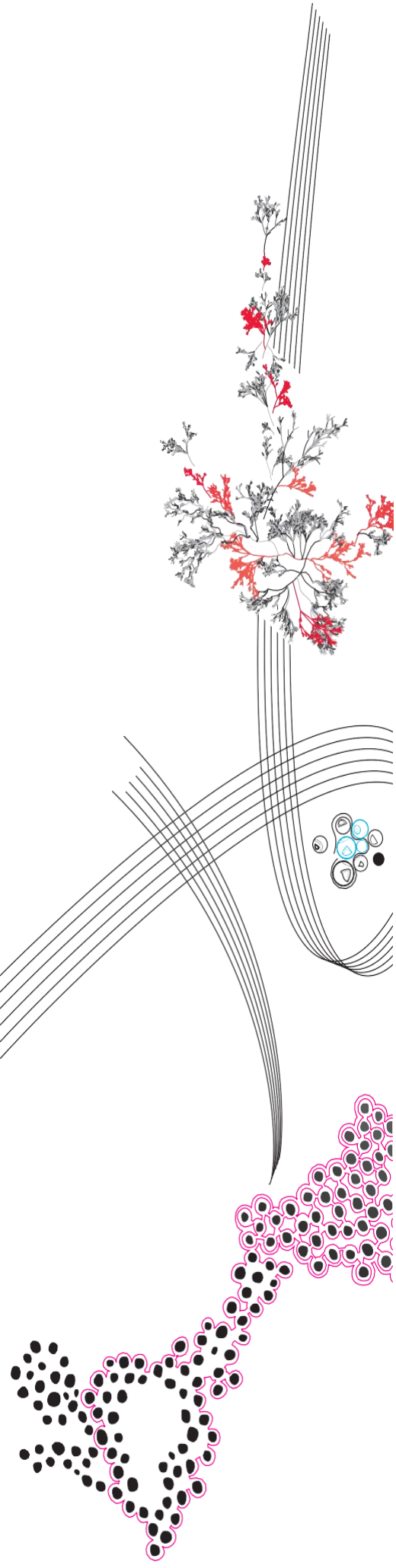

BSc Thesis Creative Technology

The Button Nudger; a possible solution to influence toilet flushing behaviour.

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Abstract

This research addresses the issue of excessive water consumption in toilet flushing, specifically in dual-flush toilets. This study was commissioned by the University of Twente's campus facility management (CFM). The study uses nudging techniques to influence the flushing behavior of users, focusing solely on norm-setting nudging techniques. It aims to answer the question: to what extent can nudging influence the toilet flushing behavior of the Zilverling community. The Button Nudger including a button press registration setup was created to convey the nudging message and to measure which flushing button was used. A zero measurement and intervention measurement were conducted to find out whether the implementation of The Button Nudger had an effect on flushing behaviour. It was concluded that it is plausible that norm setting nudging can influence toilet flushing behavior within a certain group of the Zilverling community. A user evaluation revealed that approximately 20% of participants felt influenced to alter their flushing behaviour, but also highlighted the need for improvements in the perceived privacy, intrusiveness, and design of The Button Nudger. While there is uncertainty on the lasting effects on water conservation, the study suggests that norm-setting nudging is promising when implemented to stimulate correct toilet flushing behaviour.

Acknowledgements

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Furthermore, the assistance of Ilja Westra, MSc in implementing the button press registration on the toilets is very much appreciated. As well as her guidance and outsiders view on any issue that presented itself throughout the entire research period.

Lastly, the author wants to express gratitude towards Joris Kuiper and Jop Paulissen, BSc for their help with coding and bug fixing in Python and Arduino.

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1 Introduction

To introduce the reader to the topic of this research, this chapter will firstly address the context of the research topic. Hereafter the problem statement will be expound and the research question and sub questions will be posed. Lastly, a structure of this thesis is provided to the reader.

1.1 Context

Over the last couple of years, it has become all the more apparent that the climate is changing, and humankind is using its natural resources excessively (IPCC, 2021; Ali et al., 2021). One of these excessively used resources is drinking water, especially in the western world the availability of water is often taken for granted. This is illustrated by the fact that research has shown that Europeans greatly underestimate their personal water usage (Seelen et al., 2019). On a large scale, sustainability goals are approached at a global or national level (Biermann et al., 2017). More locally, studies suggest that Universities in particular are capable of impacting and initiating sustainability (Beynaghi et al., 2016; Leal Filho et al., 2019) .

Likewise, the Campus Facility Management (CFM) of the University of Twente (UT) is exploring different manners of limiting the usage of drinking water as well as cleaning their own wastewater. Apart from using rainwater to flush a select portion of campus toilets, another way to achieve these goals is reducing the water usage when flushing toilets. Dual-flush toilets are capable of preserving an average of 3 Litres per flush when used for solely flushing urine (Özel & Baykal, 2013). When this system is compared to a regular, single-flush-option toilet, up to 6 Litres of water could be preserved with a liquid waste-only flush (Özel & Baykal, 2013). However, this system is widely misused and as such is not yet living up to its full potential of water conservation (Arocha & Mccann, 2013).

1.2 Problem Statement

The main challenge is to find out a manner of nudging UT community members into a certain toilet flushing behaviour without being too directive, as well as the extent to which this is possible. Eventually, the goal is to influence these people's flushing behaviour towards correct use of a dual-flush toilet. Hopefully, people's behaviour will not only be influenced at the University buildings or when they are confronted with an intervention. Instead, it would be desirable that people who have encountered the intervention, will take this newly gained awareness and apply in at their homes or other public spaces. However, the research focus is in this case on the Zilverling building community.

1.3 Research Questions

In order to successfully find a solution to the stated problem, the main research question that will have to be answered is:

- To what extent can nudging influence the toilet flushing behaviour of the Zilverling community?

To ensure the research question is correctly assessed, an additional sub-question needs to be answered. To obtain insight into people's flushing data, it is necessary to find the correct way of instrumenting the toilets in order to measure flushing behaviour.

The subsequent sub-question that needs to be answered is:

- How to instrument the Zilverling toilets to measure flushing behaviour?

1.4 Structure of the thesis

This thesis is structured in nine chapters with the addition of appendices and references at the end. The first chapter poses an introduction to the research as well as the problem statement and (sub-) research questions. The second chapter sets out the background research by means of a survey on current flushing behaviour at the UT, a review on the existing literature on nudging and water conservation and a review on the state of the art. The third chapter introduces the research methods and techniques that will be utilised throughout the research. In chapter four, the ideation is introduced by identifying the stakeholders, analysing their requirements and generating concepts. From chapter four a final concept is extracted which is specified in chapter five. This specification is performed through describing interaction scenario's based on distinctive personae, setting system requirements based on the stakeholder requirements, and describing the functional architecture of the prototype. Chapter six then describes the realisation of the entire prototype. In chapter seven, the results obtained by the prototype are analysed and a user evaluation is given. Chapter eight includes the discussion of the results and suggestions for future work, after which chapter nine concludes the research.

Due to the contrast of pictures throughout this thesis, it is best viewed in colour.

2 Background Research

In order to obtain a theoretical framework into the topic of the research through assessing the literature as well as painting a picture of what is out there as state of the art regarding the topic, background research was performed. In the first part, nudging techniques towards influencing behaviour are being elaborated upon, thereafter the application of nudging techniques in a pro-environmental and, more specifically, water use reduction context is being discussed.

2.1 Survey on UT community flushing behaviour

To gain insight into the relevance of the research topic as well as the target audience knowledge and behaviour, a survey was conducted on the UT campus. The survey was held between 17-03-2022 and 24-03-2022 in university buildings Spiegel, Bastille, Vrijhof, Cubicus, Ravelijn, Zilverling, Waaier, Carre, Horst and Gallery at both the male and female toilet facilities.

The survey was conducted by means of placing A4 papers containing a brief explanation and a QR-code (Appendix A) leading to the survey on several spots in the toilet facilities. The A4 papers were placed above the toilet flush button inside the cubicles, on mirrors above the sink and on the wall somewhere in the toilet facility.

The survey was hosted by Google forms and consisted of three questions. Firstly, information on the survey was given and confirmation on informed consent of partaking in the survey was asked (Appendix B). Thereafter, the questions were posed (Appendix C).

The survey received 746 responses over the week of it being held. The results are being illustrated by means of three pie charts, these link to the three individual questions and are displayed in Figure 1, 2 and 3.

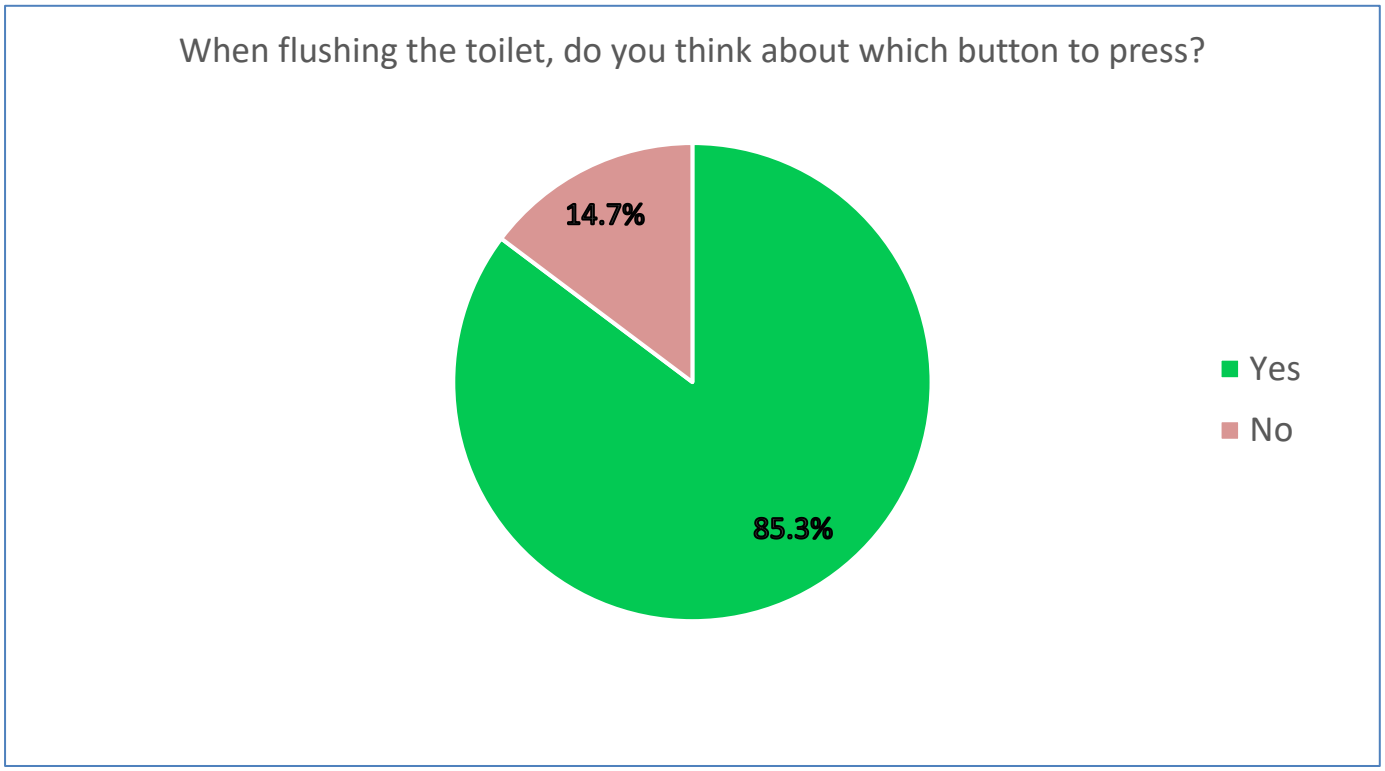


Figure 1: Survey question 1: "When flushing the toilet, do you think about which button to press?"

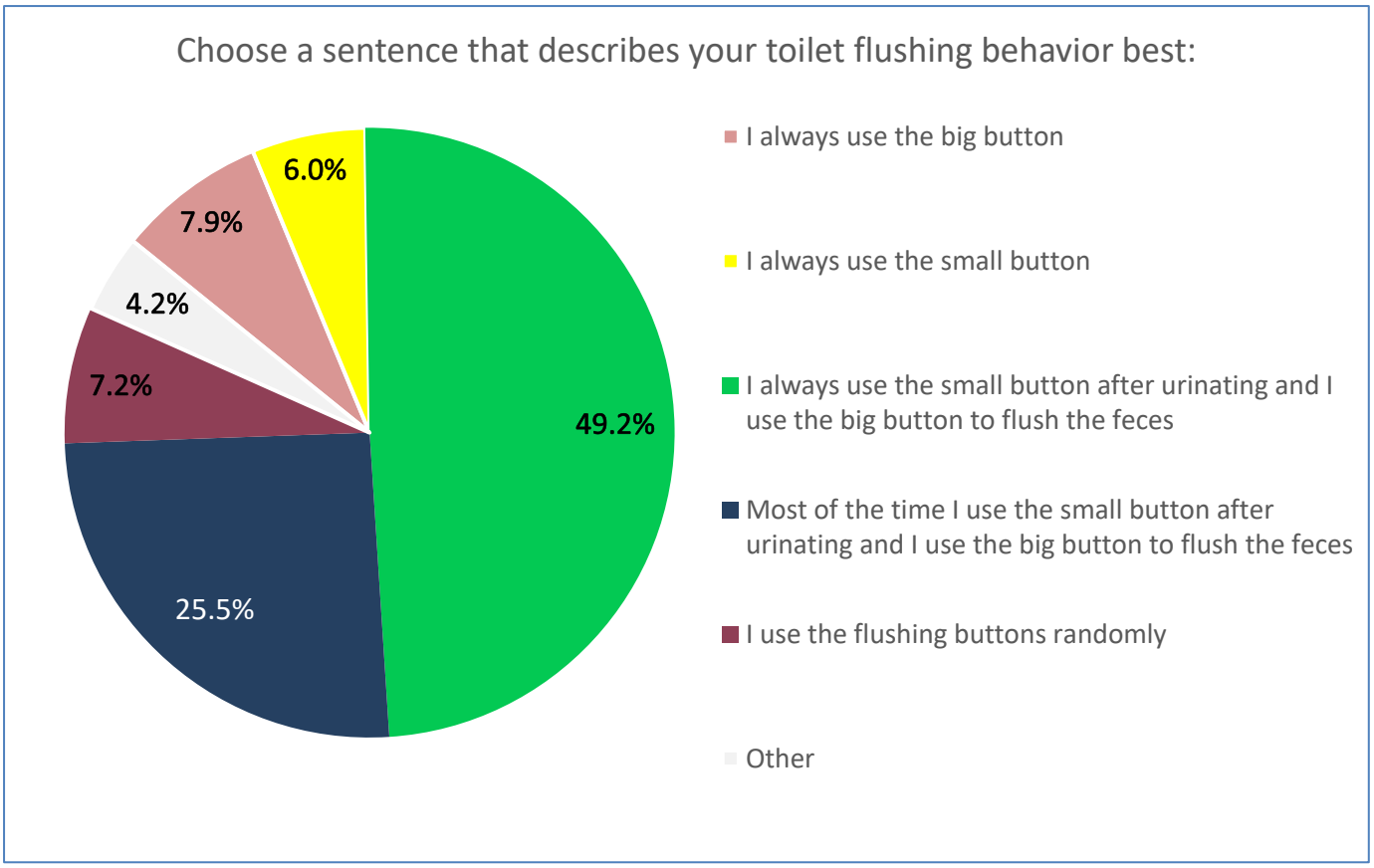


Figure 2: Survey question 2: "Choose a sentence that describes your toilet flushing behavior best:"

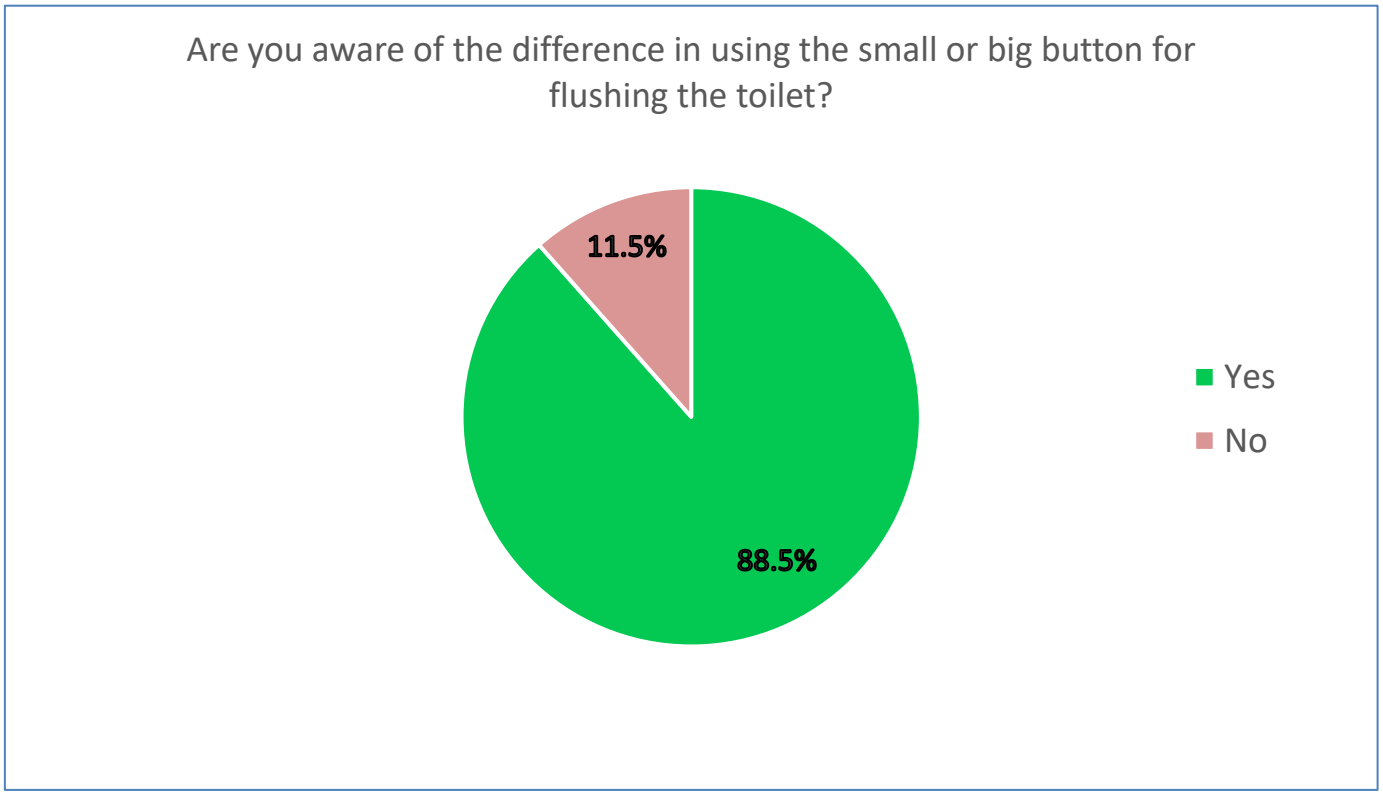


Figure 3: Survey question 3: "Are you aware of the difference in using the small or big button for flushing the toilet?"

When considering these survey results, it can be seen that there is room for improvement in the toilet flushing behaviour of UT community. From question 1, it becomes clear that 14.7% of people is flushing the toilet without thinking about it. These individuals could benefit from a reminder of sorts as to let them think about their actions. From question 2, it can be concluded that for 50.8% (The persons that did not indicate that they 'always use the small button after urinating and use the big button to flush the feces') there is something to gain regarding water conservation as a result of their flushing behaviour. As for question 3, the persons that indicated that they were not aware of the difference between both buttons could benefit from providing information about the use of the toilet buttons.

2.1.1 Survey findings compared to literature

When literature was related to the findings in this survey, fairly similar research conducted by Özel and Baykal (2013) was found to be useful. It is especially useful to look at their first survey data, the one before any implementation of an intervention. In this survey they asked the participants to their awareness of the use of dual-flush toilets; a question somewhat similar to question 3 on the UT survey. Only 43% of respondents in the Özel and Baykal responded affirmative, in comparison with 88.5% on the UT survey. Another similar question in both survey's is 'How do you use the dual-flush toilets?' and question 2 on the UT survey, but due to the different nature of answer possibilities, the answers on this question are not comparable.
An interesting fact is that the survey by Özel and Baykal was conducted with a very similar demographic group as the UT survey, although the survey conducted by Özel and Baykal was only focussed on university library toilet users instead of a whole university campus community. Also, there could be cultural and/or locational differences between the two surveys. Further differences could be attributed to the large difference in participants (n=119 at the Özel and Baykal survey, n=746 at the UT survey).

Concluding from the question 3 comparison, literature on this topic confirms and even goes further as for the need in raising button usage awareness than the conducted UT survey.

2.2 Literature research

In order to evaluate the knowledge there is regarding nudging, the literature on this topic is researched. First, an overview is given for nudging in a more general sense, thereafter, an increasingly zoomed in view about nudging techniques is presented towards nudge usage for water reduction in toilets.

2.2.1 Nudging

To be able to answer the research question, it first has to be established what nudging entails and which different nudging techniques there are. Below, two definitions of nudging are given. Thereafter, several frameworks regarding nudging categorisation are provided.

2.2.1.1 Definition

The Cambridge dictionary defines nudging in this context as: "to encourage or persuade someone to do something in a way that is gentle rather than forceful or direct" (Cambridge University Press & Assessment, 2023). The literal sense of nudging is too broad for this research. Another definition can be drawn from Thaler and Sunstein (2009, p. 6). By nudge they mean "any intervention in the 'choice architecture,' that is, in the structure of the decision context, that 'alters

people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives,' with the intervention remaining 'easy and cheap to avoid'".

2.2.1.2 Nudging Frameworks

There are several nudging frameworks identified throughout literature. The term framework is used here as a means for addressing a set of nudging techniques as identified as such by a paper in literature. An overview of two of these frameworks will be given below, as well as a comparison between frameworks. The relevance to nudging for influencing toilet flushing behaviour will be evaluated when discussing the different techniques within these frameworks.

2.2.1.2.1 Framework Mertens et al.

Mertens et al. (2022) who draw from 200 studies, identify nine distinct intervention techniques grouped into three categories in their meta-analysis. These categories are:

1) Decision information;
2) Decision structure;
3) Decision assistance.

Behavioural interventions in these categories target respectively the description of alternatives, the structure and organisation of choice alternatives, and the reinforcement of behavioural intentions.
Decision information is based on the limitation on access to information that is relevant for the decision. Nudging with decision information entails providing decision-relevant information or increasing the availability, accessibility, comprehensibility or personal relevance thereof to the user. One could think of techniques like increasing visibility of certain information, providing translations of information to improve comprehensibility, or the conveying of social norms or reference points to reduce ambiguity. Regarding the dual-flush toilet system this could be translated to clear visible information inside the toilet cubicle on the working of the system and the buttons. Also, messaging about the social norms regarding flushing behaviour could be conveyed as to make users aware of their behaviour in comparison to their peers.

Decision structure is centred around the limited capacity to evaluate or compare choice options. People often use contextual cues to make their decisions instead of an extensive cost-benefit analysis, therefore not always making the most beneficial choice. Techniques that could be implemented in order to overcome this barrier are changing the default option, changing the effort it takes to choose certain options, changing how the options are composed, or changing the consequences of choice options. In practice, on the toilet this could mean creating a default flushing option, changing where the individual buttons are located, changing their size, changing the physical friction of a certain flushing button or introducing a financial incentive to promote certain choice. Additionally, introducing option consequences on a social level would not be applicable due to the private nature of toilet behaviour.

Decision assistance has to do with the limited self-control and attention of users and aims to facilitate self-regulation. This intervention category intervenes behaviour-wise between the intended behaviour and the actual behaviour in the case that intentions do not translate into desired actions. Providing reminders by making the desirable behaviour more salient or implementing commitments are intervention techniques that can be implemented in order to tackle this lack of self-control or attention. Introducing a commitment to increase the water consumption of toilets by a certain percentage or putting up correct flushing behaviour reminders could be considered in this case as toilet interventions.

2.2.1.2.2 Framework Ledderer et al.

Ledderer et al. (2020) provide another categorisation in their review of 66 individual papers, the vast majority of which were about diet and nutrition. This is the case because the scope of their review was limited to public health and lifestyle interventions. For this reason, the nudging techniques in their categorisation were mainly based on diet and nutrition interventions. Nevertheless, they point out eight categories of which some could be applicable in the toilet domain. These categories are discussed briefly below:

1) Accessibility; in this case the accessibility of individual food items. This intervention is based on the replacement or repositioning of individual items in order to increase or decrease the visibility or the accessibility of these items.
2) Presentation; in this case the presentation of individual food items. One could think about the form or number of individual items. This in order to draw attention to the unusual shape or to prevent an unhealthy choice to be made due to the smaller amount of food.
3) Usage of messages and pictures; the implementation of labels, signs, posters or any kind of conveying a message in order to inform or persuade the user. Technology-supported information; provision of feedback through technological or digital means. Or the provision of digital information in order to educate users.
4) Financial incentives; increasing or decreasing the price of certain choices or implementing rewards or rebates. This in order to increase or decrease the likeliness of certain choices being made.
5) Affecting the senses; influence choice by means of activating sight, smell, taste or touch stimuli.
6) Cognitive loading; increasing the cognitive load while making decisions leads to making unhealthier choices, therefore a reduction in cognitive load could lead to an increased ability to choose healthy options.
7) Miscellaneous; interventions that were not categorisable into the above categories. One intervention was based of the setting of defaults. Another included adding a charity incentive to nudge for healthier choices.

While some of these categories are not relevant within the scope of this research, some others, such as technology-supported information and affecting the senses certainly are. These could be implemented in the toilet as for instance a way of providing information about correct usage through digital means.

When comparing the frameworks of Mertens et al. and Ledderer et al. it can be concluded that there are certain similarities to be noted. The accessibility of information or food can be seen as such a similarity. Also, both frameworks mention the setting of default choice options to be a technique that can be implemented to generate behavioural change. Apart from these two examples, there are many more similarities noticeable between the frameworks. When looking at differences between frameworks, it is remarkable that there are surprisingly little. Even though both frameworks are set up entirely differently, near every technique from one framework could be translated into one of the other. The only significant difference is the ‘affecting the senses’ technique, as discussed by Ledderer et al. is not mentioned by Mertens et al.. A reason for this could be the high affinity of this category to the food domain rather than in a general sense.

In conclusion, these both frameworks display a very complete overview of possible nudging techniques. Whilst they may not all be as applicable as another in the scope of this research, it still shows the complete range of nudge implementations possible to eventually pick and perhaps combine techniques in order to let the nudge be as effective as possible.

2.2.2 Applying nudging in pro-environmental setting

When narrowing the scope of nudging techniques from nudging in a general sense to nudging with a pro-environmental goal, the work of Byerly et al. (2018) provides a framework of six environmentally challenging domains. These are accompanied by eight behaviour change interventions grouped into contextual and traditional interventions. A diagram of the domains and interventions as identified by Byerly et al. is shown in Figure 4.

To evaluate which domain could benefit from which behaviour change intervention, a second diagram was set up to display which intervention techniques are deemed promising, are received as mixed or display no effect. To produce this diagram, Byerly et al. reviewed 72 individual studies of which most were field studies. The results are displayed in Figure 5.
From this second diagram, it becomes clear that not all nudging techniques are as effective as others depending on the which domain the technique is being used. However, some nudging techniques do seem to be somewhat more universally applicable in comparison with others. From Figure 5 it can be seen for instance, that commitments and defaults have proven to work throughout different domains.

Wee et al. (2021) in turn, provide a different framework of techniques that have proven to work on a pro-environmental level. These techniques are mainly focused on the visual design space. The seven techniques that Wee et al. list are:

1) Prompting: Raising awareness by providing knowledge and social norm information
2) Sizing: Increasing or decreasing the size of an object to increase or decrease attention to this object respectively.
3) Proximity: Increasing or decreasing the distance to an object to increase or decrease the effort it takes to interact with this object respectively.
4) Priming: The placement of cues in the environment to influence decisions subconsciously.
5) Presentation: Re-designing the presentation of an object to attract attention.
6) Labelling: Providing specific details or information of an object or option.
7) Functional design: Functionally re-designing an object or environment to either increase or decrease consumption.

It can be seen that some of the categories by Wee et al. do correspond to the categories identified by Byerly et al.. Examples are priming or prompting in comparison to norms and education. The similarities between the framework by Wee et al. and both frameworks by Mertens et al. and Ledderer et al. are also clearly visible, showing that general nudging concepts also work when implemented for pro-environmental goals.

Apart from all above-mentioned techniques, Carlsson et al. (2019) give a fairly similar framework of ‘green nudges’. However, the important distinction they make is the identification of moral suasion, to be another nudging technique. Moral suasion shares similarities with conveying norms, yet the difference between these techniques is that moral suasion is not providing social comparisons. In contrast, conveying norms does provide social comparisons. To illustrate, Carlsson et al. describe this technique as follows: “Moral suasion nudges inform people of the right, moral behavior without explicitly providing social comparisons” (p.12).

In conclusion, the framework of nudging techniques in a pro-environmental setting remains by and large the same compared to nudging techniques in a general sense. Between the discussed frameworks there are subtle differences to be seen, however Carlsson et al. provides a certain distinction of moral suasion that was not identified by any of the other frameworks. As for the most universally applicable pro-environmental nudges both setting commitments and implementing defaults can be considered.

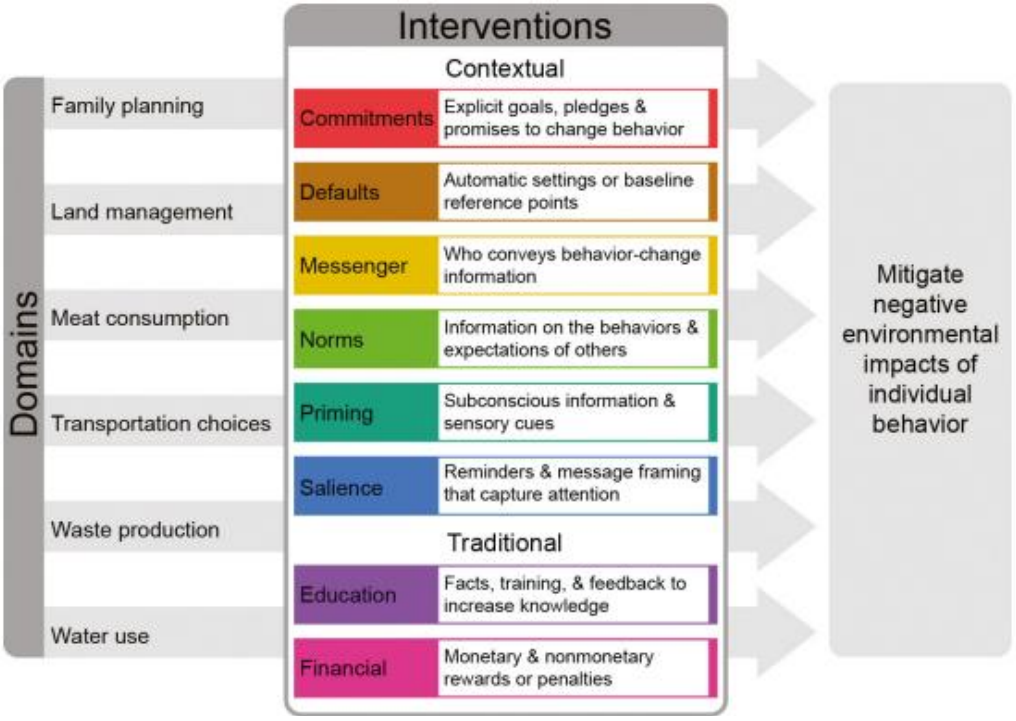


Figure 4: This diagram was produced by Byerly et al. in 2018, providing a clear overview of pro-environmental behaviour domains and behavioural interventions that could be effective.

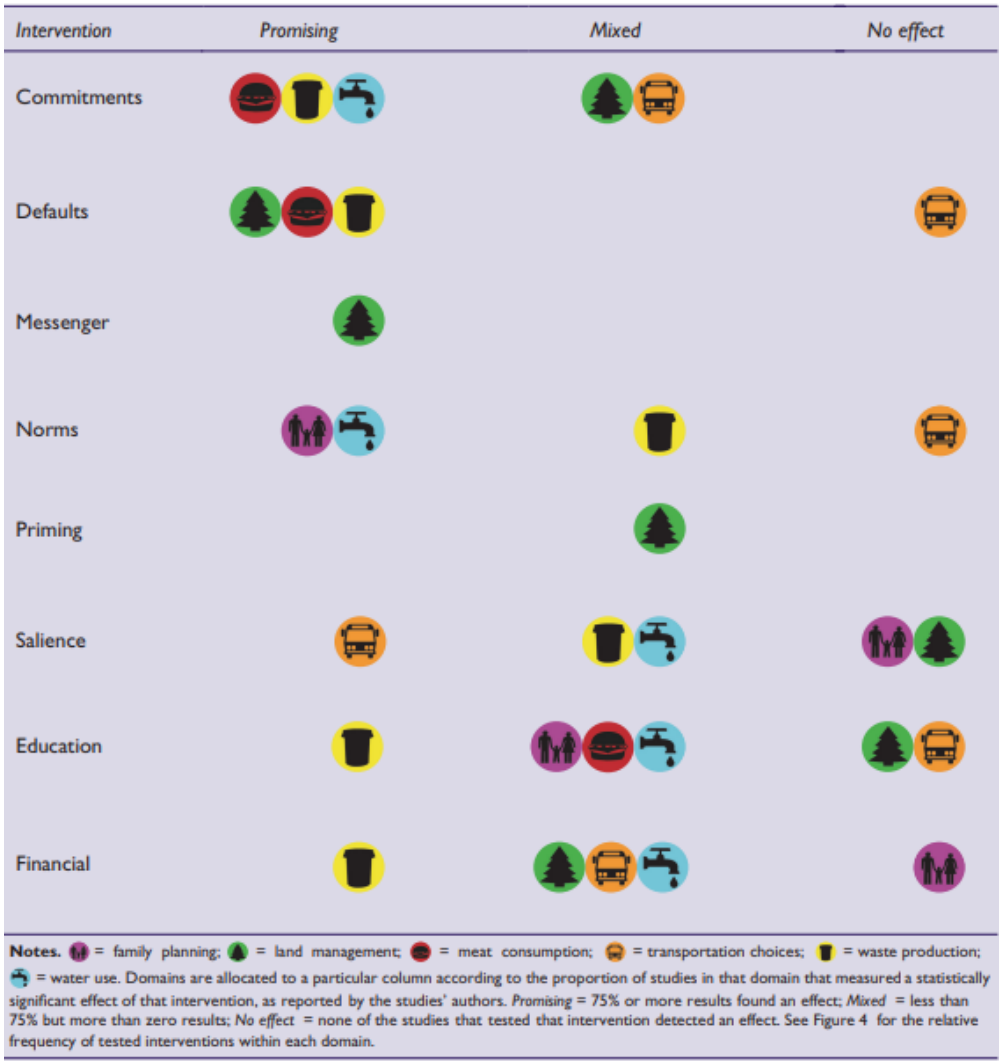


Figure 5: This diagram was provided by Byerly et al. in 2018, providing a representation of the effectiveness of several behavioural interventions according to the environmental domain they are tested on.

2.2.3 Applying nudging to accomplish water reduction

When scoping down once more from environmental nudging to water reduction nudging, the usefulness is being discussed by Wee et al. who identify nudging for water conservation purposes as useful. In doing so, they draw from research done by Bhanot (2021) on the effectiveness of nudge usage for water conservation amongst Californian households. This research showed a clear effect of the implementation of both injunctive and non-injunctive norms on reduced water consumption amongst 40000 Californian households.

When trying to identify types of nudging that have proven to be effective in water use reduction, the diagrams of Byerly et al. (see Figure 4 & 5) can be taken into consideration once more. It becomes clear that both the usage of commitments and norms have proven to be effective in the water use domain. In doing so, the conclusions made by Bhanot about norm usage are echoed. Further, there are mixed results in the salience, education and financial nudge categories, meaning that there are still studies that have found effects regarding these nudging techniques to some extent. Especially regarding salience, simple reminders have proven to be rather effective as Byerly et al. conclude from a study by Kurz et al. (2005, p. 1) on the "influence of information leaflets, attunement labels, and socially comparative feedback on the actual levels of energy and water consumption".

Concluding, the variety of nudges to be used successfully when aiming for reduced water usage shrinks in comparison to nudging in general or pro-environmental sense. Both setting commitments and the conveying of norms have shown to be effective. Next to that, using salience has also shown to be effective in some cases as well as educating and financial nudge strategies.

2.2.4 Applying nudging to accomplish water reduction in toilet flushes

Unfortunately, for the highly specific case of nudge application to accomplish toilet water consumption reduction not much research has been done. There is however, one paper by Arocha & Mccann (2013) which investigated the implementation of an informational wall plate, which had any effect on the flushing behaviour of the users of an American municipal building. This way of nudging shows similarities to prompting as described by Wee et al.. The implemented wall plate was placed above the flush handle and on the rear of the stall door. The wall plate is depicted in Figure 6. It should be noted that the design of the flushing mechanism was a handle. The default option is a downward motion handle movement, resulting in a full flush. The upward motion handle movement results in a partial flush. This design is significantly different compared to a button configuration where there is not such a dominant default option. While the big flushing could also be seen as a default option, there is still always a visible small button present. The upward motion handle movement on the contrary, is widely unknown and not a visible entity.

When looking at the results of the implementation of this nudging technique compared to the control period, a 12,2% increase in up flushes can be seen. While the effect of the nudge is visible, the effectiveness is debatable. Both the control period as well as the treatment period did not attain this number with respectively 26,6% and 38,8% of flushes being upward. Comparing this to a truthful ratio of flushes that should be upward as a part of the total amount of flushes is fairly difficult, as it is strongly dependant on factors including but not limited to age, gender, diet, and overall health of a particular human being. There are however sources that state a daily urination to defecation (U/D) ratio of 60/40 (Zakaria et al., 2018), a U/D of 2:1 (Arocha & Mccann, 2013) or a U/D of 3:1 (Veritec Consulting Inc., 2002).

From this single example it can be concluded that prompting techniques might be effective to a certain extent when implemented in order to accomplish water reduction on the toilet. However,

there are severe limitations regarding the lack of further research to either confirm or falsify these hypotheses. Furthermore, for this same reason, it is not possible to elaborate on the other nudging techniques provided by the aforementioned frameworks.

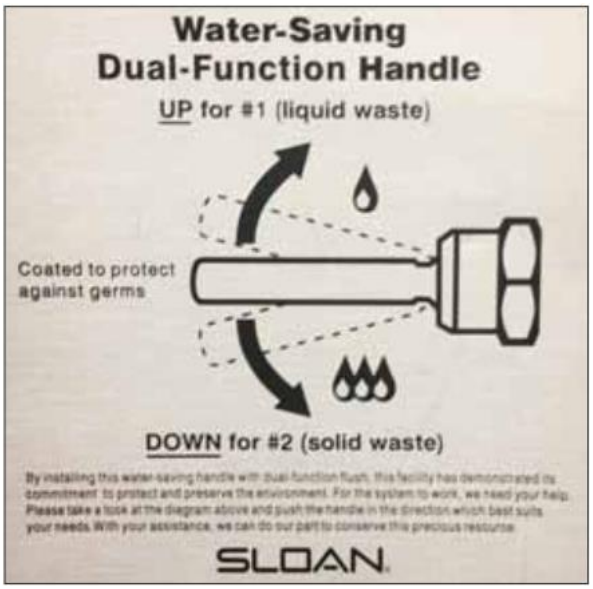


Figure 6: This figure was provided by Arocha and Mccann in 2013, displaying the wall plate being used in the treatment period of their experiment.

2.3 State of the Art

This section discusses the State of the Art research, which consists of existing installations, products or technologies that could be of use as a means of inspiration or starting point for this research. First, a solution for measuring the water usage of a toilet will be presented. Thereafter, several already existing nudging techniques in the toilet domain are introduced. Lastly, a couple of water use insight products and awareness raising tools for correct toilet button usage are presented.

2.3.1 Button press sensing

In order to record flushing data, it is necessary to know how many times either of both flushing buttons is being pressed within a certain measuring timeframe. A technique for sensing when which button is being presses was already thought of by Kadijk (2021). He came up with implementing two Grove Piezo Vibration sensors, one on each button. Together with a SparkFun ESP32 Thing microcontroller and RF Link Transmitter the pressing of buttons could be sensed, recorded and transmitted without compromising the toilet user privacy. Kadijk reported on the working of his button press sensing setup that the sensor works fine for most of the time. However, the sensitivity could be higher since it did not always respond when the button is pressed in a softer than usual way.

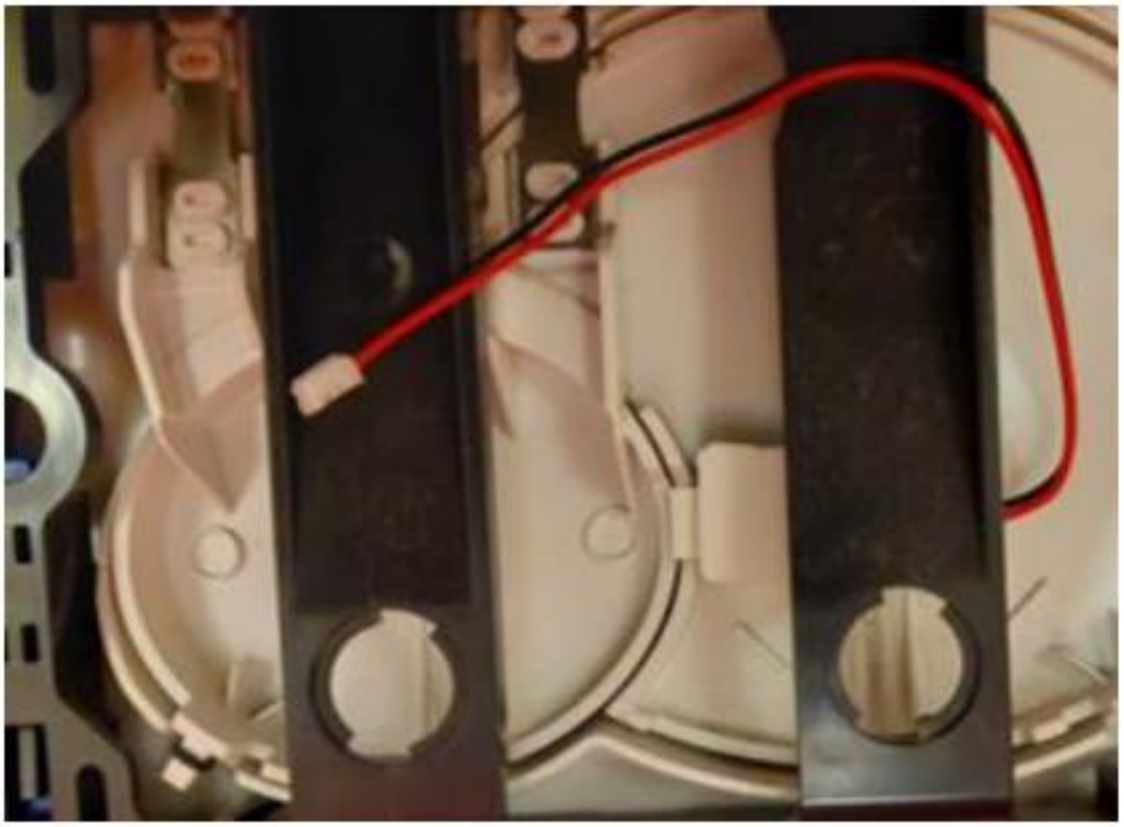


Figure 7: Implementation of a Piezo sensor behind a toilet button in order to sense when that button is being pressed. (Kadijk, 2021)

2.3.2 Nudging at the toilet

Several concepts regarding nudging at the toilet already exist. Below, these are listed and explained further.

2.3.2.1 Fly in the toilet

The fly in the toilet (Evans-Pritchard, 2013), as seen in Figure 8, is a well-known concept which is widely in use. It can be placed in a regular toilet bowl as well as in a urinal. The problem this fly is trying to prevent is the potential messiness of urinating whilst standing upright. The fly gives a certain target to aim the urine stream at. By hitting the fly, no urine will be splattered back or up leading to a tidy toilet. The nudging technique used in this case is priming (as seen in chapter 2.2.2.) The fly acts as a visual cue for the user. Evans-Pritchard quotes Aad Kieboom, the introducer of the first urinal fly at Schiphol Airport, on the effectiveness of the fly in the toilet on the reduction in spillage. Kieboom mentions a ‘very empirical’ 80% reduction in spillage and a subsequent 8% reduction in cleaning costs. Klaus Reichardt, the inventor of the waterless toilet, on the other hand, is more sceptical. He estimates roughly a 50% reduction in spillage.

Figure 8: Nudging technique of a fly in the toilet/urinal. (Evans-Pritchard, 2013)

2.3.2.2 Put the toilet seat down sticker

Related to the principles of conveying norms and using salience as described by Byerly et al. the sticker visible in Figure 9, is to remind people to put down the toilet seat (Lalas, 2017) is implemented. The placement of the sticker is such that it is very striking when needed, whilst not visible when not needed. The design is bold and captures attention, along with the downward pointing finger the expected behaviour is clearly conveyed. Any evidence on the effectiveness of the "put me down" sticker however, is unfortunately unknown.

Figure 9: Nudging technique of a sticker on the underside of a toilet seat, as a reminder to put it down. (Lalas, 2017).

2.3.2.3 Bad nudging at the toilet

As well as good and working nudging examples on the toilet, there are also bad examples. The very size of the flushing buttons which are central in this research are an example of bad nudging, as stated by iNudgeyou (2012). Since the small flushing button is the one that should be used the most often, as became clear in chapter 2.2.4, one would expect the small flushing button to be the most prominent of the two buttons. This reasoning falls back on the principle of sizing as identified in chapter 2.2.2. The effect is clearly visible in Figure 10 as well, the wear and tear on the big flushing button is clearly more significant than that of the small flushing button. While there could be argued that the big flushing button insinuates a big flush and the small flushing button insinuates a small flush, this is categorically untrue from a nudging point of view.

Figure 10: Bad nudging at the toilet by incorrect usage of sizing, visible by wear and tear. (iNudgeyou, 2012)

2.3.3 Water use insight

In the next piece, a few devices that provide insight in water usage will be discussed. By knowing which techniques there are for providing users with water use insight, inspiration for possible solution aspects can be obtained.

2.3.3.1 Showerhead that tells consumption and temperature of water

The smart shower head, depicted in Figure 11, shows in real time the amount of water that has passed through it since the beginning of the shower (Waterhawk save water save money, 2016). Additionally, it shows the live temperature of the shower. This is useful because you are immediately aware of the moment the shower is hot enough to start showering. Therefore, the amount of water that is wasted before the shower is minimised.

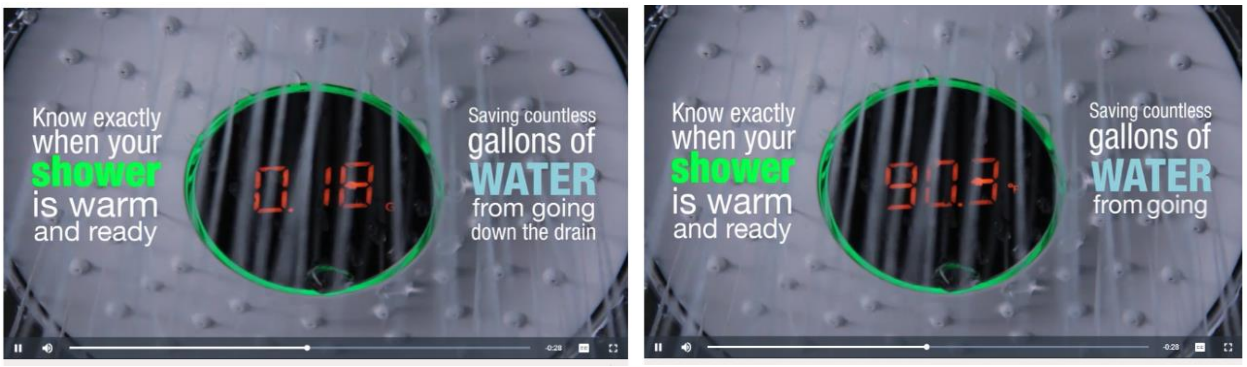


Figure 11: Smart shower head. (Waterhawk save water save money, 2016)

2.3.3.2 Smart home water monitoring

The Flume Water Monitor device can be installed around your plumbing and gives real time information about your water usage by means of insightful statistics (Flume, 2018). The device and the accompanying app are shown in Figure 12. When using the Flume Water Monitor, there is no need for installation, making it an easy-to-use solution for overall residential water tracking. The statistics compare usage against the average; therefore, they are making use of norm conveying nudging techniques.

Figure 12: Smart home water monitoring device. (Flume, 2018)

2.3.4 Educational tool for toilet button usage

The next section provides an educational tool that has already been implemented to get people to use the toilet buttons correctly.

2.3.4.1 Meme screen

As was mentioned before, this research has been done in 2021 by Kadijk in a similar fashion. He came up with a solution to educate on correct button usage with his awareness improving device. The device also had an entertaining function, therefore the interaction would last longer in de mind of the users. The solution thought of by Kadijk was to place a meme screen above the toilet. This device can be seen in Figure 13. These memes would then convey the information regarding correct button usage to the toilet user. The effectiveness was measured by a survey amongst the people that had interacted with the meme-screen (n=19). It was reported that the surveyed participants deemed the awareness of the user to be raised with an average score of 3.9 where 1 meant “fully disagree” and 5 was “fully agree”. Additionally, the participants were asked if they plan on using the small button more often from now on. Of the participants, 31.6% indicated that they would do so.

Figure 13: The meme screen, a solution for making toilet users more aware of their flushing behaviour. (Kadijk, 2021).

2.4 Conclusion & Discussion

It is proven that there is relevance in trying to improve the toilet flushing behaviour at the University of Twente. This is confirmed by the survey that was held at the University. When considering the survey results, it can be seen that 14.7% of people is flushing the toilet without thinking about it. Furthermore, it can be concluded that for 50.8% there is something to gain regarding water conservation as a result of their flushing behaviour. Also, 11.5% of people was not aware of the difference between the toilet buttons. These results are partly echoed by research on the awareness on the difference between flushing buttons.

When reviewing the literature on nudging frameworks there are several which display a very complete overview of possible nudging techniques. It can also be concluded that the available frameworks share many similarities amongst them. When scoping down to pro-environmental nudging frameworks, there are little differences to be noted compared to the general nudging frameworks. A few somewhat universally applicable techniques are identified as the usage of commitments or defaults. When looking into visual focussed nudge design, both prompting and priming are mentioned by multiple researchers and are therefore interesting techniques to take into consideration. Also, the distinction between conveying norms and the use of moral suasion is explained by Carlsson et al.. Looking at nudge usage to accomplish reduced water usage resulted in a reduction in the variety of nudge techniques to be used successfully compared to nudging in general or pro-environmental sense. Both setting commitments and the conveying of norms have shown to be effective. Next to that, using salience has also shown to be effective in some cases as well as educating and financial nudge strategies. For the specific case of nudge usage to accomplish toilet water reduction there is little existing research. However, there are some indications that prompting might be somewhat effective in this case.

Regarding the state of the art, there are examples of devices or products that are interesting to use as inspiration when designing the concept. The pillars that the solution should include, being nudge usage at the toilet, insight in water usage and education on correct toilet button usage are being mentioned and provided with examples. Also, a manner of registering which button is pressed to evaluate the effectiveness of the implemented device is given.

3 Methods and Techniques

This chapter will go into the methods and techniques that will be used in every step of the design process of this research. First the design process model that is being used in this research will be introduced. Thereafter, the individual phases of the research will be addressed one by one, describing the steps to undertake in order to obtain information to advance in the process of designing solution.

3.1 Design process model

In this research, the Creative Technology design process as provided by Mader and Eggink is being used (Mader & Eggink, 2014). A schematic overview of this design process is depicted in Figure 14. The Creative Technology design process is based on the identification of four phases in design, those being Ideation, Specification, Realisation and Evaluation respectively. Whitin each of the first three of the identified phases, a strategy of divergence followed by convergence is being used. This is done in order to first broaden the design space to allow for creativity to flourish, thereafter the design space is restricted in order to work towards a solution. After the completion of each of the four individual phases, a strategy of implementing the obtained feedback from the next phase to one of the previous phases is pursued.

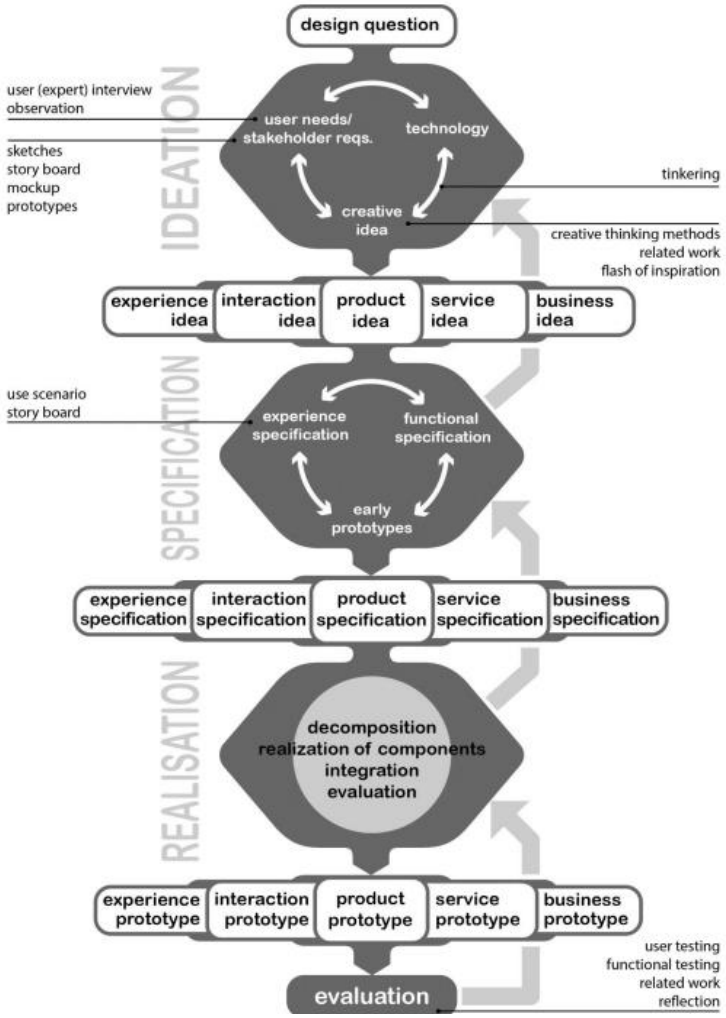


Figure 14: This image was provided by Mader and Eggink in 2014. It shows a schematic overview of the Creative Technology design process.

3.2 Ideation

During the ideation phase, the design question is taken as an input. The design question is in this case a slightly altered version of the main research question, which is formulated as follows: 'How can nudging be implemented to influence the toilet flushing behaviour of the Zilverling community?'. To start of the ideation phase, it is first required to identify all stakeholders involved and thereafter perform an analysis on the identified stakeholders.

3.2.1 Power-Interest evaluation

To evaluate the involved stakeholders and identify their role and influence in the project, The widely used Power-Interest evaluation is being performed, as first identified by Ackermann & Eden (Ackermann & Eden, 1998). In this Power-Interest matrix, an overview of all stakeholders is given in order to clearly portray their involvement in the full research and development process.

The matrix is divided into four quadrants to give a general understanding of the attitude the research should have towards a stakeholder in the matrix. The empty matrix is visible in Figure 15. The quadrants this Power-Interest matrix is comprised of are:

1) Monitor – The stakeholders with little power and little interest in the research.
2) Keep informed – The stakeholders with little power but a considerable interest in the research.
3) Keep satisfied – The stakeholders with considerable power but little interest in the research.
4) Manage closely – The stakeholders with considerable power as well as considerable interest in the research.

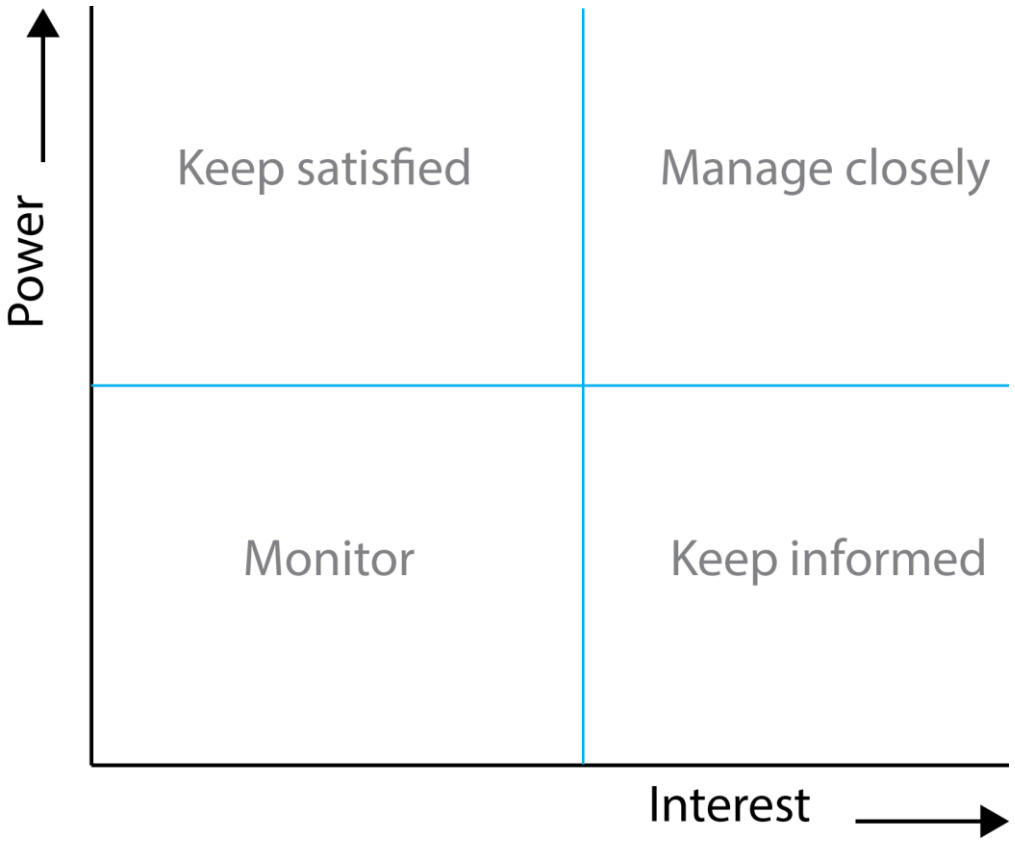


Figure 15: Empty Power-Interest matrix.

3.2.2 Stakeholder requirements

Once the stakeholders are known, and their respective involvement is analysed by the power-interest matrix, the requirements of each of the stakeholders must be discovered. This is done by interviewing the stakeholders which have to be managed closely, as their power and interest in the research is substantial. Other stakeholder requirements are obtained otherwise, either directly or indirectly. Thereafter, the MoSCoW method will be applied to categorise these requirements.

3.2.2.1 Interview

In order to obtain important information, such as motives, objectives and requirements, from the most powerful and interest-holding stakeholders, these stakeholders will be interviewed. Dependant on the stakeholder, a different interview style will be chosen.

In this case, the client is such a stakeholder and will be interviewed semi-structurally. This entails a structured list of questions to gain all important information from the client, whilst still having the possibility and freedom to further expand upon questions and ask follow-up questions in case of particularly interesting answers.

Another case of such key stakeholders are the main researcher and the research supervisors. They will confer on a weekly base with each other in a loosely structured manner to accompany for their own requirements, as well as to tend to the interests of other stakeholders. Furthermore, they discuss ideation ideas amongst themselves to generate concepts.

3.2.2.2 The MoSCoW method

To distinguish an especially prioritize between the identified stakeholder requirements, the MoSCoW method is being used (Clegg & Barker, 1994). This method is designed to categorise stakeholder requirements in four distinct groups. Those groups are:

1) Must have
2) Should have
3) Could have
4) Won't have

"Must have" requirements indicate the requirements which should minimally be met to let the project succeed. "Should have" requirements are important but not vital to the project, these are unfortunate when left out, but without them it is still a viable project. "Could have" requirements have less importance than "Should have" requirements, they are still wanted, but have less impact if left out. "Won't have" requirements are specifically excluded to manage expectations or to define the scope of the project.

3.2.3 Individual brainstorm

To turn the design question together with all obtained stakeholder requirements and additional information into an interaction idea, a creative thinking method in the form of an individual brainstorm by the main researcher will be performed. The focus of this brainstorm is to identify a relevant technical aspect to incorporate into the project. During this individual brainstorm, related work as well as the background research will be used as an inspiration. The results of this brainstorm will be visualised into a categorised mind map of ideas.

3.2.4 Concept generation

From the created mind map by brainstorming, there will be moved to concept generation. This will be done incremental, by first performing a rapid paper prototyping session. In this session, a template will be used to quickly draw multiple mock-up ideas in the template picture. To switch quickly between ideas and to easily discard unwanted concepts, this rapid paper prototyping method will be used. After the rapid paper prototyping session, the concepts will be redrawn in a more sophisticated method as well as further thought through. Every concept that is further developed will also be given a short interaction scenario in order to discover the possibilities of that particular concept. Once this sophisticated concept generation phase is worked out, there will be chosen one final concept or a final combination of concepts. This concept will subsequently be developed even further and will be provided with a short concept story board to further explain the interaction scenario. Finally, by means of a group brainstorm, consideration will be given to the design of the nudges according to the stakeholder requirements.

3.3 Specification

Once the stakeholder requirements, technological aspect brainstorm and creative concepts generation have distilled down to a final interaction idea, the specification of that interaction idea can be executed. The specification will be achieved in a couple of steps. Firstly, identifying distinct relevant persona and the way they interact with the final concept. Secondly, the stakeholder requirements will be translated into system requirements. Thirdly, the functional architecture along with a flow diagram will be drawn up. Lastly, a final selection of nudges will be specified.

3.3.1 Interaction scenario description

To design and specify the complete interaction, it is initially vital to pinpoint relevant persona to act as exemplary users. This will be done by considering which character trait or demographic is distinguishing when interacting with the envisioned final concept. When these personae are identified, an extensive persona description will be given according to the framework provided by the Interaction Design Foundation (Interaction Design Foundation, 2017). Thereafter a comprehensive storyboard and interaction scenario of each of the identified persona will be given in order to lay out the different possible interactions one could have with the final concept.

3.3.2 System requirement specification

The stakeholder requirements that were inventoried during the ideation, will be translated into system requirements in order to specify the exact working of the eventual interaction prototype. These system requirements will be specified into functional requirements and non-functional requirements. These requirements will be categorised using the MoSCoW method as stated in chapter 3.2.2.2.

3.3.3 Functional architecture

To understand the working of all functionalities of the prototype, a functional architecture will be drawn up. This is done by an incrementally deeper levelled decomposition. Hereby, user behaviour will be taken as input and prototype reaction to the user input will be taken as output. The internal workings of the prototype will be subdivided into blocks of which the inter-block interactions are made clear. Blocks of which the full working is not entirely clear in a given decomposition level, will be expanded upon in a deeper level.

3.3.4 Nudge specification

When the full working of the prototype is specified, it is further important to specify which nudges are going to be used and how they are designed. In the nudge specification the nudge design choices of the ideation chapter will be narrowed down to a final selection of nudges.

3.4 Realisation

Once the specification is completed, the prototype will be realised. The realisation is guided by the system requirements and functional architecture from the specification chapter. The initial focus will be on satisfying the requirements that have been given a 'Must' categorisation in the specification. Thereafter, efforts will be made to fulfil the 'Should' category requirements as well. There will be two separate periods of data collection which will eventually be compared to one another. These two periods are referred to as Phase 1 and Phase 2. The realisation of Phase 2 builds further upon the realisation of Phase 1, therefore the way of approach will be to first focus on realising Phase 1. Once Phase 1 is realised, a transition will be made to Phase 2. In both phases, the operation of individual components will first be ensured, after which the components will be combined into a final prototype. The realisation chapter will discuss the components used, the embedded software, the implementation and ultimately the data collection.

3.5 Evaluation

When The Button Nudger is made and the data for both phases is collected, the obtained data will be evaluated. This will firstly be done per phase, after which the phases will comparatively and statistically be evaluated. Since no consent will be asked during any of the data collection phases, the rationale for doing so will be explained in section 3.5.1.

Conclusively, a user evaluation will be performed during the last stages of the data collection of Phase 2. This user evaluation will make use of a five-point Likert scale to assess the attitudes and views of the respondents toward the Phase 2 system (Likert, 1932). The Likert scale will consist of the following attitude levels:

1) Strongly disagree / Strongly negative
2) Disagree / Negative
3) Neutral
4) Agree / Positive
5) Strongly agree / Strongly positive

3.5.1 Consent

During both the Phase 1 and the Phase 2 data collection, no information will be given beforehand. Also, the participants will not be asked to explicitly give their consent. Participants will not be briefed directly afterwards, however, they will be briefed after the data collection is finished. The reason for this is that it is absolutely necessary to not influence the participants decision making before interacting with The Button Nudger.

Giving information beforehand could help participants to understand the reason for the data collection and therefore could influence their behaviour in another way than purely interacting with The Button Nudger. This phenomenon is better known as priming (Schacter & Buckner, 1998). To quote Schacter & Buckner: Priming is "a nonconscious influence on current performance or behavior". This would subsequently reduce the truth value of the collected data.

Regarding consent of the participants, there will always be another (or multiple other) toilet cubicle(s) available in the same toilet facility. Refraining from participation can be done by choosing another cubicle. Passive consent is chosen in this case for the reason that active consent will prime the participants, just as providing information beforehand. The anticipation of an experiment which is taking place can also have an influence on the participant other that purely the interaction with The Button Nudger. Which again, would be undesirable.

For the fact that the interaction with The Button Nudger will have to work for multiple times for the same participant, it is chosen to not immediately debrief participants after an interaction. After all, it is probable that the same participant will visit the same toilet several times in the timeframe of the data collection. This debriefing will again result in this participant visiting the toilet next time with prior knowledge, and thus primed. Instead, the choice is made to provide a debriefing in the form of a poster with information and results of the experiment at the end of data collection.

After deliberation, the EEMCS ethical committee (University of Twente, 2023b), approves of this course of research.

4 Ideation

Throughout this chapter, the different stakeholders in this project will first be identified. Thereafter, these stakeholders will be analysed, and their individual requirements will be listed. Then, based on these requirements a brainstorming session will be held and elaborated upon, after which the generation of a number of concepts will be worked out. Finally, the final concept will be presented.

4.1 Stakeholder identification

To ensure that the interests of all involved stakeholders are taken into account, these stakeholders first have to be identified. As such, they are summed up in Table 1 as well as explained why these (groups of) people are stakeholders in this research and its possible outcomes.

Table 1: Stakeholder identification.

Stakeholder	Role	Name	Stakeholder abbreviation
University of Twente Campus Facility Management	Client	Brechje Marenchal MSc	C
Zilverling toilet facility users	Main users	Various	U
Research supervisors	Supervisors	Ir. Ing. R.G.A. Bults Dr. K. Zalewska	S
Zilverling team manager	Building responsible	Ivo Bijker Michel ten Bulte	T
Campus cleaning personnel	Maintenance	Asito	M
Main researcher	Researcher	C.J.G. Verstappen	R

4.2 Stakeholder analysis

To get a better understanding about the identified stakeholders, they will be analysed. This will be done by firstly addressing them individually. Thereafter, an analysis will be executed using the stakeholder mapping methods described by Mendelow (1991). A Power-Interest plot will be provided to map the stakeholders accordingly.

4.2.1 University of Twente Campus Facility Management

The University of Twente Campus Facility Management (CFM) is the client of this project. They will decide on the eventual possibilities within the project regarding implementation of a solution. The CFM has great interest in accomplishing a reduction of water at the University of Twente through a variety of means, of which toilet water is one. They lay out their ambitions in their Sustainability policy driven by the Sustainability, Energy & Environmental (SEE) programme (University of Twente, 2023a). Regarding water, they strive to have a zero-water footprint by 2030, as well as a closed water cycle. The power of the CFM is significant, in the sense that their approval is consequential in the pursuit of any concepts that want to be developed further.

4.2.2 Zilverling toilet facility users

The second, and perhaps most important, stakeholder are the users of the toilets and therefore the persons that will interact with the eventual solution. These users want to be able to use their toilet facilities as they are used to. Their approval or disproval of the worked-out concept that is going to be implemented is going to decide whether or not it will be an effective intervention. The design of the implanted solution as well as the kind of nudge usage will have to be tailored to this group of stakeholders in order to achieve the desired outcome of a significant reduction in toilet water usage.

4.2.3 Research supervisors

Another important stakeholder group is the two supervisors that guide this research. They are closely involved in making research related decisions as well as structural project decisions. They do not directly benefit from a positive outcome of the research; however, they hold great interest in the research topic, and they could merit indirectly from the results of the project.

4.2.4 Zilverling team manager

The team manager of the Zilverling is responsible for the operational management in the building where the testing of the solution will take place. His approval is necessary before implementation is possible. He will also instruct the technical service workers if any disassembly of the current facilities is needed to implement any technologies. His involvement is of a short duration, since only the assembly and disassembly of the installation will require his aid. His power is relatively low, as he will, given he will voice his own concerns, follow the order of the CFM. His interest is also relatively low, as he does not harvest any direct benefits from a successful research execution.

4.2.5 Campus cleaning personnel

A stakeholder that will interact with the eventual solution on a different level is the campus cleaning personnel. These people will clean the toilet facilities, and therefore also the solution that will be put in place. It is necessary to take into account their usual routines in use of cleaning products and liquids as to be sure that the solution will be durable and unable to be affected by these products. Also, the routine of cleaning the toilet facility must not change significantly so that the cleaning personnel is able to go about their job as regular. Their power within the project is low, as their interaction with the solution is occasional and they do not have a direct say in the design or function of the solution. Their interests are safeguarded by the CFM and the team manager. Their interest is relatively low and solely cleaning related.

4.2.6 Main researcher

The researcher of this project has great interest in a positive conclusion of this research. Not only since performing this research will enable the researcher to graduate, the researcher also holds a personal interest in innovative ways of increasing environmental awareness. As all research decisions are made or co-made with the main researcher, he holds great power within the research.

4.2.7 Power-Interest evaluation

To obtain an understanding of the different stakeholders and how they relate to each other, as well as assessing their influence on the project, a power-interest matrix is provided in Figure 16. They are addressed using the abbreviations established in Table 1.

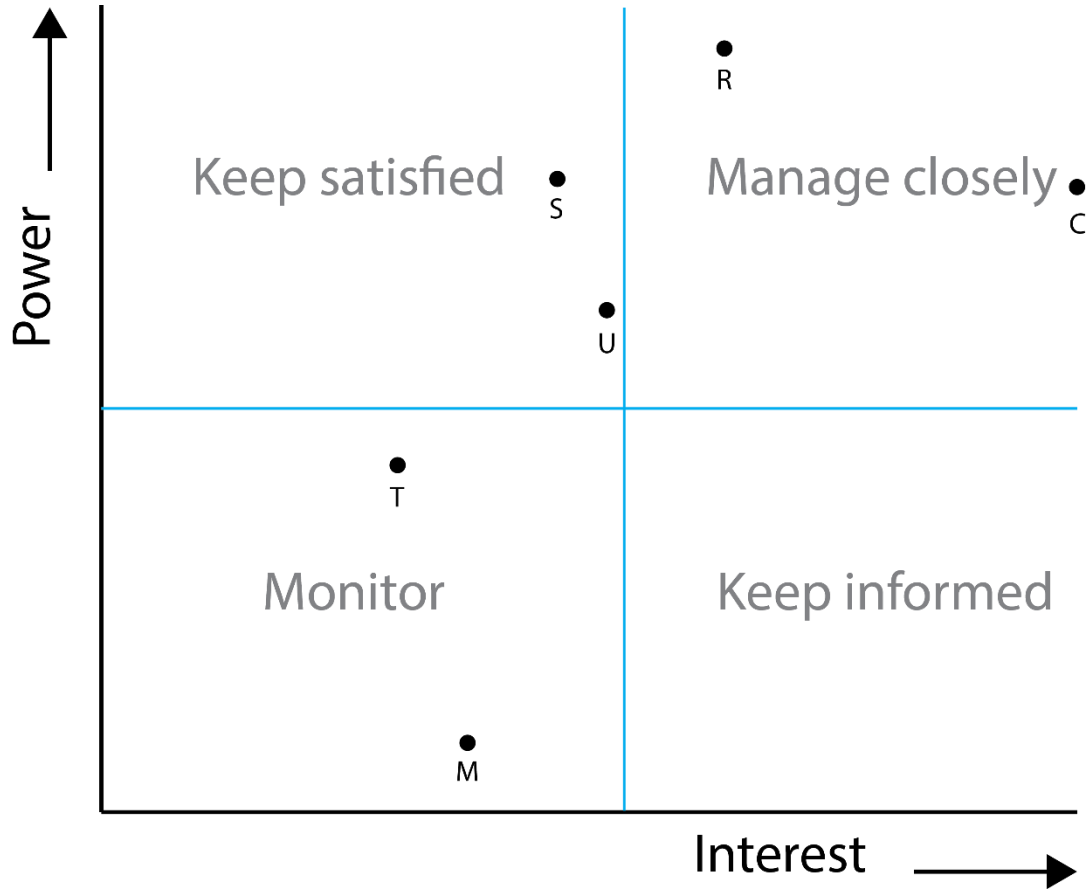


Figure 16: Power-Interest matrix of the identified stakeholders.

4.3 Stakeholder Requirements

Now that the stakeholders are known, and their level of involvement in the project is made clear, the stakeholder requirements can be listed. These requirements are categorised by 10 different values. All requirements are provided with an ID for referencing, the abbreviation of the stakeholder who holds a vested interest in this requirement, and a priority on the MoSCoW scale as explained in chapter 3.2.2.2. All requirements are given in Table 2.

Table 2: Stakeholder requirements.

Value	Requirement	Requirement ID	Stakeholder	Priority (MoSCoW)
Privacy	Does not violate privacy of the user	A1	U, S	Must
	Does not recognize what is in the toilet bowl	A2	U	Must
Intrusiveness	Does not obstruct the user	B1	U	Should
	Is not unnecessarily distractive	B2	U	Should

	Is not discriminatory	B3	U	Must
	Is easy to use	B4	U, R	Should
Compatibility	Does fit the current Zilverling toilet facilities	C1	C, T	Must
User interaction	Is engaging	D1	R, S, U	Should
	Is interesting for multiple interactions	D2	R, S, U	Should
	Uses humour as an engagement strategy	D3	R, S	Could
Hygiene	Does not have to be touched to use	E1	U	Could
	Is easy to clean	E2	M	Should
	Is resistant to cleaning, cleaning products and water	E3	R	Must
Maintenance	Does work unaided when in use	F1	R, T	Must
	Is able to power itself or is compatible with the available power sources	F2	R, T	Must
Installation	Has an installation time of < 1 hour	G1	C, T	Should
	Does not require permanent alterations to the current button panel and/or toilet itself	G2	C, T	Must
	Does not leave permanent changes to the current facilities when removed	G3	C, T	Must
	Is installed at a quiet time	G4	C	Should
Behavioural influence	Does use nudging techniques to influence user behaviour	H1	R, S	Must
	Does use commitment setting nudging techniques	H2	R, S	Won't
	Does use norm setting nudging techniques	H3	R, S	Must
	Does use salience nudging techniques	H4	R, S	Won't
Data acquisition	Is accurate in recording which button was pressed	I1	R, C	Must
	Is able to distinguish which flushing data fits which toilet cubicle. (In case of multiple data transmitters)	I2	R, S	Should
	Does save the time a button press is recorded	I3	R, S	Should
Technological	Does use presence sensors based on the principle of ultrasonic waves	J1	R	Must

4.4 Brainstorm

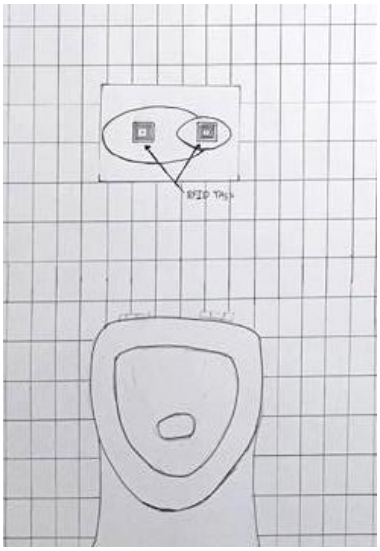
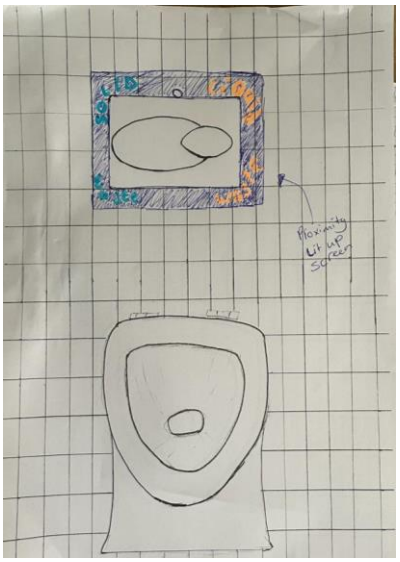
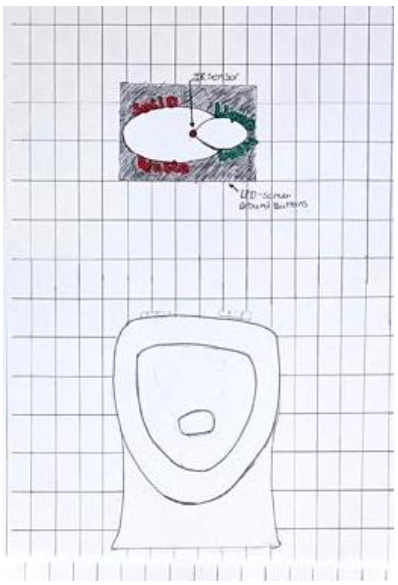
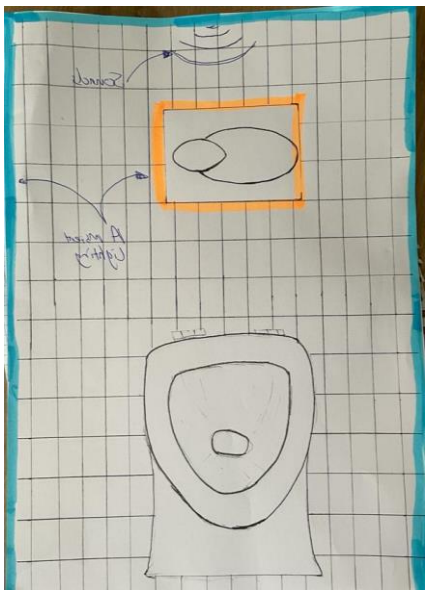
To explore the possibilities for possible concepts, the background research as well as the stakeholder requirements are taken into consideration in the execution of an individual brainstorm session. The result of this brainstorm has taken the shape of a mind map. In Figure 17, this mind map is depicted. From the mind map, it becomes clear that there are multiple different text messages possible to display as a nudging technique. These text messages fall in the nudging categories discussed in the background research, or are a combination of multiple of these techniques. The usage of icons and lighting are also explored as forms of nudging that could be implemented. Further focus was laid on detecting user presence and the possibilities to grab the attention of the user.

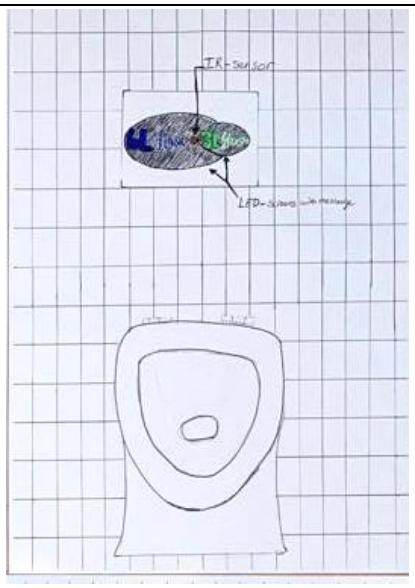
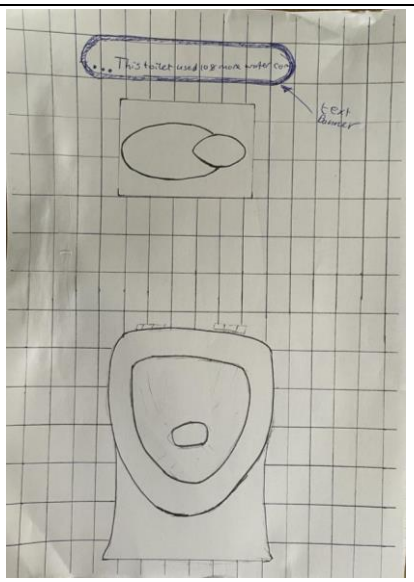
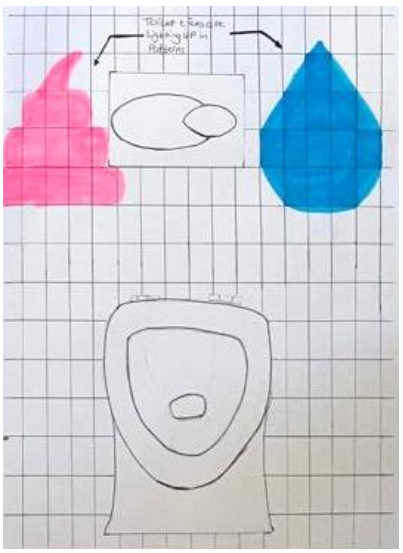
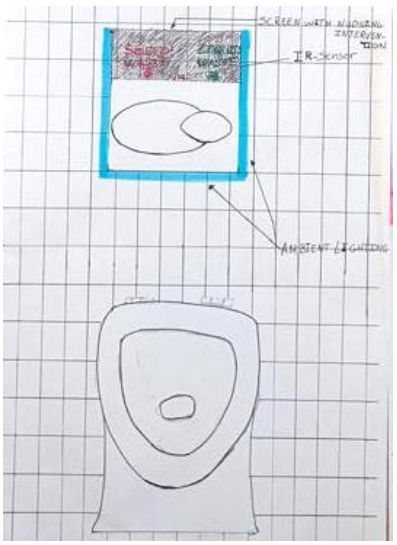
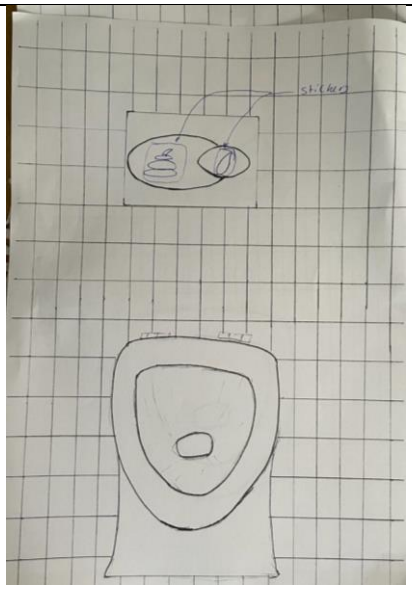
Figure 17: Ideation mind map.

4.5 Concept generation

Based on the ideas and inspiration gained from the brainstorm, and with the stakeholder requirements in mind, concepts could be developed. At first, several hand drawn sketches were made to get a basic idea of the concepts. Thereafter, more sophisticated images were made to increase the clarity of the concept and the interaction, as well as providing a more aesthetically pleasing image. An overview of the hand drawn concepts is provided in Table 3.

Table 3: Concept sketches.

Concept ID	Sketch		Concept ID	Sketch
3a			3f	
3b			3g	

3c	 IR-Sensor		3h	 This toilet used for more water con... LED Dimmer
3d	 Toilet Flusher lighting up in Patterns		3i	 SCREEN WITH NUDGING INTERVENTION IR-Sensor AMBIENT LIGHTING
3e	 SWITCH			

4.5.1 Close proximity communication

The first concept, based on sketch 3a, is the placement of close proximity communication devices on or near one or both toilet buttons. This can be seen in Figure 18. Close proximity communication will be able to generate a connection with the phone of the toilet user through already build in readers in the phone. The user will be encouraged to find out what the information behind the close proximity communication has to tell them. The user has to tap the close proximity communication device or sticker with their phone to gain access to the information behind it. The information could include Nudging messages of any kind which will be displayed on the phone of the user. However, as stated in the stakeholder requirements, solely norm setting nudges will be used. These Nudging messages would be designed to make the user think about their actions regarding toilet flushing.

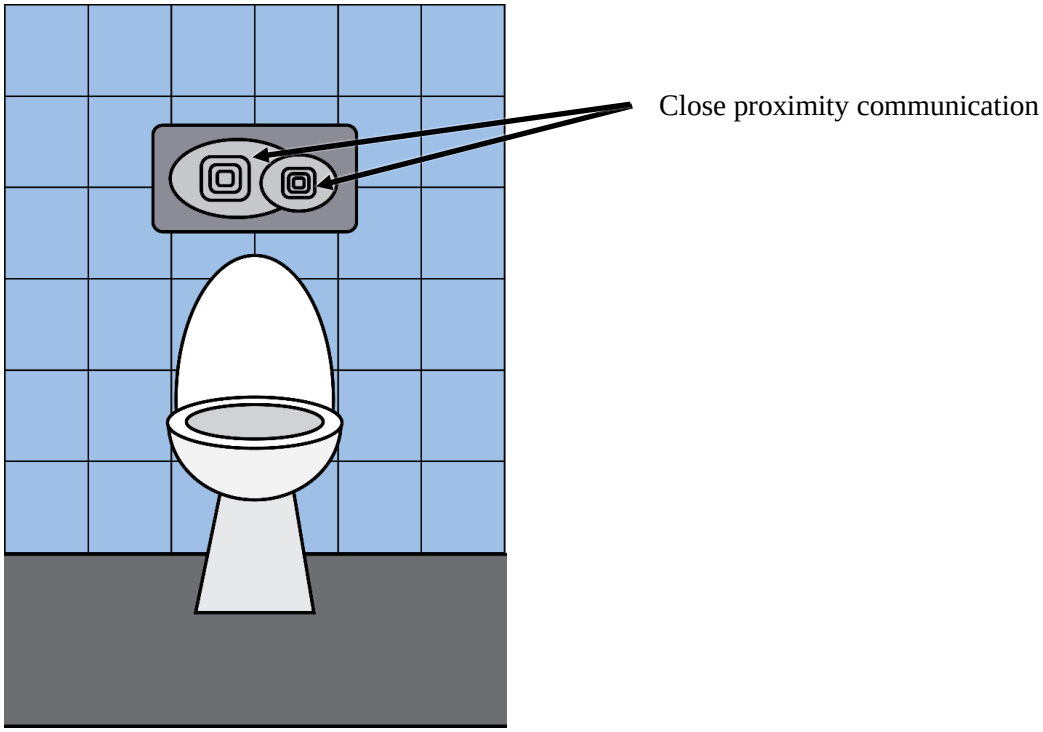


Figure 18: Toilet buttons equipped with close proximity communication.

4.5.2 Stickers

Concept 3e is making use of stickers on the toilet buttons. The usage of stickers could be a really simple, yet effective method of conveying the message to the user. Simply placing an icon of the kind of defecation that needs to be flushed down for both individual buttons will help the user to be nudged in the right direction. The nudging technique that is used here is a combination of salience usage and norm setting. For users who are unaware of the intended usage of the dual-flush system, these stickers would give information on correct button usage, in which case it could also be regarded as educational nudge usage. The stickers are in the direct line of sight when reaching for the flushing button, therefore it will nudge the user at the moment of making the choice between either of the buttons into potentially a different option. One could also think about sticker usage with a different image in the case that defecation-imitating icons are deemed too explicit. In this case, the type of nudging technique might change as well, dependant on the contents of the sticker image. Concept 3e is visible in Figure 19.

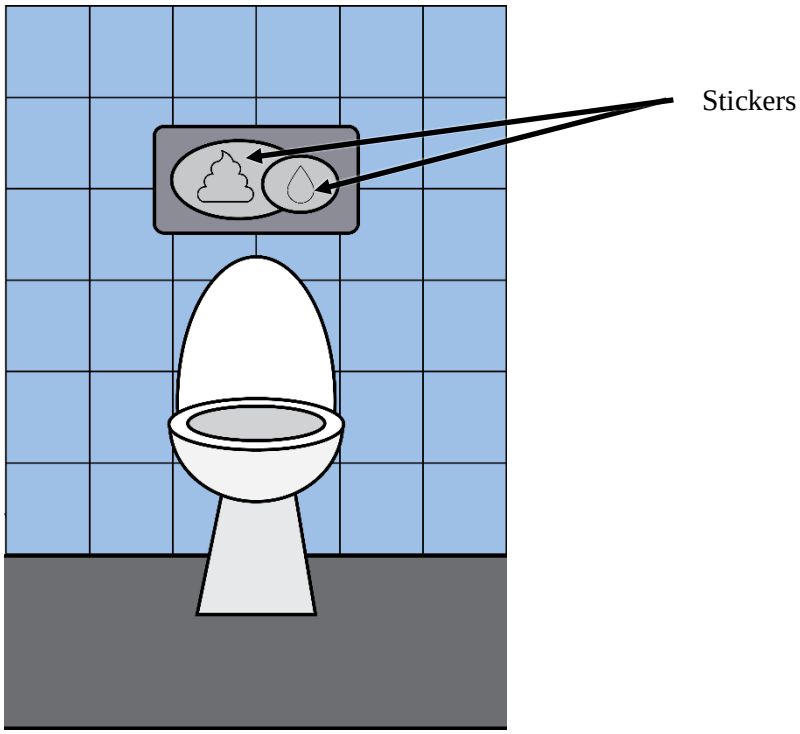


Figure 19: Toilet buttons equipped with stickers.

4.5.3 Ambient light/sound experience

Concept 3g is the implementation of an ambient experience by making use of lighting and sounds. An example of how this might look is depicted in Figure 20. The sounds will be used as a voice to convey certain messages to nudge the user. Any of the non-visual techniques could be used here, for instance conveying commitments or the required norm setting nudges. The lighting will be used to set a certain mood, perhaps to relax the user or to let the user focus. Lighting will also be used as an indicatory tool. Areas will be highlighted or consciously not highlighted at certain moments during the interaction. The ambient lighting on the walls will be triggered when the user enters the toilet cubicle, sensing the presence of a person will be done through the same sensor as the general lighting makes use of. With some delay after the ambient wall lighting turns on, the sound system will activate to auditorily nudge the person while on the toilet. The ambient lighting around the buttons will activate through measuring proximity to the users reaching hand, to give a final cue. Different colours will be used as indications for the buttons. Here it is important to be aware of the cultural differences in colour perception, the colours should be picked such that they cannot be misinterpreted.

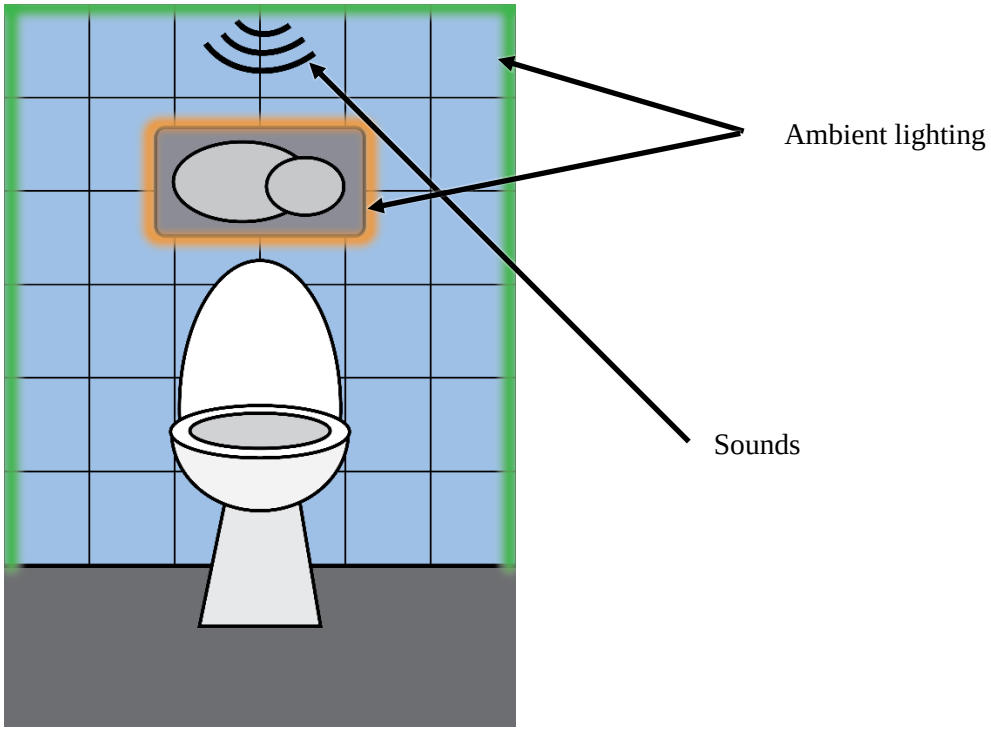


Figure 20: Ambient light/sound experience.

4.5.4 Proximity lit up screen

The next three concepts, 3b, 3c and 3f, can be grouped, as their basis is the usage of a screen that is placed in the line of sight of a user that is in the act of flushing the toilet. This screen could be placed at several spots in said line of sight, these possibilities are shortly addressed below. The idea of this screen is that it only displays a welcome message during the act of going to the toilet. However, when the user is done, the screen will have changed to a Nudging message. The user will be confronted with this message before the flushing action takes place, leading to their attention being drawn to the screen.

The surprise of the change in the contents of the screen could possibly also make the memory of the interaction last longer. The contents of what is on the screen could be any message that is making use of a nudging technique that is portrayable on a small screen, in this case the norm setting nudge text as required by the stakeholders. The type and content of these Nudging messages would be the same for each of the three below mentioned options. These messages could also be alternated to maintain the novelty effect when the interaction is experienced a next time.

4.5.4.1 On the buttons

The first place where this screen could be implemented is on the toilet buttons itself, as is the case in concept 3e. The toilet button is what the user is reaching for when trying to flush, thus in this concept, the interaction would be in the direct focus spot of the user. An example of this is given in Figure 21. To maintain hygienic standards in this concept, plexiglass caps will be placed over the screens. In this case, cleaning the buttons is similar to when there would not be an installation in place.

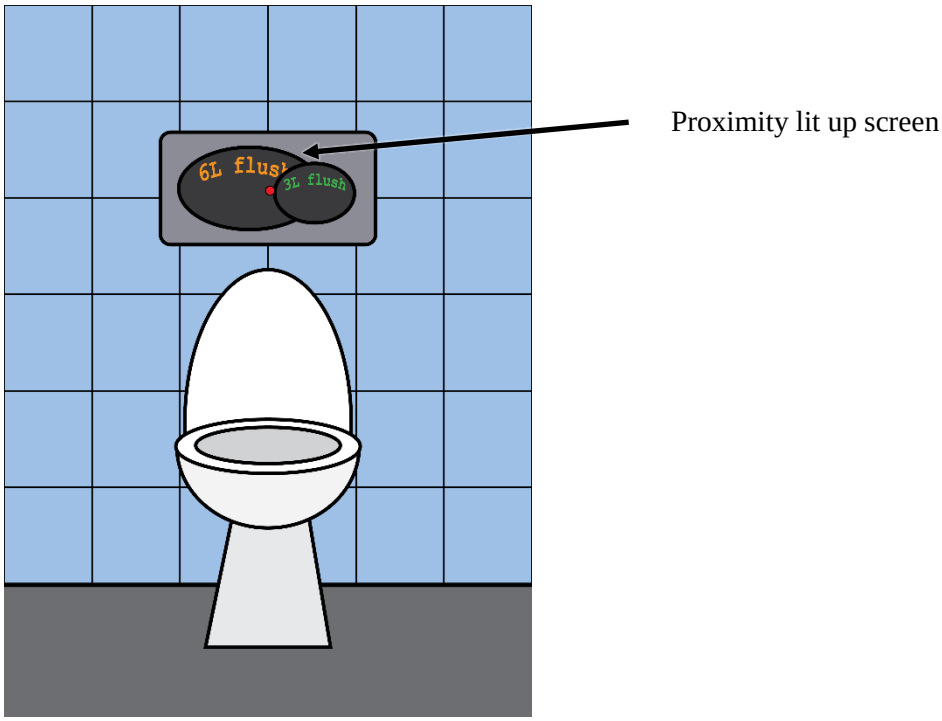


Figure 21: Toilet buttons with an IR-sensor (shown in red) integrated, and LED screens on the buttons, displaying a Nudging message.

4.5.4.2 Around the buttons

Another place where this proximity lit up screen could be placed is on the flushing panel, around the buttons, like concept 3b. This is depicted in Figure 22. This would prevent that the user has to physically touch the screen while using the flushing buttons. The further working of the system is similar to the one that is placed on the buttons.

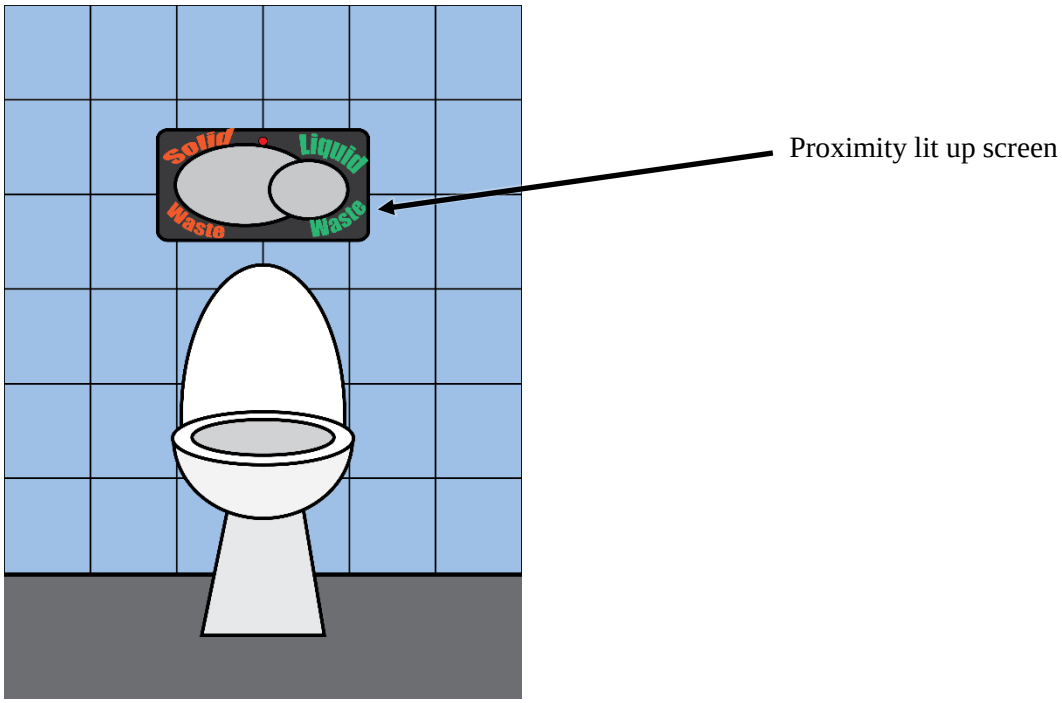


Figure 22: Toilet buttons with an IR-sensor (shown in red) integrated, and LED screens around the buttons, displaying a Nudging message.

4.5.4.3 Around the button panel

A third option, would be to put the proximity lit up screen around the button panel, as can be seen in Figure 23. This option is based on concept 3f. In this case, no modifications to the button panel need to be made whatsoever. Also, the proximity sensor is placed outside of the panel itself for the same reason. While this solution might not be completely in the line sight of where the focus of the user is, it is still really close to it and it will certainly be noticed.

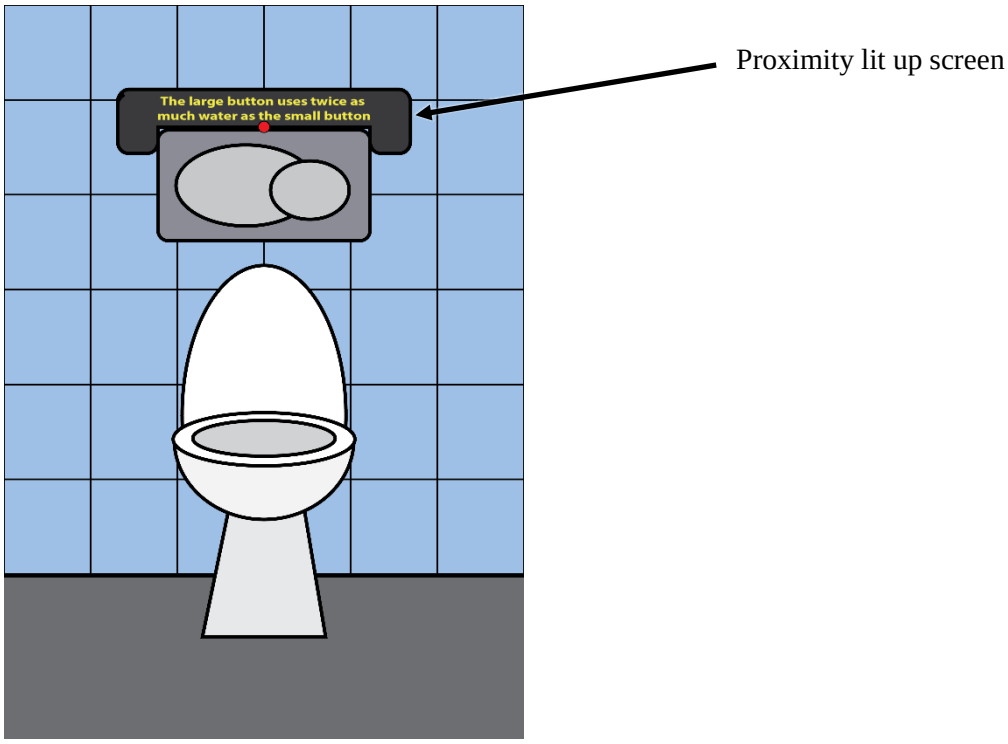


Figure 23: Toilet buttons with an IR-sensor (shown in red) integrated, and LED screens around the button panel, displaying a Nudging message.

4.5.5 Information/text banner

An information banner, as seen in Figure 24 is another way of getting the users attention to the message you want to convey. This draws from concept 3h. The text banner will be activated through the same sensory mechanism as the general lighting, making them both turn on at the same time. Because the text on the banner is running it captures attention. The banner will be grabbing the user's attention when walking into the toilet cubicle and when facing the button fixture when the user wants to flush. Therefore, the user can let the message sink in while on the toilet and thereafter he/she will be confronted with the same, or another message when they are ready to flush. The banner is running so it depends on which of the pre-set messages is showing when the user is looking at it. The content of the message will be changed over time to preserve the novelty effect. The content of the Nudging messages can be chosen from a wide scale of options, as was also the case with the proximity lit up screen.

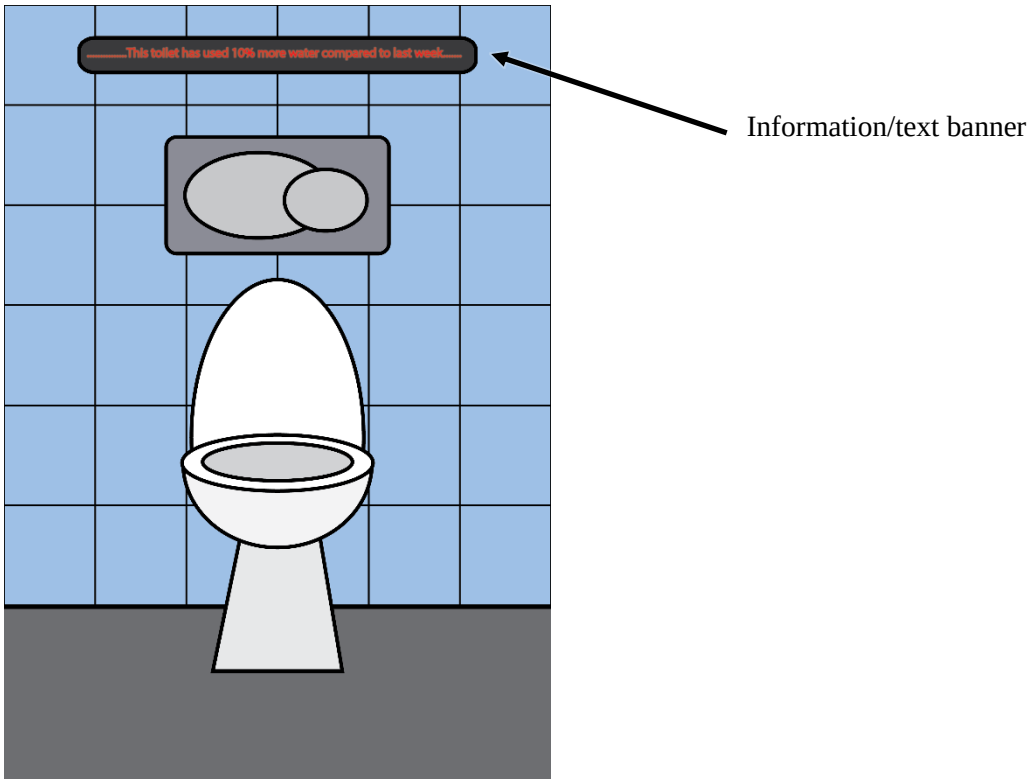


Figure 24: Information banner above the toilet buttons.

4.5.6 Lit up toilet wall tiles

This last concept, concept 3d, makes the tiles of the toilet stall convey messages by lighting up in specific patterns. An example of this is depicted in Figure 25. The focus is in this case on nudging by making use of icons instead of text. This makes use of priming and salience techniques and could also be applied in a norm setting manner. This concept could be used in a similar way as concept 3e, as is the case in Figure 25, by making use of similar icons. However, there is more variability possible regarding interchangeability of the depicted icons. The activation of these toilet tiles will be done in a similar manner to some of the above-mentioned concept, that is through making use of the existing general lighting activation sensors. When the user is then facing the buttons fixture, the icons are very noticeable because of their size. The overall impact on the user would therefore also be quite large.

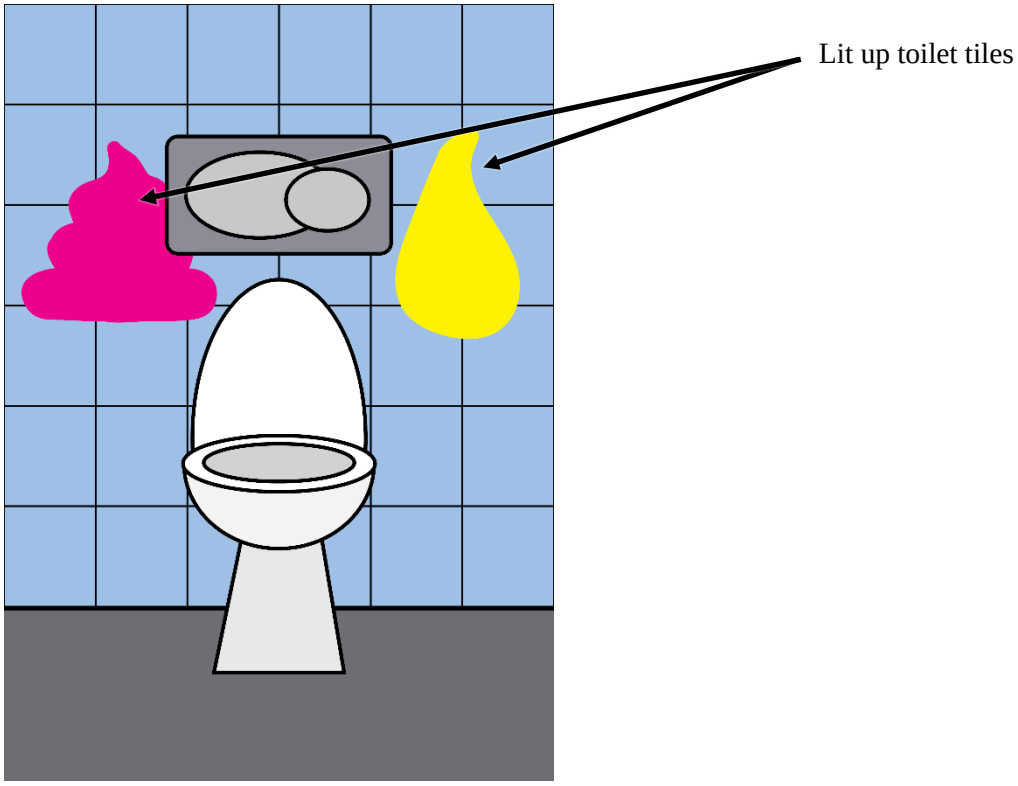


Figure 25: Toilet tiles that light up in specific patterns.

4.6 Final Concept

For the final concept, there is chosen for a hybrid between two of the above concepts. The concepts that are being combined are concept 3f, the ‘proximity lit up screen around the button panel’ and concept 3g, the ‘ambient lighting experience’. These two concepts are combined into concept 3i. The proximity lit up screen is able to show a variety of Nudging messages. While messages using the effectively proven nudging techniques of commitment conveyance, norm setting and salience usage could all be displayed, the Nudging messages will be limited to norm setting as follows from the stakeholder requirements. Thereby requirement H1 through H4 are fulfilled. The ambient lighting taps into the priming nudging technique of subconsciously influencing through sensory cues. Different moods, feelings or cues could be conveyed through the usage of different coloured lighting.

Further, this concept meets requirement A1 and A2, since there is no privacy violation of any sorts going on. Additionally, the system is unable to recognise what kind of defecation is in the toilet bowl. Since, this concept is placed around the toilet buttons, it does not obstruct the user in the use of the buttons. Therefore, requirements B1 and E1 can be met. The user engagement with the solution presented in this concept is achieved by the surprise effect of this concept as discussed in chapter 4.5.4. Lastly, there are possibilities to accommodate the fulfilment of the other requirements in the ‘must category’ for this concept. Those requirements are B3, C1, E3, F1, F2, G2, G3, I1 and J1. A frontal view of the final concept is provided in Figure 26.

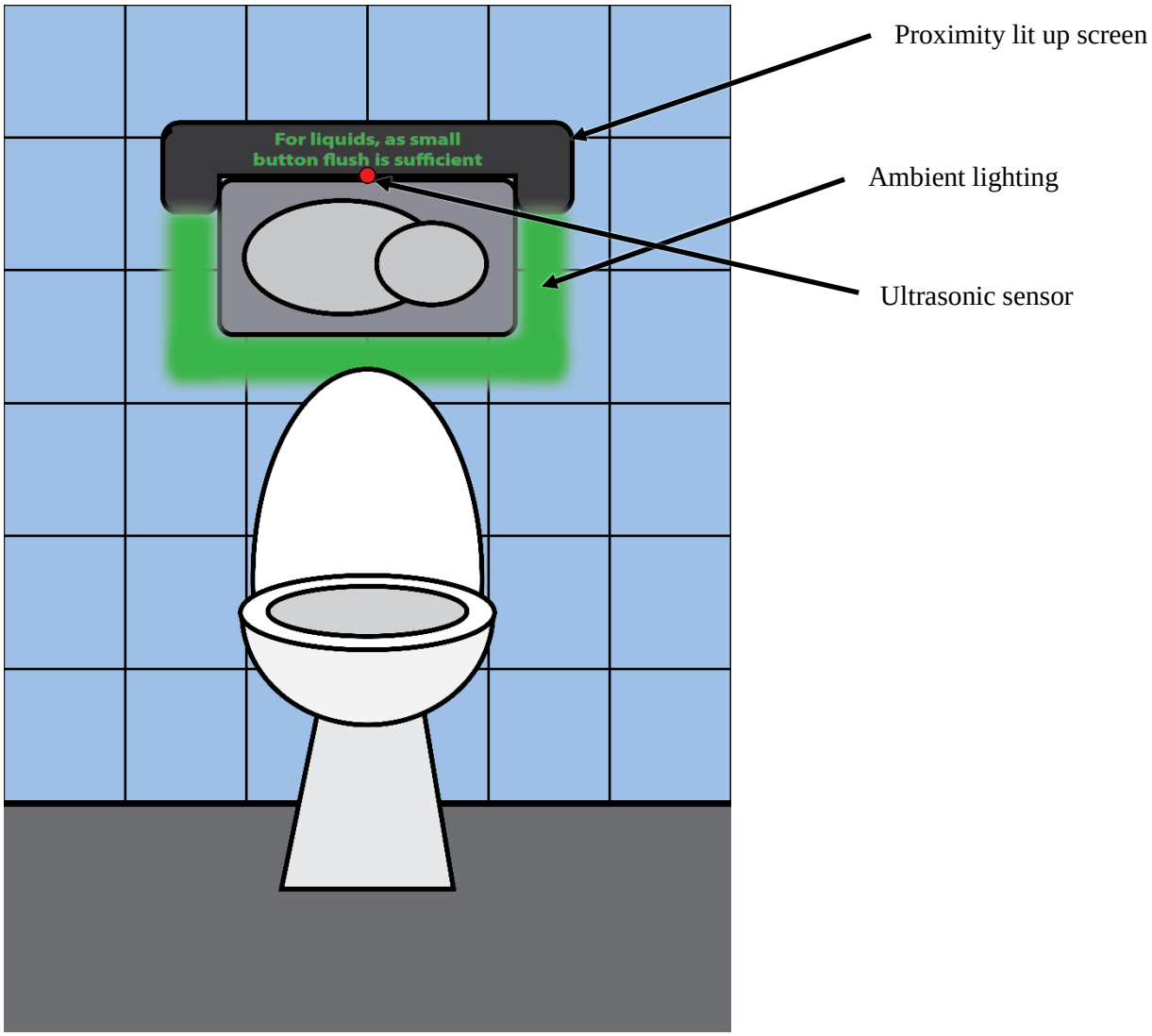


Figure 26: Proximity lit screen around the button panel with ambient lighting around the button panel.

4.6.1 Storyline final concept

Scene 1: The toilet user enters the toilet and sees the toilet as usual, except he/she/they might notice a device around the button panel. The device is displaying the word 'Welcome' upon entering the stall. It might be that the user does not take notice of the device. The user proceeds to go to the toilet as he/she/they would do normally.

Scene 2: The toilet user has finished and has now stood up to flush the toilet. He/she/they reaches for the toilet button. Meanwhile, the Welcome message has disappeared, and another message has taken its place.

Scene 3: The user might be surprised by the change of display and is interested in what might have changed on the device. He/she/they decide to read the message that is displayed on the screen above the buttons. The message tells him/her/them that for liquids, a small button flush is sufficient. Also, green lights have lit up around the button panel. The message and lights let the user think about what button he/she/they should press. He/she/they decide to act upon the message and flush the toilet accordingly. The user then continues their day as usual.

4.6.2 Storyboard final concept

The scenes described in chapter 4.6.1 are depicted as a storyboard in Figure 27, 28 and 29.

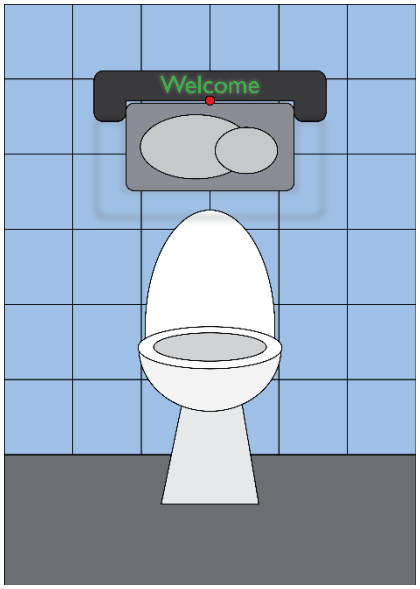


Figure 27: Storyboard scene 1.

Figure 28: Storyboard scene 2.

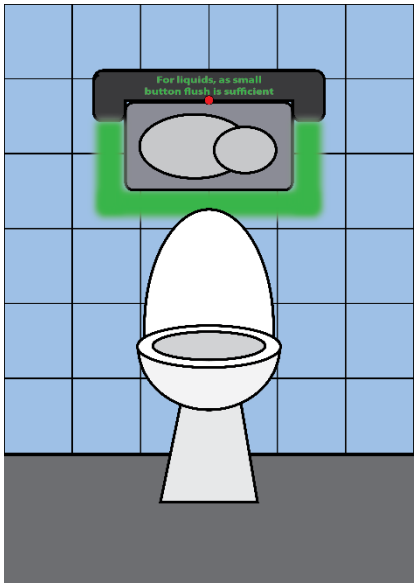


Figure 29: Storyboard scene 3.

4.6.3 Nudge design

The nudge design in this final concept consists of two parts, the textual part on the screen, and the ambient lighting part. As for the textual part, the nudge will solely be based on norm setting nudges as per the stakeholder requirements. To gain a vast number of text possibilities to select from in the specification, a group brainstorm between the main researcher and the research supervisors was performed. Additionally, the input of the client upon the results of this brainstorm was consulted. Stakeholder requirement D3, using humour as an engagement strategy, was taken into account especially during this brainstorm. The complete list of possible nudge texts can be found in Appendix D.

For the lighting part of the nudge, the main purpose is to support the textual message. Setting the correct mood for the user in certain stages of the interaction is essential in eliciting the sought-after emotion at that time in the interaction. By means of colour usage of the lighting, this is accomplished.

5 Specification

In this chapter, the final concept is specified as to get a precise understanding of the workings of the system in order to realise a prototype. From now on, the prototype will hold the name: 'The Button Nudger". Firstly, the interaction scenario is described by means of identifying multiple distinguished personae and describing them. For these personae, an interaction scenario is given with the aid of a storyboard. Secondly, the stakeholder requirements are translated into functional and non-functional requirements. Thirdly, the functional architecture of The Button Nudger is systematically described by applying a functional decomposition technique. Lastly, a flow diagram will be provided and explained in order to get a better understanding about the events that take place during the whole interaction of a user with The Button Nudger from a level 1 perspective.

5.1 Interaction Scenario

In the interaction scenario, the aim is to get a better understanding about the interaction that different types of users have with The Button Nudger. This is done in order to understand how The Button Nudger and the envisioned interactions are perceived by the potential users. First off, a couple of distinct personae that will encounter The Button Nudger are identified as well as described. Thereafter, a storyboard about a possible interaction of these persona is provided. Then the interaction of different persona with The Button Nudger is described in detail. In these scenarios, the storyboard is used to exemplify the interactions.

5.1.1 Persona description

In order to get a better understanding of the future users of The Button Nudger, a couple of personae are described. Since the potential users are not all similar to each other, one key difference between user groups is being made. The distinction that will make a difference in the behaviour as a reaction on the presented interaction is the level of environmental awareness. Whether someone is having good environmental intentions or is indifferent to the matter will define the reaction to The Button Nudger, therefore the two persona that are identified as such. These personae are described in detail below by means of a profile based on the framework provided by the Interaction Design Foundation (Interaction Design Foundation, 2017).

5.1.1.1 Persona with good environmental intentions

The first persona is Lucia, she has good environmental intentions. Her profile is visible in Figure 30.

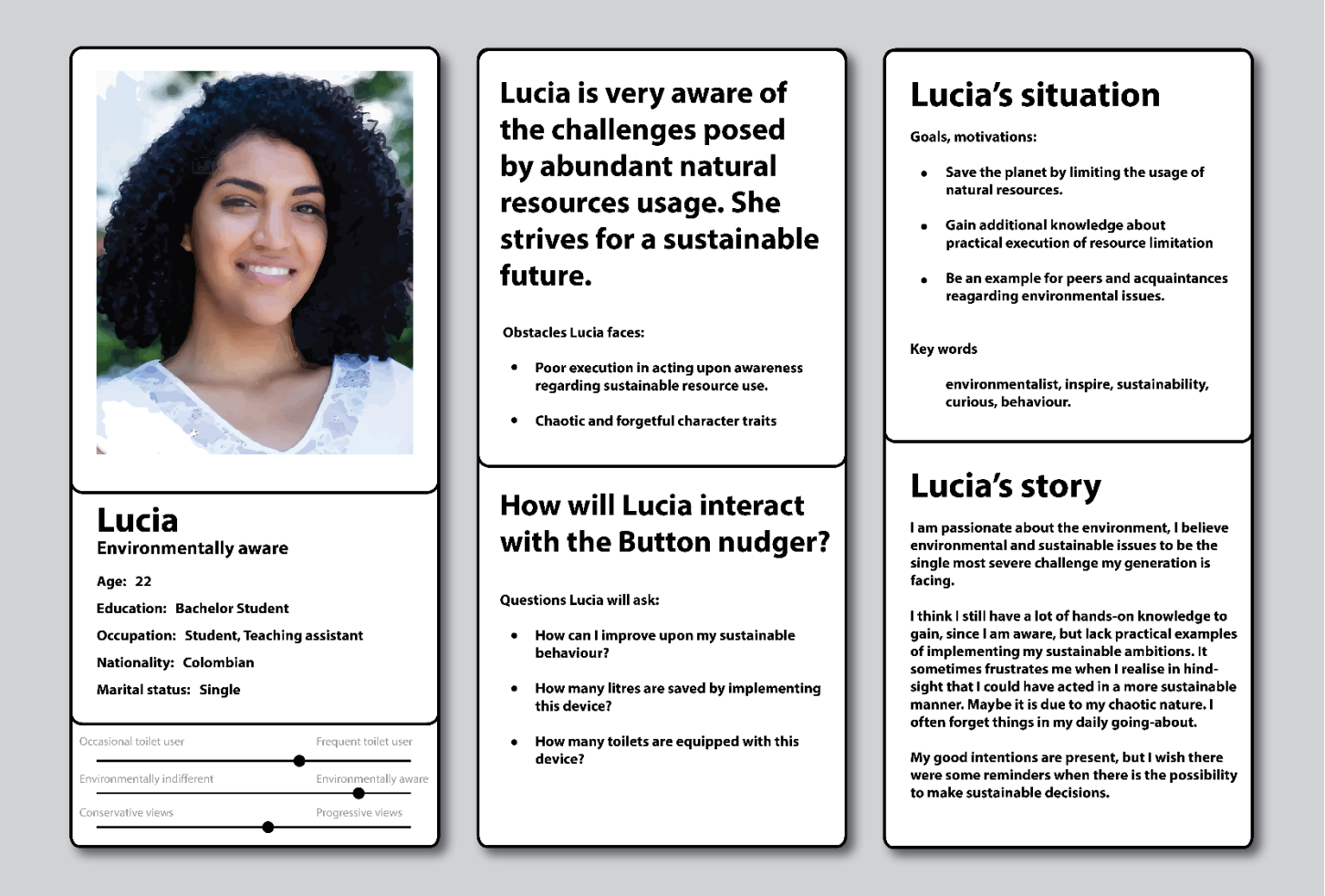


Figure 30: Lucia: persona with good environmental intentions.

5.1.1.2 Indifferent persona

The second persona is Peter, he is indifferent to environmental issues. His profile is visible in Figure 31.

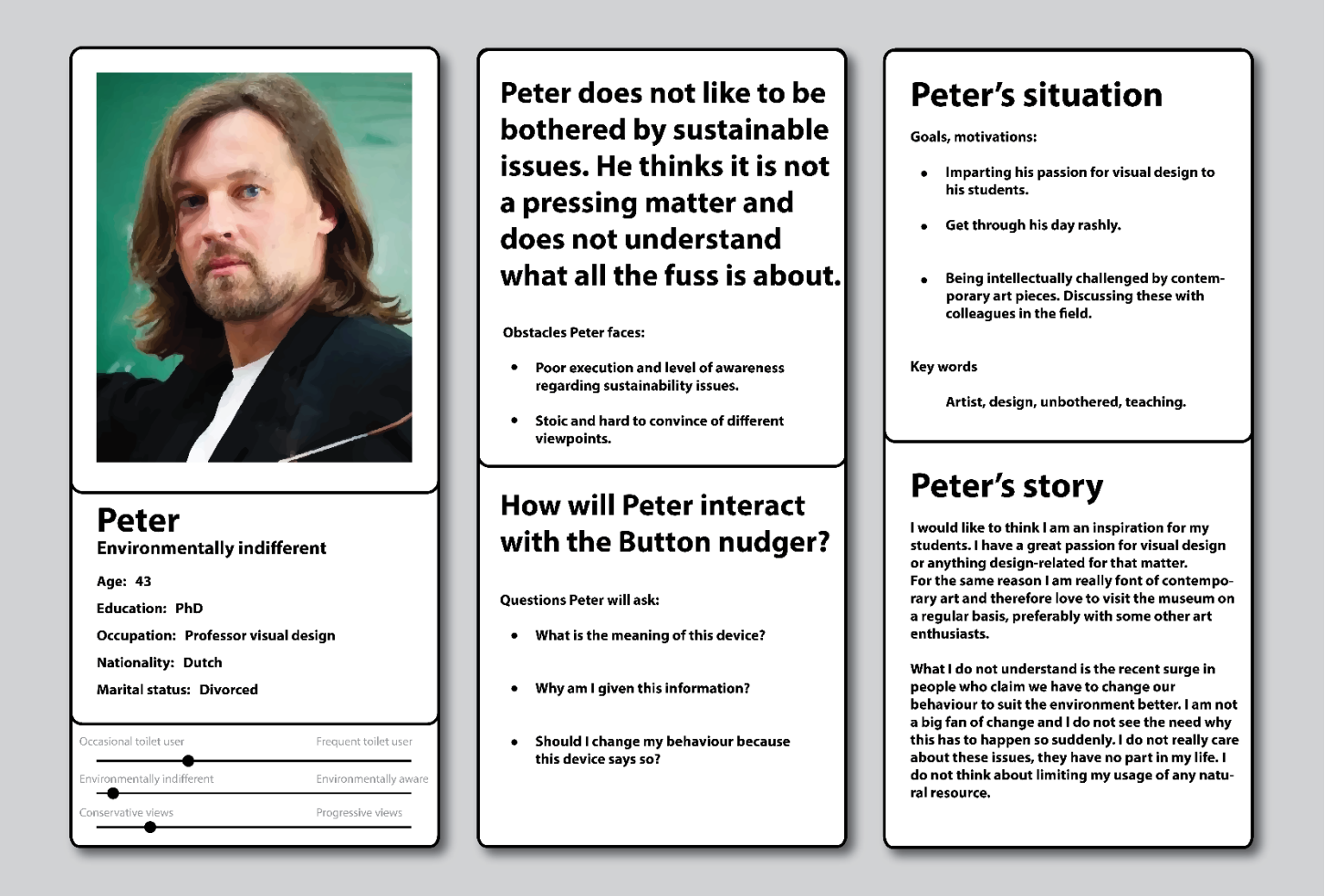


Figure 31: Peter: persona who is indifferent to environmental issues.

5.1.2 Interaction scenarios

To understand the interaction of a persona with The Button Nudger, a detailed description of the interaction scenario is given. This interaction scenario is accompanied with a storyboard to further clarify the individual steps of the interaction. The storyboards of Lucia's and Peter's interactions are shown in Figure 32 and Figure 33 respectively.

5.1.2.1 Scenario Lucia

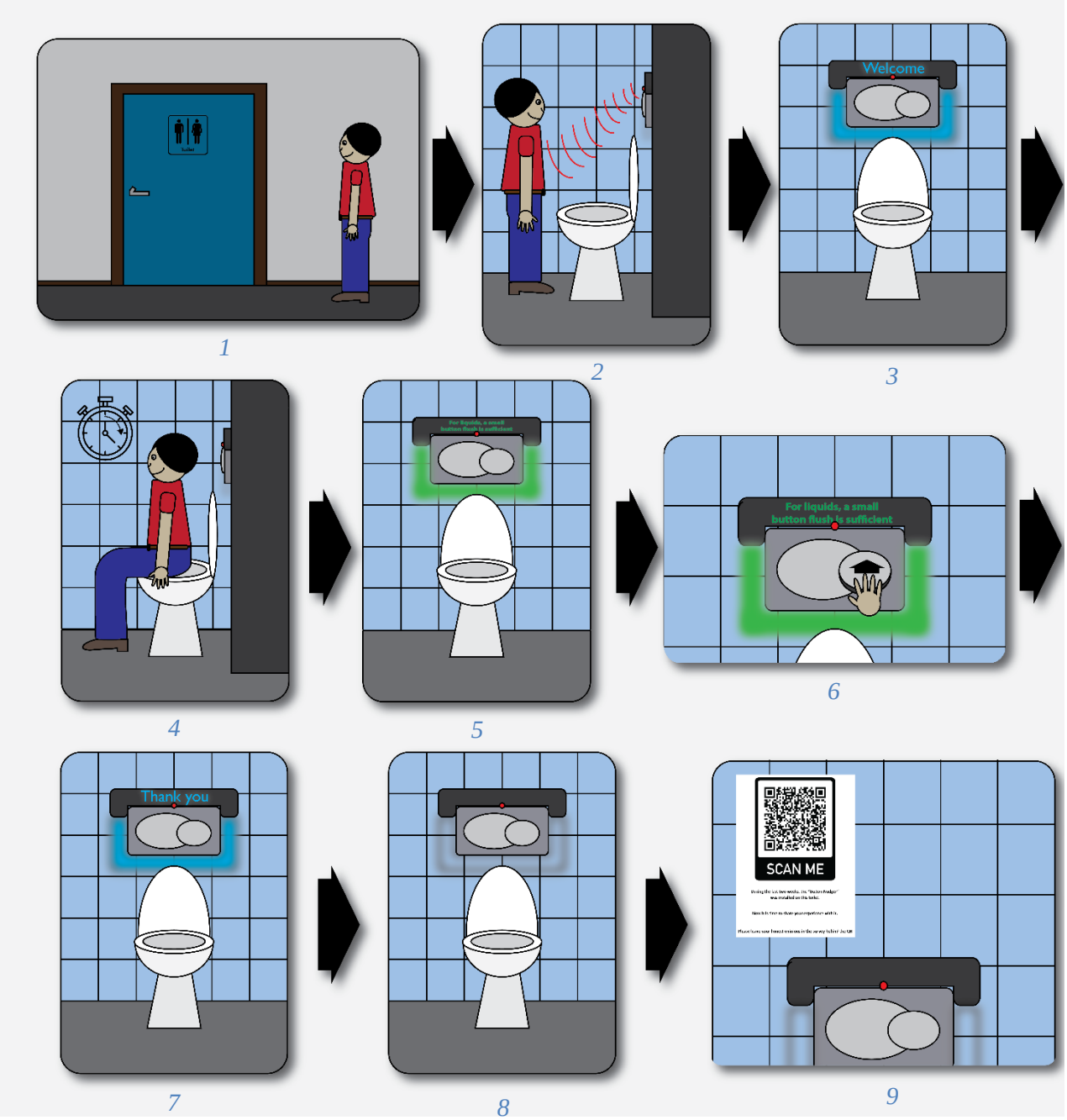


Figure 32: Scenario storyboard of Lucia's interaction.

1) Lucia has just finished her class in the Carré building and is on her way to the Starbucks where she is meeting up with friends over coffee. She notices that it is raining outside and therefore decides to walk through the Zilverling building to the Starbucks. She had to go to the toilet for a while during her class, so she rushes to one of the toilets on the ground floor of the Zilverling. She storms through the door and enters the cubicle.
2) Lucia breaches the proximity sensor threshold of 90cm from the sensor position, while she barges in.
3) In all her chaos, she did not notice anything different on the toilet. But without her knowing, she entered a cubicle that was equipped with The Button Nudger meant to influence her toilet flushing button choice in order to conserve flushing water. Lucia has not noticed it, but The Button Nudger turned on and displayed the text 'Welcome'

when she entered the cubicle and thereby breached the 90cm sensor threshold. Additionally, blue LED lighting turned on in a swiping motion, from the left-top of the flushing button panel, around the underside and up to the right-top of the flushing button panel.

4) Lucia sits down and is relieved to finally be able to go to the toilet. She catches her breath for a bit, she is quite tired from rushing to the toilet. She still has not noticed The Button Nudger since it is behind her. In the meantime, The Button Nudger screen message changed after 20 seconds since it showed 'Welcome'. The change of screen message happened behind Lucia's back, therefore she has not noticed it.
5) When Lucia is finished on the toilet she stands up and turns around. She finally notices The Button Nudger. She is surprised and she whispers to herself: 'wow, I did not expect that'. The Button Nudger has a couple of norm conveying Nudging messages related to which flushing button one should use in its local storage, of which it picks one randomly and displays that message on the display. This time, the screen above the buttons fixture displays the text: 'For liquids, a small button flush is sufficient' in green lettering. In the same manner as happened with the blue LED lighting swipe, now a bright green light has swiped around the flushing button panel. Lucia reads the text and she realises: 'This is what I need! I almost made a wrong choice, but I can save water here, great!' This was exactly the practical situation of executing pro-environmental behaviour she is always struggling with. Lucia wonders how many litres of water are wasted in toilets daily and how many litres The Button Nudger is saving. She hopes that The Button Nudger is implemented on more toilets to increase the impact it has.
6) Lucia is eager to make the correct decision and flushes with the small button. The Button Nudger records the small button flush and adds the timestamp and the type of flush (small in this case) to the database. The database stores a list of timestamps and type of flush events locally, which will later be retrieved by the main researcher to be analysed.
7) Upon flushing the toilet, The Button Nudger screen message changes and displays the text 'Thank you'. At the same time as The Button Nudger screen changed to the Thank you message, the green lighting around the flushing button panel swipes back to a blue colour. Lucia has a good feeling about her action.
8) After 3 seconds of displaying the Thank you message, the screen turns black, 5 seconds later, the LED lighting swipes, similarly as it did previously, to off. Lucia believes that this is the end of the interaction.
9) Lucia is about to leave the toilet when she spots a poster on the toilet cubicle wall with the text "The Button Nudger is installed on this toilet. Now it is time to share your experience with it. Please leave your honest opinions in the survey behind the QR" on it. Above the text is a QR-code which links to a survey hosted on Google Forms. Lucia washes her hands and decides to scan the QR-code. She fills in the survey questions when she leaves the toilet facility. She walks to the Starbucks to see that her friends are already waiting for her. She joins them and tells them about her experience on the toilet.

5.1.2.2 Scenario Peter

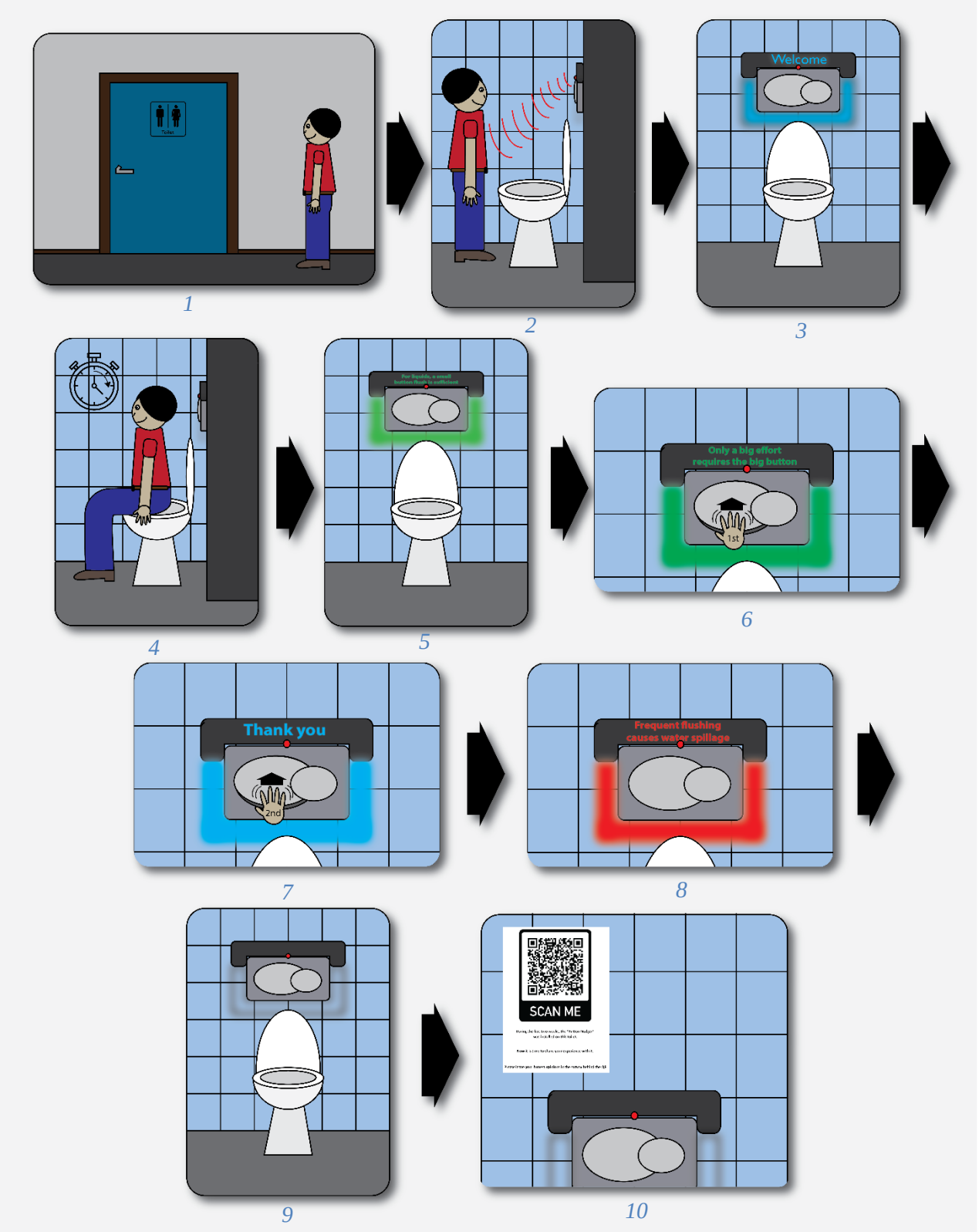


Figure 33: Scenario storyboard of Peter's interaction.

1) Peter concludes his conversation with one of his fellow professors about his visit to the Stedelijk Museum in Amsterdam last weekend. It was interesting to share opinions on the museum pieces, but now Peter has to go to the toilet. His office is situated in the Zilverling. He decides to visit the toilet nearest to his office, as he always does. He walks up there and enters the toilet facility and thereafter the toilet stall.

2) When he enters the toilet cubicle, Peter breaches The Button Nudger's proximity sensor threshold of 90cm.
3) Peter immediately notices that there is something different on the toilet. This is after all the toilet he always visits. Yesterday, The Button Nudger that is hanging around the buttons fixture was not there yet. Peter noticed that The Button Nudger turned on upon him entering the toilet cubicle and thereby breaching the sensor threshold, it now displays a Welcome text. Also, blue LED lighting turned on in a swiping motion, from the left-top of the flushing button panel, around the underside and up to the right-top of the flushing button panel. Peter is questioning what the meaning of installing The Button Nudger might be. He is intrigued about the design of The Button Nudger, 'it could be digital art because of the screen and LED's' Peter thinks.
4) Peter eventually sits down on the toilet and goes about his business as normal. By the time he finishes, he has almost forgot about The Button Nudger. In the meantime, 20 seconds since Peter breached the sensor threshold (and the Welcome message and blue lighting appeared) has passed. Without him noticing the screen has changed behind his back.
5) Peter gets up and is confronted with The Button Nudger again, now the text on the display has changed. The Button Nudger has a couple of Nudging messages in its local storage of which it picks one randomly and displays that message on the display. This time the display shows the text: 'Only a big effort requires the big button'. The LED lights are coloured bright green around the sides and underneath the buttons fixture. The change of lighting happened behind Peter's back as well, in a similar fashion as it turned blue previously. Peter is immediately agitated, he says to himself: 'Why am I given this information? Should I change my behaviour because The Button Nudger says so?' He is taking his time to think about The Button Nudger.
6) Peter is not amused by the message on the display, he has had enough of it. He is reluctant to change his behaviour and smashes the big button two times in irritation. In this case that was coincidentally the correct button to use.
7) Upon the first flush, The Button Nudger screen message changes and displays the text 'Thank you'. At the same time as The Button Nudger screen changed to the Thank you message, the green lighting around the flushing button panel swipes back to a blue colour.
8) However, because Peter has flushed the toilet and he has not waited 4 seconds to go by for the initial flush to fully end and he flushed another time, The Button Nudger is triggered to send a water spillage prevention message. The text on the display changes immediately after displaying the Thank you message to say the following: "Frequent flushing causes water spillage". At the same time, the LED's which were blue before now swipe red. In the background, The Button Nudger records the big button flush and transmits the timestamp and the type of flush (big in this case) to the database. The database stores a list of timestamps and type of flush events locally, which will later be retrieved by the main researcher to be analysed. In this case, since there was less than 4 seconds between the individual flushes, The Button Nudger prevents the second flush from being incorporated in the database, as these flushes were most likely from the same person using the toilet buttons improperly. Peter still appreciates the work that has gone into the design; however, he is done with all the messaging on what he should and should not do.
9) 3 seconds since the water spillage prevention message have passed, which makes The Button Nudger screen turn black, 5 seconds later, the LED lighting swipes, similarly as it did previously, to off.

10) Peter is about to leave the toilet when he spots a piece of paper with the text “The Button Nudger is installed on this toilet. Now it is time to share your experience with it. Please leave your honest opinions in the survey behind the QR” on it. Underneath the text is a QR-code which links to a survey hosted on Google Forms. He decides to scan the QR-code and fills in the survey questions to convey his dissatisfaction with The Button Nudger. Eventually, Peter leaves the toilet facility. Peter washes his hands and walks back to his office. He quickly forgets about the interaction when he notices that he has a new e-mail.

5.2 System requirements

In order to implement the stakeholder requirements mentioned in chapter 4.3 these requirements need to be translated into functional requirements and non-functional requirements. Functional requirements indicate what The Button Nudger will do; non-functional requirements indicate how The Button Nudger will do it. In this section the requirements of Table 2 are addressed and translated into concrete system requirements either functional or non-functional. The functional requirements are grouped by priority in Table 4 and the non-functional requirements are grouped by priority in Table 5.

5.2.1 Functional requirements

Table 4: Functional requirements.

Priority (MoSCoW)	Functional system requirement	Related Requirement ID
Must	The Button Nudger boots up fully when the power socket is switched on	F2
Must	The Button Nudger wakes up when someone is closer than 90cm in front of it	J1
Must	The Button Nudger displays a Welcome message upon waking up	-
Must	The Button Nudger swipes blue LED lighting around the flushing button panel counter-clockwise starting from the top-left corner of the flushing button panel upon waking up	-
Must	The Button Nudger switches to a Nudging message after 20 seconds of displaying the Welcome message	-
Must	The Button Nudger swipes green LED lighting around the flushing button panel counter-clockwise starting from the top-left corner of the flushing button panel after 20 seconds of displaying the Welcome message	-
Must	The Button Nudger switches to a Thank you message after 60 seconds of displaying the Nudging message	-
Must	The Button Nudger swipes blue LED lighting around the flushing button panel counter-clockwise starting from the top-left corner of the flushing button panel after 60 seconds of displaying the Nudging message	-
Must	The Button Nudger switches to a Thank you message upon pressing either of the flushing buttons	-
Must	The Button Nudger swipes blue LED lighting around the flushing button panel counter-clockwise starting from the	-

	top-left corner of the flushing button panel upon pressing either of the flushing buttons	
Must	The Button Nudger switches to a black screen after 3 seconds of displaying the Thank you message	-
Must	The Button Nudger swipes off the LED lighting around the flushing button panel counter-clockwise starting from the top-left corner of the flushing button panel after 5 seconds of having the black screen	-
Must	The Button Nudger switches to a frequent flushing prevention message if the Δt of two flushes is > 1 second AND < 4 seconds	-
Must	The Button Nudger swipes red LED lighting around the flushing button panel counter-clockwise starting from the top-left corner of the flushing button panel if the Δt of two flushes is > 1 second AND < 4 seconds	-
Must	The Button Nudger registers a pressing of the Big flushing button	I1
Must	The Button Nudger registers a pressing of the Small flushing button	I1
Must	The Button Nudger locally stores the input of the Big flushing button in a .csv file	I2
Must	The Button Nudger locally stores the input of the Small flushing button in a .csv file	I2
Must	The Button Nudger adds a timestamp to a stored input into the same .csv file	I3
Must	The Button Nudger does not have any sensing capabilities to recognize what is in the toilet bowl	A2
Must	The Button Nudger does not have any sensing capabilities to discriminate between users	B3
Must	The Button Nudger is not programmed to keep track of the duration of a toilet visit	A1
Should	The Button Nudger works for a full day without malfunctioning, crashing or having to be rebooted	F1
Should/ Could	The Button Nudger does not need any input from the user to operate	B4, E1
Should	The Button Nudger chooses the Nudging message randomly from a selection of 10 Nudging messages	D2
Should	The Button Nudger writes every 3 minutes the time it has been on for to a .csv file	I3

5.2.2 Non-functional requirements

Table 5: Non-functional requirements.

Priority (MoSCoW)	**Non-functional system requirement**	**Related Requirement ID**
Must	The Button Nudger fits the current Zilverling toilet facilities	C1
Must	The Button Nudger is resistant to cleaning, cleaning products and water	E3
Must	The Button Nudger does not require permanent alterations to the current button panel and/or toilet itself	G2
Must	The Button Nudger does not leave permanent changes to the current facilities when removed	G3
Must	The Button Nudger uses nudging techniques to influence	H1

	user behaviour	
Must	The Button Nudger uses norm setting nudging techniques	H3
Should	The Button Nudger picks a nudge from 10 possible norm setting Nudging messages	H3
Should	The Button Nudger does not obstruct the user	B1
Should	The Button Nudger is not unnecessarily distractive	B2
Should	The Button Nudger is engaging	D1
Should	The Button Nudger is easy to clean	E2
Should	The Button Nudger can be installed within 1 hour	G1
Should	The Button Nudger is installed at a quiet time	G4
Could	The Button Nudger makes use of humour to engage users	D3

5.3 Functional architecture

The functional architecture describes the precise working of The Button Nudger in a functional manner. First, The Button Nudger as a whole is regarded in the level 0 analysis. Then the inner workings are described by dividing The Button Nudger into different functional building blocks and describing the communication between those building blocks in the level 1 analysis. These building blocks are then described in further detail in the level 2 analysis, which is the smallest decomposition necessary to understand the functional workings of The Button Nudger.

5.3.1 Level 0 decomposition

In the level 0 decomposition, The Button Nudger as a whole is regarded as a black box with only the interaction with the user being described. A schematic overview of the level 0 analysis is given in Figure 34. In this system, there are two inputs the user gives to the system, here denoted with ‘X’ and ‘Y’. The outputs that are fed back to the user are denoted with ‘Z’ and ‘Z′’. Everything that happens in the system itself is disregarded in the level 0 analysis. The inputs the user gives to the system are:

- X: Entering the toilet cubicle and being situated in front of The Button Nudger closer than 90cm, waking up the system.
- Y: Pressing a (or multiple) flushing button(s), which results in a button press registration.

The output the user receives back from the system is as follows:

- Z: A lit up screen above the flushing buttons displaying a message
- Z′: Lit up LED lighting around the flushing button panel in a colour dependant on the stage of the interaction.

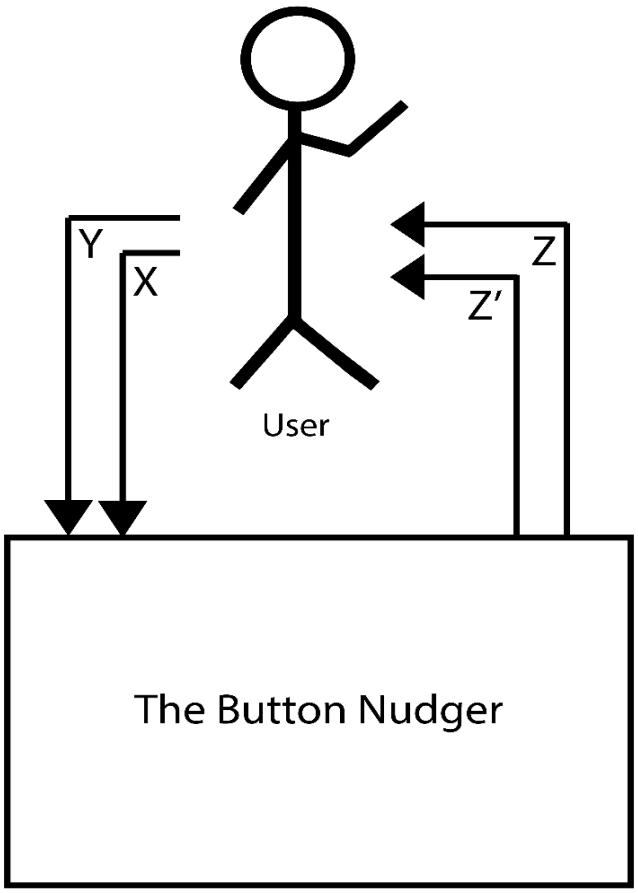


Figure 34: Level 0 decomposition scheme of The Button Nudger.

5.3.2 Level 1 decomposition

In the level 1 decomposition, The Button Nudger is decomposed into six functional building blocks, as visible in Figure 35. As described in the level 0 decomposition, there are two inputs of the user: proximity and press button.

When proximity is detected by the Proximity detection it sends out a Welcome message as well as a timestamp. The Welcome message is an input for the Output generator, it immediately sends the Welcome message display back to the user.

The timestamp from the Proximity detection is an input for the Nudge selector. After 20 seconds, the Nudge selector requests a nudge type from the Storage and the Storage responds back a nudge type to the Nudge selector. The Nudge selector sends a nudge message + time stamp to the Output generator when it has received the nudge response. The Output generator then sends the nudge message display to the user.

When press button is detected by the Button registration it sends the button type as well as the timestamp of the button press to the Storage. It also sends that a press is detected including the timestamp to the Frequent flush handler. The Frequent flush handler is able to use the input of the Button registration in order to pass on a Thank you message or a Frequent flush prevention message to the Output generator dependant on the conditions of the input it receives. The Thank you message is send instantaneous upon receiving a button pressed or upon no inputs received 60 seconds after the Nudge selector timestamp output. The Frequent flush prevention message is activated when two or more button pressed events are input to the Frequent flush handler within 4 seconds of each other. These messages are in turn, being output to the user.

Lastly, the Output generator activates coloured LED’s as an output to the user. The colour of the LED’s is dependant on which message is output.

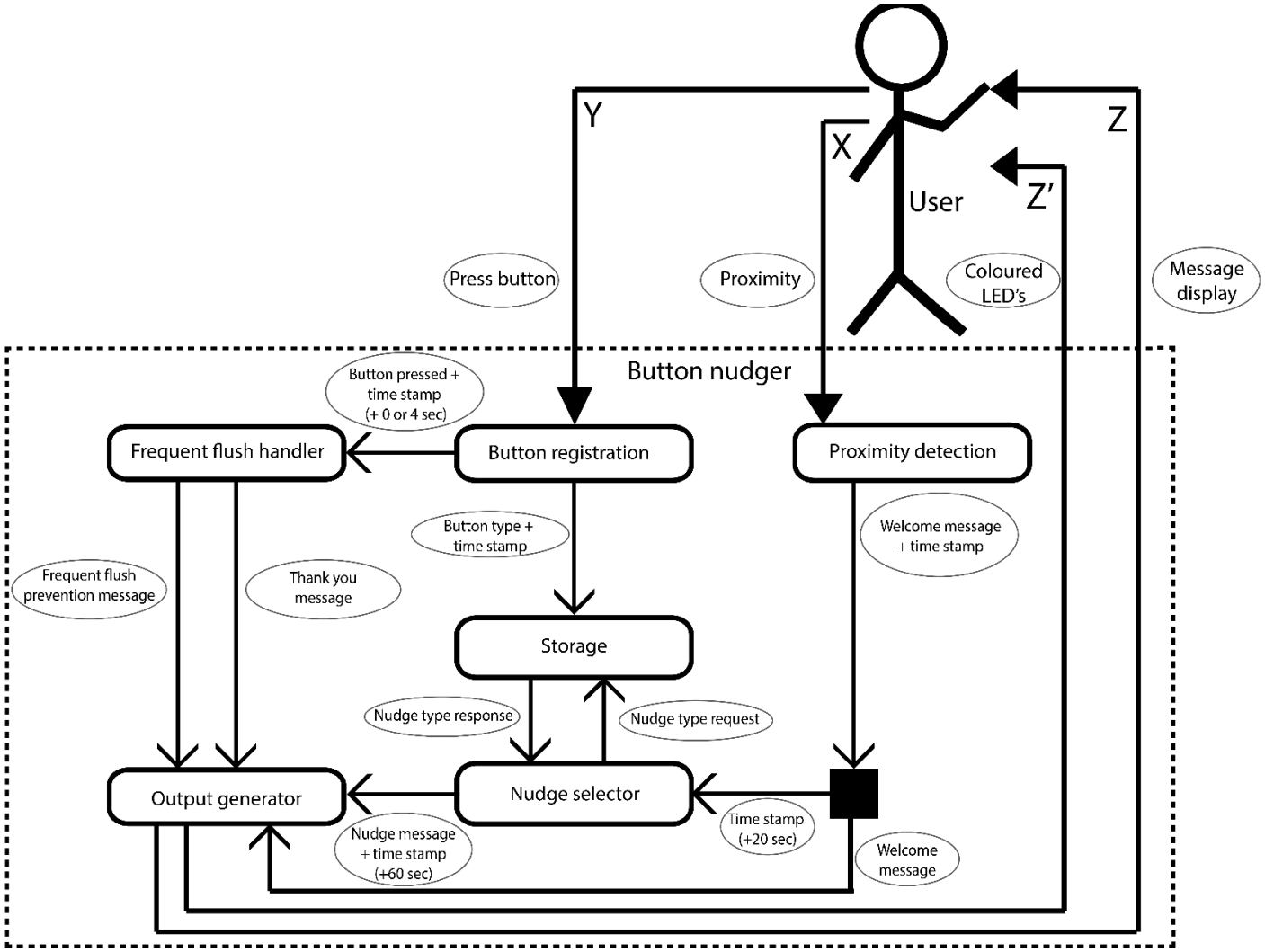


Figure 35: Level 1 decomposition scheme of The Button Nudger.

5.3.3 Level 2 decomposition

In the level 2 decomposition, the building blocks of level 1 are further explored. These building blocks are listed and individually described below.

5.3.3.1 Button Registration

The Button registration senses the press button event from the user. This event is subsequently split to three different components and acts as an input for the Sensing input blocker, the Multiple flush overruler and the Press detector.

The Press detector send the button pressed event to the Time interpreter. The combined button pressed and timestamp event are subsequently sent to the Frequent flush handler.

The Multiple flush overruler detects multiple flushes and sends an activate event to the Sensing input blocker.

The Sensing input blocker passes through the press button event whenever it does not receive the activate event from the Multiple flush overruler.

The press button event from the Sensing input blocker is than split into two which are both an input for the Button type identifier and the Time interpreter. These respectively output the button type and the timestamp, which are then combined and send out to the Storage. The schematic overview of the Button registration is depicted in Figure 36.

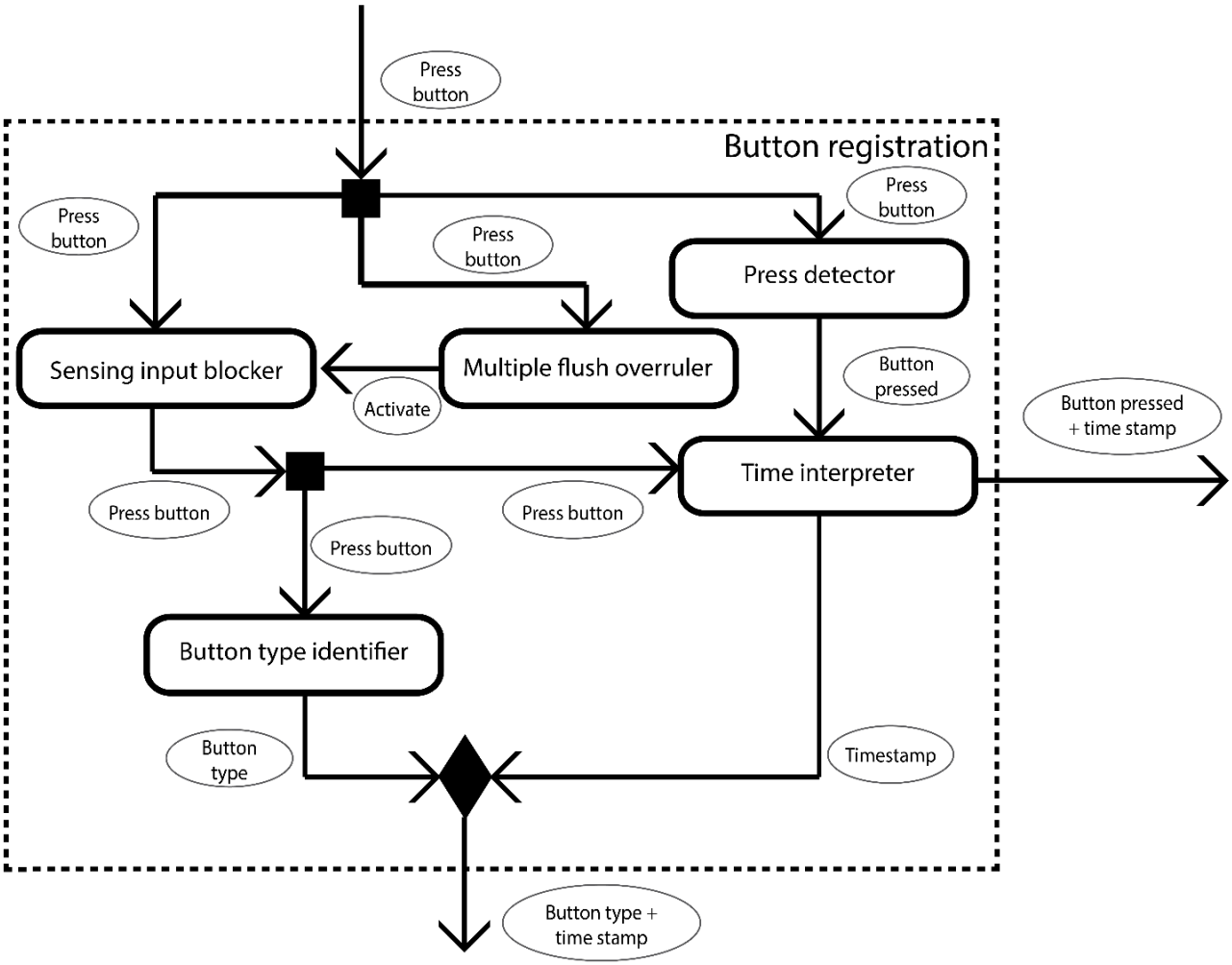


Figure 36: Level 2 decomposition scheme of the Button registration.

5.3.3.2 Proximity detection

The proximity input is split in two in the Proximity detection. Then it is put into the User detector and the Time interpreter. The User detector subsequently sends the user detected event to the Interaction loop initiator, which in turn outputs the Welcome message event, the first event of the interaction loop. This event, together with the timestamp event from the Time interpreter is combined into a Welcome message + timestamp event, which is then send to the Nudge selector and the Output generator. An overview of the Proximity detection is given in Figure 37.

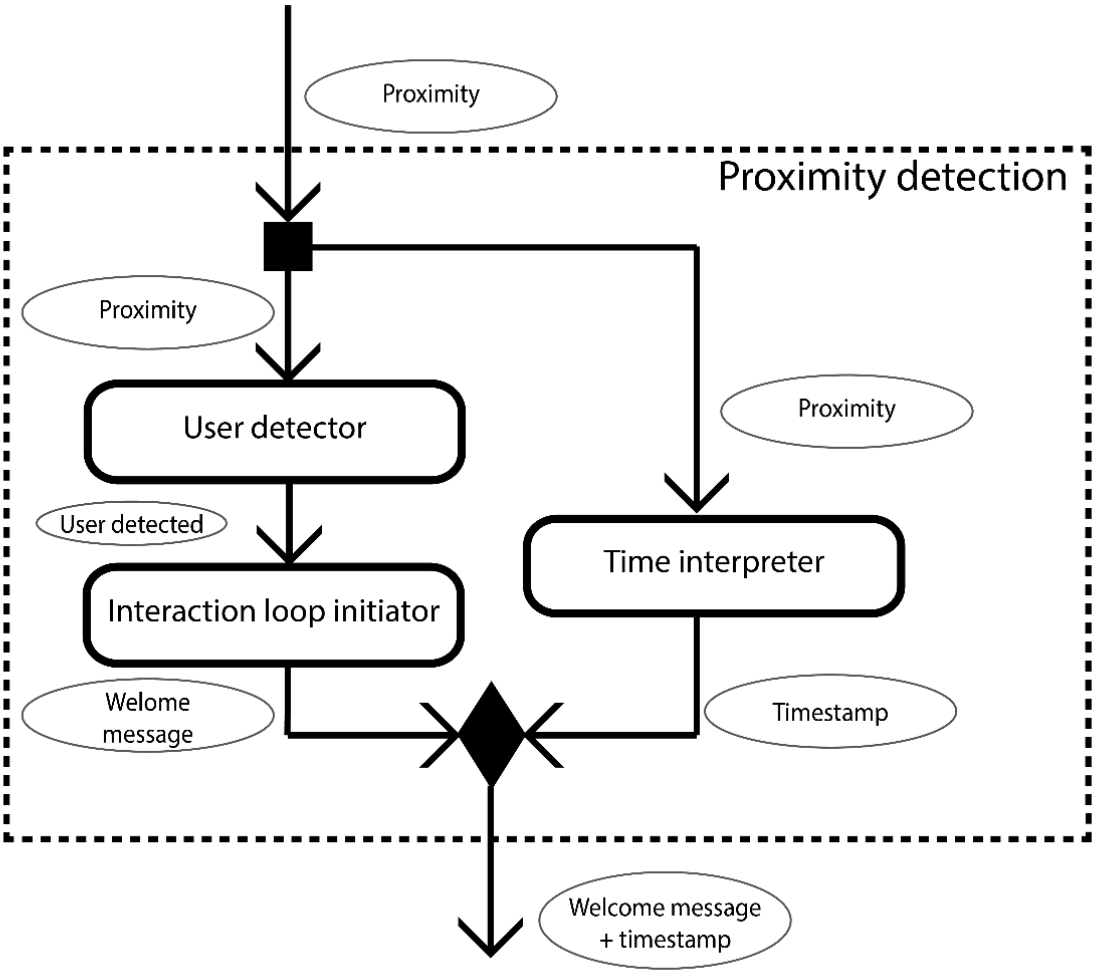


Figure 37: Level 2 decomposition scheme of the Proximity detection.

5.3.3.3 Nudge selector

The Nudge selector is depicted in Figure 38. The time stamp event input is first put into a counter which counts 20 seconds. If 20 seconds have passed since the time stamp event, the counter sends an activate event to the Random generator. The Random generator in turn, generates a random nudge number that acts as an input for the Request generator. This Request generator then requests a nudge type from the Storage. The Storage has a collection of 10 different nudge types it can return. It depends on the randomly picked nudge number which nudge type the Storage is going to return. The Message composer receives the response of the Storage and converts it into a nudge message event. The Time interpreter provides the nudge message event with a time stamp before it sends the nudge message + time stamp event to the Output generator.

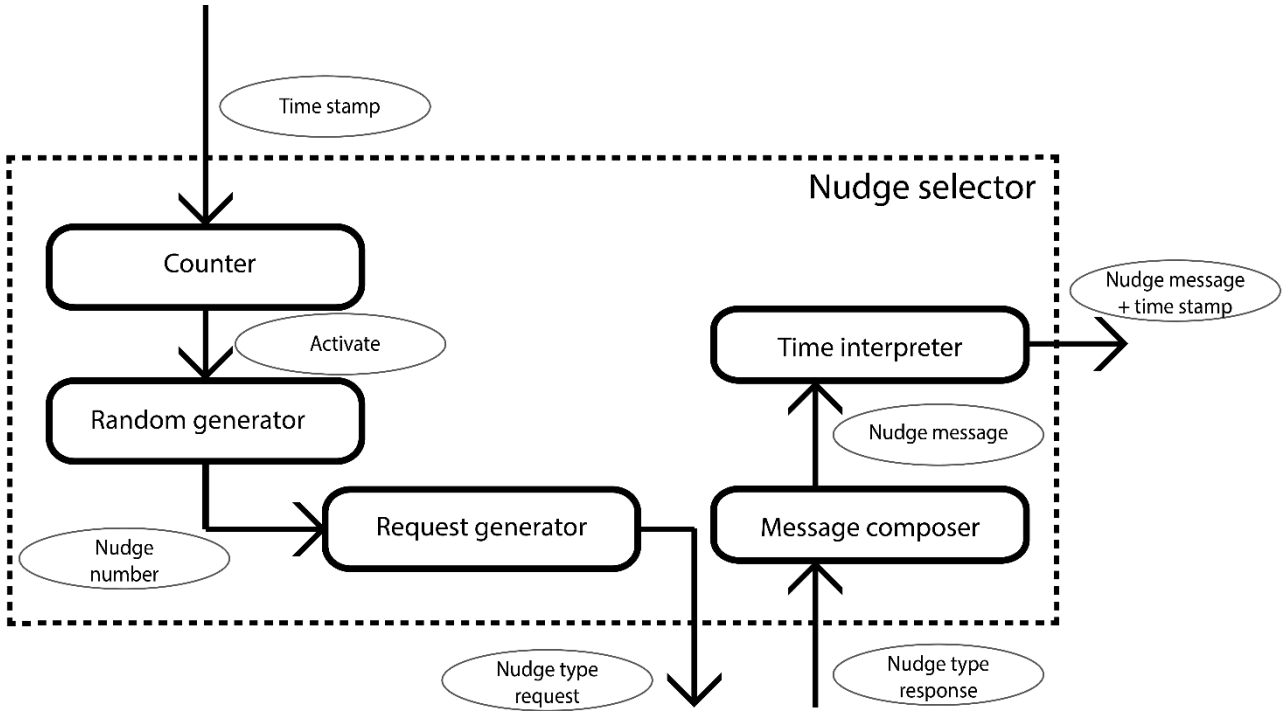


Figure 38: Level 2 decomposition scheme of the Nudge selector.

5.3.3.4 Storage

The Storage receives a button type + timestamp event from the Button registration, which it stores in the Flushing data collection. The Storage also interacts with the Nudge selector. It receives a nudge type request, including a nudge number from the Nudge selector. Based on the nudge number, it sends back one of its 10 possible nudge type responses to the Nudge selector. The Storage is depicted in Figure 39.

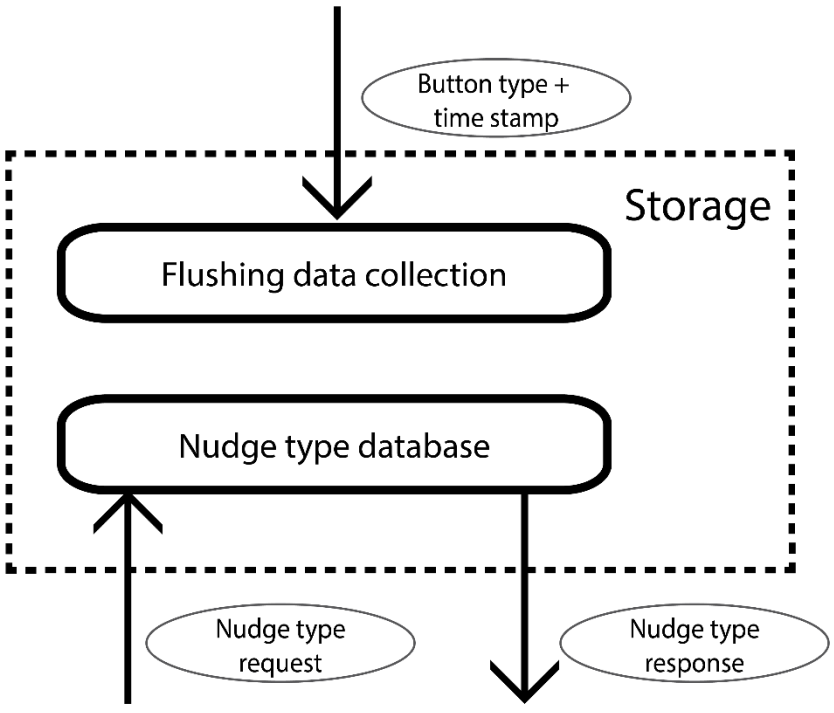


Figure 39: Level 2 decomposition scheme of the Storage.

5.3.3.5 Frequent flush handler

The Frequent flush handler is depicted in Figure 40. It receives a button pressed + time stamp event from the Button registration. This event is than split into a button pressed event and a time stamp event. The button pressed event is the input to the Interaction loop terminator, which immediately sends a Thank you message to the Output generator. The time stamp is put into a Counter which sends the order to activate to the Frequent flush warning initiator whenever it receives two timestamps that are within 1 and 4 seconds from each other. The Frequent flush warning initiator, when activated, sends a frequent flush prevention message to the Output generator.

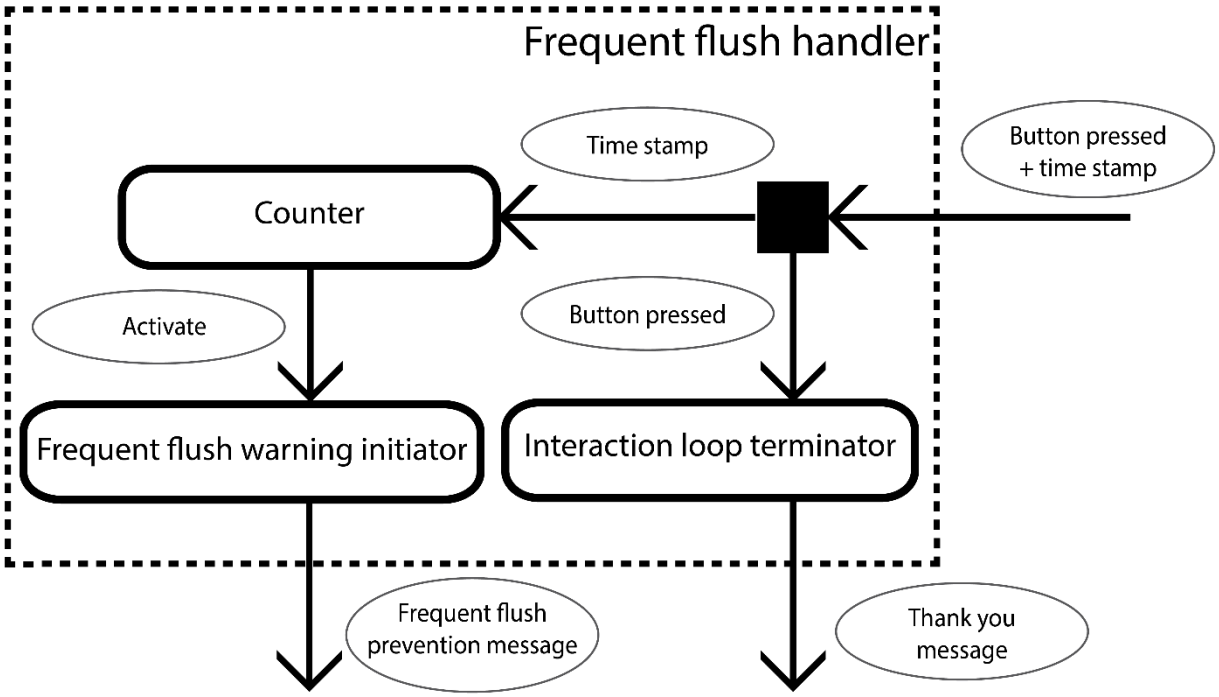


Figure 40: Level 2 decomposition scheme of the Frequent flush handler.

5.3.3.6 Output generator

The Output generator gets its inputs from the Nudge selector and the Frequent flush handler. The input from the Nudge selector is a Nudge message + time stamp, which is split up into a nudge message event and a time stamp event.

The Nudge message event is put into the Message interpreter which in turn outputs a text pattern and a lighting colour belonging to that nudge message. This text pattern and lighting colour are sent to the Text generator and the Light pattern generator respectively. The Text generator sends a message display to the user, the light pattern generator outputs coloured LED's to the user.

The time stamp event is put into a Counter which sends a Thank you message to the Message interpreter if 60 seconds since the time stamp have passed. From there on, the Thank you message follows the same route as the Nudge message.

The inputs from the Frequent flush handler are a Thank you message and a Frequent flush prevention message, which are both input to the Message interpreter. From there on, each of these messages follow the same route as the Nudge message. The schematic overview of the Output generator is given in Figure 41.

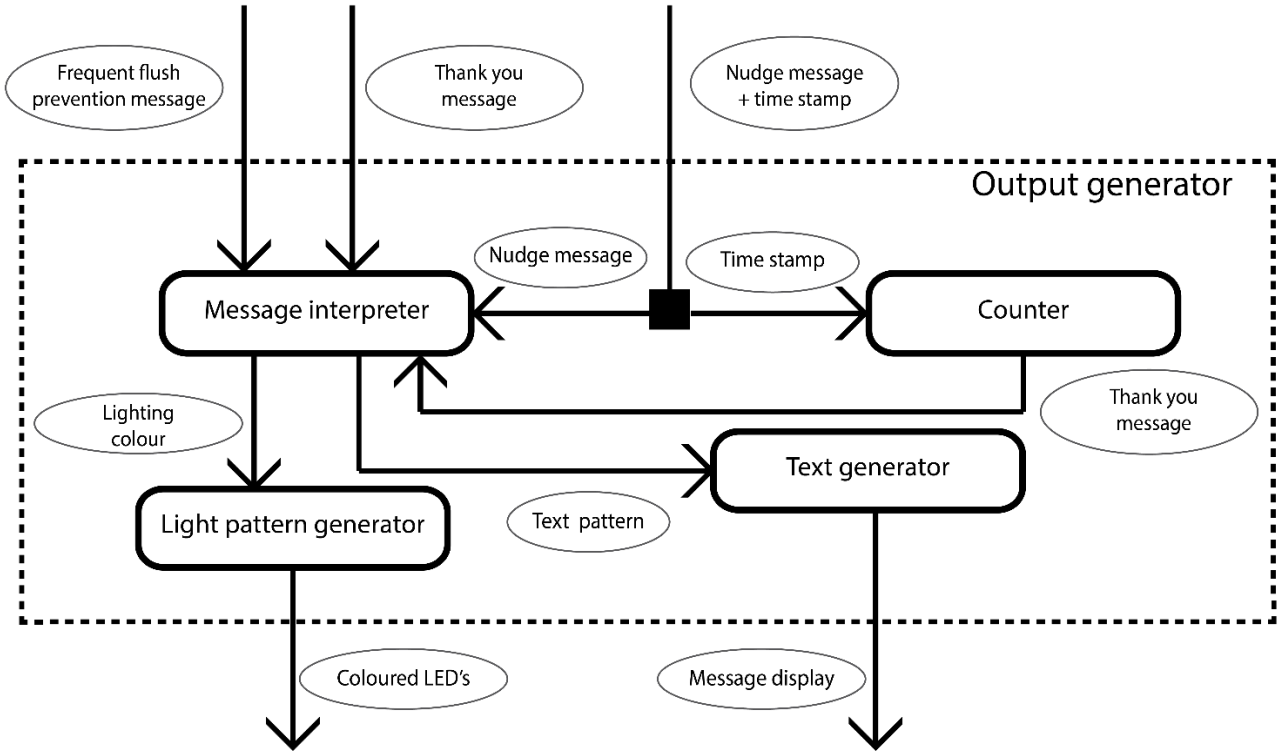


Figure 41: Level 2 decomposition scheme of the Output generator.

5.4 Flow diagram

In order to understand the flow of all possible interaction with The Button Nudger from a level 1 perspective, a flow diagram is provided in Figure 42.

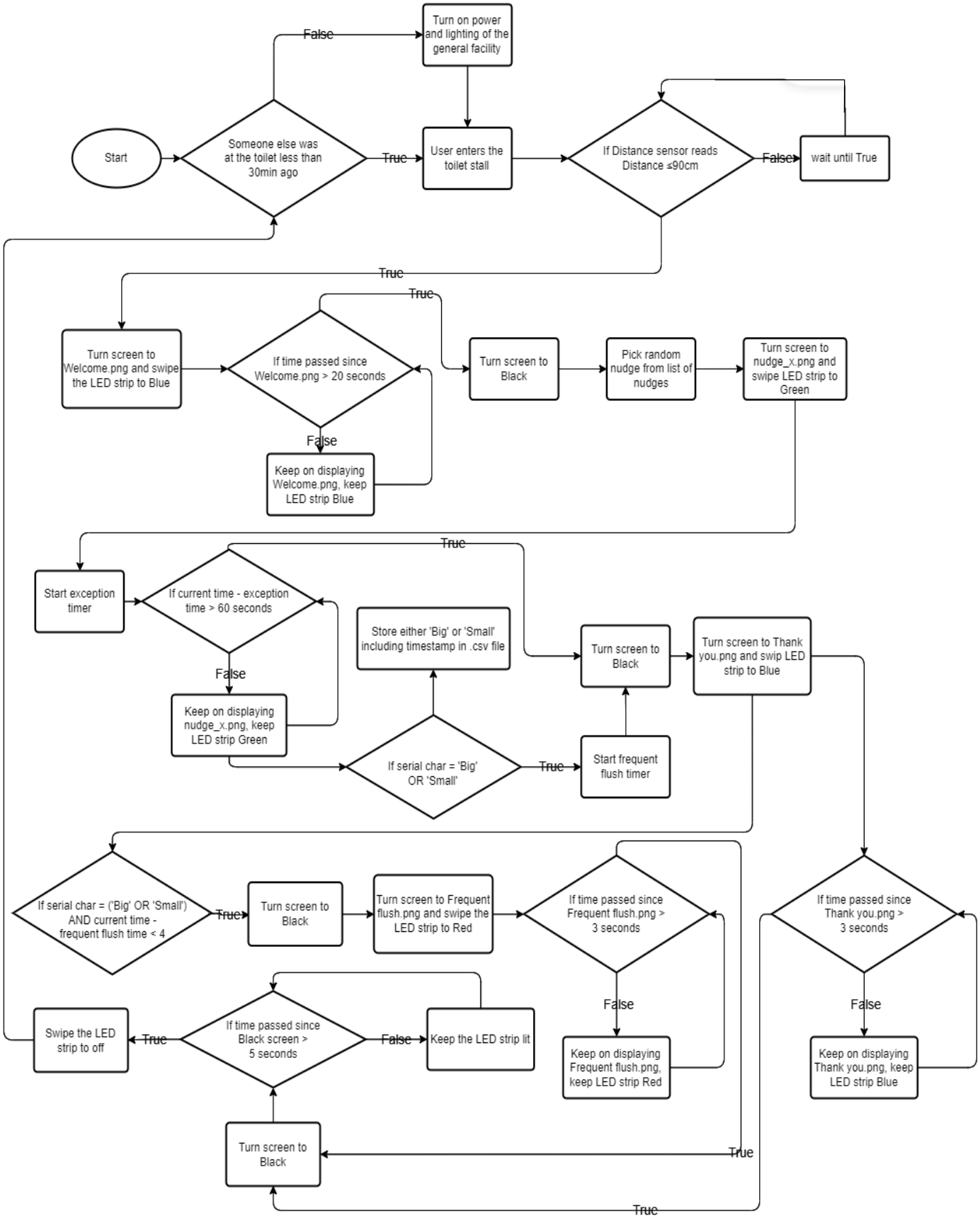


Figure 42: Flow diagram of The Button Nudger.

5.5 Nudge specification

To specify the eventual nudge messages that will be used, the nudge design of chapter 4.6.3 will be narrowed down to 10 different nudges of which one will be chosen randomly each interaction loop. As was mentioned before, these nudges will be norm setting in nature and humoristic by design. The nudge messages which are chosen are as follows:

1) For efforts without a puff, the small button is enough
2) With only little in the bowl, the small button is your goal
3) If it was just a bluff, the small button is enough
4) For liquids, a small button flush is sufficient
5) Are you impressed? Big button needs a press!
6) Big button flush = 6 litres
   Small button flush = 3 litres
7) Only a big effort requires the big button
8) After a nr. 1, flush with the small button when you're done
9) Pressing the big button on the loo, is only for nr. 2
10) If you smell and blush, go with the big flush!

Figure 43 shows how one of these nudges will be displayed. This format will be the same for all the other nudges. Additionally, the Welcome, Thank you and Frequent flush prevention messages are also portrayed in this format. However, the colour of the text and border is adjusted to fit the lighting colour as described below.

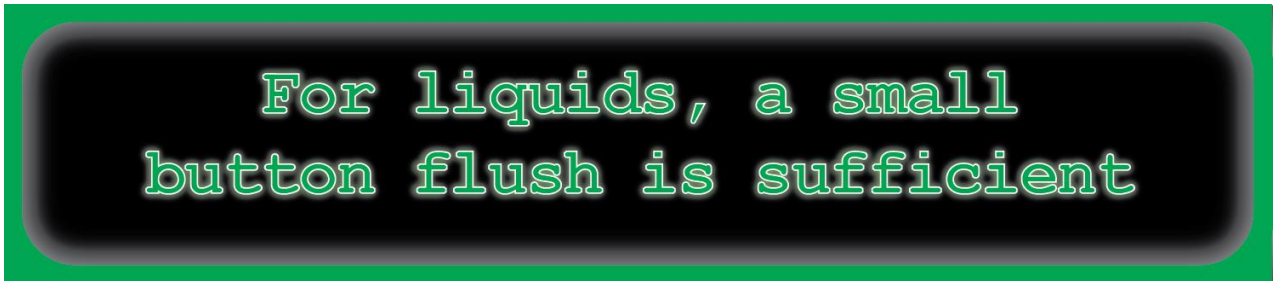


Figure 43: The display for one of the nudge messages.

Next to the nudge message, there is also the supporting lighting, The colouring of the lighting serves the purpose of setting the correct mood to aid the interaction. The choices made regarding colour use are solely based on theoretic colour association evidence. Firstly, the 'Effects of Color on Emotions' article by Valdez and Mehrabian (1994) is consulted. Three different colours will be used by The Button Nudger.

Blue will be used during the Welcome and Thank you message. Blue is chosen in this case because it is 'associated with "secure/comfortable" and "tender/soothing," which imply pleasure and low arousal' (Valdez & Mehrabian, 1994, p. 396). These associations aid the goal of comforting the user while being introduced to The Button Nudger (for the Welcome message) and leaving a positive feeling at the end of the interaction (for the Thank you message).

Green will be used during the Nudge message, because it is associated with positivity and success (Moller et al., 2009). These associations are beneficial because the goal of The Button Nudger is to elicit a positive behavioural change.

Red will be used during the Frequent flush prevention message for the fact that red is "associated with the danger of failure in achievement settings" (Moller et al., 2009, p. 898). Which is the exact goal of the Frequent flush prevention message. Behaviour that is counterproductive towards the goal of The Button Nudger is thus accompanied with colour that aims to make the user aware of the danger of failure towards that goal.

6 Realisation

This chapter is dedicated to the realisation aspect of The Button Nudger. As touched upon in chapter 3, there will first be a period of data collection without The Button Nudger present, to establish a baseline ratio of small and big button presses. For this phase (Phase 1), only the button press registration is necessary. Thereafter, The Button Nudger is placed for an identical timeframe, along with the button press registration in a second phase (Phase 2). The differences in button press events between Phase 1 & 2 are then analysed in chapter 7. For the sake of clarity in this chapter, first the realisation of Phase 1 will be discussed. Thereafter the additions to accomplish the realisation of Phase 2 are discussed. Appendix E Table 15 provides a full list of used components.

6.1 Phase 1 – Button press registration

In this section, only the realisation of Phase 1 will be discussed. This phase focus is on the realisation of the button press registration setup.

6.1.1 The button press registration setup - Piezo vibration sensors

The button press registration setup utilises two sensors, one behind each flushing button, to register a button press. Initially, the button press registration setup made use of Grove Piezo vibration sensors v1.1 (Kiwi electronics, 2023). They were chosen for the reason that they were used in the earlier research by Kadijk (2021). These sensors were tested extensively in order to optimize their sensitivity. The sensors were placed inside different test contraptions to find out where to clamp the sensor to ensure optimal sensitivity. As can be seen in Figure 44, the sensor is placed in six different test contraptions, every next contraption fixates the sensor a bit further up in steps of 0.25cm. Eventually, contraption "+0.75cm" was deemed the most effective. Also, the amount a sensor needed to be flexed was tested in iterative steps, however this was found to have no influence on the sensitivity.

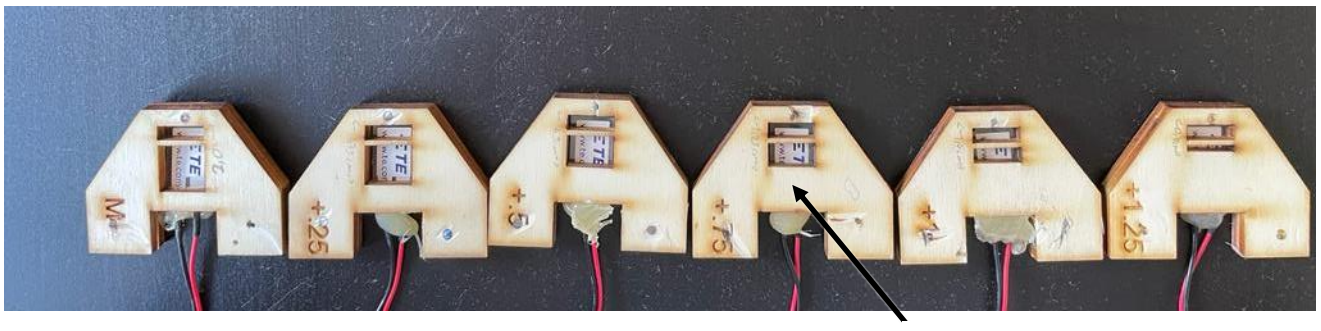


Figure 44: Piezo vibration sensors in different test contraptions.

These sensors were subsequently fixated in another contraption, as seen in Figure 45, to be placed inside the flushing fixture behind the flushing buttons. In this contraption, the sensors were clamped at 0.75cm upwards from its base as concluded from the test contraptions. In Figure 45, the implemented Piezo vibration sensors inside their contraption can be seen.

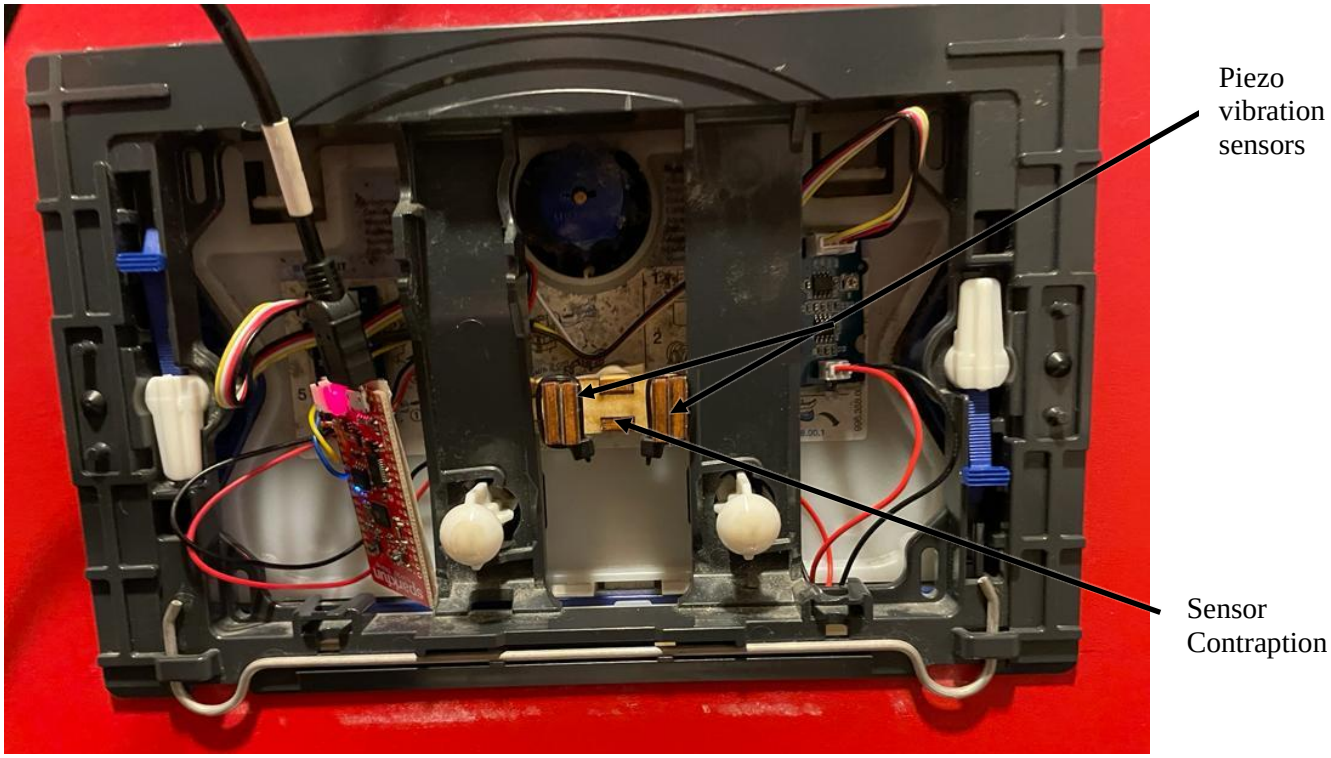


Figure 45: The fixated Piezo vibration sensors, implemented into the flushing fixture.

Eventually, these sensors were deemed ineffective as they did not register a button press reliably. The reason for this is mainly that a button press did not flex the sensor in the same way as they were flexed in the test environment. Additionally, since these are vibration sensors, they work optimally when being vibrated. Flexing the sensors in a single direction did trigger the sensors at times, however the response was eventually too unreliably.

6.1.2 The button press registration setup - Microswitches

The alternative for the piezo vibration sensors was found in microswitches. In this case Omron Simulated Roller Lever Micro Switches (RS Components Ltd., 2023). Microswitches were chosen because they output a digital signal, opposed to the analogue signal outputted by the piezo vibration sensors. Therefore, the microswitch is either activated or not activated, and sensitivity problems are omitted. These microswitches are also chosen for their small size and high accuracy in registering a press. Furthermore, these switches are quite sturdy, especially for their small size. This makes for less possibility for a defect during a forceful press action of a button.

6.1.3 Preferred solution

The button press registration setup consists of three main components. These are: the sensors, an ESP microcontroller and a Raspberry Pi. The sensors are, as described in section 6.1.2, microswitches by Omron. The ESP microcontroller is necessary for interpreting the signals from the microswitches, whilst being small enough to fit inside the flushing fixture. A Sparkfun ESP32 Thing (Sparkfun, 2016) was chosen. This was chosen mainly for its relatively small size and low power consumption. Especially the thickness of this microcontroller, which was only 2mm at its thinnest and 7mm at its thickest, would be beneficial during the implementation. The Raspberry Pi was necessary to store the flushing data which was interpreted by the Sparkfun ESP32 Thing. A

Raspberry Pi model 3B (Raspberry Pi, 2016) was used, which was chosen for the fact that this model was freely available. The other reason for using this model is that it is one of the more modern Raspberry Pi's that is still equipped with a full-size HDMI port, something that is important for Phase 2. The Raspberry Pi could not be used without the Sparkfun ESP32 because the Raspberry would not fit inside the flushing fixture.

During the testing of the button press registration setup, problems arose around uploading code to the Sparkfun from Arduino IDE. The error message was: "Failed to connect to ESP32: Timed out waiting for packet header". Whilst it seemed to be a software issue at first, the eventual solution was hardware related. It appears to be that in some cases, the Sparkfun is experiencing this error when either GPIO0 or GPIO2 are connected (Dcartman et al., 2018). As GPIO 2 was connected, no new software could be uploaded to the Sparkfun. GPIO2 and GPIO0 were omitted and GPIO17 and GPIO18 were used instead, resulting in a proper functioning setup.

The eventual preferred solution is visible in Figure 46. The microswitches are connected to the Sparkfun ESP32 using 2 additional 10KΩ pull up resistors to ensure the voltage level remains high until a switch is actually pressed. This is also visible in Figure 47. Furthermore, a USB male A to USB male micro-B cable is used to enable communication between the Sparkfun and the Raspberry Pi. The USB connection simultaneously acts as a power source for the Sparkfun.

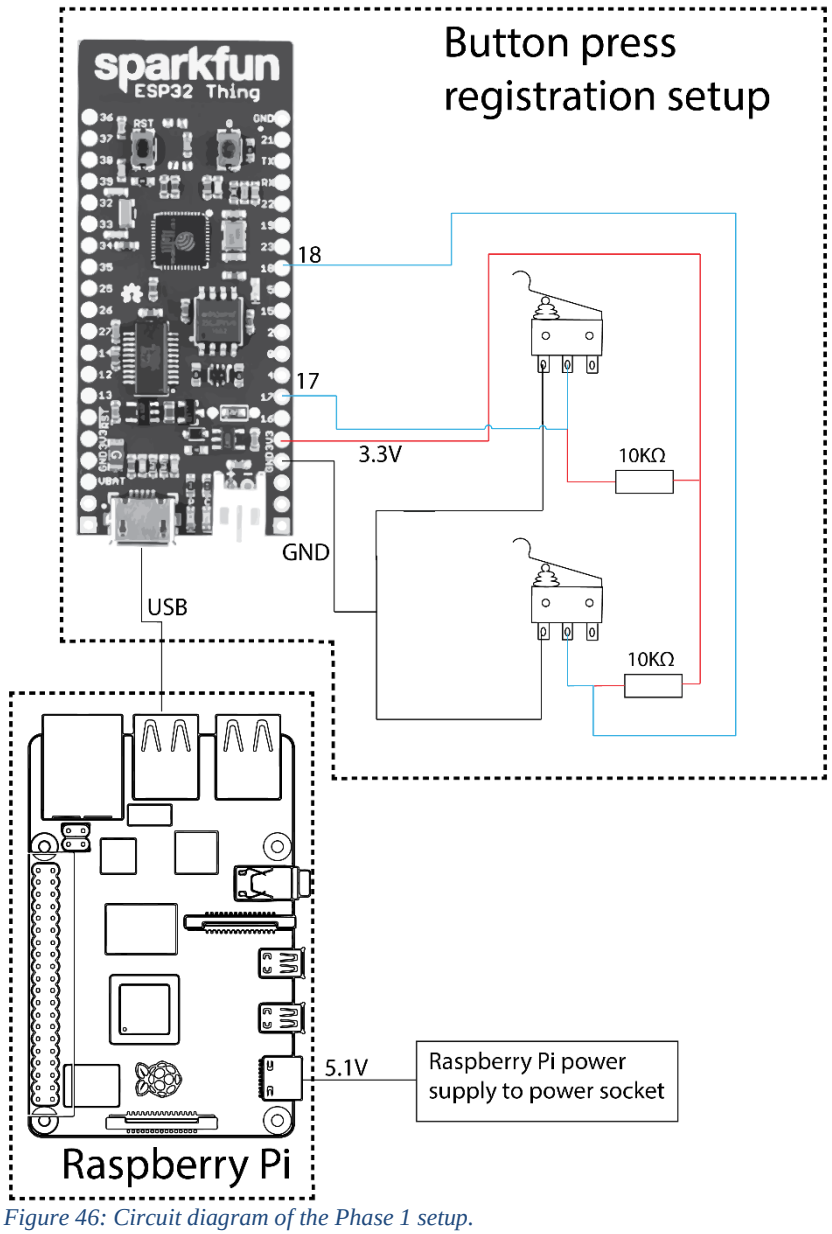


Figure 46: Circuit diagram of the Phase 1 setup.

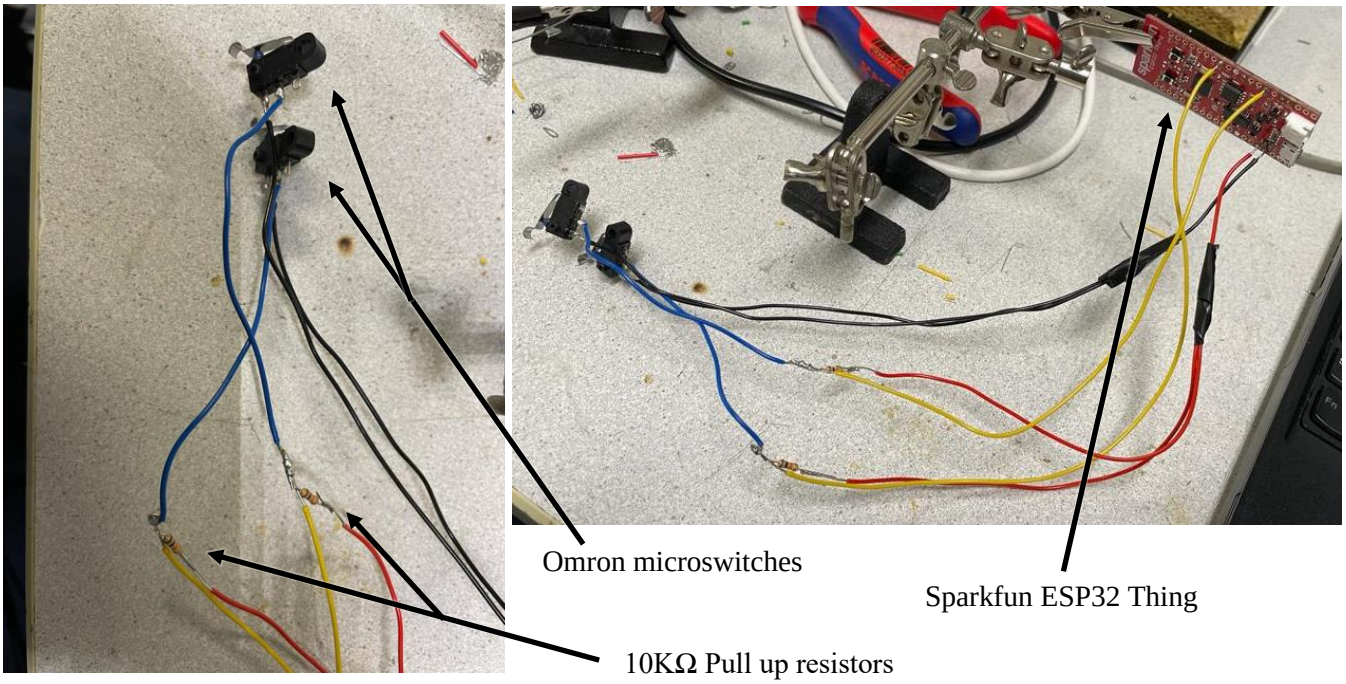


Figure 47: Microswitches soldered to the resistors (left). The microswitches soldered to the Sparkfun ESP32 Thing (right).

6.1.4 Embedded Software

The Sparkfun ESP32 is programmed with Arduino IDE 2.0.0 (Karl Söderby, 2021). It interprets the voltage input from a microswitch when it is pressed and converts it to a string, dependant on which switch is pressed this string is either “Big” or “Small”. The code for this part can be found in Appendix F.

The Raspberry Pi is running Raspberry Pi OS (Raspberry Pi, 2015) and is programmed with Python on the Thonny Python IDE (Thonny, 2017). It runs two programs simultaneously. The first program is receiving the serial data from the Sparkfun and writes that data to a csv file stored locally. It also adds the time stamp of every datapoint. The code for this part can be found in Appendix G. The second program is monitoring the time the Raspberry Pi has been on and writes this to a different csv file. The code for this part can be found in Appendix H. The necessity for this last program arose from the fact that the Raspberry Pi is not connected to the internet. Therefore, the system time it assumes is potentially incorrect. It is noted that a Real Time Clock (RTC) module (Lady ada, 2012) could be implemented to ensure a reliable timestamp. However, due to too limited space in Phase 2, there was chosen to refrain from implementing this module. To still be able to monitor somewhat retrospectively what happened, this “uptime log” can give some context to the collected data.

Furthermore, there was a need for the programs on the Raspberry Pi to run automatically upon a (re)boot, since the power socket which powers the Raspberry Pi is linked to a movement sensor in the toilet facility. This meant that the power is cut off whenever there has not been anyone present in the toilet facility for more than 30 minutes, which is at least every night. To deal with this incontiguous power source, the Crontab is edited (Dexter Industries, 2015) to let the two Python programs launch at reboot.

6.1.5 Implementation

As was discussed in section 6.1.4, the only power socket available in the toilet is normally used for powering the lighting. This lighting is switched off after 30 minutes of inactivity. Powering the Phase 1 implementation without the use of batteries that need to be charged or replaced when using for prolonged time, requires the usage of that power socket. Therefore, the lighting is taken out of the power socket and plugged in a junction box. In this junction box, the power supply of the Raspberry Pi is plugged in as well. This all is invisible for the toilet visitor as it is situated above the toilet ceiling and can only be accessed by lifting the suspended ceiling plates.

The Raspberry Pi itself is situated above the ceiling as well. A 3 meter USB cable is plugged into the Raspberry Pi and fed through a cable gutter along the wall. This cable will enter the flushing fixture and is clamped between the wall and the top of the flushing button panel. The inside of the flushing fixture as it looks before implementing the electronics is visible in Figure 48. Figure 49 shows the cubicle as a toilet visitor would see it during the data collection in this phase. Figures 48 and 49 also show how the different parts will be referred to.

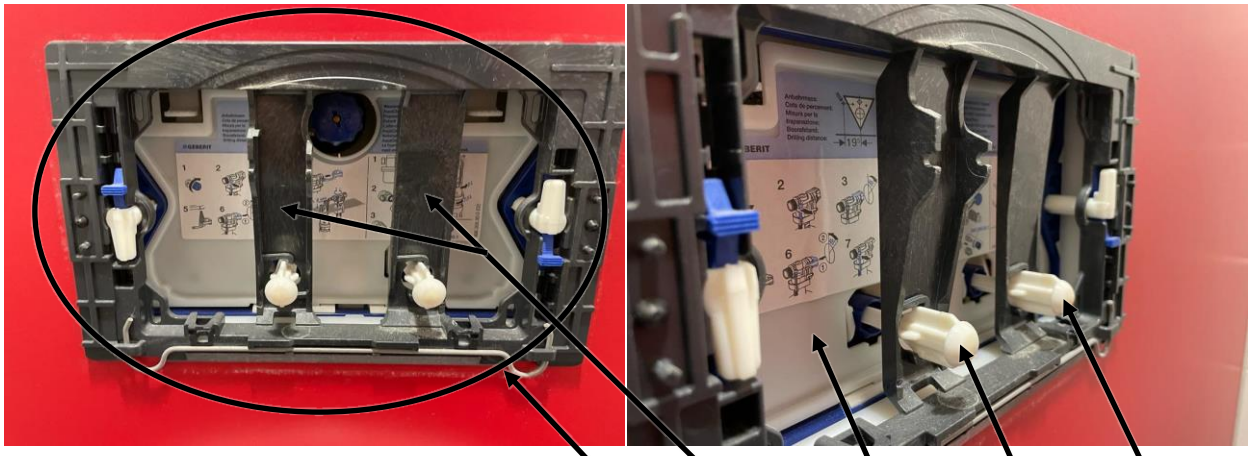


Figure 48: Flushing mechanics when the button panel is removed. Front view (left) and side view (right).

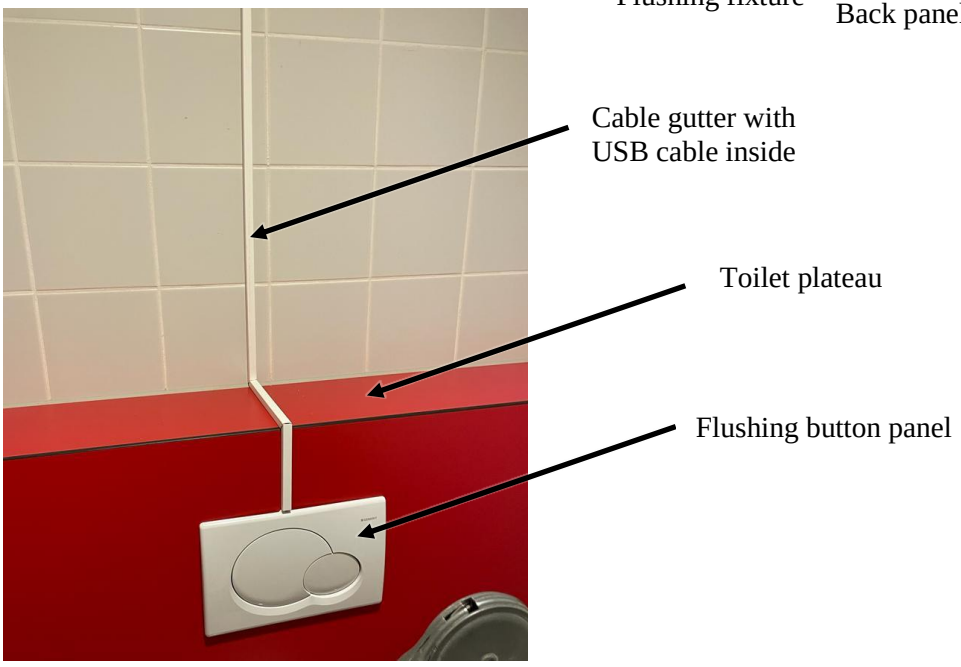


Figure 49: Flushing button panel and cable gutter as a toilet visitor would see it during the Phase 1 data collection.

The cable is subsequently plugged into the Sparkfun, which is inside the flushing fixture, behind the flushing button panel. The space inside the flushing fixture very small, therefore the small electronic components are well suited for this application.

Inside the flushing fixture, the microswitches need to be held in place. This is done by fixating them in a lasercutted wooden contraption and held together by a small nut and bolt. Figure 50 shows how the microswitch is fixated in the wooden contraption. Figure 51 shows the whole button press registration setup, consisting of the microswitches inside their contraption and connected to the Sparkfun. (electrical) tape is applied to all exposed electronics in order to cover them to prevent water damage.

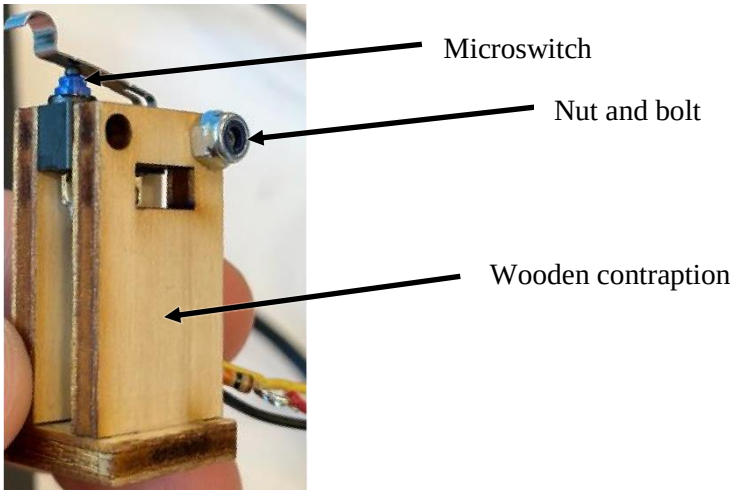


Figure 50: Microswitch fixated in a wooden contraption.

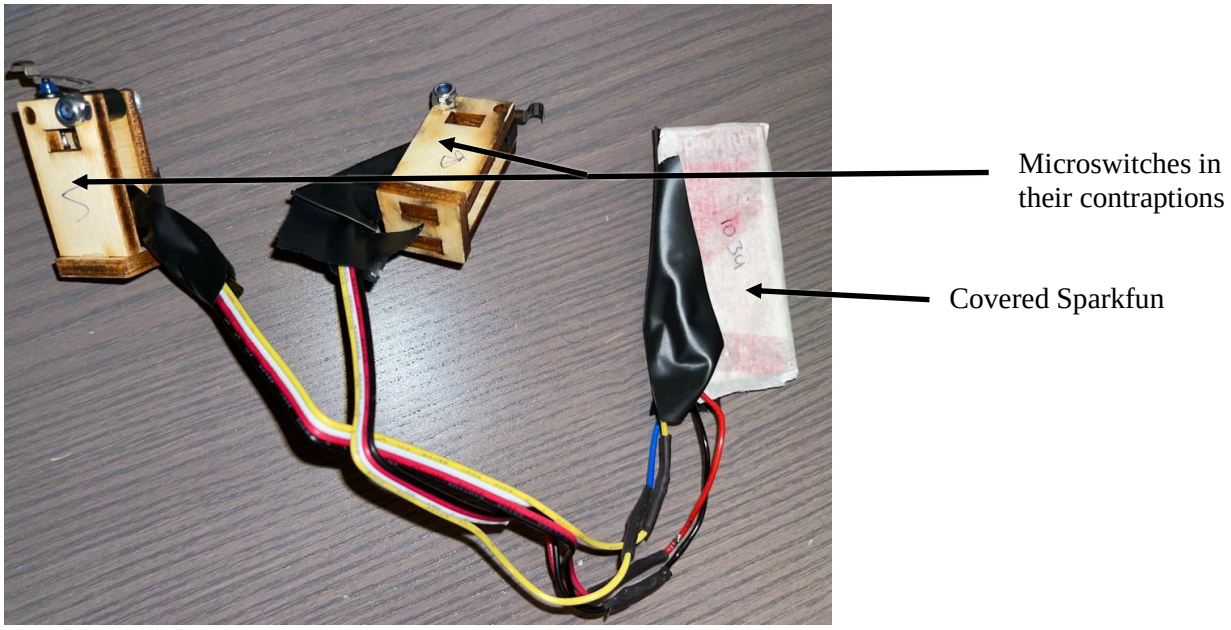


Figure 51: Complete button press registration setup. Consisting of microswitches in their contraptions, Sparkfun and covered electrical components.

The complete button press registration setup is then placed inside the flushing fixture, the wooden contraptions placed between both uprights and are stuck to the back panel with double sided tape. They are further reinforced to the uprights with cable ties. In this position the microswitches make contact with the back side of either of the flushing buttons when it is pressed to flush the toilet. The Sparkfun is placed on the left-hand side of the left upright. The implemented button press registration setup is visible in Figure 52.

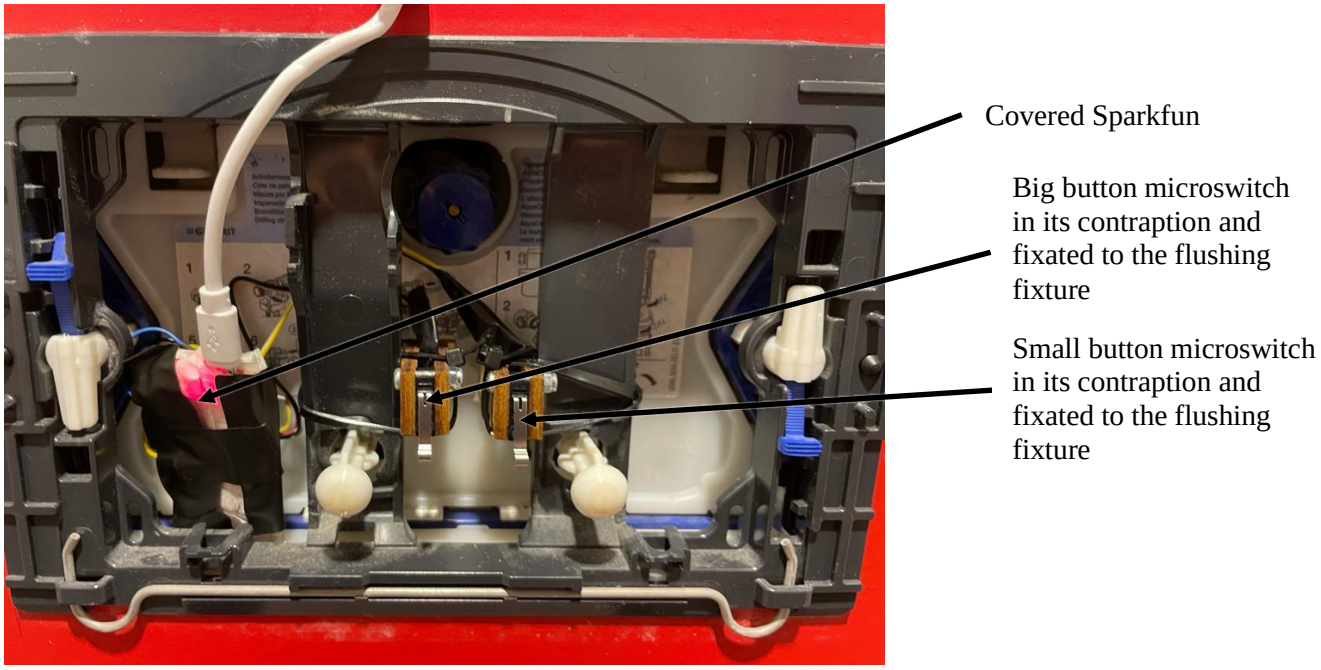


Figure 52: The implemented button press registration setup.

6.1.6 Data collection

The implemented button press registration setup is first tested without covering the flushing fixture with the flushing button panel by pressing both microswitches with varying force applied. This to ensure they operate at all different button press forces being applied. Thereafter the flushing button panel is placed over the flushing fixture and the same process of button press testing is repeated. After each button press the .csv file is checked to ensure that the press is registered. A part of the .csv file of the test data log is visible in Figure 53. The "uptime log" was tested as well for at least an hour, the result of the .csv file of the test uptime log is visible in Figure 54. The tests conclude that both programs are working as intended.

```
Big,12:44:27,21-10-22
Small,12:44:42,21-10-22
Big,12:44:53,21-10-22
Small,12:45:05,21-10-22
Big,12:45:15,21-10-22
Small,12:45:27,21-10-22
Big,12:45:40,21-10-22
Big,12:45:59,21-10-22
Big,12:46:12,21-10-22
Big,12:46:27,21-10-22
Big,12:46:43,21-10-22
Big,12:46:54,21-10-22
Small,12:47:04,21-10-22
Small,12:47:20,21-10-22
Small,12:47:36,21-10-22
Small,12:47:56,21-10-22
Small,12:48:08,21-10-22
Small,12:48:20,21-10-22
Big,12:48:41,21-10-22
Small,12:48:54,21-10-22
```

Figure 53: A part of the test data log, showing which button is pressed and the time stamp.

```
"(b'up 0 minutes\n', None)"
"(b'up 3 minutes\n', None)"
"(b'up 6 minutes\n', None)"
"(b'up 9 minutes\n', None)"
"(b'up 12 minutes\n', None)"
"(b'up 15 minutes\n', None)"
"(b'up 18 minutes\n', None)"
"(b'up 21 minutes\n', None)"
"(b'up 24 minutes\n', None)"
"(b'up 27 minutes\n', None)"
"(b'up 30 minutes\n', None)"
"(b'up 33 minutes\n', None)"
"(b'up 36 minutes\n', None)"
"(b'up 39 minutes\n', None)"
"(b'up 42 minutes\n', None)"
"(b'up 45 minutes\n', None)"
"(b'up 48 minutes\n', None)"
"(b'up 51 minutes\n', None)"
"(b'up 54 minutes\n', None)"
"(b'up 57 minutes\n', None)"
```

Figure 54: A part of the test uptime log, showing every three minutes how low the Raspberry Pi has been on for.

6.2 Phase 2 – The Button Nudger

All components of Phase 1 will still be present in the same manner in Phase 2. This phase focus is on the realisation of The Button Nudger.

6.2.1 The Button Nudger

The Button Nudger consists of five main components: display screen, ultrasonic proximity sensor, RGB LED strip, Raspberry Pi and delay relay. Additionally, the Phase 1 setup will still be kept in place in the same way it did. These are all connected as can be seen in Figure 55.

The display screen a Waveshare 11.9inch capacitive touch display (Waveshare, 2023). The reason this display is chosen specifically is the wide but flat shape of it, which is exactly what is needed to portray a single nudge sentence, whilst still being not too bulky to take up much space. This specific display has the added benefit that is specifically made to cooperate with a Raspberry Pi, which can easily be mounted on the back side of the screen. Furthermore, it comes with mounts for fixating the screen itself included.

The ultrasonic proximity sensor is an AJ-SR04-M (Otronic, 2023). This sensor is able to measure proximity from 20cm to 500cm accurately, which is appropriate since the flushing button panel is around 100 cm from the opposing wall. It is also waterproof, which is beneficial since the sensor is exposed and will be cleaned by the campus cleaning personnel.

The RGB LED strip is a WS281B digital 5050 RGB LED strip containing 60 LED's on 1 meter (Tinytronics, 2023). The WS281 LED series is properly documented and is therefore chosen in this case. It is also equipped with an adhesive backside such that it can be taped to an object.

The Raspberry Pi remains the same as in Phase 1.

The delay relay is based on a NE555 timer chip and a Songle relay (Opencircuit, 2022), it further consisted of an adjustable potentiometer to change the time of delay between 0 and 10 seconds. The delay relay was initially not a component deemed necessary. Its necessity became apparent by having to accompany for the aforementioned incontiguous power source. For this reason, upon regaining power, the Raspberry Pi and the display would turn on simultaneously. As a result, the display would immediately go into power saving mode. To work around this, an experiment was performed to figure out in which case the screen would not immediately go into power saving mode. It was discovered, that in the case that the Raspberry Pi received power 5 seconds later than the display, the display would not be triggered into power saving mode. However, further investigation is necessary to determine the cause of this behaviour.

As can be seen in Figure 55, the ultrasonic proximity sensor circuitry makes use of a 1KΩ and a 2KΩ resistor. The LED strip also requires a 2.5A power source to power the 60 LED's. This requires a separate power supply since the Raspberry Pi cannot supply that much power.

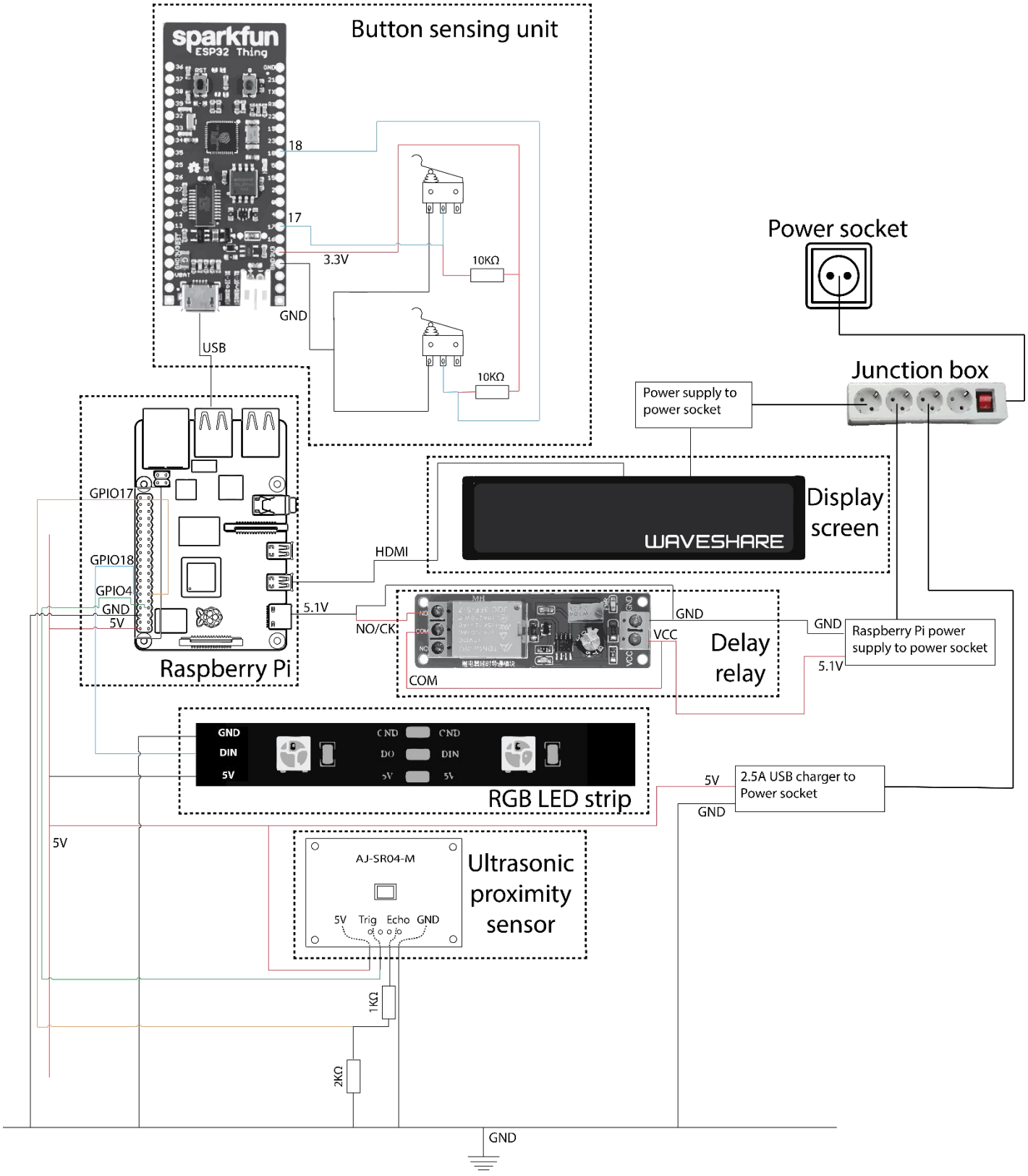


Figure 55: Circuit diagram of the Phase 2 setup.

6.2.2 Embedded Software

As was the case in Phase 1, the Sparkfun is programmed with Arduino IDE 2.0.0. It interprets the voltage input from the microswitch when it is pressed and converts it to a string, dependant on which switch is pressed this string is either “Big” or “Small”. The code for this part can be found in Appendix I (the only difference with Appendix F is a short delay than in Phase 1 in the “void GetSmall” and “void GetBig”, as this was necessary to interpret multiple flushes after one another).

The Raspberry Pi is running Raspbian OS and is programmed with Python on the Thonny Python IDE. It runs two programs simultaneously. The first one is the unchanged program which keeps track of the time the Raspberry Pi has been on as can be found in Appendix H. The second program is operating the complete Button Nudger system as well as receiving the serial data from the Sparkfun and writing that data, along with the timestamp to a csv file stored locally. The code for this program can be found in Appendix J.

6.2.3 Raspberry Pi settings

To let these programs work properly, there are a couple of settings that have to be added or changed in the Raspberry Pi. Some of those are for making sure that the correct libraries are installed for components to work, others are related to coping with the aforementioned incontiguous power supply.

First of all, to make the RGB LED strip work, the rpi_ws281x library needs to be installed (Gadgetoid et al., 2017). This library is only accessible as super user, so in order to run the program, “sudo” should be used. Also, in the /boot/config.txt file, “dtparam=audio” must be set to “off” to make use of GPIO 18.

To make sure that the display works, the display settings from Waveshare should be added into the /boot/config.txt file (Waveshare, 2015). Additionally, “hdmi_force_hotplug” needs to be set to “1” and “config_hdmi_boost” need to be set to “4” (Jomar Dela Cruz, 2022).

Furthermore, as was the case in Phase 1, the Crontab needs to be edited to accompany the launch of the programs at a reboot. (Dexter Industries, 2015). However, in this case, Crontab does not hold the permission to launch the complete Button Nudger software, because of the aforementioned necessary super user permissions for the rpi_ws281x library. It is noted that “sudo” can also be used in Crontab, however implementing this did not make the program launch at a reboot. Therefore, in this case, it is only used to launch the “uptime log”. To launch The Button Nudger software at reboot, a Desktop entry is created (Klricks, 2020).

Lastly, in order to ease the process of accessing the Raspberry Pi remotely via PC, VNC is installed (RealVNC, 2005). VNC was particularly useful when retrieving files from Raspberry Pi without having physical access to it.

6.2.4 The Button Nudger case

In order to house all components of The Button Nudger, a case was made. First, two iterations of wooden prototypes were produced in order to determine the fitting in a toilet cabin and around the flushing button panel. As can be seen from Figure 56, the first prototype was bulkier and the fitting around the flushing button panel is larger. Another issue with the first prototype was that it was sticking out above the toilet plateau (as indicated in Figure 49). For the second wooden prototype, the distance sensor was moved down to lose some height above the flushing button panel to match the height of the toilet plateau. The fitting around the flushing button panel was made tighter.

Eventually, the case was made to the specifications of the second prototype, but this time in 6mm transparent acrylic. The whole case was engraved except for the space where the display would be. This was done to diffuse the LED lighting, to generate a nice lighting effect. Two slots were cut out, one from the top plate, one from the bottom plate. This was done to let heat from the Raspberry Pi dissipate as well as to get rid of any unwanted moisture or water getting inside the case. A third slot was cut out of the back plate to feed the USB cable from the Raspberry Pi to the Sparkfun through. Lastly, an additional hole was cut out of the top plate to feed the power cables through. The whole case was glued together with acrylic glue, except for the back plate. By doing so, the front could still be removed from the back to service The Button Nudger when needed. The front and the back plate were held together by six patent bolts. All unglued connections were provided with a silicon sealant to prevent water seeping through. The finished Button Nudger case can be seen in Figure 57.

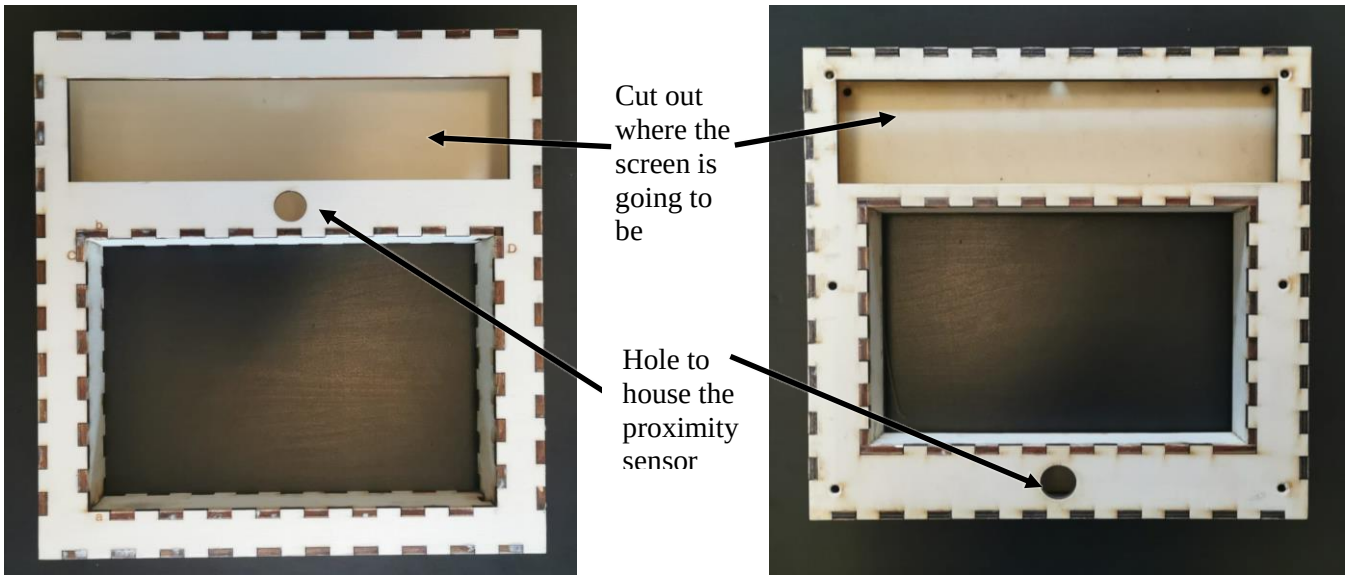


Figure 56: First wooden prototype (left) and second wooden prototype (right).

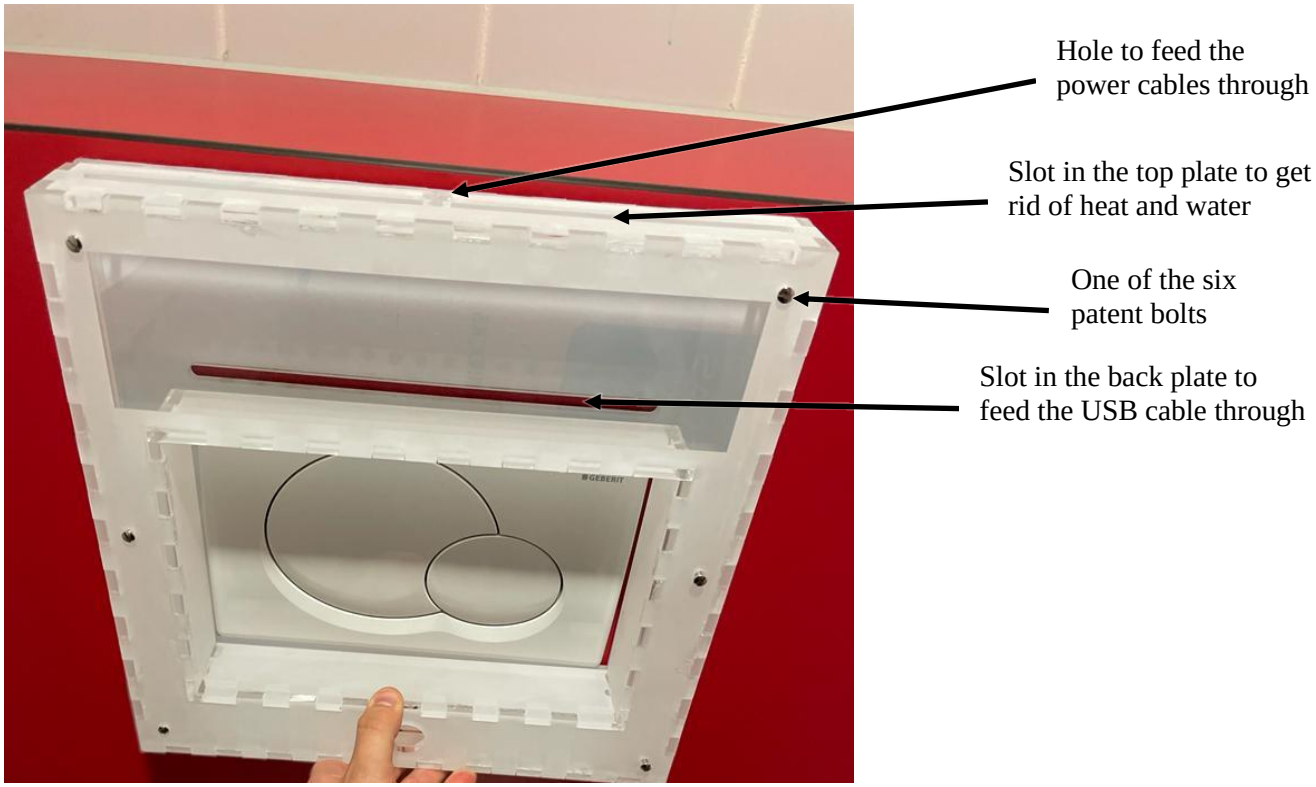


Figure 57: Finished Button Nudger case in acrylic, held in place around the flushing button panel.

6.2.5 Component integration

Regarding the placement of all components into the case, the Raspberry Pi was mounted on the backside of the display with screws. The display was subsequently screwed to the back plate with the included mounts. This can be seen in Figure 58. The HDMI connection between them was made by the included 180-degree HDMI adapter. The LED strip was fed through the acrylic case all the way round. It was mounted with its adhesive side to acrylic uprights inside the case. The proximity sensor cable was fed through the inside of the acrylic case as well, the excess cable was tied together and placed under one side of the display. On the same side underneath the display, the delay relay was glued in place. The glue was applied to 3D-printed mounts which were screwed to each of the four corners of the delay relay. On the other side underneath the display, the distance sensor circuitry was placed. This can be seen in Figure 59. All cables were tied together with cable ties. Lastly, the plastic front side of a binder was used as a water deflector. It was held in place by, on one side, clamping it between the back plate and the display mounts, and on the other side, glued to acrylic mounts situated just above the display.

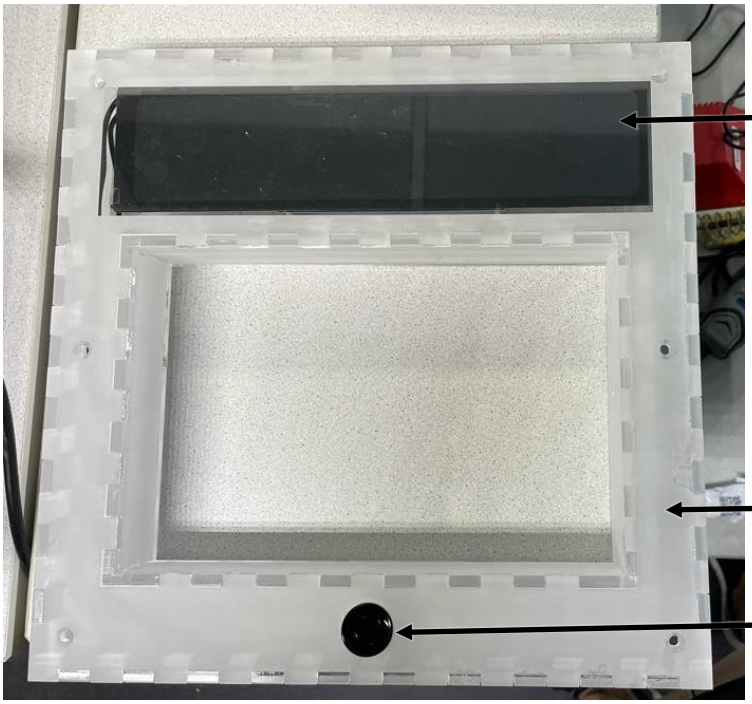


Figure 58: The display, LED strip and proximity sensor implemented in the case (top), and the Raspberry Pi mounted to the display mounted to the back plate (bottom).

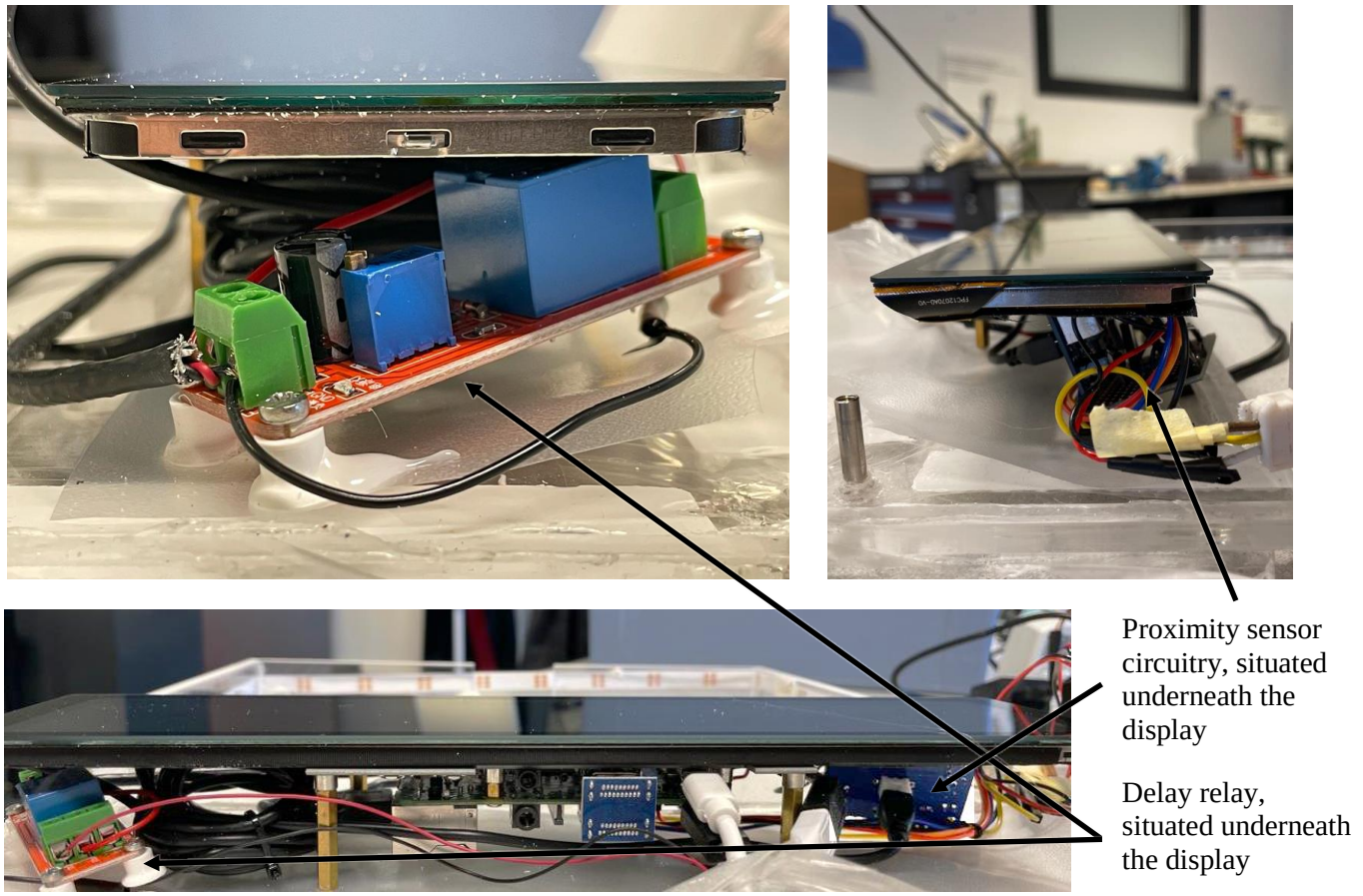


Figure 59: Placement of the delay relay (top-left) and the proximity sensor circuitry (top-right & bottom) underneath the display.

6.2.6 Implementation

Regarding the implementation of the button press registration setup, nothing has changed with respect to Phase 1. However, for Phase 2, the Raspberry Pi was placed inside The Button Nudger case opposed to above the ceiling as in Phase 1. Therefore, the USB cable connecting the Sparkfun and the Raspberry Pi ran from inside the flushing fixture directly into The Button Nudger case.

The Button Nudger case was placed tightly around the flushing button panel, fixated with Tesa powerbond ultra strong double sided adhesive tape (Tesa®, 2023) to the wall. Three power cables exited The Button Nudger case, being the Raspberry Pi power cable, the display power cable and the LED strip power cable. These three cables were fed through the same cable gutter as used in Phase 1 up to the ceiling. Above the ceiling, these power cables were plugged into the same junction box as the toilet lighting power cable. The installed Button Nudger can be seen in Figure 60.

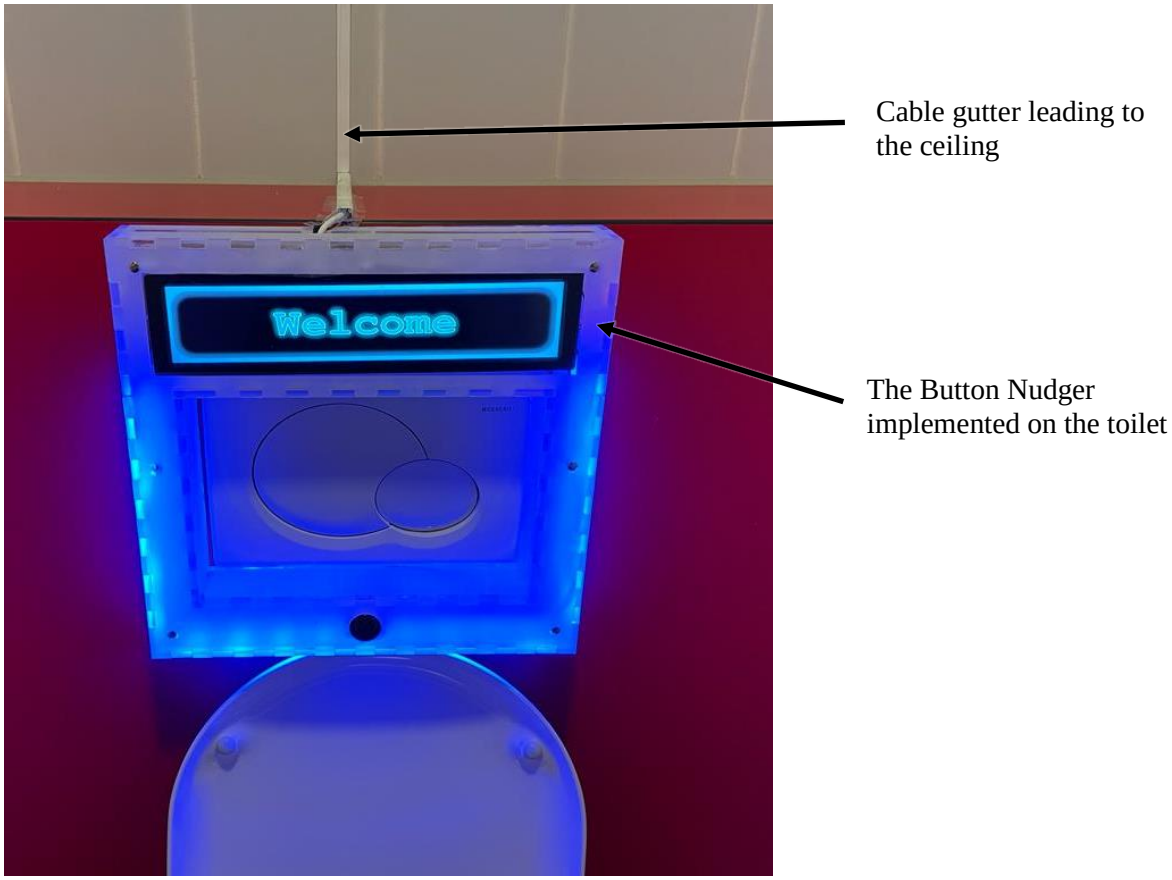


Figure 60: The Button Nudger implemented on the toilet.

6.2.7 Data collection

The Button Nudger is tested thoroughly in every step of the realisation. Initially, the individual components, being the display, LED strip, ultrasonic proximity sensor, delay relay and Raspberry Pi, are tested separately. Thereafter, the components are connected to each other and their functioning has been tested in conjunction with each other.

The Phase 2 data collection does not change compared to Phase 1. The data that is collected is in Phase 2 also the flush data log, as seen in Figure 53 and the "uptime log" as seen in Figure 54. From section 6.1.7, it can be concluded that these data collection methods are operational and functioning properly.

6.2.8 Functioning

Revisiting the functional requirements from section 5.2.1 it can be concluded that all requirements from the 'Must' category are accomplished. The Button Nudger as well as the button press registration are working fully and reliably. They are fully compatible with their environment and the challenges that brought with it. Additionally, no privacy violations and potentially discriminating sensing capabilities were present in the prototype.

Regarding the 'Should' and 'Could' categorised requirements, most are satisfied as well. Unfortunately, the requirement that The Button Nudger should work for a full day without malfunctioning, crashing or having to be rebooted is not satisfied. It is the case that sometimes it appears to be that the code has crashed and the Raspberry Pi displays its home screen running on the Raspberry Pi. Consequently, flushes are not registered at this time. The latter being the upside

in this undesirable situation, as the data is not ‘clouded’ with unwanted (i.e. flushes that were not preceded with a nudge) data. This issue first appeared after the first day of implementation. Conversely, multiple prolonged tests of up to six hours did not elicit this problem, therefore the cause is unknown. A quick reboot, either forcefully or after a ‘natural’ reboot when no one was present at the toilet for thirty minutes solves the problem.

Lastly, it is difficult to install The Button Nudger around the flushing button panel. The cut-out for the flushing button panel is made almost seamlessly tight around the panel to allow for enough space for the components inside The Button Nudger, whilst still be able to not let The Button Nudger stick above the toilet plateau, as was described in section 6.2.4. This considerably hampers the space for installation, as the USB cable from the Sparkfun to the Raspberry Pi needs to be neatly packed inside the flushing fixture.

7 Evaluation

In this chapter, the button press registration and The Button Nudger will be evaluated. The button press registration has collected two datasets for each toilet, one for Phase 1 and one for Phase 2. Phase 1 is the zero measurement and Phase 2 is the intervention measurement. Lastly, a user evaluation will be given.

7.1 Flushing data evaluation

First of all, it is important to exactly know the experiment context of each of the data collection phases. Thereafter, each phase will be analysed separately, after which a statistical comparison between the two phases will be made.

7.1.1 Experiment context

In order to understand the flushing data and to provide proper context to it, the setting of the toilets which were equipped with The Button Nudger is described. A total of four toilets were equipped with The Button Nudger, two ladies and two gentlemen. The chosen toilet cubicles in each toilet facility were the same for Phase 1 and Phase 2. All toilets are situated on the ground floor of the Zilverling building. A floorplan of the Zilverling is provided in Figure 66 in Appendix L, indicating the four toilets which were equipped.

The toilets that were equipped are indicated with their room number. Those are: Zi1066 (gentlemen), Zi1050 (ladies), Zi1014 (gentlemen), Zi1034 (ladies). It should be noted that the combination of Zi1014 and Zi1034 are the closest toilets to the Starbucks study and drinks area. The combination of Zi1066 and Zi1050 are the closest toilets to the SmartXP study area. A further area of interest is the composition of each of the toilet facilities, which vary in size and number of toilets. The common factor between all toilet facilities is that one toilet cubicle was equipped with The Button Nudger to allow users to choose an alternative cubicle. Table 6 shows the composition of each toilet facility.

Table 6: Composition of the equipped toilet facilities.

Room number	Ladies/Gentlemen	No. of toilet cubicles	No. of urinals
Zi1066	Gentlemen	2	3
Zi1050	Ladies	2	0
Zi1014	Gentlemen	2	3
Zi1034	Ladies	4	0

It should further be noted that the availability of urinals at the gentlemen toilets will cause the gentlemen to use the toilet cubicles less for urinating. Therefore, the data collection results for the gentlemen toilets are expected to be skewed more towards big button flushes than would biologically be the case. The to be expected ratio Big : Small button flushes is unknown.

7.1.2 Phase 1 analysis – Zero measurement

Phase 1 started on Monday 17-10-22 in the afternoon and ran until Thursday 10-11-22 in the afternoon. This resulted in a total of 18 weekdays and 6 weekend days for a total of 24 days. The first two weeks of data collection (until 30-10-22) were normal college weeks without any particularities. The last two weeks of data collection (31-10-22 until 10-11-22) were exam weeks at

the university. The latter decreases the traffic to the toilets significantly. In order to ensure homogeneity between Phase 1 and Phase 2, the data collection is limited to the first 17 days (including 4 weekend days) of Phase 1. The last week of Phase 1 was excluded rather than any other week, because this was the least representative week. The Phase 1 data collection results are visible in Table 7.

Table 7: Phase 1 data collection results.

Room number	Ladies/ Gentlemen	No. of data entries	Big button total	Small button total	Ratio Big:Small	Ratio Small:Big	Percentage Big	Percentage Small
Zi1066	Gentlemen	876	454	422	1.076	0.930	51.8%	48.2%
Zi1050*	Ladies	715	338	377	0.897	1.115	47.3%	52.7%
Zi1014*	Gentlemen	940	547	393	1.392	0.718	58.2%	41.8%
Zi1034	Ladies	428	157	271	0.573	1.726	36.7%	63.3%

When comparing the data from table 7 to the biological ratios that are used in literature and mentioned in section 2.2.4, it can be concluded that only the 62.3/37.7 ratio of Zi1034 comes close to this. However, the influence of the availability of urinals as described in section 7.3.1 is not accounted for. Since this influence has an unknown significance, it is impossible to make any meaningful conclusion in this regard.

There are some remarks that need to be made for Phase 1. These are specific for certain toilets, and therefore will be addressed as such.

Zi1014*:

- It was discovered on 10-11-22 that the data log was unusual and solely indicated Big presses every 10 seconds after a certain point. This was diagnosed to be a loose jumper wire, which caused the Big input to float and thereby being constantly triggered. After backtracking the data along with the 'uptime log' it can be concluded that the last week of the data collection of Zi1014 is unreliable and therefore excluded from the data collection. The 940th data entry was deemed the last reliable one. The limitation caused by this issue eventually preceded the limitation imposed by the endeavour for homogeneity between Phase 1 and Phase 2.
- It was discovered on 19-10-22 that the USB cable was not connected to the Sparkfun anymore. This means that part of the flushes on 18-10-22 were not registered.

Zi1050*:

- The SD card in the Raspberry Pi got corrupted on the evening of 20-10-22. Eventually, the flush data from 21-10-22 was unrecoverable and the SD card was replaced.

7.1.3 Phase 2 analysis – Intervention measurement

Phase 2 started on Monday 06-02-23 in the afternoon and ran until Thursday 23-02-23 in the afternoon. This resulted in a total of 13 weekdays and 4 weekend days for a total of 17 days. All three weeks of data collection were normal college weeks, the only particularities were the master's introduction on 06-02-23 and 07-02-23, and an information day on 17-02-23. The influence of these particularities would be somewhat decreased traffic to the toilets. The Phase 2 data collection results are visible in Table 8.

Table 8: Phase 2 data collection results.

Room number	Ladies/ Gentlemen	No. of data entries	Big button total	Small button total	Ratio Big:Small	Ratio Small:Big	Percentage Big	Percentage Small
Zi1066	Gentlemen	244	128	116	1.103	0.906	52.5%	47.5%
Zi1050*	Ladies	167	141	26	5.423	0.1844	84.4%	15.5%
Zi1014	Gentlemen	355	160	195	0.821	1.219	45.1%	54.9%
Zi1034	Ladies	271	60	211	0.284	3.517	22.1%	77.9%

The first thing to notice is that there are far fewer data entries in the Phase 2 data collection than was the case in Phase 1. There are a number of possible explanations for this. Firstly, The Button Nudger is likely to act as a deterrent for a proportion of toilet users. Certain toilet users will be more inclined to choose another toilet cubicle when confronted with an unfamiliar installation in a private sphere such as the toilet. Secondly, and perhaps the most important reason, is the fact that in Phase 2, The Button Nudger only registers a flush when it is at the nudge part of its timed sequence. This is to counteract the inclusion of flushes that are not influenced by a nudge, and therefore render the data unreliable. As a result, toilet users who flushed in a different part of the timed sequence than the nudge, did not get their flush registered.

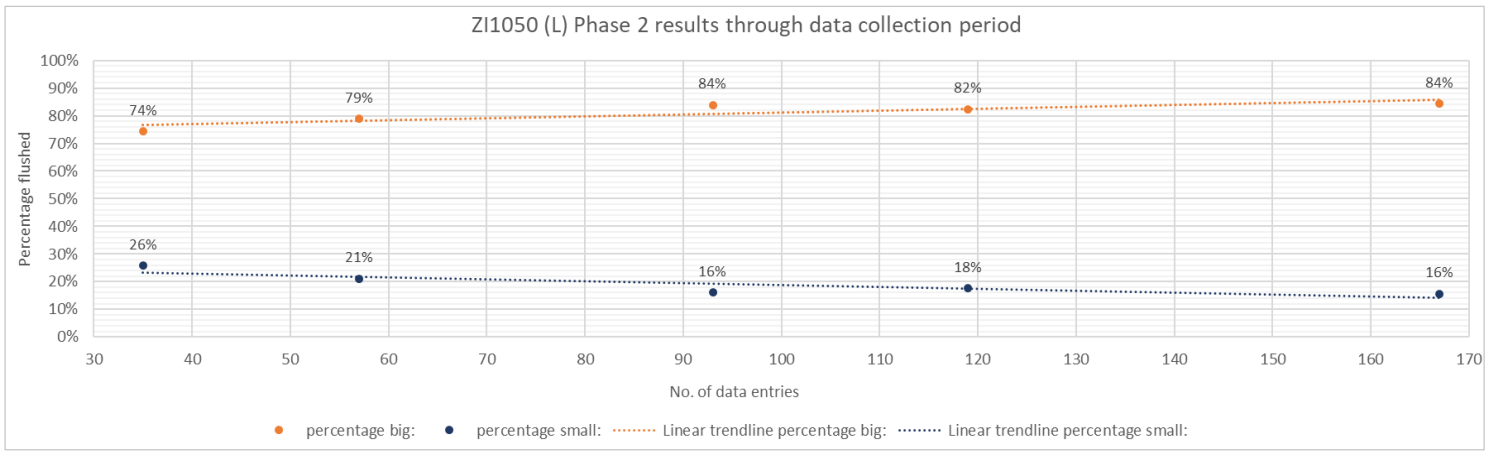
Comparing the Phase 2 data to biologically expected ratio's from section 2.2.4, it can be concluded that Zi1034 exceeds the most extreme estimation of Veritec Consulting Inc. (2002). Additionally, Zi1014 approaches the 60/40 ratio set by Zakaria et al. (2018). Zi1066 looks to be largely unchanged with respect to Phase 1.

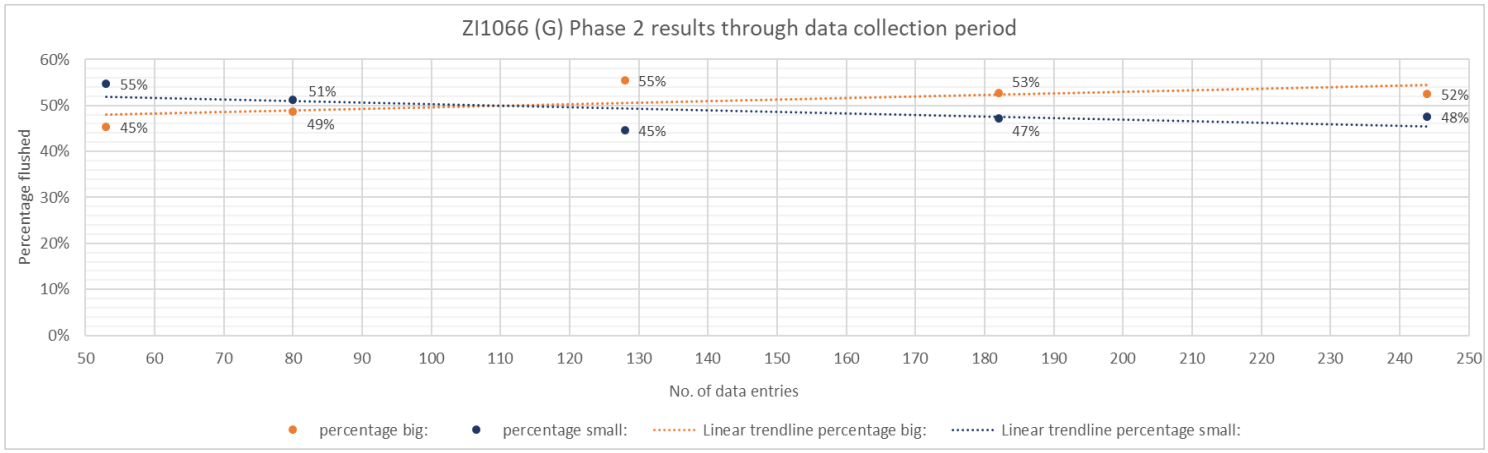
There is one toilet specific remark for Phase 2.

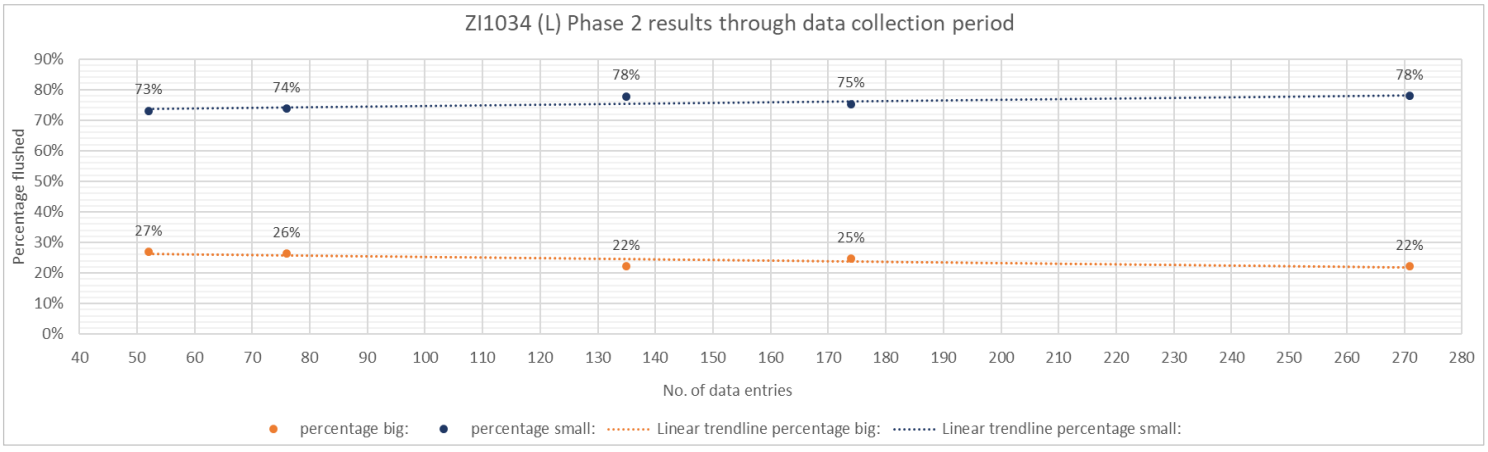
Zi1050*:

- Due to a mistake in installation, the Small button was internally obstructed by a cable. The effect this had on the data collection is clearly visible in Table 8. The Small button is underrepresented, because this obstruction prevented the microswitch from being triggered in many flushes. The data from this toilet is included, however, there will not be drawn any conclusions from this data, nor will this data be statistically evaluated in section 7.1.4.

A further interesting phenomenon to investigate is the novelty effect of The Button Nudger. This can also be explained as the tendency for toilet uses to initially change their flushing behaviour when new technology, like The Button Nudger is instituted, not because of any actual improvement in behaviour, but in response to an interest in the new technology itself. To investigate this, an analysis over the data acquisition time was performed. The results of this analysis are visible in Figure 61. It can be seen that for both Zi1014 and Zi1034 the percentages of Small and Big flushes vary over time, but not very significantly. This would indicate the absence of a novelty effect, although that is limited to the three weeks of data collection. In the case of Zi1066 there is a visible switch to be noted around data entry 110, where the flushing behaviour returns to similar ratio's as Phase 1 when compared to the data in Table 7. This could possibly indicate a novelty effect taking place in Zi1066. Of course, it should be noted that habitual behaviour is default. If a situation is not new anymore and the situation does not require any attention, people fall back into old habits. This is because it takes the least effort.







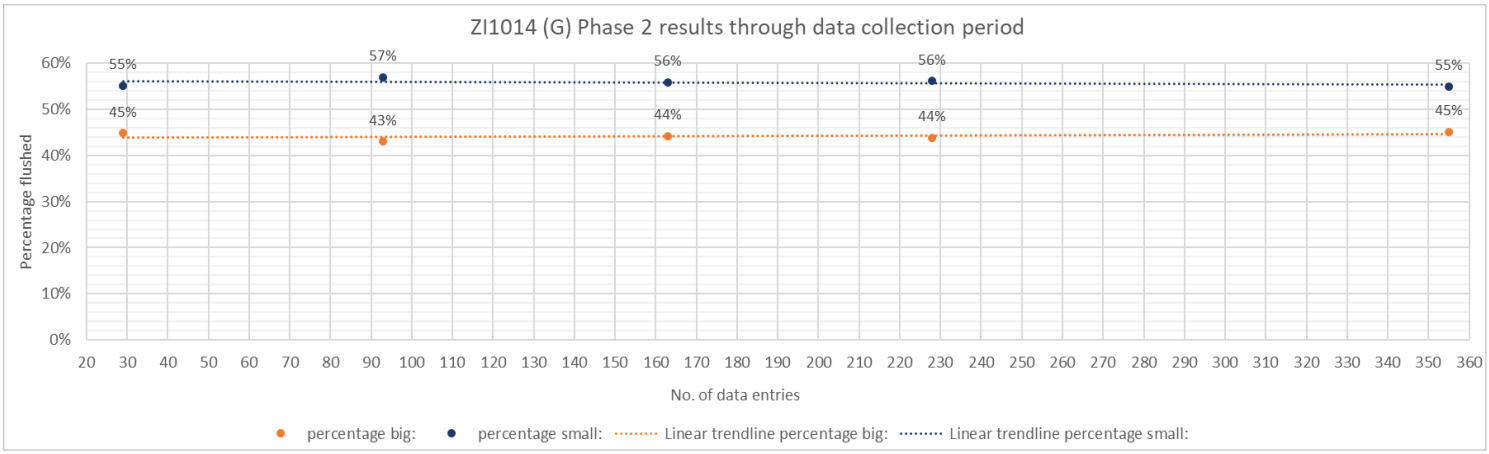


Figure 61: Phase 2 data collection through time.

7.1.4 Compared analysis

Figure 62 shows the distributions for the three toilets for both Phase 1 and Phase 2. There are clear differences visible in Zi1034 and Zi1014, where the percentage of Small button presses in Phase 2 has increased at the expense of Big button presses with respect to Phase 1. Zi1066 shows little visible difference between both phases.

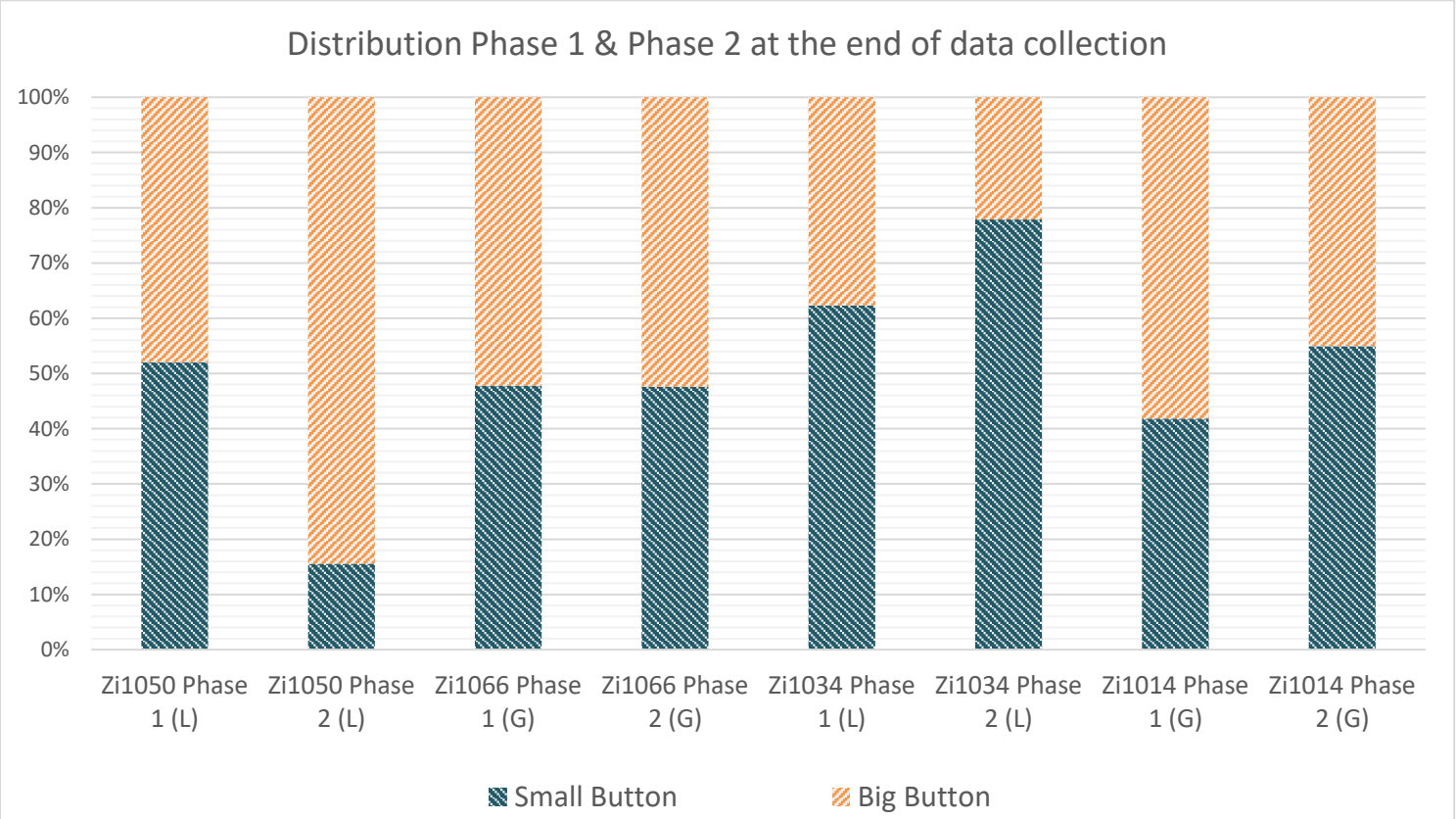


Figure 62: Distribution of Phase 1 & Phase 2 data.

To assess the significance of the changes, a statistical hypothesis test using a Chi-square test of independence is performed to test how likely it is that an observed distribution is due to chance. This test is used because the collected data is categorical and is comprised of a frequency of occurrence count. The null hypothesis is formulated as follows:

H_0: Using The Button Nudger will have absolutely no effect on the button type pressed.

The significance level is chosen to be the common value of 0.05. The choice of 0.05 as a significance level is based on a balance between the risk of making a type I error (rejecting a true null hypothesis) and the risk of making a type II error (failing to reject a false null hypothesis). A significance level of 0.05 is considered to be a reasonable compromise between these two types of errors. The contingency table for the three toilets in consideration is given in Table 9.

Table 9: Contingency table.

	Zi1066 Ph1 (876)	Zi1066 Ph2 (244)	Zi1034 Ph1 (428)	Zi1034 Ph2 (271)	Zi1014 Ph1 (940)	Zi1014 Ph2 (355)
Big occurrence	454	128	157	60	547	160
Small occurrence	422	116	271	211	393	195

The expected values for each cell are calculated by Equation 1:

Equation 1

$$\frac{Row\ total\ (for\ that\ toilet)\ *\ column\ total}{Grand\ total\ (for\ that\ toilet)}$$

This results in an expected value table, which is given by Table 10.

Table 10: Expected value table.

	Zi1066 Ph1 (876)	Zi1066 Ph2 (244)	Zi1034 Ph1 (428)	Zi1034 Ph2 (271)	Zi1014 Ph1 (940)	Zi1014 Ph2 (355)
Big occurrence	455.21	126.79	132.87	84.13	513.19	193.81
Small occurrence	420.79	117.21	295.13	186.87	426.81	161.19

The Chi-square statistic for each cell is calculated by Equation 2:

Equation 2

$$\frac{(observed\ value - expected\ value)^2}{expected\ value}$$

This results in a Chi-square statistic table, which is given by Table 11.

Table 11: Chi-square statistic table.

	Zi1066 Ph1 (876)	Zi1066 Ph2 (244)	Zi1034 Ph1 (428)	Zi1034 Ph2 (271)	Zi1014 Ph1 (940)	Zi1014 Ph2 (355)
Big occurrence	0.0032	0.0115	4.3822	6.9210	2.2276	5.8984
Small occurrence	0.0035	0.0124	1.9729	3.1159	2.6784	7.0921

The Chi-square statistic for each toilet is obtained by sum the contributions to the Chi-square statistic of each cell. This results in the Chi-square statistics in Table 12:

Table 12: Chi-square values.

	Chi-square statistic
Zi1066	0.0306
Zi1034	16.3920
Zi1014	17.8965

To calculate the degrees of freedom, Equation 3 is used:

Equation 3

$$(Number\ of\ rows - 1) * (Number\ of\ columns - 1)$$

In all cases this would be: $(2-1)\ *\ (2-1)\ =\ 1$ degree of freedom.

From the Chi-square statistic and the number of degrees of freedom, the p-value can be determined. The Chi-Square calculator by Social Science Statistics is used in this case (Social Science Statistics, 2018). This results in the p-values in Table 13.

Table 13: P-values.

	P-value
Zi1066	0.861136
Zi1034	0.000052
Zi1014	0.000023

From Table 13, it must be concluded that both Zi1034 and Zi1014 have p-values below the significance level of 0.05. This means that in those two toilets, H_0 must be rejected, implying that there is a significant effect on which button type is pressed by using The Button Nudger.
Further, it must be concluded that Zi1066 has a p-value higher than the significance level of 0.05. This means that in that toilet, H_0 cannot be rejected, implying that using The Button Nudger has absolutely no effect on the button type pressed.

7.2 User evaluation

To assess the experience a user has while interacting with The Button Nudger, a user evaluation was performed. This user evaluation was introduced to the toilets, by means of two posters with a QR code (visible in Appendix K, Figure 65) per toilet facility. The placement of those posters was inside the cubicle equipped with The Button Nudger, and near the mirror above the faucet. The user evaluation was introduced on the afternoon of 15-2-23 and was present until the end of the Phase 2 data collection for a total of eight days (including two weekend days). The reason the survey was introduced later than The Button Nudger itself is because the survey revealed information about the aim of The Button Nudger.

The reason for wanting to prevent this is identical to the reasons stated in section 3.5.1. The survey received 44 responses and consisted of 12 mandatory closed questions and 3 non-mandatory open questions. The information given to the participants beforehand is provided in Appendix M, Figure 67, the survey questions and answer possibilities are given in Appendix N. The full results of the closed survey questions are given in Appendix O, Table 16.

The survey was predominantly filled in by students, but there were some responses of academic staff, supporting staff and others. Table 14 shows an overview of the answers of the evaluation submission, the column colours match the pie chart colours from Appendix O. n

The open survey questions disclosed more information about the reasons why participants felt the way they did. Firstly, about why participants felt observed by The Button Nudger, the main reason given was the round black ultrasonic proximity sensor. Twenty respondents likened it to a camera, because of its appearance or where otherwise concerned about the sensor. Nine other respondents felt the observation through the fact that The Button Nudger respondent to their movements. The rest of the fifteen participants either did not answer this open question or were non-constructive in their feedback. When asked about possible improvements for The Button Nudger, eight respondents indicated that improvements on design, placement and size could be made. Additionally, five people mentioned the interaction timing not aligning with their toilet behaviour, three people mentioned the lack of transparency, two respondents indicated the removal of the black proximity sensor, and three respondents mentioned the code crashing issue as mentioned in section 6.2.8. The remaining participants either did not answer this open question or were non-constructive in their feedback.

Table 14: User evaluation survey results.

Question	**Percentage**				
Answer possibilities	**Prefer not to say**	**Academic staff**	**Other**	**Supporting staff**	**Student**
What UT community member categorizes me the best:	89%	2%	2%		2%
Answer possibilities	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I felt surprised by the presence of the “Button Nudger” in the toilet cubicle I visited.	-	-	2%	27%	71%
Did the presence of the “Button Nudger” in the toilet cabin felt like your privacy was being violated?	-	10%	7%	42%	41%
I felt the “Button Nudger” was observing me.	2%	12%	2%	57%	27%
The presence of the "Button Nudger" caused me to choose another toilet cubicle.	16%	25%	16%	14%	29%
Did the presence of the “Button Nudger” influenced your choice of pressing a flush button?	52%	20%	7%	16%	5%
Installing the “Button Nudger” in more toilet cubicles helps to educate UT community members to adapt their flushing behavior.	30%	27%	23%	16%	4%
I felt like I understood the interaction with the “Button Nudger”.	20%	18%	14%	39%	9%
Answer possibilities	**Strongly Offensive**	**Offensive**	**Neutral**	**Positive**	**Humorous**
How would you rate the text in the green scene of the “Button Nudger”?	9%	11%	39%	9%	32%
Answer possibilities	**Strongly Negative**	**Negative**	**Neutral**	**Positive**	**Strongly Positive**
How do you rate the interaction with the “Button Nudger”?	25%	32%	27%	11%	5%
My overall impression of the system was:	23%	41%	18%	16%	2%
Answer possibilities	**Awful**	**Boring**	**Neutral**	**Nice**	**Beautiful**
How would you rate the design of the prototype “Button Nudger”?	36%	9%	21%	32%	2%

8 Discussion & Future Work

The aim of this research was to find out the extend in which nudging can influence the toilet flushing behaviour of the Zilverling community. After determining a baseline ratio for toilets in the Zilverling, The Button Nudger was implemented as an intervention to influence said toilet flushing behaviour. It did so by using norm setting nudging techniques. The statistical analysis in comparing Phase 1 to Phase 2 indicates a significant effect on two out of three evaluated toilets. These two toilets consist of both a gentlemen's and a ladies toilet. The third evaluated toilet (being a gentlemen's toilet) shows no perceivable effect of the implementation of The Button Nudger. This means that over the total group of toilet users, it is plausible that implementing The Button Nudger did influence the flushing behaviour. However, the evidence is not incontrovertible for the fact that not all toilets indicated conclusive data on changed flushing behaviour.

When utilising the user evaluation to interpret the statistical analysis, there is reason to believe The Button Nudger has an influence on a number of toilet users, around 20%. This part of toilet users could explain the behavioural influence effect displayed by the flushing data. However, the limited number of survey participants restrict a conclusive answer on this.

In the end, The Button Nudger in two out of three cases caused the flushing data to be more aligned with what is biologically expected. The sources on true biological stool data are divided in their urination to defecation ratio. Nonetheless, the Phase 2 data of the aforementioned two significantly changed toilets indicates a distribution of small to big flushes closer to the ideal one than the Phase 1 data.

A limitation of The Button Nudger at the time is a lack of knowledge on the novelty effect in continued implementation. It is reasonable to believe habitual behaviour is going to dominate once again. Both the lasting effect after removing The Button Nudger as well as the persisting effect after prolonged implementation are currently unknown.

8.1 Future work

There are several areas in which The Button Nudger could still be improved. Also, The Button Nudger in its current state can be used to further research behavioural influence regarding toilet flushing, in different manners than were used in this research.

The Button Nudger itself could be improved in the first regard by looking into the ultrasonic distance sensor. Many participants in the user evaluation survey felt uncomfortable by the appearance of this sensor. Possible improvements could be using another, less camera-resembling, sensor, or concealing the current sensor such that it is not as visible to the toilet user as it is currently.

Secondly, improvements on the design could be made. The design of The Button Nudger was deemed big and bulky. A smaller and slimmer case could contribute towards lessening the intrusiveness of The Button Nudger on the toilet user. A more organic shape of the case could counteract the bulky feeling. Directly related to the size of the case is packaging of the components. To ensure a good fit inside the case, the components should be packaged more efficiently and excess cable should be made redundant. The utilisation of integrated circuitry to replace certain sizable components could also be considered in this regard. With respect to the design of the interaction, the timing of the nudging message could be optimised. While no toilet user has the same toilet habits, there could be looked into the possibility of delivering the nudging message at the correct time, regardless of a certain toilet user's habits. However, this might require additional sensors to be implemented, which could consequently have a negative effect on the perceived intrusiveness of The Button Nudger.

Lastly, the resilience of The Button Nudger in the toilet environment could be improved. There should be looked into the reason why the programme crashed after being on for multiple hours

in the toilet, but not during testing. Further, an RTC module should be implemented if packaging improvements allow for it. This to place the obtained data in a more correct time context for analysis. Ideally, other, non-incontiguous, power sources should be considered to ensure that The Button Nudger remains on during the complete day, after which it turns off by design at night.

The Button Nudger in its current state could also be used for testing the effects of other nudging types. As per the literature, the nudging types of conveying commitments or educational nudges could be implemented amongst others. These results could then be compared with each other to obtain deeper knowledge on which nudge types work best in this situation. Additionally, The Button Nudger could be implemented as it is now for a prolonged time to gain a deeper understanding on the novelty effect of the current interaction with The Button Nudger.

9 Conclusion

The problem this research aimed to address is that of excessive water consumption. Specifically, this research focused on the prevention of excessive water consumption in toilet flushing. In dual-flush toilets, this means utilising the correct flushing button to ensure an adequate amount of water is used. Presently, there is ample reason to believe the current flushing behaviour is generally dissatisfactory. In this study, norm setting nudging techniques were used to stimulate behavioural influence in toilet users.

To effectively find a solution to ensure adequate toilet flushing in toilet users, the following main research question was posed:

- To what extent can nudging influence the toilet flushing behaviour of the Zilverling community?

To ensure a successful answer to the main research question, the subsequent sub-question was raised:

- How to instrument the Zilverling toilets to measure flushing behaviour?

A button press registration setup based on two microswitches behind the two flushing buttons was created, the microswitch inputs were interpreted by a Sparkfun ESP32 microcontroller and saved to a Raspberry Pi. This setup was an effective and resilient answer to the sub-question. Subsequently, The Button Nudger was created to provide an interaction with toilet users in order to convey the norm setting nudging message. The button press registration setup was incorporated into The Button Nudger.

A zero measurement and an intervention measurement were conducted, with the former exclusively consisting of the button press registration setup and the latter consisting of The Button Nudger with the incorporated button press registration setup. Both measurements ran for 17 consecutive days, on two gentlemen's and two ladies toilets.

After comparison of the zero measurement with the intervention measurement it was concluded that one gentlemen's and one ladies toilet showed a statistically significant difference between both measurements. One gentlemen's toilet showed no significant difference. The remaining ladies toilet intervention measurement data was deemed unreliable. A user evaluation further showed that approximately 20% felt influenced to alter their flushing behaviour. However, it also indicated that improvements should still be made regarding perceived privacy, intrusiveness and design of The Button Nudger.

In conclusion, there is plausible reason to believe that norm setting nudging can influence toilet flushing behaviour within a certain group of the Zilverling community. At the same time, the influence is not visible in all instrumented toilets, and the lasting effects on water conservation are still uncertain.

10 Appendices

10.1 Appendix A

Figure 63: Poster with QR code which was placed at toilets across the UT campus to distribute the survey.

10.2 Appendix B

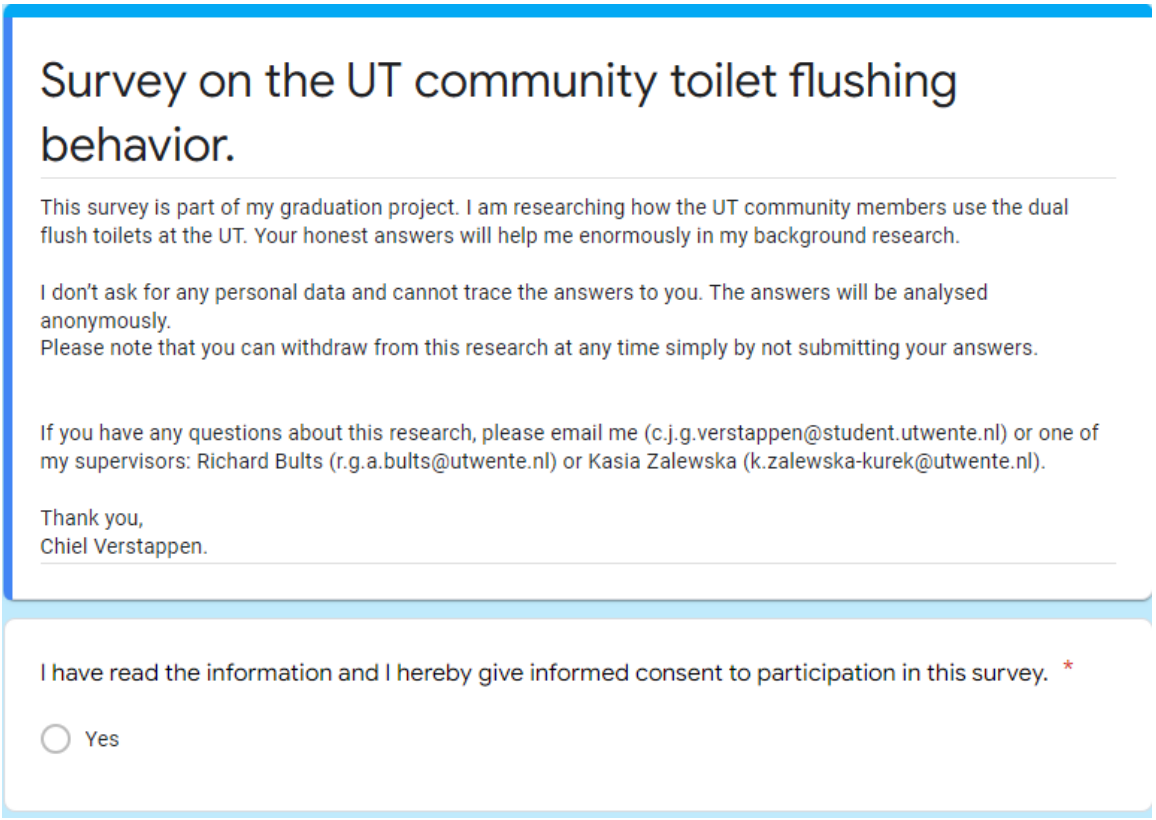


Figure 64: Information that was provided before starting the survey.

10.3 Appendix C

Q1: When flushing the toilet, do you think about which button to press?

- *Yes*
- *No*

Q2: Choose a sentence that describes your toilet flushing behavior best:

- *I always use the small button*
- *I always use the big button*
- *I use the flushing buttons randomly*
- *I always use the small button after urinating and I use the big button to flush the feces*
- *Most of the time I use the small button after urinating and I use the big button to flush the feces*
- *Other:*

Q3: Are you aware of the difference in using the small or big button for flushing the toilet?

- *Yes*
- *No*

10.4 Appendix D

- For liquids, a small button flush is sufficient
- For an effort without resistance, the small button is sufficient
- A small effort only requires the small button
- If it was just a bluff, the small button is enough
- If the effort was not so though, the small button is enough
- For efforts without a puff, the small button is enough
- With only little in the bowl, the small button is your goal
- Big button flush = 6 litres
  Small button flush = 3 litres
- Only a big effort requires the big button
- After a nr. 1, flush with the small button when you're done
- Pressing the big button on the loo, is only for nr. 2
- Press small, when you've only left a nr. 1 in this stall
- The big button is only for solid waste
- If it smells foul, go for waterfall!
- If the smell is foul, big one is your goal!
- Flush it in a wink (or blink) if it doesn't stink.
- Does it smell? Flush it well!
- One splash is enough if it wasn't rough.
- No stinky stuff? Small flush is enough!
- Only liquid stuff? Small flush is enough!
- Did you have to use a brush, that calls for a big flush!
- Yellow liquid in the bowl? Go for the small!
- Don't start with water spree for a little pee.
- Does it look like otter? Flush it with big water!
- If it's solid matter, flush it with a spatter!
- If you smell and blush, go with the big flush!
- Smells like a piggy? Go for the biggie!
- Press the biggie if you're piggy!
- Small is the answer to your need if you just peed.
- There's no need to press the big if you only peed.
- Only peepee? Use the mini!
- Stay away from big if you only peed.
- Got tears in the eyes? Select the king-size!
- Red and teary eyes? That the big one implies!
- Stinging feeling in the eyes, a big flush implies.
- Have you done your best? Big one needs a press.
- Spare your neighbours smell surprise, press the button in king-size!
- Got an ugly stinky wonder? Let the water flow like thunder!
- Only peepee done? Go for little one!
- Smells like mountain troll? Don't you press the small!
- Flush your pee away, with a small button play
- Flush a whole lot away, with a big button play
- Use a big flush, when you need a push
- Use a big flush, when you need a big push
- Small button push, creates a small flush
- Big button push, creates a big flush
- Being impressed? Big button pressed!
- Are you impressed? Big button needs a press!
- Are you impressed? Big button does the rest!
- Big is wasteful!
- Think before you flush!
- Flushing right, keeps the water bill tight.

10.5 Appendix E

Table 15: Full list of components Phase 1 and Phase 2.

Brand	Type	Model	Amount
Phase 1			
Sparkfun	Microcontroller	ESP32 Thing	4
Omron	Simulated Roller Lever Micro Switch	2 A @ 12 V dc, SPDT-NO/NC, IP67	8
Raspberry Pi	Computer	3B	4
-	Resistor	10KΩ	8
Phase 1 supporting material			
-	Cable	USB A Male to USB micro–B Male	4 * 3 meter
-	Poplar plate	6mm thick	-
-	Soldering jumper wires	Solid core	Many
Raspberry Pi	Power cable	-	4
-	Junction box	≥ 3 outlets	4
-	Nuts and bolts	1.8cm long, 3mm wide	8
-	Cable ties	Medium sized	±16
Tesa	Double sided tape	Ultra-strong	2 meters
Phase 2			
Sparkfun	Microcontroller	ESP32 Thing	4
Omron	Simulated Roller Lever Micro Switch	2 A @ 12 V dc, SPDT-NO/NC, IP67	8
Raspberry Pi	Computer	3B	4
-	Resistor	10KΩ	8
-	Resistor	1KΩ	4
-	Resistor	2KΩ	4
-	Ultrasonic proximity sensor	AJ-SR04-M	4
WorldSemi	RGB LED strip	WS2812B Digital 5050 RGB LED Strip - 60 LEDs	4 * 1 meter
Waveshare	Display screen	11.9inch HDMI LCD	4
Songle relay NE555 timer chip	Delay relay	5V adjustable delay (0S - 10S)	4
Phase 2 supporting material			
-	USB Cable	USB A Male to USB micro–B Male	4 * 3 meter
-	Poplar plate	6mm thick	-
-	Soldering jumper wires	Solid core	Many
-	Soldering jumper wires	Female to male	20
Raspberry Pi	Power cable	5.1V 2.5A	4
-	Junction box	≥ 4 outlets	4
-	Screws and bolts	1.8cm long, 3mm wide	8
Waveshare	180° HDMI to HDMI adapter	Supplied with Waveshare screen	4
-	Acrylic plate	6mm thick	-
	Acrylic glue	-	-
-	Screws	M2.5	20

Gebrema	Patent bolt	M4*55mm	24
Bison	Silicone sealant	-	-
HN Power	USB charger	HNP12-USBV2 2400mA	4
Apple/JBL	USB Charger	≥ 1A	4
Hema	Binder	Front plastic piece	4
-	Cable ties	Medium sized	±16
Tesa	Double sided tape	Ultra-strong	6 meters

10.6 Appendix F

```
/* This code is developed for a Creative Technology Graduation project on the University
of Twente.
The code is meant for interpreting a set of two microswitches by a Sparkfun ESP32 Thing
microcontroller.
The code was developed by Chiel Verstappen, with the help of Jop Paulissen.
*/
#include <SPI.h>
#include <dummy.h>
#define LIMIT_SWITCH_PIN_SMALL 18
#define LIMIT_SWITCH_PIN_BIG 17
bool isTriggered;

void setup() {
  Serial.begin(9600);
  pinMode(LIMIT_SWITCH_PIN_SMALL, INPUT);
  pinMode(LIMIT_SWITCH_PIN_BIG, INPUT);
  isTriggered = false;
  delay(100);
}

void loop() {
  if (digitalRead(LIMIT_SWITCH_PIN_SMALL) == LOW) {
    GetSmall();
  }

  else if (digitalRead(LIMIT_SWITCH_PIN_BIG) == LOW) {
    GetBig();
  }
  delay(10);
}

void GetSmall() {
  if (isTriggered == false) {
    Serial.println("Small");
    isTriggered = true;
    delay(10000);

  } else if (isTriggered == true) {
    isTriggered = false;
  }
}

void GetBig() {
  if (isTriggered == false) {
    Serial.println("Big");
    isTriggered = true;
    delay(10000);
```

```
  } else if (isTriggered == true) {
    isTriggered = false;
  }
}
```

10.7 Appendix G

```
#This code is developed for a Creative Technology Graduation project on the
University of Twente.
#The code is meant for interpreting incoming strings from a Sparkfun ESP32 Thing
microcontroller via USB connection.
#These strings are then logged in a csv file along with the date and time of
writing.
#The code was developed by Chiel Verstappen, with the help of
https://roboticsbackend.com/raspberry-pi-arduino-serial-communication/.
#!/usr/bin/env python3
import serial
from datetime import datetime
import csv


if __name__ == '__main__':
    ser = serial.Serial('/dev/ttyUSB0', 9600)
    ser.reset_input_buffer()

    while True:
        flushData = ser.readline().decode('utf-8').rstrip()
        print(flushData)

        with open('Flushdatalog.csv', 'a', newline='') as file:
            writer = csv.writer(file)
            now = datetime.now()
            current_time = now.strftime("%H:%M:%S")
            current_date = now.strftime("%d-%m-%Y")
            writer.writerow([flushData, current_time, current_date])
```

10.8 Appendix H

```
#This code is developed for a Creative Technology Graduation project on the
University of Twente.
#The code is meant for writing the time a Raspberry Pi has been on every 3 minutes
to a csv file.
#The code was developed by Chiel Verstappen, with the help of
https://forums.raspberrypi.com/viewtopic.php?t=164276
import shlex, subprocess, time, csv
while True:
    cmd="uptime -p"
    args=shlex.split(cmd)
    p = subprocess.Popen(args, stdout=subprocess.PIPE)
    output = p.communicate()
    with open('P2uptimelogZi1050.csv', 'a', newline='') as file:
        writer = csv.writer(file)
        writer.writerow([output])
        time.sleep(180)
```

10.9 Appendix I

```
/* This code is developed for a Creative Technology Graduation project on the University
of Twente.
The code is meant for interpreting a set of two microswitches by a Sparkfun ESP32 Thing
microcontroller.
The code was developed by Chiel Verstappen, with the help of Jop Paulissen.
*/
#include <SPI.h>
#include <dummy.h>
#define LIMIT_SWITCH_PIN_SMALL 18
#define LIMIT_SWITCH_PIN_BIG 17
bool isTriggered;

void setup() {
  Serial.begin(9600);
  pinMode(LIMIT_SWITCH_PIN_SMALL, INPUT);
  pinMode(LIMIT_SWITCH_PIN_BIG, INPUT);
  isTriggered = false;
  delay(100);
}

void loop() {
  if (digitalRead(LIMIT_SWITCH_PIN_SMALL) == LOW) {
    GetSmall();
  }

  else if (digitalRead(LIMIT_SWITCH_PIN_BIG) == LOW) {
    GetBig();
  }
  delay(10);
}

void GetSmall() {
  if (isTriggered == false) {
    Serial.println("Small");
    isTriggered = true;
    delay(1000);

  } else if (isTriggered == true) {
    isTriggered = false;
  }
}

void GetBig() {
  if (isTriggered == false) {
    Serial.println("Big");
    isTriggered = true;
    delay(1000);
```

```
  } else if (isTriggered == true) {
    isTriggered = false;
  }
}
```

10.10 Appendix J

```
#This code is developed for a Creative Technology Graduation project on the
University of Twente.
#The code is meant for operating a device called the Button Nudger, as well as to
retrieve toilet flushing data by storing serial input of two microswitches into a
csv file
#The code was developed by Chiel Verstappen, with the help of Joris Kuiper,
#https://github.com/rpi-ws281x/rpi-ws281x-
python/blob/master/examples/strandtest.py,
#https://pimylifeup.com/raspberry-pi-distance-sensor/ and
#https://www.pygame.org/docs/ref/display.html#pygame.display.set_mode
#!usr/bin/python
# Import necessary libraries
from os import environ
environ['PYGAME_HIDE_SUPPORT_PROMPT'] = '1'
import pygame
from pygame.locals import *
import RPi.GPIO as GPIO
import time
from datetime import datetime
import random
from rpi_ws281x import PixelStrip, Color
import argparse
import serial
import csv

# Disable GPIO warnings (optional)
GPIO.setwarnings(False)

# Initialize Pygame
pygame.init()

# Define screen dimensions and colors
WIDTH = 1480
HEIGHT = 320
black = (0,0,0)
white = (255,255,255)

# Set flag for if program has crashed
crashed = False

# Create the Pygame window
windowSurface = pygame.display.set_mode((WIDTH, HEIGHT), pygame.NOFRAME,
pygame.RESIZABLE)

# Load images
nudge1 = pygame.image.load("BigSmall.png")
nudge2 = pygame.image.load("Nr1.png")
nudge3 = pygame.image.load("Nr2.png")
nudge4 = pygame.image.load("Effort.png")
nudge5 = pygame.image.load("Puff.png")
nudge6 = pygame.image.load("Blush.png")
nudge7 = pygame.image.load("Impressed.png")
nudge8 = pygame.image.load("Liquids.png")
nudge9 = pygame.image.load("Bowl.png")
nudge10 = pygame.image.load("Bluff.png")
welcome = pygame.image.load("Welcome.png")
thankyou = pygame.image.load("Thank you.png")
frequent = pygame.image.load("Frequent flushing.png")

# Create a list of all the loaded images
```

```
nudges = [nudge1, nudge2, nudge3, nudge4, nudge5, nudge6, nudge7, nudge8, nudge9,
nudge10]

# Fill the window with the background color
windowSurface.fill(black)

# LED strip configuration
LED_COUNT = 60        # Number of LED pixels
LED_PIN = 18          # GPIO pin connected to the pixels
LED_FREQ_HZ = 800000  # LED signal frequency in hertz
LED_DMA = 10          # DMA channel to use for generating signal
LED_BRIGHTNESS = 255  # Set to 0 for darkest and 255 for brightest
LED_INVERT = False    # True to invert the signal
LED_CHANNEL = 0       # set to '1' for GPIOs 13, 19, 41, 45 or 53

# Define a function to wipe the LED colors across the strip
def colorWipe(strip, color):
    """Wipe color across display a pixel at a time."""
    for i in range(strip.numPixels()):
        strip.setPixelColor(i, color)
        strip.show()
        time.sleep(0.025)

# Define a function to display a screen based on a passed type and a timeout
def showScreen(screenType, timeout):
    # Draw the screen
    windowSurface.blit(screenType, (-8, -3)) #Replace (0, 0) with desired
coordinates
    pygame.display.flip()
    # Wipe the LEDs with a blue color
    colorWipe(strip, Color(0, 0, 255)) # Blue wipe
    # Wait for the specified timeout
    time.sleep(timeout)
    # Fill the window with the background color and update the display
    windowSurface.fill(black)
    pygame.display.flip()

# Main program logic follows:
if __name__ == '__main__':
    #receive serial from sparkfun
    # Set up serial connection with the Sparkfun device
    ser = serial.Serial('/dev/ttyUSB0', 9600)
    ser.reset_input_buffer()

    # Process arguments
    # Set up command line argument parser
    parser = argparse.ArgumentParser()
    parser.add_argument('-c', '--clear', action='store_true', help='clear the
display on exit')
    args = parser.parse_args()

    # Create NeoPixel object with appropriate configuration.
    # Set up the NeoPixel LED strip
    strip = PixelStrip(LED_COUNT, LED_PIN, LED_FREQ_HZ, LED_DMA, LED_INVERT,
LED_BRIGHTNESS, LED_CHANNEL)
    # Intialize the library (must be called once before other functions).
    strip.begin()

    # Print message to console
    print('Press Ctrl-C to quit.')
    if not args.clear:
        # Print message to console if LEDs won't be cleared on exit
        print('Use "-c" argument to clear LEDs on exit')
```

```
try:
    # Set up ultrasonic sensor
    GPIO.setmode(GPIO.BOARD)
    PIN_TRIGGER = 7
    PIN_ECHO = 11
    GPIO.setup(PIN_TRIGGER, GPIO.OUT)
    GPIO.setup(PIN_ECHO, GPIO.IN)
    GPIO.output(PIN_TRIGGER, GPIO.LOW)
    #print('Waiting for sensor to settle')
    time.sleep(1)

    # Loop to detect and respond to users approaching the device
    while(True):
        #print('caluculating distance')
        GPIO.output(PIN_TRIGGER, GPIO.HIGH)
        time.sleep(0.00001)
        GPIO.output(PIN_TRIGGER, GPIO.LOW)

        # Determine the distance from the user to the device using the ultrasonic
sensor
        while GPIO.input(PIN_ECHO)==0:
            pulse_start_time = time.time()
        while GPIO.input(PIN_ECHO)==1:
            pulse_end_time = time.time()
        pulse_duration = pulse_end_time - pulse_start_time
        distance = round(pulse_duration * 17150, 2)
        print("Distance:", distance, "cm")

        # Trigger if user is closer than 90 cm
        if(distance < 90):
            print("I am triggered")
            distanceTrigger = True
        else:
            print("not triggered")
            distanceTrigger = False
        time.sleep(0.5)

        # Show welcome message and activate LED strip if user is within 90 cm
        while not crashed and distanceTrigger:
            ser.reset_input_buffer()
            showScreen(welcome, 20)
            ser.reset_input_buffer()
            # Grab random screen out of list with options
            windowSurface.blit(random.choice(nudges), (-8, -3)) #Replace (0, 0)
with desired coordinates
            pygame.display.flip()
            # Turn green
            colorWipe(strip, Color(0, 255, 0)) # Green wipe
            start_time = time.time()
            print(start_time)

            # Loop to handle different scenarios once the user has triggered the
device
            while distanceTrigger:
                elapsed_time = time.time() - start_time
                print(elapsed_time)

                # If nothing happens for a while then say thank you and go back to
idle state
                if (elapsed_time > 60):
                    print("bye cleaner")
                    windowSurface.fill(black)
```

```
                    pygame.display.flip()
                    showScreen(thankyou, 5)
                    colorWipe(strip, Color(0, 0, 255)) # Blue
                    distanceTrigger = False
                # Check if there's data in serial buffer
                if (ser.in_waiting > 0):
                    # If triggered then show new screen
                    flushData = ser.readline().decode('utf-8').rstrip()
                    # Save the flush data to a CSV file along with the timestamp
                    with open('P2FlushdatalogZI1050.csv', 'a', newline='') as file:
                        writer = csv.writer(file)
                        now = datetime.now()
                        current_time = now.strftime("%H:%M:%S")
                        current_date = now.strftime("%d-%m-%Y")
                        writer.writerow([flushData, current_time, current_date])
                    if (flushData == "Big" or flushData == "Small"):
                        # Go to thank you menu upon flushing
                        windowSurface.fill(black)
                        pygame.display.flip()
                        showScreen(thankyou, 0)
                        distanceTrigger = False
                # Set the current time
                frequent_time = time.time()
                # If frequent flush then show nudge
                while ((time.time() - frequent_time) < 4):
                    print("under 4 seconds")
                    # Wait till data available
                    if (ser.in_waiting > 0):
                        # If triggered then show new screen
                        flushData = ser.readline().decode('utf-8').rstrip()
                        if (flushData == "Big" or "Small"):
                            windowSurface.fill(black)
                            pygame.display.flip()
                            windowSurface.blit(frequent, (-8, -3)) #Replace (0, 0)
with desired coordinates
                            pygame.display.flip()
                            # Turn red
                            colorWipe(strip, Color(255, 0, 0)) # red wipe
                            windowSurface.fill(black)
                            pygame.display.flip()
                            distanceTrigger = False

                # Wait for 2 seconds
                time.sleep(2)
                # Turn the LED off
                colorWipe(strip, Color(0, 0, 0)) # Off
                distanceTrigger = False

                # Cleanup the GPIO pins
                try:
                    # If the user stops the program with Ctrl-C, turn the LED off
and clean up the pins
                    if args.clear:
                        colorWipe(strip, Color(0, 0, 0), 10)
                finally:
                    GPIO.cleanup()
```

10.11 Appendix K

Figure 65: Poster with QR code, which was placed at toilet with a Button Nudger, as well as near the mirrors.

10.12 Appendix L

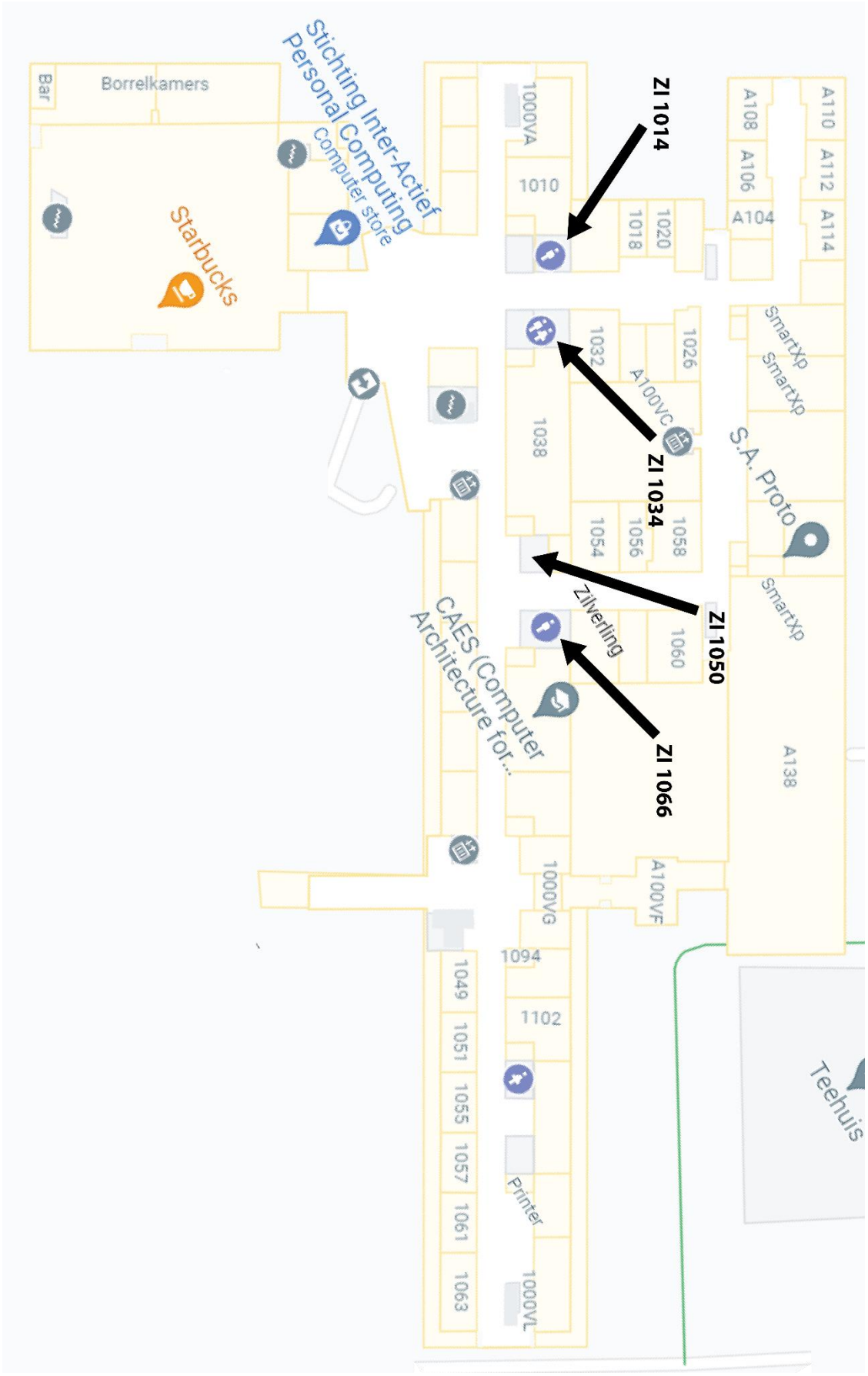


Figure 66: Floorplan of the Zilverling building, indicating the toilets equipped with The Button Nudger.

10.13 Appendix M

The Button Nudger experience

This survey is part of my graduation project. I am researching the experience a toilet user like yourself has as a result of interacting with this installation called the "Button Nudger". The goal of the "Button Nudger" is to accomplish water conservation by flushing the toilet not more than necessary. Your honest answers will help me enormously in my evaluation. The survey is only 15 questions and can be completed within a couple of minutes.

I cannot trace the answers to you, and the answers will be analysed anonymously.
Please note that you can withdraw from this research at any time simply by not submitting your answers.

If you have any questions about this research, please email me (c.j.g.verstappen@student.utwente.nl) or one of my supervisors: Richard Bults (r.g.a.bults@utwente.nl) or Kasia Zalewska (k.zalewska-kurek@utwente.nl).

Thank you,
Chiel Verstappen.

The Button Nudger

I have read the information and I hereby give informed consent to participation in this survey. *

Yes

Figure 67: Information that was provided before starting the user experience survey.

10.14 Appendix N

Q1: What UT community member categorizes me the best:

- *Student*
- *Academic staff*
- *Supporting staff*
- *Other*
- *Prefer not to say*

Q2: I felt surprised by the presence of the "Button Nudger" in the toilet cubicle I visited.

Strongly disagree

- *Disagree*
- *Neutral*
- *Agree*
- *Strongly agree*

Q3: Did the presence of the "Button Nudger" in the toilet cabin felt like your privacy was being violated?

- *Strongly disagree*
- *Disagree*
- *Neutral*
- *Agree*
- *Strongly agree*

Q4: I felt the "Button Nudger" was observing me.

- *Strongly disagree*
- *Disagree*
- *Neutral*
- *Agree*
- *Strongly agree*

Q5: Please describe how the "Button Nudger" was observing you.

- *Open question*

Q6: The presence of the "Button Nudger" caused me to choose another toilet cubicle.

- *Strongly disagree*
- *Disagree*
- *Neutral*
- *Agree*
- *Strongly Agree*

Q7: Did the presence of the "Button Nudger" influenced your choice of pressing a flush button?

- *Strongly disagree*
- *Disagree*
- *Neutral*
- *Agree*
- *Strongly agree*

Q8: Installing the "Button Nudger" in more toilet cubicles helps to educate UT community members to adapt their flushing behavior.

- *Strongly disagree*
- *Disagree*
- *Neutral*
- *Agree*
- *Strongly agree*

Q9: How would you rate the text in the green scene of the "Button Nudger"?

- *Strongly offensive*
- *Offensive*
- *Neutral*
- *Positive*
- *Humorous*

Q10: I felt like I understood the interaction with the "Button Nudger".

- *Strongly disagree*
- *Disagree*
- *Neutral*
- *Agree*
- *Strongly agree*

Q11: How do you rate the interaction with the "Button Nudger"?

- *Strongly negative*
- *Negative*
- *Neutral*
- *Positive*
- *Strongly positive*

Q12: How would you rate the design of the prototype "Button Nudger"?

- *Awful*
- *Boring*
- *Neutral*
- *Nice*
- *Beautiful*

Q13: My overall impression of the system was:

- *Very negative*
- *Negative*
- *Neutral*
- *Positive*
- *Very positive*

Q14: How can the "Button Nudger" be improved to better educate UT community members on their flushing behavior?

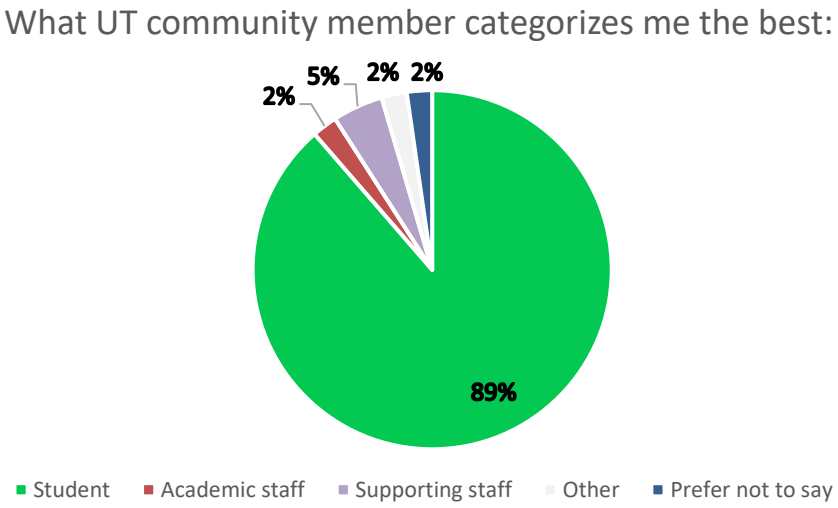
- *Open question*

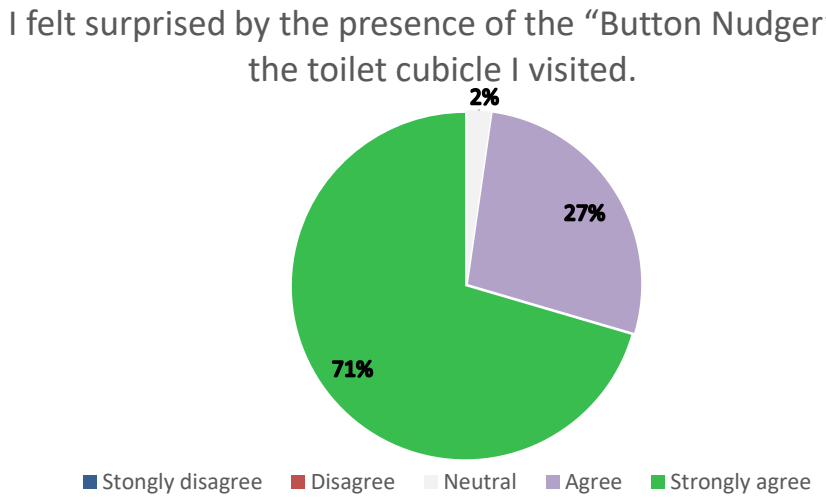
Q15: What are your conclusive thoughts on the "Button Nudger"?

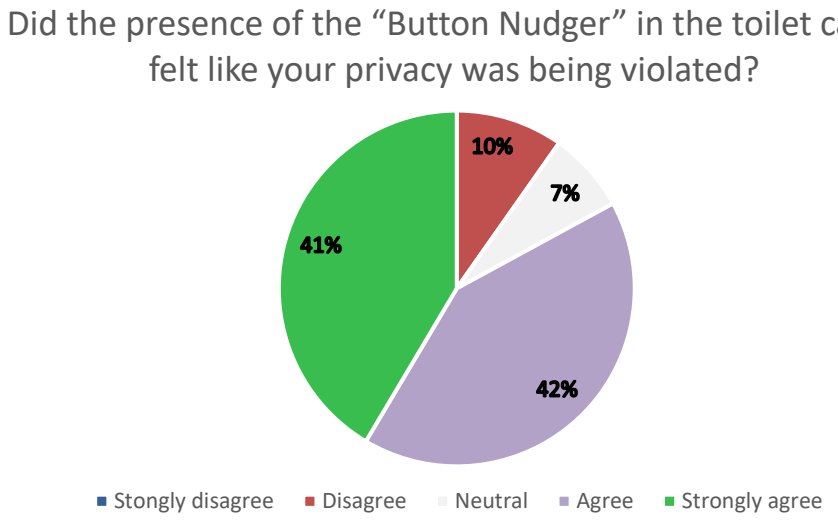
- *Open question*

10.15 Appendix O

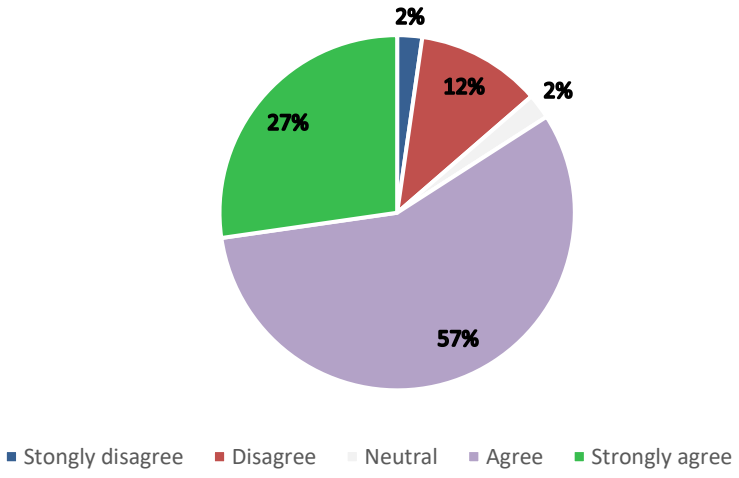
Table 16: User evaluation survey results.



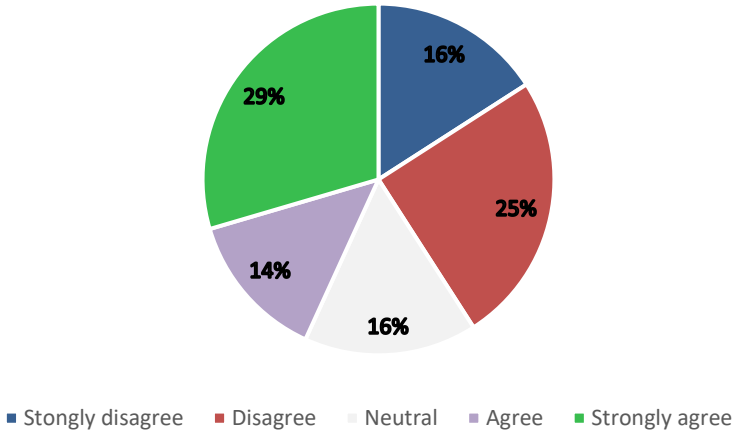




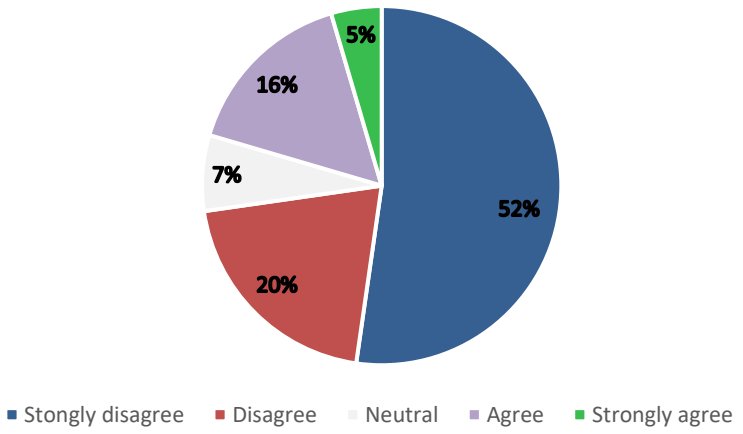
I felt the “Button Nudger” was observing me.



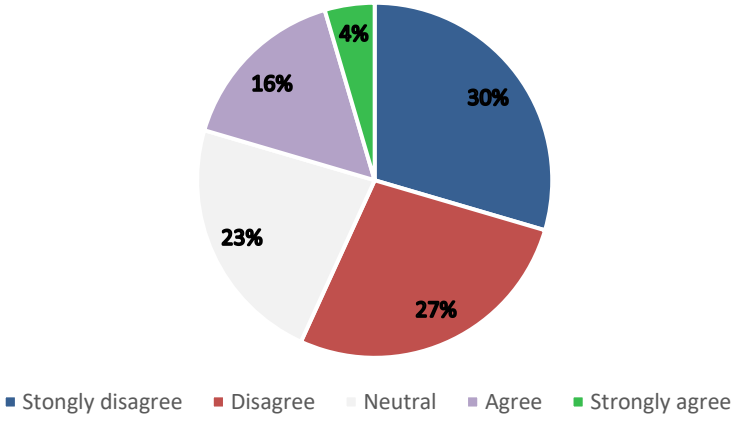
The presence of the "Button Nudger" caused me to choose another toilet cubicle.



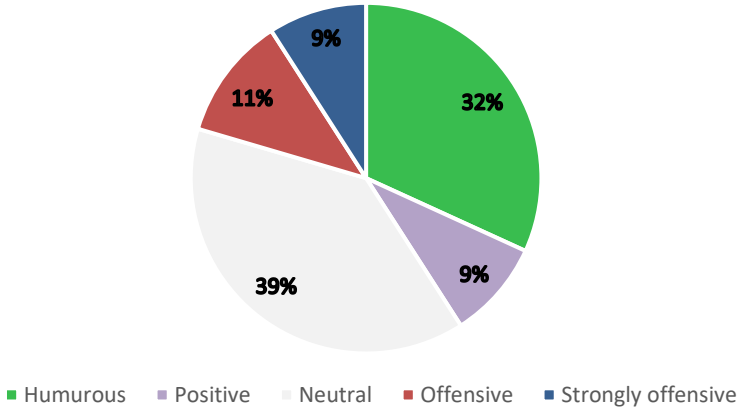
Did the presence of the “Button Nudger” influenced your choice of pressing a flush button?



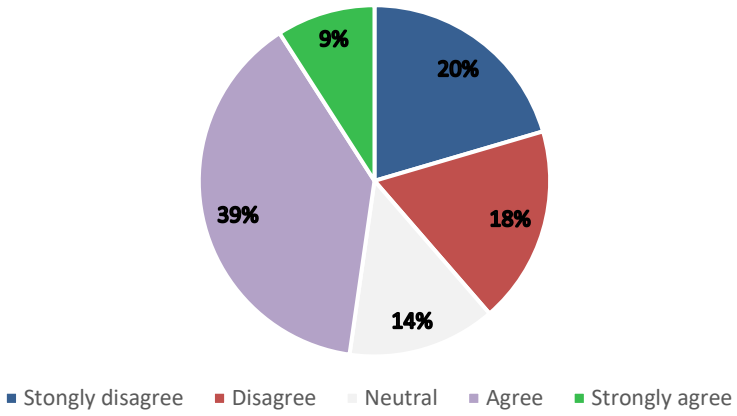
Installing the “Button Nudger” in more toilet cubicles helps to educate UT community members to adapt their flushing behavior.



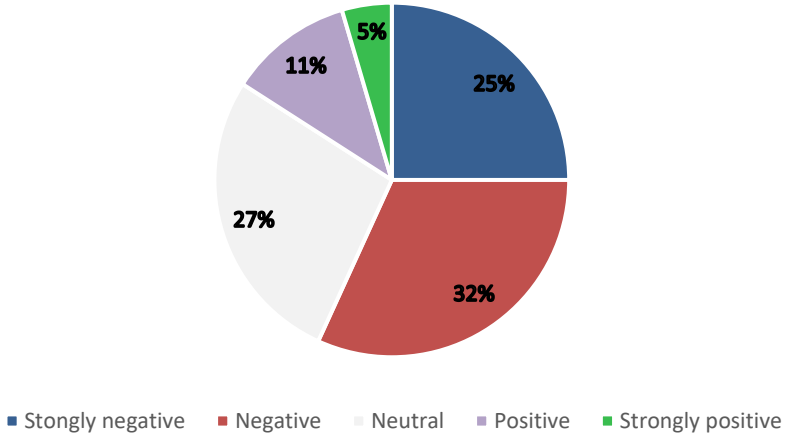
How would you rate the text in the green scene of the “Button Nudger”?



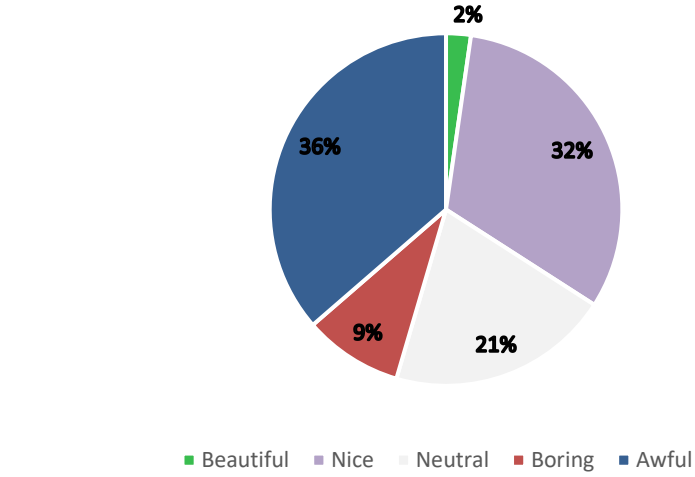
I felt like I understood the interaction with the “Button Nudger”.



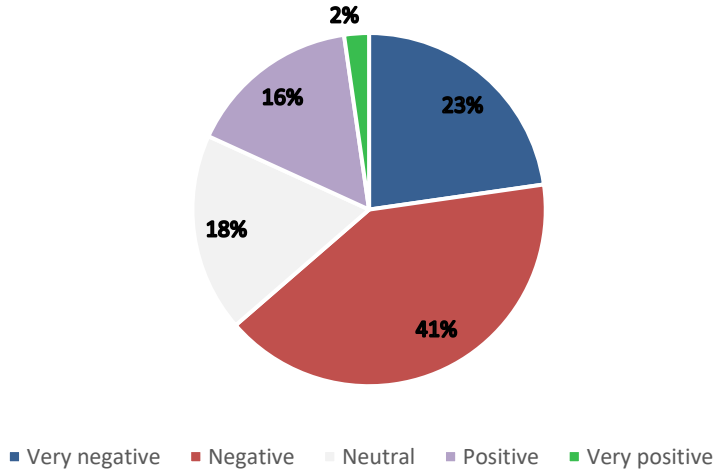
How do you rate the interaction with the “Button Nudger”?



How would you rate the design of the prototype “Button Nudger”?



My overall impression of the system was:



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