cm)	16 pc	
Stepper motor cable, 4 wires, 100cm	16 pc	To connect motor to driver
Sparkfun Big easy driver	16 pc	
Arduino Mega 2560	1 pc	
PROTO BOARD, ARDUINO MEGA, REV 3	1 pc	
Power supply (36A @ 12v, 20A @ 5V => ~550W)	1 pc	Computer power supply used.
Frame		
Extrusion 15x15mm		
Extrusion Corners		
Extrusion Screws and nut		
Sheet materials		
Satin Acrylic 3mm	16	60x20cm for outer casing (special order at Alfred)
Transparent 3mm		~50x150cm sheets at Alfred
Wood 8mm	2	60x100cm sheets at Alfred
Assorted parts electronic		
Flatcable 16pin	10m	All cable lengths are high estimates
Flatcable 16pin connectors female	8 pc	
Flatcable 16pin connector male	8 pc	
XLR wall male	2 pc	
XLR wall female	2 pc	
XLR cable male	2 pc	
XLR cable female	2 pc	
Power cable 4^2mm	7m	
Power cable 1,5^2mm	5m	
Resistor 1K	16 pc	
Capacitor 10uf	16 pc	
Thin wire assorted colours	5-10m	

Appendix E Consent and Questionnaire

E.1 Consent Form for Spirit of Create installation evaluation

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 04/06/2018, 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 video recordings of my interactions with the installation which will be destroyed after project completion and a questionnaire which will be stored in University of Twente archives	○	○
Use of the information in the study		
I understand that information I provide will be used for a the evaluation stage of a graduation project report.	○	○
I understand that personal information collected about me that can identify me, such as my appearance will not be shared beyond the study team.	○	○
Consent to be Video Recorded		
I agree to be video recorded. Yes/no	○	○
Future use and reuse of the information by others		
I give permission for the answers to the questionnaire that I provide to be archived in University of Twente archives so it can be used for future research and learning	○	○

Signatures

________________________ ________________________ _________

Name of participant [printed] 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.

___________________________ ____________________ _________

Researcher name [printed] Signature Date

Study contact details for further information: Abel Gerritse
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E.2 Questionnaire

Page1: Spirit of Create
Hello,

I am currently developing an installation for the Spirit of Create project, it is meant to be place in public space and invoke user interaction form passers-by.
This purpose of this installation is to interact with users using movement and colour and invoke a response of emotional presence to the user.
This questionnaire is to determine whether the system properly communicates emotion towards the user. This survey is research conducted for the University of Twente, and your personal information and the answers will be kept private. The survey will take up to 10 minutes. Your participation is very much appreciated.

There is an open comment field at the end.

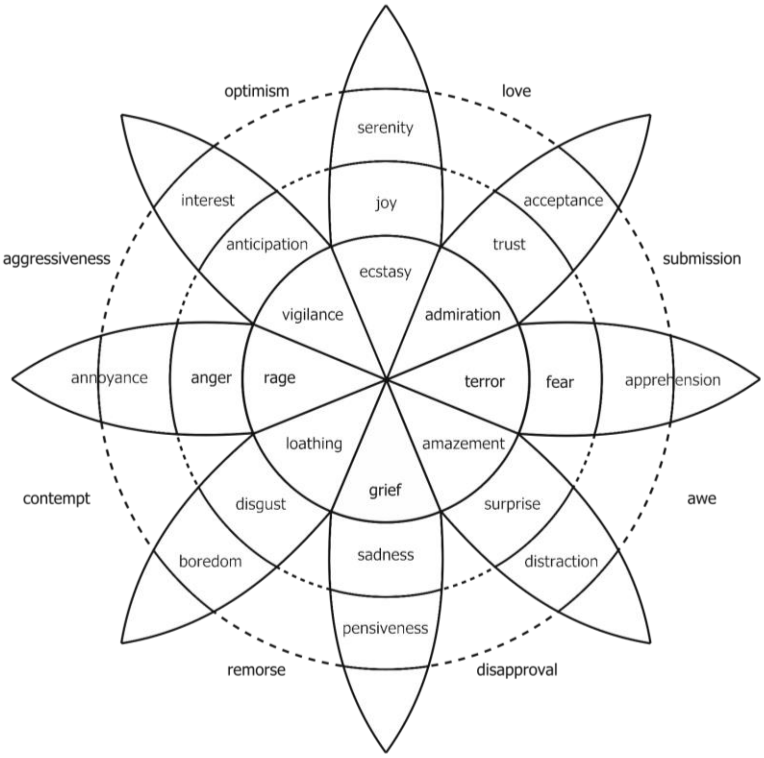
Gender?
Age?
Country of origin?
Years of student?
Study?
With which emotional machine(s) have you ever interacted before?

Page 2: General impressions
Please rate the installation on the following attributes for each of the scenario's?
1-6 scale per scenario
For the installation while off: *short answer*
Presence
Emotional presence
Aesthetically pleasing
Interesting
Fun

For the installation using only colour:
Presence
Emotional presence
Aesthetically pleasing
Interesting
Fun

For the installation using colour and movement:
Presence
Emotional presence
Aesthetically pleasing
Interesting
Fun

Page 3: Emotional association
Below Plutchiks emotional wheel can be seen. It is a model for which emotions people have and how they can move between them. For this questionnaire only the emotions themselves are needed and the layout is used for oversight and easy reading,



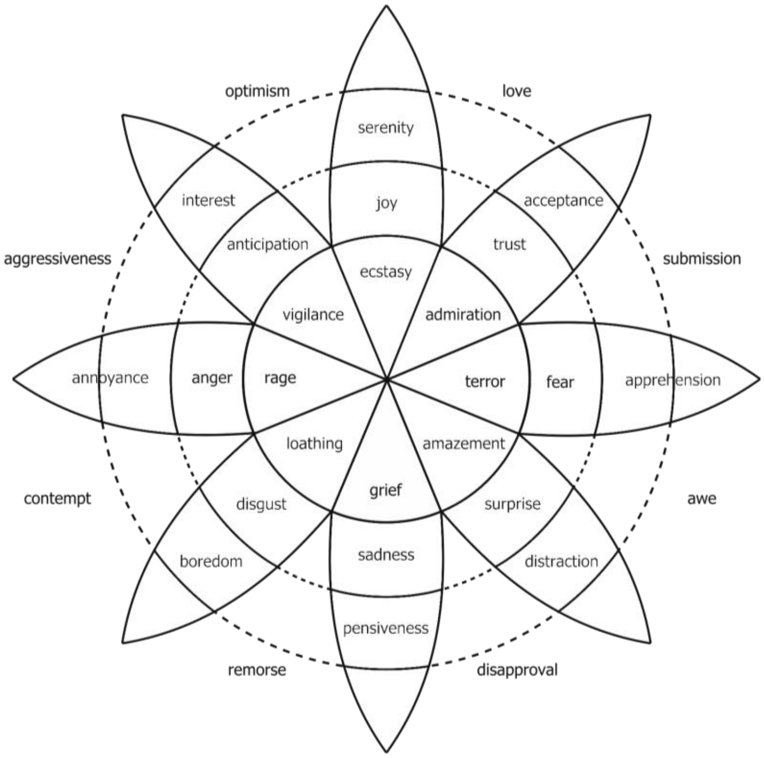
The installation displayed a few different reactions or stages. For each stage please select an emotion you feel fits best, you can use several if required, please write them in order of importance separated by comma's. If you feel that other descriptions are required you can add them as well.

For the installation while off: *short answer*

For the installation using only colour:
While the installation was orange: *short answer*
While the installation was yellow: *short answer*
While the installation was bright green: *short answer*
While the installation was dark green: *short answer*

For the installation using colour and movement:
While the installation was orange: *short answer*
While the installation was yellow: *short answer*
While the installation was bright green: *short answer*
While the installation was dark green: *short answer*

Page 4: Emotional intensity
For the next few questions, are based on Plutchik's wheel of emotions again. (also available on handout)



For part three, in which the installation used colour and movement:
Rate certain aspects of interactions with each other on 0-6 scale:
During the interaction, how strongly did you feel like the robot feared you ?
During the interaction, how strongly did you feel like the robot trusted you ?
During the interaction, how strongly did you feel like the robot enjoyed interacting with you ?
During the interaction, how strongly did you feel like the robot anticipated interacting with you?
During the interaction, how strongly did you feel like the robot was angry with you?
During the interaction, how strongly did you feel like the robot was disgusted with you?
During the interaction, how strongly did you feel like the robot was sad?
During the interaction, how strongly did you feel like the robot was surprised of you?
Did you change your perception of the installation during this 3rd phase of the experiment? (long answer)

Page 5: Perception

Do you feel like the device in the experiment felt/expressed emotion? (1-6 no, like machine—yes, like a person)
Was it clear to you how and why the system was responding to your interaction? (1-6 seemed random – was perfectly clear)

Do you think technology can express emotion in a non-anthropomorphic way? (anthropomorphic means human characteristics) (yes/no)
Could you explain why? (not mandatory) (long answer)
How likely would you be to interact with this installation if you came across it in the walkways and were not in a hurry? (scale 1-7)
Could you explain why? Not mandatory (long answer)

Page 6: Last points
Is there anything else that you want to share regarding the topic of this survey?
Is there anything else that you want to share regarding the contents of this survey?

Page 7:
Thank you for your participation, dont forget to tell me what you want from the omnomcom.

E.3 Questionnaire results

See digital archive in Appendix F for an Excel file containing all questions and answers to the questionnaire.

Appendix F Digital Appendix

All files are included in the digital archive zip which is available upon request at Richard Bults (r.g.a.bults@utwente.nl) in the following hierarchy:

- Code
  - Libraries (for Arduino)
  - Src (ino/cpp)
- Design
  - Sketches (image)
- Evaluation
  - Questionnaire results (excel)
  - Test support files (consent forms and such)
- Images -- Images of installation
  - Build process
  - Completed installation
- Realisation
  - Fusion 360 files -- CAD files
    - Autodesk Fusion 360 export (f3d) (a zip file)

      It can be uploaded in to a free Autodesk
  - Production files
    - Cutting files (dxf)
    - Printing files (stl)
  - Electrical drawings (fzz, fritzing)
- UML – meta design of the installation (image, xml)