CRANFIELD UNIVERSITY

Jake Larsson

Aspirational Toilet User Experiences:
Translating latent user needs into aspirational user experiences

School of Water, Energy and Environment

PhD
Academic Year: 2014 - 2018

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This thesis is submitted in partial fulfilment of the requirements for the degree of PhD

ABSTRACT

What makes a product user experience aspirational? What do people truly want from their products? The aim of this research is to assess the implementation of latent needs to design an innovative aspirational product user experience. The thesis details reflective action-based research on the study of the design of an aspirational toilet user experience; a taboo subject that has little to no aspiration attributed to it. Toilets have not changed in the past 200 years and arguably the user experience is not considered aspirational. The reflections on an admittedly extreme case could in turn have implications for the other practitioners. Latent needs were elicited from 77 households in Kumasi Ghana to understand the motivations for acquiring a toilet while latent needs of the user experience were gathered from hackers online. The results suggest that the negative *'shut away'* nature of a toilet means people do not attribute value to them while there is a universal fear of the invisibility of disease. The study resulted in the construction of a wellbeing monitoring toilet prototype that would change the meaning people attribute to toilets while beginning to satisfy the fear of disease. A final test was arranged where the improved user experience is shown to be more valuable and aspirational to users by questionnaire because the new concept affords new meaning beyond the utility that toilets currently provide. The reflections on the case study suggest that when implementing latent needs in the design of an aspirational product user experience, it is worth considering that what users say is not what they do and meaning is a dimension of innovation that is as important as technology.

Keywords: Aspirational Products, Innovation, Human-centred Design, Design-Driven Innovation, Lead user

PREFACE

Personal Motivations: As an infinitely curious person, my interests span from technology to philosophy and art to politics. I am a principally driven character who believes in a future directed by considerate design for the environment, societal cohesion as well as an individual's wellbeing. This present thesis is a good example of my diverse interests and my passion to fully immerse myself into a new challenge. I have taken great care in sculpting the thesis to be informative for readers from a variety of disciplines so the different sections about latent needs, creativity or electronics are enjoyable for all. My intention is that upon reading the thesis, one can see I have been actively reflexive with my views and beliefs throughout the research and I have constructed the narrative to take the reader on a journey that describes my own discovery of learning, calling upon contemporary as well as well-established perspectives from literature. I hope it is a pleasant read for whomever reads it and readers from the Design Thinking and human-centred design communities and curious minds alike, can leave with a new perspective.

Study Motivations: The instigator and sponsor for the present research is the Bill and Melinda Gates Foundation. The research is part of their Reinvent the Toilet Challenge initiated in 2011 to provide sustainable sanitation solutions to the 2.4 billion people worldwide who do not have access to adequate and affordable sanitation. The focus of the project is to combat developing countries' sanitary needs since the major contributor to the spread of disease in developing countries is inadequate sanitation. The Bill and Melinda Gates Foundation require the following deliverables:

- Valuable resources can be harvested from the solution (such as energy, clean water, and nutrients) that is germ and pathogen free.
- The toilet operates without connections to water, sewer, or electrical lines.
- That it costs no more than US$0.05 per user per day.
- Sustainable and commercially viable sanitation services that can operate in poor, urban settings.

- It is an aspirational product that is desirable in both developed and developing nations.

It is remarkable in 2018 that so many of the world's population do not have access to toilets. Whilst others investigate the deliverables from a technical dimension, as a student of design, I find how one can make a toilet user experience aspirational the most compelling deliverable and how an aspirational toilet user experience may help rectifying the toilet diffusion imbalance.

Disclaimer: All research conducted as part of this thesis has been reviewed and approved by the Cranfield University Health Research Ethics Committee (CURES).

AUDIENCE

This thesis is multidisciplinary in nature and spans subjects ranging from anthropology to design, electrical engineering and even urology. The transferable learnings depend on the reader's interests or focus. The intended audience for this thesis are those who are interested in how latent needs may be utilised to enhance human-centred design to bring more value to the everyday products we use. For this reason, the thesis is weighted heavily towards the psychology of unspoken tacit needs and how this contributes to aspirational product user experiences; the content is used to better understand how the process allows us to achieve this end. The audience this thesis is not explicitly intended for are sanitation experts, though there is transferable knowledge. Instead toilets in this context are used to highlight how latent needs can create aspirational product user experiences – *since toilet practices are a taboo subject and toilets are viewed as utilitarian products*. The impact of this research intends to broaden the knowledge base of techniques used in human-centred design. The focus is on how user latent needs may reframe project briefs and produce aspirational and innovative value propositions. Research by practise lends itself well to this audience.

An apology to those reading this thesis that may be offended by the language used when talking about excretions. One observation made during the research is there are only three types of language used when talking about faeces: the scientific - *faeces, excrement* - the offensive - *shit, crap* - and the comedic - *poo, turd*. Although this thesis uses scientific terminology, some quotes throughout use the offensive kind.

ACKNOWLEDGEMENTS

The journey of this research has been long and arduous and I would like to thank several people for their continued support over the three year duration. Firstly, I could not have completed the thesis without the support of my family who have helped me immensely in many ways. My mum Gill, for helping my align my thoughts; my dad Jim, who helped me vent; my brother Adam and his girlfriend Rosie for housing me during the final months and my Grandma Rita who has always given non-stop positivity. On campus I really appreciate the support from Keith Goffin, Ewan McAdam, Alison Parker, Bhavin Engineer and Pauline Buck who all have given me their precious time. I am especially thankful for their genuine care. I appreciate that my supervisors Leon Williams and Tim Rose have been incredibly patient. Lastly, I very much appreciate the care from all my friends who have helped me remain positive throughout this experience. In no particular order, Zoe Rowe, Cynthia Adu, Ben Sedgwick, Jay Lucas, Zaira Peni Gonzales, Citlali Ruiz Trejo, Omar Huerta Cardoso, Ale Gutiérrez and of course my partner in crime throughout all of this; Ross Tierney who has nothing, but a joy to work and live with.

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LIST OF ABREVIATIONS

C1-C9	Contradictions identified from ethnographic research
CBS	Container Based Sanitation
COREQ	COnsolidated criteria for Reporting Qualitative Research
CURES	Cranfield University's Research Ethics System
DIY	Do It Yourself
DMU	Decision Making Unit
EC	Electrical Conductivity
ECG	ElectroCardioGram
H1-H6	Hacks identified from participatory photography
HOD	Harmonic Oscillation Densitometry
I1-I11	Intangible observations from ethnographic research
IBM-WASH	Integrated Behavioural Model for WAter, Sanitation and Hygiene
KVIP	Kumasi Ventilated Improved Pit latrine
LED	Light Emitting Diode
LCD	Lyquid Crystal Display
MBBR	Moving Bed Biofilm Filtration
NPD	New Product Deveopment
NPK	Nitrogen Phosporous Potasium
PoC	Proof-of-Concept
PoP	Proof-of-Principle
RGB	Red Green Blue
SG	Specific Gravity
T1-T36	Themes and codes identified from ethnographic research
W1-W12	Workarounds identified from ethnographic research
WBM	WellBeing Monitor
WC	Water Closet

“Of the world’s seven billion people, six billion have mobile phones. However, only 4.5 billion have access to toilets or latrines”

United Nations

1 INTRODUCTION

The advancements in hygiene are considered a critical chapter in the development of human civilization (Pathak, 1995). A notable turning point in the toilets history was in the *"golden age"* when the understanding of water-borne diseases was discovered (Horan, 1996). After this point, the necessity for innovation in the development of sanitation infrastructure was prevalent and people's perception of the toilet experience had changed; toilets represents a milestone that bears the responsibility for maintaining a pleasant environment (Chun, 2002).

The history of the evolution of toilet technology change from pit latrine to the dual flush is described and shown visually in Figure 1-1 to show how pivotal developments have affected the user experience. The need for comfort and privacy in the act of defecation is as old as civilisation. The earliest forms of latrines are seen from the Mesopotamian era (Horan, 1996). Up until the Middle Ages, the disposal of one's waste was either dumped in rivers or cesspits, a Gongfermor was someone who worked during the night to clean cesspits in London. It was John Harrington who first invented the Ajax – *a primitive cistern* - in 1596, that was coined a *"sweet smelling"* privy that did not need the river Thames to wash away the impurities (Horan, 1996). The addition of a valve-trap to separate the home from cumulating waste outside was incorporated by a London watchmaker Alexander Cummings nearly 200 years later in 1775. Uptake of toilets was still slow since London had no sewer system and operated on a cesspit and collection system. Famously, a British Doctor John Snow traced an outbreak of cholera to a neighbourhood water supply in 1854 and so began the *"golden age"* of toilets where water flushing toilets and sewage systems were incorporated with every new construction. Thomas Crapper found his fame in 1884 by improving on the flush by developing the cistern flush to reduce water that we know today.

Technology Change

Dual Flush					Dual Flush (1980)
Vac Flush				Plane Toilets (1925)	
Cistern					Cistern Flush (1884)
Dry Earth System				Dry Earth (1858)	
Sewage System			Sewage System (1849)		
Valve-trap			Toilet inside the home (1775)		
Ajax		Flushing Toilet (1596)			
Disposal Service		Gongfermor (< 1500)			
No Technology	Pit Latrine (< A.D)	Chamber pot (< A.D)			
	Toilets for Privacy	*Toilets Away from Rivers*	*Toilets in Household*	*Toilets in Remote Places*	*Water Saving Toilet*

User Experience Change

Figure 1-1 Change in toilet technology.

The change in toilet technology and user experience over time. Source J Larsson.

There have been additional and niche requirements of toilets; such as a mobile-toilet in trains or in taxis, or low water toilets for areas suffering from water scarcity. The development of sanitation across history has been driven by the societal need to control the state of the environment and the personal need for privacy[1] (Gramigna, 2013; Leone, 2012). Investigating the personal need of toilets from a semiotic perspective further, people's general relationship with excrement is largely un-investigated in academic literature - *despite the anthropological lessons to be learnt*. The almost universal attitude toward toilets is that they are *"technologies of concealment... containers of the unclean"* (Gramigna, 2013).

> *"The everyday practice of getting rid of one's bodily waste is made apparently meaningless by the 'excrementitious' routines that we learn and interiorize since early childhood and that make us forgetful about their cultural character."*
>
> (Leone, 2012)

Leone (2012) argues that the act of going to the toilet is an insignificant daily routine and as such the meaning that we then attribute to toilets is meaningless. Interestingly, the positive image we have of our own identity is a mirror-like image of the negative image we have of waste; where other invisible habitual routines shape our identity. Gramigna (2013) states that the toilet itself, represents a boundary between a user's inner space – *the home* – and outer space – *the environment* - and so the action of flushing the toilet semantically represents the deletion of the filthy or profane, rendering the inner space clean, decent and acceptable. It is the action of turning the lever and the cascading of water that we associate with toilets and in turn associate with the deletion of the profane. The attitudes towards toilets are generalised, but the perceptions of toilets differ greatly even across Europe and the designs differ to reflect this.

---

[1] Latrines were known as *"Privies"* derived from *"private"* or *"privatus"* (Horan, 1996).

> *"In a traditional German lavatory, the hole in which shit disappears after we flush water is way in front, so that the shit is first laid out for us to sniff at and inspect for traces of some illness; in the typical French lavatory, on the contrary, the hole is in the back - that is, the shit is supposed to disappear as soon as possible; finally, the Anglo-Saxon (English or American) lavatory presents a kind of synthesis, a mediation between these two opposed poles - the basin is full of water, so that the shit floats in it - visible, but not to be inspected."*
>
> (Žižek, 1997)

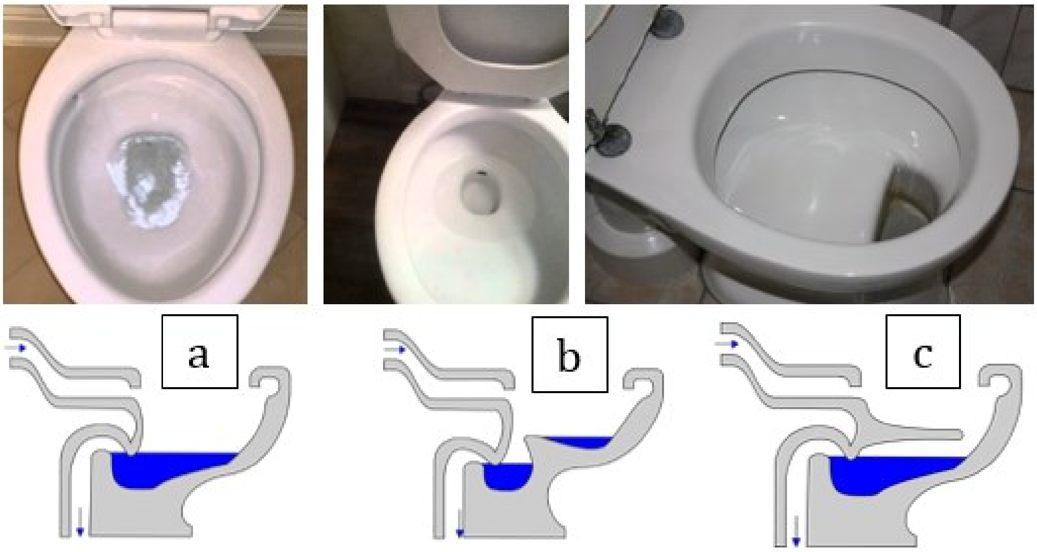

Figure 1-2 Differences between European toilet design.

Set of photographs and visual drawing showing the difference between the form of European toilets, showing the Anglo-Saxon (a), French (b) and German toilets (c). Source: https://www.google.co.uk/.

Žižek (1997) proposes the three different toilet designs, are influenced by the three different cultural attitudes towards excrement. The German toilet in Figure 1-2c, is embodies the *"ambiguous contemplative fascination".* The French design in Figure 1-2b, is influenced by "*hasty attempt to get rid of the unpleasant excess as fast as possible"* and the British toilet in Figure 1-2a is designed as a "*pragmatic approach to treat the excess as an ordinary object to be disposed of in an appropriate way".* The abovementioned example illustrates how toilets are a great example of how the cultural differences that shape people's latent needs can manifest in different design preferences.

At present toilet practices differ somewhat across cultures; the styles of defecation across the world is primarily sitting, squatting, or standing alongside a riverbank; the methods of anal cleansing are with paper, water, pebble, rope, leaf or spray (Chun, 2002). In high-income countries, the most dominant practice is a sitting posture, using paper for anal cleansing. Whereas squatting is a more prevalent style in low-income countries such as Kenya, India, Mongolia and Indonesia, with many different cleaning techniques. The *'outhouse'* perception in low-income countries is similar to the *'shut away'* perception of toilets in high income countries because of the polluting activities experienced in toilet spaces (Chun, 2002).

> *"…toilets as spaces that mediate between culture and nature, in which dirt plays a crucial role as marker of difference in a given cultural setting… the toilet can be thought of as a boundary place in between nature and culture."*
>
> (Gramigna, 2013)

The necessity of hygiene, that is taken for granted by people more fortunate, has still some distance to go with 2.4 billion people without adequate sanitation (Bill & Melinda Gates Foundation, 2015; UNICEF and World Health Organization, 2015). Inadequate sanitation is the biggest contributor to water-borne pathogens and leads to the death of at least 1.6 million children under five per year shown in the faeco-oral pathways diagram in Figure 1-3 (World Health Organization and Unicef, 2006). In fact, inadequate sanitation can be disease spreading, not disease preventing in many low-income cases (Rosenquist, 2005). Whilst a third of the population of the planet is without adequate sanitation, it shows that revolutionary innovation is necessary to reach the economic bottom of the pyramid (Castillo, Diehl and Brezet, 2012). In the same way mobile phones have been revolutionary innovations – *shown in the quote at the beginning* - the role of prestige in the uptake of toilets amongst those in low-income countries is important (Jenkins and Curtis, 2005; Seymour and Hughes, 2014).

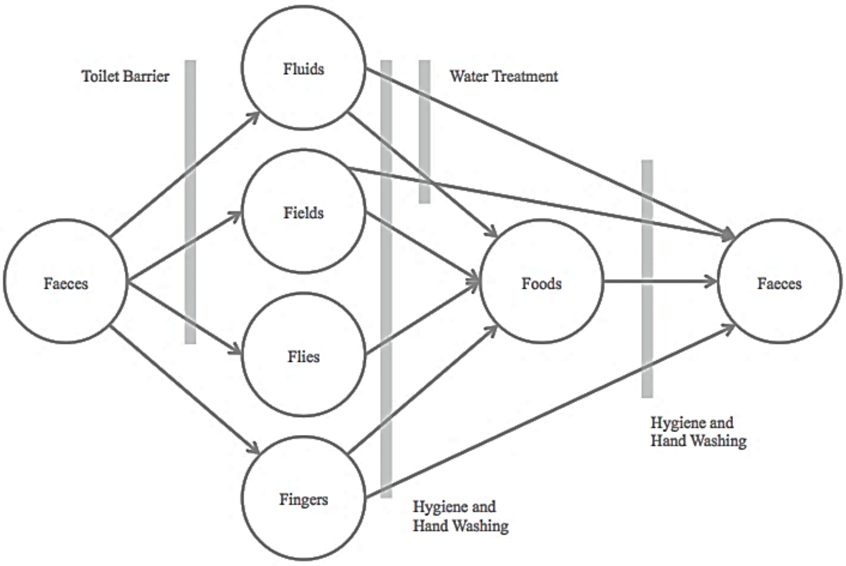

Figure 1-3 Faeco-oral pathways.

Faeco-oral pathways diagram showing the transfer of water-borne pathogens. Source: adapted from Water1st International (2015).

Broadly speaking there are two types of innovation; incremental innovation and radical or revolutionary innovation. Incremental innovations are improvements within a given frame of solutions; doing better what is already done, usually from a 'market pull' (Castillo, Diehl and Brezet, 2012; Verganti, 2009). Whereas revolutionary innovation is a change of frame; doing what has not been done before, when technological breakthroughs combine with novel meanings to the users (Dorst and Cross, 2001; Norman and Verganti, 2012; Rogers, 1995, p.426). Norman and Verganti (2012) use the analogy of hill-climbing to illustrate the differences between incremental and revolutionary innovation; a blindfolded man can only reach a local peak if he always follows an upwards slope incrementally, the only way to reach the absolute peak of a mountain is to radically change slopes through meaning or technology; this analogy collapses when there is no explanation of how to jump from one hill to another.

1.1 Need for the Research

Understanding customers' needs early in the New Product Development (NPD) process is the cornerstone of a human-centred design and is growing as an emergent theme in NPD literature (Luchs, Swan and Creusen, 2015). This research provides an opportunity to trial latent needs on a taboo and embarrassing subject – *arguably with more latent needs than another product* – eliciting the role of prestige in the creation of a revolutionary innovation for an aspirational toilet user experience that is more desirable to own.

> *"While the average American changes his automobile every two and a half years, gets a new suit about every nine months, buys a refrigerator every ten years, and even changes his residence about every five years, he never buys a new toilet bowl. If one could design the sort of bowl that would make people want to 'trade in' their old one, this industry would benefit greatly".*
>
> (Papenek, 1985)

The prestige and aspiration to own a car is an ambitious comparison for toilets, but it is an interesting contrast. The origin for the automobile did not come from an international horse crisis, some of the greatest innovations can come from desire and not just from necessity (Basalla, 1988). An innovative shift for toilet user experiences may not be possible, but there may be learnings in the process of implementing latent needs.

When pursuing revolutionary innovations, it is necessary to discover the *"the need behind the need"* by considering the context in which the innovation exists (Goffin, Lemke and Koners, 2010). The conscious and spoken needs of users may be superficial and there are deeper needs and more tacit needs that are unarticulated (Hussain, Lockett and Vasantha, 2012; Tukker and Tischner, 2006). Users may not consciously know why they act a certain way and behaviours are not understood by asking users directly (Norman and Verganti, 2012)[2].

> *"Good designers never start by trying to solve the problem given to them: they start by trying to understand what the real issues are. As a result, rather than converge upon a solution, they diverge, studying people and what they are trying to accomplish, generating idea after idea after idea."*
>
> (Norman, 2013)

After studying people, ideation and the generation of ideas is central to design – *a core part of innovation*. Verganti and Öberg (2013), innovation is a *"process of interpreting and envisioning"* where the role of design represents a subjective, intuitive and emotional stance. They claim designer intuition plays an important role *"by trying to put oneself into the situation at hand, to feel and to live it, new understanding can be created"*. Within the language of design, interpreting and envisioning is referred to as reframing the problem (Carlgren, 2013). Intuition is needed to question, frame and reframe the user needs and again, intuition is needed getting to the core of the problem. Intuition is also present in envisioning and exploring creative tension and the intersection of new ideas for enhanced meaning (Castillo, Diehl and Brezet, 2012; Norman and Verganti, 2012). A necessary component of the intuitive nature of ideation and reframing is incubation and suspended judgement, purposeful delay can allow sub-conscious processing to take place (Hernandez, Shah and Smith, 2010).

---

[2] For example, someone watches the news to gain more knowledge of what is going on in the world - *or at least to them* - however, a newspaper would be more thorough and informative. There is a degree of detaching from the world and watching the television is tacitly about unwinding (Rexfelt and Ornäs, 2009). The latent need of the individual is about relaxation instead of gaining knowledge, although not realised by the individual.

1.2 Revolutionary Innovations for User Experience

A revolutionary toilet user experience *affords* many different concepts for the future; *affordance* in this instance, means what can be done as discussed by Norman (2013). As an example, currently the toilet affords concepts related to private serenity or comfortable peace and quiet because of the sitting posture and the solitary environment. It may also afford concepts for self-inspection and personal hygiene again because of the environment and the necessity to unclothe oneself. The value proposition of the toilet user experience is primarily a utility focused experience that meets one's physiological needs, *would any of the affordances create a value proposition that is more aspirational?*

There are several affordances - *shown in the inner circle in Figure 1-4* - are apparently not crucial attributes, namely; the *Sitting* posture, since an ergonomic sitting posture albeit comfortable is not necessary synonymous with what is good for us (Rosenquist, 2005); being *Alone*, shared publics urinals or the more recent outdoor urban urinals; or even having to *Unclothe* oneself, with the existence of adult sanitary pads. Arguably, these unnecessary attributes have always been attributes of the toilet user experience and remain for social acceptance (Arthur, 2009; Brewer, 1991; Harni, 2010). Deviation from these attributes can be explored once new and meaningful value is identified for toilet user experiences, this leaves four opportunities for revolutionary innovation shown in Figure 1-5[3].

---

[3] Detailed research of current technologies that meet the four attributes for revolutionary innovation and the opportunities not currently met, can be found in Appendix A.

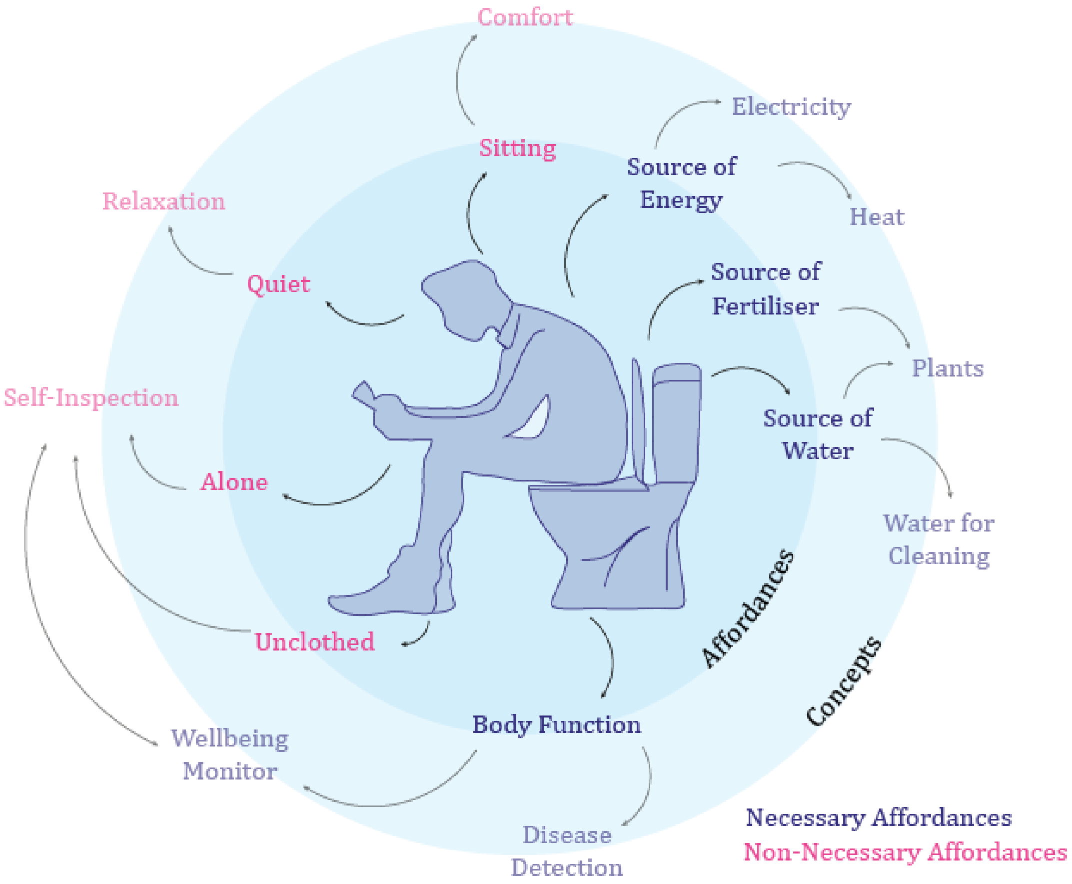

Figure 1-4 Toilet affordances.

Concept Map of what the toilet affords and the possible consequences. Source: J Larsson.

The lengthy Introduction has detailed how important latent needs research is in the creation of revolutionary and aspirational user experiences. Translating the latent too is important in the creation of a new value proposition. Knowing the existing solutions in the marketplace and how they meet the insights identified is key. Then finally developing a prototype to test and assess the change in aspiration is also important. The question arises, '*How may aspirational toilet user experiences manifest?'.* The aim and objectives are discussed below.

Technology Change

Cistern and Sewer		Flushing Toilet				
Hole in Ground	Pit Latrine					
		Defecating at Home	*Source of Water*	*Source of Fertiliser*	*Source of Energy*	*Monitoring Health and Wellbeing*

User Experience

Figure 1-5 The future potentials of toilets.

The future direction of toilets and what technologies will create an aspirational concept. Source J Larsson.

1.3 Aim and Objectives

Aim: To assess the implementation of latent needs to design an innovative aspirational toilet user experience.

> **Objective 1:** Elicit latent needs regarding motivations for acquisition and user experience.
>
> **Objective 2:** Translate latent needs and reframe the problem.
>
> **Objective 3:** Review the marketplace and horizon scan current solutions.
>
> **Objective 4:** Develop a toilet user experience for the experimental plan based on the gaps identified by insights and marketplace.
>
> **Objective 5:** Assess the change in aspiration and user experience of the revolutionary innovation.

1.4 Methodology

As a current research project there is an opportunity to reflect upon an immersive research study in an explorative sense. The taboo and embarrassing nature of toilets and toilet practices compliment a latent needs approach, where the concealment of true behaviours or attitudes are more likely. A Design Thinking approach has been chosen following two series of divergent and convergent processes to find the correct problem and correct solution respectively (Brown, 2008; Design Council, 2010; Ideo, 2014; Norman, 2013). The methodology is depicted in Figure 1-6.

The rationale for the methods used are detailed in the Literature Review in the following chapter. Each chapter of the thesis has its own approach and is discussed at the beginning of each chapter, Figure 1-6 is an overall depiction of the research approach.

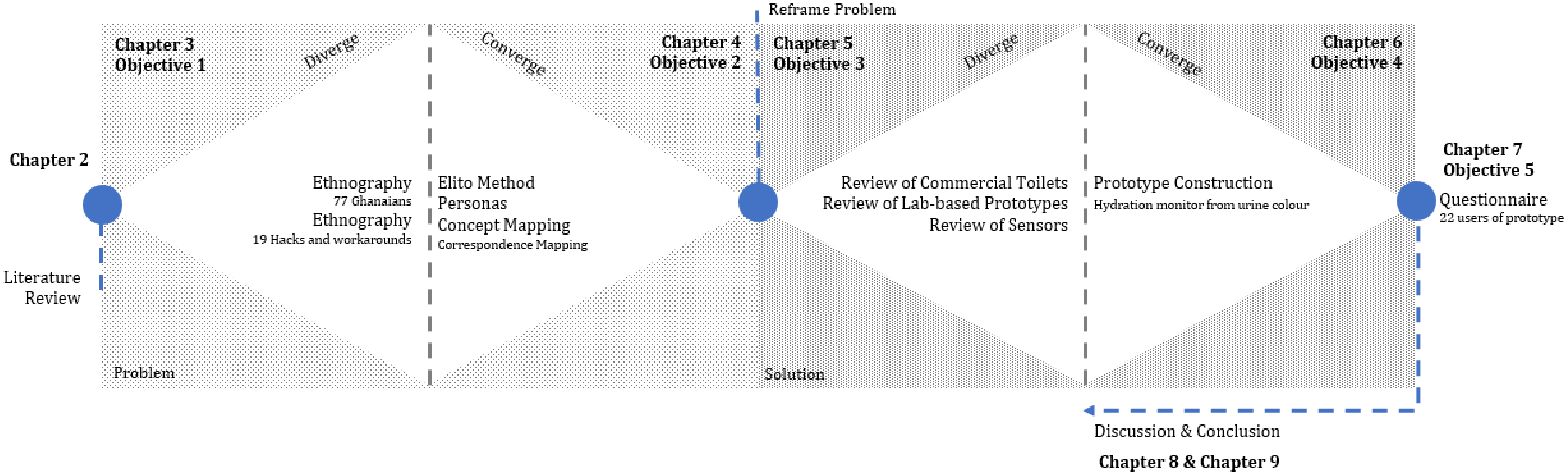

Figure 1-6: Visual representation of research methodology.

Diagram depicting the methodology of the research using the Double Diamond framework to reframe the problem.

1.5 Thesis Structure

Chapter 1 – Introduction: The Introduction discussed the history of toilet user experiences and future directions of innovation, establishing the need for the research.

Chapter 2 – Literature Review: This chapter investigates the variety of methodologies for eliciting latent needs and how they are applied in other research settings. The scope is to review the different methods for eliciting latent needs. To critique how other research studies have incorporated them and identification of gaps in the knowledge.

Chapter 3 – Eliciting Latent Needs: This chapter is devoted to the gathering of insights to determine what the latent needs are in the acquisition of toilets and the user experience. The scope is to identify lead users for latent needs research, undertake latent needs research on lead users and consolidate insights.

Chapter 4 – Translating Insights: This chapter provides connectivity and reasoning between the output of the insights found and a newly developed Proof-of-Concept (PoC) that is used in the experimental plan for user test. The scope is to identify methods for assimilating insights and to synthesise latent needs to a value proposition.

Chapter 5 – Review of the Marketplace: This chapter will look to survey the marketplace for existing toilets, commercial or otherwise, to gauge the viability of the concept and whether the latent needs of individuals are being met. The scope is to survey current technologies in the domain identified and to produce a rationale for understanding how the PoC can be used in a real-life context.

Chapter 6 – Proof-of-Concept Feasibility: This chapter is dedicated to the construction of the PoC with structured sequence of component testing. This will demonstrate how the solution will be prepared for human user testing in a bathroom. The scope is to produce a graphical flow chart declaring the sequence of the development for the human user testing experimental prototype, conduct a series of controlled tests to ensure the prototype meets the functional needs of the human user testing and finally complete a technical drawing and a list of specification requirements for the human user testing.

Chapter 7 - Human User Testing: This chapter will test whether the PoC has changed aspiration in the user experience. The scope is to conduct a comparison test with a normal toilet user experience and the proposed solution. The follow up questionnaire focuses on perception and user experience of the value proposition.

Chapter 8 – Discussion: There is an Analysis of Findings section devoted to each chapter and how the results may be interpreted to then inform the following chapter. The Discussion in this instance, will draw upon the key findings from Chapters 2 through 6 to analyse the impact if whether a toilet user experience can be aspirational in preparation of answering the research question in the Conclusion reflecting upon the contributions of knowledge.

Chapter 9 – Conclusion: The Conclusion is an overview of whether the research aim and objectives were met and answer the question *how may aspirational toilet user experiences manifest?* The Conclusion will critique the limitations for the research and make recommendations for future research.

"The mind is like an iceberg, it floats with one-seventh of its bulk above water."

Sigmund Freud

2 LITERATURE REVIEW

This chapter reviews the different methods available for eliciting and translating latent needs. It first begins with a structured search for latent needs and a review of the methods used in previous studies on the subject. Following this is a review of methods which translate the insights into a design specification. The methods are then discussed followed by a Definition of Terms used throughout the thesis is discussed from perspectives from literature finishing with a summary.

2.1 Need for the Research

There are many different methods one can use to elicit needs from users and again many different methods to translate the needs into something tangible. This chapter will review the different methods to inform which would be appropriate in this research.

Expected Outcomes

The expectations from this chapter is to review the different methods for eliciting user needs – *particularly latent needs* – and translating the insights. Upon completion of this chapter, success would be:

- Review of methods used in previous research.
- Selection of appropriate methods to use in this research.
- Definition of terms lead user and aspiration.

2.2 Research Approach

A near exhaustive search of literature was retrieved using the search terms a variety of search terms. “*latent needs*”, "*hidden needs*" and "*tacit needs*" were chosen because these terms were used by prolific authors with respect to understanding customer needs that are not readily expressed. Carlgren (2013) refers to latent needs as the complex mix between customer expectations, wants, needs and desires. Prasetio and Dhewanto (2011) refers to hidden needs lying on a sub-conscious level where Goffin and Koners (2011) refers to all terms latent, hidden and tacit needs as concepts that are difficult to articulate where metaphors and story-telling is used to articulate experiences. The terms *"latent needs"* OR *"hidden needs"* OR *"tacit needs"* were used on the Scopus database; the search returned 159 publications. Figure 2-1 shows the frequency of latent needs publications over time, showing an increase in recent years and how it is a growing subject.

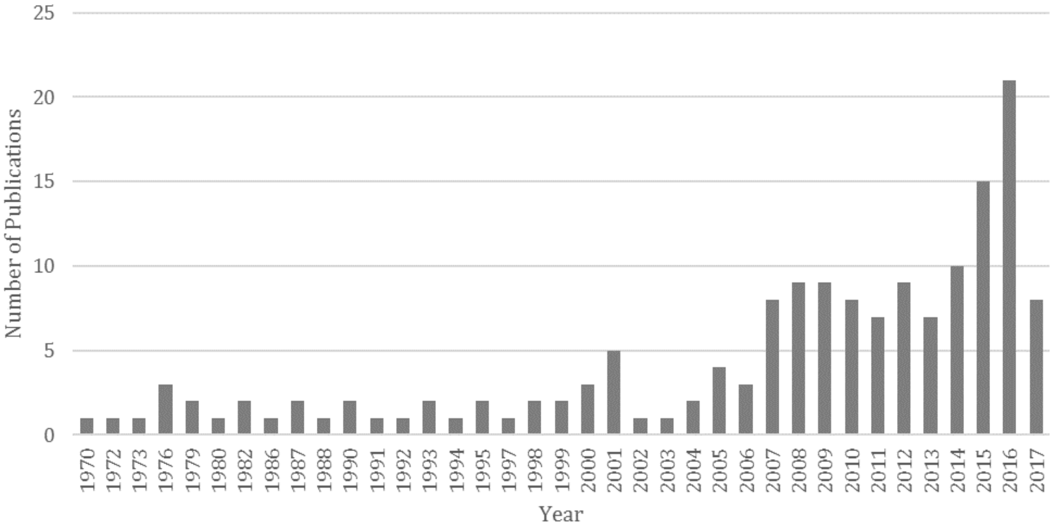

Figure 2-1 Latent needs publications over time.

Graph to show the publications of "latent needs" OR "hidden needs" OR "tacit needs" over time. Source: Adapted from Scopus.

After filtering by journal paper publications in the last ten years, title review and finally abstract review, there remained 14 journal papers shown in the Prisma diagram in Figure 2-2. The methods used were questionnaire or survey by three authors (Fu et al., 2017; Judge, Hölttä-Otto and Winter, 2015; Straker and Wrigley, 2016); Kano analysis by three (Carlgren, 2013; Hu et al., 2012; Yang, 2013); interviews were conducted by two (Byrskog et al., 2016; Wingham, Frost and Britten, 2017); repertory grid analysis was conducted by two (Baxter, Goffin and Szwejczewski, 2014; Clauss and Döppe, 2016); focus groups were used by two authors (Carvalho et al., 2016; Idyawati et al., 2016); observation or ethnographic research was used by Hahn, Marconnet and Reid (2016), although mentioned as complementary to other research studies by many (Carlgren, 2013; Carvalho et al., 2016; Clauss and Döppe, 2016; Idyawati et al., 2016; Judge, Hölttä-Otto and Winter, 2015) and finally methods of internet searching was also used by just one author

(Fehér et al., 2014). These methods are discussed individually in detail calling upon wider sources.

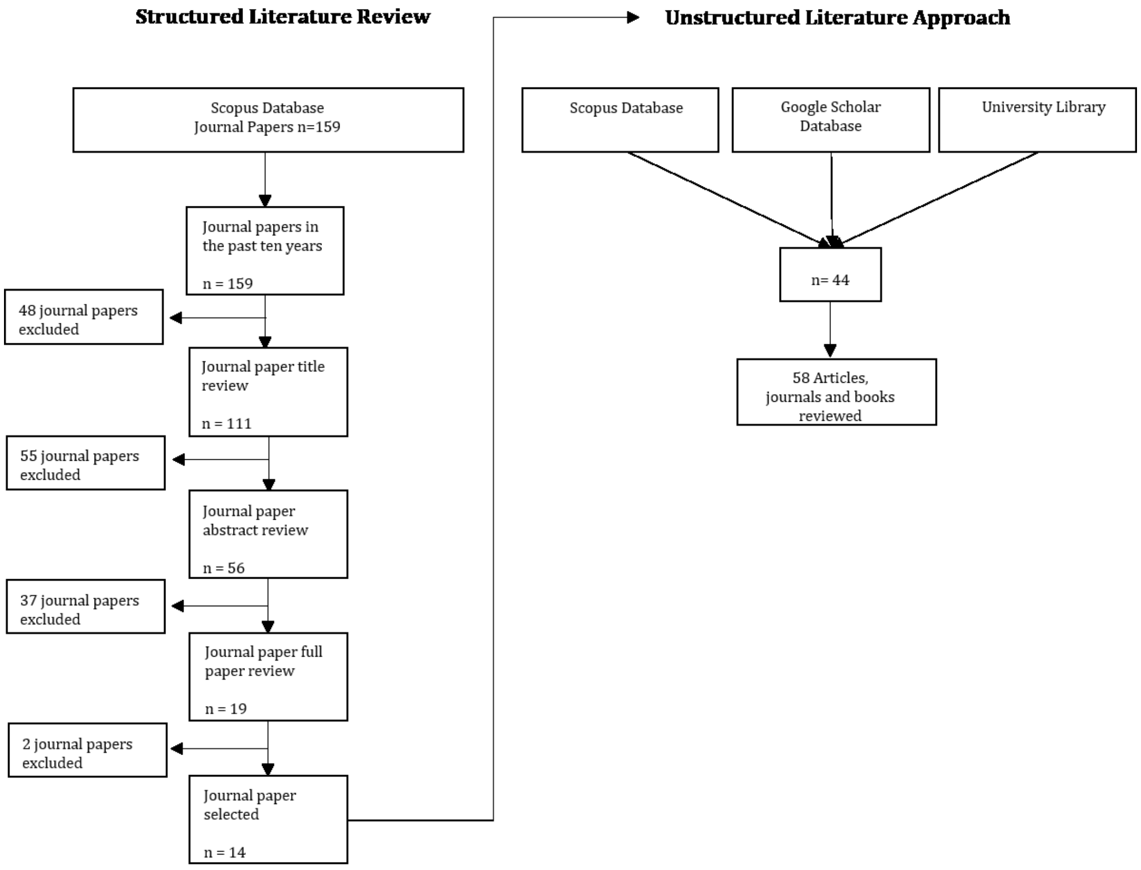

Figure 2-2 Prisma diagram of journal paper filter.

Prisma diagram showing the filter of publications related to latent needs.

2.3 Latent Needs

Questionnaire

A questionnaire or survey is where a researcher asks people - *written or verbally* – a fixed set of direct questions where the researcher does not manipulate the situation or conditions under which this is conducted and records the answers (Goffin, Lemke and Koners, 2010). They serve as useful tools in quantifying users' explicit and conscious attitudes towards product user experiences. Questionnaires allow consumers to rank the product attributes and determine the relative importance of the individual product criteria (Sauerwein et al., 1996). The correct choice of questions in a questionnaire is a complex task where the wrong choice by researcher bias or priming can skew the results (Feldman and Lynch, 1988). For instance, the choice of the questions may be centred on hygiene when all that is important to the respondent is the colour of a toilet. In this scenario, the results would not reflect their true feelings because of the questionnaire's ridged structure.

The order of questions is also important to avoid issues with priming respondents; the results may be different when the same questions are asked:

'Are you happy?'
'Yes'
'Are you in a relationship?'
'No'

Compared to:

'Are you in a relationship?'
'No'
'Are you happy?'
'I guess not, no'

The results of these two trivial questionnaires could result in a different outcome. Asking direct questions about a product that does not exist yet also presents problems. Respondents do not often know why they feel the way they feel or what would best satisfy their needs (Goffin, Lemke and Koners, 2010; Norman and Verganti, 2012). Features and benefits can sound attractive without an idea of context or even price. Respondents also may not imagine the future landscape and how new products will fit inside their lives and how the product may meet their needs (Cooper and Evans, 2006).

In summary, questionnaires are excellent at gathering demographic information with little effort or resource, however gathering data on a participant's emotion or attitude towards a product is limited since respondents may not consciously know why they do what they do, and may not be able to imagine the future (Goffin, Lemke and Koners, 2010).

Kano Analysis

The premise behind Kano analysis is that not all attributes and features are equally important to users (Kano et al., 1984). Kano analysis classifies which attributes have the greatest importance to the user that is detailed in Table 2-1 (Goffin, Lemke and Koners, 2010). Usually the features are established by a quantifiable, Likert scale questionnaire and it is a powerful tool for product design to ensure the most important features are salient to the user and the least important are not given priority (Sauerwein et al. 1996; Tsontini 2007).

Table 2-1 Table showing the classification of product features based on satisfaction questionnaire. Adapted from (Martin, Hanington and Hanington, 2012).

Question: *If feature is present, the user feels…*

		Satisfied	Neutral	Dissatisfied
Question: *If feature is absent, the user feels…*	Dissatisfied	Questionable	Anti-feature	Anti-feature
	Neutral	Exciter/Delighter	Neutral	Anti-feature
	Satisfied	Desired	Required	Questionable

Focus Group

A focus group is a group discussion with selected participants having a relatively unstructured discussion on a certain topic or product (Goffin, Lemke and Koners, 2010). There is a moderator that encourages the group to talk about certain topics and allows that everyone has a fair share of the conversation by *'steering'* the conversation. Focus groups are usually in an observable area that is filmed, where content analysis is later conducted on the conversation.

Beneficially group discussions can bring the best out of respondents and it is an easy and low-cost way of getting the viewpoints of key stakeholders in a manageable format. The limitations of focus groups are that respondents can often answer what they think the moderator wants to hear or may not want to air their true feelings in a group environment. This is known as the social desirability bias. Focus groups are best used when users of interest are identified and deeper insights are needed (Goffin, Lemke and Koners, 2010). Similarly, focus groups are beneficial for co-design or when a prototype can be placed in front of them for feedback on design.

Repertory Grid

The repertory grid comes from a psychoanalysis technique developed by Kelly (1955) following Personal Construct Theory. The repertory grid technique elicits personal constructs by comparing and contrasting elements such as different products (Goffin, Lemke and Koners, 2010). The algorithmic process of having the respondent compare and contrast each product while explaining the benefits of each, helps elicit the meaning that the respondent attributes to a particular product, a meaning perhaps not explicitly known by them. The benefit of this method is that the researcher gets an unbiased view of the respondent's tacit perception of products that otherwise may not be obtainable by direct questioning (van Kleef, van Trijp and Luning, 2005). Unfortunately, it is quite a complicated technique for respondents to understand and is time consuming. The choice of elements to compare and contrast needs careful consideration to obtain insightful results. Elements with many design variations may not produce meaningful insights.

Observation and Ethnographic Research

Ethnographic research techniques have been used by a number of authors for enhanced customer experiences by providing insights on unarticulated needs that are particularly useful for front-end product or service development (Belasco, 1990; Rosenthal and Capper, 2006; Viswanathan and Sridharan, 2012). The use of ethnographic research, allows NPD teams to observe consumers using their products, which elicits attitude and behaviour that the respondent may have overlooked or not thought relevant. People do not use products in laboratory settings as they would do in their own home. (Goffin et al., 2012; Goffin, Lemke and Koners, 2010; Rosenthal and Capper, 2006).

Within NPD, ethnographic research has been made easier and more in-depth insights are possible with the use of cameras and microphones. These allow the respondent to freely talk about what is important to them during the interview, whilst content analysis of the recordings provides in-depth analysis into their latent needs. By situating the interview in the context of its use, NPD teams can learn about the consumers' personalities and lifestyles and observe when contradictory behaviours in use of the product do not match with respondent answers in interviews. The behaviour pattern anomalies can lead to innovative ideas (Skaggs, 2010).

Conscious or unconscious lies – *to satisfy the researcher or because of embarrassment another example of the Social Desirability Bias* – can be identified by looking for contradictions between the semi-structured interview and demonstration of use. The downside of qualitative techniques is that the repeatability of the analysis can be subjective and open to researcher interpretation. *Significance* in quantitative studies is defined as representation of the population where sampling is usually randomised to ensure a cross-section of respondents is chosen, whereas *significance* in qualitative studies is defined as the depth of an insight that may come from idiosyncratic behaviours where sampling is purposeful (Saldana, 2012). Ethnographic research encourages researchers to immerse in the culture of the subject of study, however overcoming individual bias and generating results with validity is a challenge. Codifying the observations and compiling the results with multiple researchers is one method that can reduce subjectivity and increase repeatability – *discussed in more detail in the Translating User Latent Needs Chapter 4* (Saldana, 2012).

Internet Methods

Netnographic techniques – *ethnographic techniques on the internet* – can be used as a means of gathering user insights without having to observe the user using the product (Belz and Baumbach, 2010; Kozinets, 2002; Langer and Beckman, 2005). This is particularly useful when observation of the product in use is challenging. Netnography is used to allow users to remotely detail how their products are used, which is beneficial for situations where observing the respondent is not possible or appropriate because of sensitive research projects (Langer and Beckman, 2005). On the other hand, there is a chance that being so self-aware of the process allows bias in the process. Netnography is limited since it has a narrow focus on online communities with a lack of personal identifiers are available. The need for researcher interpretive skill makes generalising difficult; it may be used in conjunction with other methods for validity (Kozinets, 2002).

Participatory photography involves auto-driven photo-interviews, in which participants are given disposable cameras – *or take photos on their smart phones* – and asked to document themselves or others in their lives. The photos are later used in an interview with the participant to explore the meaning behind why the photo was taken (Noland, 2006). Other studies have used participatory photography in understanding relationships with technologies, environments, personal relationships or behaviours and emotions of the participant (Johnsen, May and Cloke, 2008; Jorgsen and Sullivan, 2010). The absence of an observer using this technique allows respondents to act naturally, whereas in other techniques the language of the interviewer can impinge on the results and limit the depth of the insight. (Johnsen, May and Cloke, 2008). Hacks and workarounds speak of user needs where interpretation can help reframe the underlying problem (Norman, 2008).

2.4 Translating User Latent Needs

Many of the publications from the structured review did not go beyond simply gathering latent needs, Judge, Hölttä-Otto and Winter (2015) and Straker and Wrigley (2016) document the design process after the elicitation of latent needs, but do not fully express their methods. As such, a survey of methods to translate latent needs has been undertaken below acquired by pursuing the references in the previous section.

Concept Mapping

Concept mapping includes plotting out new concepts into a visual map or framework of insights or requirements to understand how the concepts fit and how new meaning can be made (Novak and Cañas, 2008). The benefit of the concept map is that it brings new connections to seemingly unrelated topics.

Creative Toolkits

Creative toolkits are collections of physical elements for stimulation, organised for user participation to inform and inspire design (Sanders and William, 2001). The toolkits can foster innovative ideas through users' creativity and reveal deeper insight through play.

Design Workshops/Design Charette

Design workshops are group workshops where users participate with designers in creative co-design activities to meet user needs. A Design Charette is similar, but principally is a method inspired by biological natural selection and genetic algorithms whereby concepts are created on multiple tables. Different tables have a different insight or source of inspiration and designers move from one table to the next using superior design features or characteristics to inspire subsequent rounds of ideas (Martin, Hanington and Hanington, 2012).

Elito Method

The Elito method is used to create design arguments and objectives derived from observations (Martin, Hanington and Hanington, 2012). The method consists of a *"logic line"* that connects observations to solutions:

- Observation - The empirical observation
- Judgement – Why the observation occurred
- Value – Values of the users led to the observation
- Concept – The concept could meet this value that led to the observation

- Key metaphor – A memorable tagline to communicate the logic line.

Generative Research

Generative research is a broad term given to creative techniques that elicit participants feelings, dreams, needs and desires in projective techniques such as storytelling or role play (Sanders, 2000).

Personas/Storyboards/User Journey Maps

A persona is a fictional character represented as a short description related to the field research, including key aspects of their life, goals and common behaviours (Chasanidou, Gasparini and Lee, 2015; Price, Wrigley and Straker, 2015). Personas consolidate the descriptions of user behaviour patterns into digestible profiles to make the focus more humanised for designers (Goodwin, 2009). Storyboards and User Journey Maps may also be used for similar reasons to represent narratives from a user's perspective. This aids the designer in understanding what a user sees, hears, thinks or feels (Crosier and Handford, 2012; Hayes et al., 2006; Mcinnes, 2010). Contemporary research criticises the use of personas, demographic or psychographic information as a method to look for correlations with behaviours where motivations (Christensen et al., 2016). Similarly, if the role of personas is to help enable empathy to enter the process of interpretation and envisioning for the design, how might a designer empathise with a fictional character (Kouprie and Visser, 2009)?

Usability Report

A Usability Report is a report is a report on whether a product is usable enough to launch or needs revisions (Martin, Hanington and Hanington, 2012). The typical format of a Usability Report will involve an Executive Summary, Number of Problems Found, Solutions to Problems, Positive Findings, Details of Scenarios. This is usually used before releasing a product and acts as a final audit once most of development has been completed.

2.5 Analysis of Findings

Traditional marketing insight gathering techniques involve surveys, questionnaires and interviews that are repeatable and quantifiable, however these have limitations in explaining the tacit reasons for behaviours (Bertrand and Mullainathan, 2001; Fellman, 1999b; Goffin et al., 2012). Direct questions in isolation, do not yield an adequate understanding of consumer needs since customers are often not able to articulate their needs and the reasons for their habitual behaviours. Similarly, users may not readily know why they do things or buy certain products and as such, users imagined use of future products is unreliable (Cooper and Evans, 2006). The latent needs techniques that are able to achieve revolutionary innovation are not conventional techniques like surveys, but instead are observations, contextual interviews and repertory grid techniques (Prasetio and Dhewanto, 2011; Price and Wrigley, 2016; Viswanathan and Sridharan, 2012). Figure 2-3 is a model of this concept and how it may affect the level of insight gathered by design researchers (Silva et al., 2012).

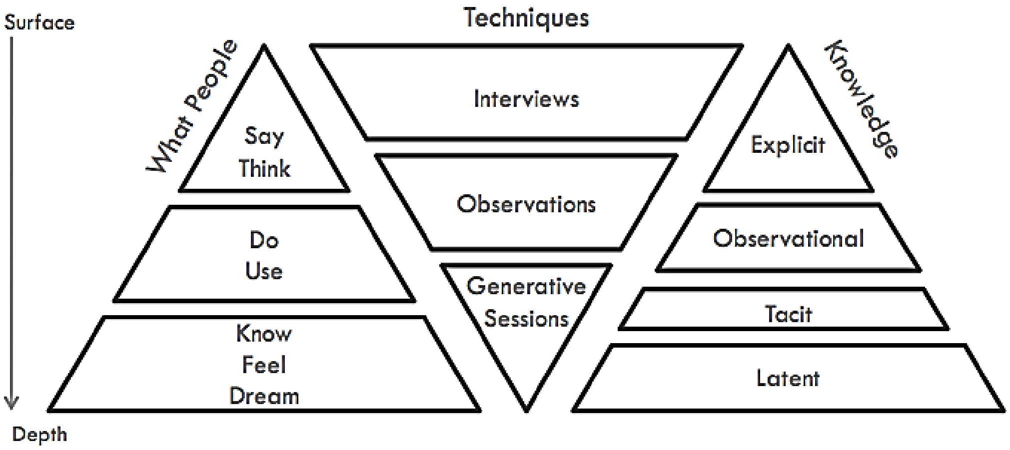

Figure 2-3 Depth of insight and the methods.

Depth of insight achieved from different types of elicitation methods. Source: Adapted from (Silva et al., 2012).

The aforementioned issues are only in part the problem with traditional marketing techniques that uncover explicit and conscious needs. Forming a questionnaire from an existing hypothesis may miss crucial elements. By its nature, ethnographic research follows a Grounded Theory[4] approach and is used by leading practitioners for innovation because hypothesis are formed from the data and nothing is assumed (Barczak, Griffin and Kahn, 2009). Ethnographic research's purpose is to paint a comprehensive view of the users under observation by deciphering patterns and extracting themes (Martin, Hanington and Hanington, 2012). In situations where observation is not practical, remote methods like Netnography or participatory photography can be very insightful while still following a Grounded Theory approach.

The history of latent needs research stems back to Construct Theory, a theory from the field of psychotherapy where the definition of a word – *construct* – may be different from one individual to another, so a series of techniques was explored to elicit their deeper meaning (Kelly, 1955). The premise of Construct Theory is that individuals develop constructs in such a way to explain events and the repertory grid technique is a way of decoding the language-meaning nexus (Goffin, Lemke and Koners, 2010). In other words, one person's version of a clean bathroom may be to do with order and neatness whereas another's may be shiny and odour free. It is only more recently that this theory and these techniques have migrated into NPD.

Table 2-2 Missing knowledge from previous ethnographic research.

Authors	More description Needed About
(Rosenthal and Capper, 2006)	Post fieldwork analysis
(Goffin et al., 2012)	Insights to design features
(Bosch-Sijtsema and Bosch, 2014)	Real-life walkthrough
(Skaggs, 2010)	Post fieldwork analysis

The gaps identified in the literature show that qualitative observations can be superior in insight generation for new user experiences, however there is a lack of knowledge in the process shown in Table 2-2. Many of the latent needs approaches

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[4] Grounded Theory comes from social sciences, where questions and hypotheses are generated inductively from the data and are answered on analysis (Glaser and Strauss, 1967).

require more time than methods that focus on explicit needs as demonstrated from the quote below:

> *"Design and marketing are two important parts of the product development group. The two fields are complementary, but each has a different focus. Design wants to know what people really need and how they actually will use the product or service under consideration. Marketing wants to know what people will buy, which includes learning how they make their purchasing decisions. These different aims lead the two groups to develop different methods of inquiry. Designers tend to use qualitative observational methods by which they can study people in depth, understanding how they do their activities and the environmental factors that come into play."*
>
> (Norman, 2013)

Understanding the problem favours qualitative methods that elicit significant insight and testing the solution favours quantitative methods where significance is in the representation of the population. For this reason, ethnographic research has been chosen to understand the reasons for purchasing toilets focusing on idiosyncratic adoption behaviours. Participatory photography of user hacks has been chosen to understand the unique user experience behaviours. Once the insights have been identified, the final prototype shall be tested with a questionnaire on the use of the prototype, to test the variables identified from the early research.

The leap from data to insight and then to developing product features, is not systematic and in many of the above studies, the arrival at an insight or innovative product may be due to the talent and intuition of the designer. There are many ways in which to inspire designers to generate new ideas. Not all of which rely on previous research. The literature suggests that idea exchange process in groups is more creative, where reflection and incubation is important (Paulus and Yang, 2000). A common misconception is that clear insights will reveal the correct concepts, however this is not proven and there are many ways in which an idea can manifest

(Norman and Verganti, 2012; Verganti, 2009). The Elito Method appears to be a superior method because it creates a coherent logic line for concepts to be generated directly from observations. However, the Elito Method is very regimented by nature and the matrix format does not allow for the cross-fertilisation of ideas or the linkages between insights. Concept Mapping would complement this method well where concepts may be visually displayed for the designer to make those linkages. Similarly, a method that is empathic in nature like Personas, would also be beneficial to connect the concepts to the people using them. These are the principle reasons for selecting these methods in this research.

2.6 Definition of Terms

The following section explores the themes discussed throughout the thesis. Several words are repeated, and the specific terminology is clarified in more detail informed by supporting literature.

Lead Users

Lead users illuminate needs that we may all feel, but not consciously know. The definition of lead users by von Hippel (1986), are *"users whose present strong needs will become general in a marketplace months or years in the future"* and importantly, regular users may not express these needs as explicitly as the lead users. In other words, the person with arthritis can identify problems with ergonomics that an able-bodied person cannot, but the adaptation in a handle design that meets the needs of an arthritic hand can be enjoyed by all. Within different sectors, the needs of lead users have contributed vastly to the development of innovations, specifically 77% of innovations in the scientific instruments field and 67% of innovations in semiconductors (von Hippel, 1986; Rogers, 1995, pp.141–144; Urban and von Hippel, 1989).

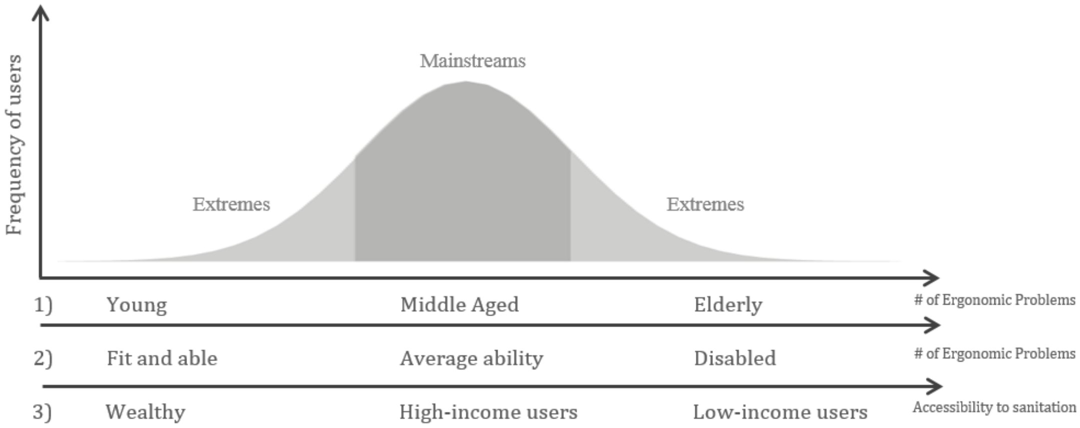


Figure 2-4 User insight research on mainstreams and extremes.
User insight research on extremes of audience segmentation from different distributions. The generalised distribution may differ for different segmentation strategies as demonstrated number of ergonomic problems (1 & 2) and accessibility to sanitation (3). Source: Adapted from (Ideo, 2014).

Innovations usually are adopted first by a selected few who appreciate the value of the new innovation more than the rest; these are called innovators and are identified by Lead User Analysis, then word spreads to the rest of the market (von Hippel, 1986; Rogers, 1995, p.85). A lead user may be identified by an audience segmentation strategy using the extreme percentiles of distribution of age, height, psychographic, wealth or their adoption time as a few examples, as depicted in Figure 2-4. Lead users may not be users of the intended product, but the needs of extreme users could help define the direction of design and development (Brem and Bilgram, 2015). Extreme users could be the elderly who struggle with ergonomic issues, athletes who push products to their extreme, even users in the developing world are considered lead users since the environment they live in is relatively extreme compared to those in the west (Judge, Hölttä-Otto and Winter, 2015). Hackers are considered innovators, since they are actively trying to satisfy their latent needs. The self-made solutions to unspoken problems of everyday users can provide further insight (Goffin, Lemke and Koners, 2010; von Hippel, 1986; Norman, 2008, 2010). The choice of lead user depends on the need of the research, where elderly may be useful if usability is the main focus of the research. The present research may not require such lead users since the focus of the research is on motivations for adoption and user experience.

The literature suggests that lead users can give great insight into ergonomic issues or shed light on unique patterns of use, but there is little knowledge on how lead users may be used to highlight intangible issues like motivations for purchasing a product or emotional attachment to products (Goffin, Lemke and Koners, 2010; von Hippel, 1986; van Kleef, van Trijp and Luning, 2005).

Aspirational Product User Experiences

Decisions for the consumption of products extend beyond the utility of the product. People purchase products that match their personality and act as projections of themselves, known as the extended self (Phillips, 2003). Belk, Wallendorf and Sherry (1988) claim *"our possessions are a major contributor to and reflect our identities".* Certain products and brands take on symbolic meaning projecting an ideal image of the user; reflecting the user's aspirations (Park, Macinnis and Priester, 2006). Some aspirational products [5] like Rolexes or Ferraris are conspicuously consumed to display status, success, and achievement (Vigneron and Johnson, 1999). Sreejesh, Abhigyan and Roy (2016) define prestigious brands - *referred to as aspiration in this thesis* - as products that have high value in the following areas:

- Perceived conspicuous value - *if viewed as a signal of status and wealth, that is expensive by normal standards*.
- Unique Value – *if not everybody owns the product.*
- Social value – *if role-playing is instrumental in the decision to buy*.

---

[5] *'Aspirational products'* in this context is not defined as *'aspirational products'* from consumer marketing, which defines aspirational products as a large segment of a brand's market audience that wishes to own a particular product, but may not be able to for economic or supply reasons.

- Hedonic Value - *if the product's intangible benefits have emotional appeal like aesthetic appeal.*
- Quality value – *if the product is technically superior or extreme care has taken place during the production process.*

These values build towards the symbolism and semiotics of consumer products, that project the image of the ideal future self. For instance, an athlete wears Nike or a good parent owns Parent Magazine (Hall, 2012). The common assumption is that meanings and aspiration are a subject for branding and marketing; the argument made by a number of authors is that meaning is equally the concern of early NPD (Castillo, Diehl and Brezet, 2012; Goffin, Lemke and Koners, 2010; Norman and Verganti, 2012). If the values and meaning discussed by Sreejesh, Abhigyan and Roy (2016) are better understood they could be translated to toilet user experiences.

There are three terms that are used somewhat interchangeably that refer to the same underlying premise; *value, meaning* and *aspiration*. Table 2-3 is a description of the definitions of the terms and how they are a fundamental concern of the discipline of design.

Table 2-3 Definitions of terms according to the Oxford English Dictionary.

Term	Definition
Value	The regard that something is held to deserve; the importance, worth, or usefulness of something.
Meaning	What is meant by a word, text, concept, or action.
Aspiration	A hope or ambition of achieving something.

Within the world of NPD, creating aspirational products by innovating the meaning of products has been mentioned by several authors and has influenced the theoretical underpinning of this thesis. Table 2-4 summarises their definitions of the concept to clarify this somewhat abstract concept.

Table 2-4 The exploration of the meaning of products according to different authors.

Author	Concept	Description
Verganti (2009).	*Innovating Value*	Revolutionary innovation is achieved by changing meaning and technology.
Chan and Mauborgne (2015).	*Value Innovation*	Innovation – *and crucially differentiation* - is achieved by offering new value not just new technology.
Csikszentmihalyi and Rochberg-Halton (1981).	*Meaning of Things*	We attribute meaning to objects in our lives and their value extends beyond their utility.
Harni (2010)	*Object Categories*	Products are compartmentalised in categories in our minds and innovation can be achieved by challenging these categories.
Norman (2004).	*Product Personality*	Our attitudes towards products are influenced by their aesthetic beyond our definition of beauty. The design of products evokes feelings that change our attitudes towards them.

Value can be defined by how well a product meets a user's needs and wants; how useful something is and how desirable it is to have. Norman (2004) describes pleasure from products to have a spectrum to range from physio-pleasure through socio-pleasure, psycho-pleasure to ideo-pleasure and one may receive value at each stage along this spectrum, not dissimilar to Maslow's hierarchy of needs shown in Figure 2-5 (Yalch and Brand, 1996). Therefore, defining value purely by how well a product's function satisfies user needs, is a rational view that does not include the emotional (Norman, 2004). As discussed, our possessions can help define who we are, or who we want to be (Csikszentmihalyi and Rochberg-Halton, 1981).

Figure 2-5 Maslow's Hierarchy of Needs.

Maslow's Hierarchy of Needs. Source: Adapted from (Yalch and Brand, 1996).

Meaning can be understood as *"the products you buy and your lifestyle both reflect and establish your self-image, as well as the images others have of you"* there exists *v*isceral, behavioural and reflective levels of design that evoke different responses from us through *"signs"* evoking memories or by association (Csikszentmihalyi and Rochberg-Halton, 1981; Norman, 2004). The acquisition of products can be an expression of *qualities of the self*, *signs of status, symbols of social integration* or *reminders for self-improvement* (Csikszentmihalyi and Rochberg-Halton, 1981). The core of generating blue oceans –*innovations with uncontested market space* – is that changing meaning is the nucleus to differentiation. Users then gain more value from these products that have increased value and disassociate the new offering from existing products (Chan and Mauborgne, 2015).

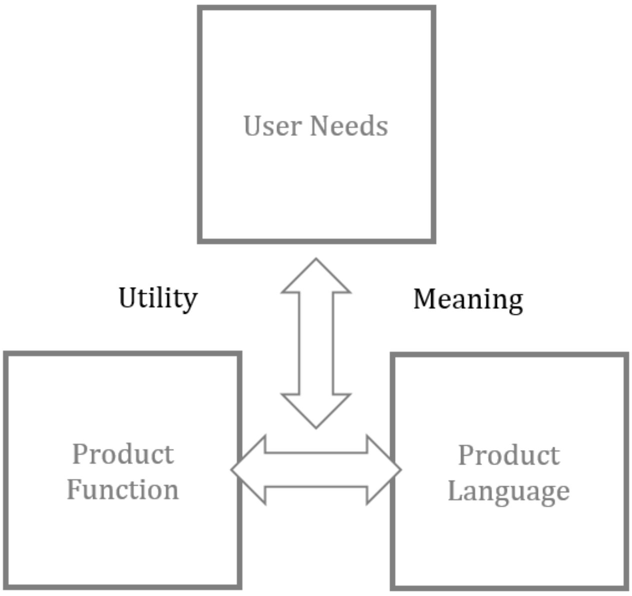


Figure 2-6 Dimensions of innovation.

Dimensions of innovation including function and meaning. Source: Adapted from (Verganti, 2003).

Aspiration is informed by the quote from the renowned Harvard Business School Professor Theodore Levitt (1974):

> *"Why do people buy products? ... Last year one million quarter-inch drill bits were sold—not because people wanted quarter-inch drills, but because they wanted quarter-inch holes. People don't buy products, they buy the expectation of benefits."*
>
> (Levitt, 1974)

The expectation of benefits, as Levitt (1974) puts it, is extended beyond the functional utility. Verganti (2009) extends Levitt's quote by incorporating the functional and the emotional saying: *"people do not buy products, they buy meaning".* The *signs* that products have, directly communicate their *meaning* (Verganti, 2003, 2009, 2014a). Verganti (2009) describes product features as semiotics or a product's *"message"* or "*language*" that conveys the *value* to the user and how the product may meet the underlying need, shown in Figure 2-6. The product's features can mean something wider than themselves and invoke meaning in a non-literal way

– *crucifixes for religion, rings for relationship or red lights to stop* – the objects we are most fond of are the objects we attach stories to rather than the things themselves (Hall, 2012). Further extending this point, the French writer Stendhal (1822) famously wrote, *"Beauty is nothing but the promise of happiness"* meaning when something is considered beautiful, you are reminded of the virtues that you associate with contentment (De Botton, 2007; Csikszentmihalyi and Rochberg-Halton, 1981). Following this, *aspiration* with reference to products users find beautiful, is considered a surface word for a vision of happiness that exists deeper in the subconscious.

Table 2-5 Definitions of terms with respect to products, according to the authors.

Term	Definition	Author
Value	The benefit and pleasure the user receives from how a product satisfies their physiological needs, social needs, psychological needs or self-fulfilment/esteem needs.	(Norman, 2004) (Verganti, 2009) (Chan and Mauborgne, 2015)
Meaning	An expression of qualities of the self, signs of status, symbols of social integration and reminders for self-improvement omitted by a product.	(Csikszentmihalyi and Rochberg-Halton, 1981) (Verganti, 2009) (Harni, 2010)
Aspiration	The desirability of a product or it's attributes and features that express virtues one associates with contentment.	(Park, Macinnis and Priester, 2006) (Belk, 1988) (Vigneron and Johnson, 1999)

The definitions of the terms are then revisited in Table 2-5 so the thesis terminology is coherent and consistent with the definitions. The thesis uses these definitions with respect to *aspiration* hereafter to answer the aim of the research.

2.7 Summary

The emergent findings from the literature show there are several methods one may use in eliciting latent needs from traditional methods such as survey and questionnaires to repertory grid technique and ethnographic research. Some studies may require one method over another for time constraints or practical constraints like the ability to observe. Translating the insights found is said to rely heavily on the intuition of the design, where incubation is considered a necessary part of ideation to allow sub-conscious processing to inform the interpretation of the insights (Hernandez, Shah and Smith, 2010). However there are analytic and empathic methods to help the designer understand the problem and come to creative solutions.

- Review of methods used in previous research.

Given the sensitive nature of toilet user experiences, a combination of methods that do not involve the observation of users on the toilet have been selected. Ethnographic research can be effective in eliciting latent needs and it is complimented with a non-observation technique of participatory photography – *over the internet*. The selection of these methods are discussed in more detail in Chapter 3 and 4.

- Selection of appropriate methods to use in this research.

A broad review of the definitions of the role of aspiration, value and meaning in with respect to NPD and there are several authors that have influenced the underlying theory in this thesis. Their definitions of the terms according to the authors are used as the premise to aspirational user experiences in the development of the prototype for user testing.

- Definition of terms lead user and aspiration.

Key Findings:

- Users do not consciously know why they do what they do.
- Direct questions elicit explicit knowledge and observations can elicit tacit or latent needs.

- The translation of insights traditionally relies heavily on the intuition of the designer.

“If I would have asked my customers what they would have wanted, they would have said a faster horse”

Henry Ford

3 ELICITING LATENT NEEDS

Objective 1: Elicit latent needs regarding motivations for acquisition and user experience.

In this chapter, the elicitation of latent needs for the acquisition of toilets and toilet user experience is explored. The chapter begins with the need for the research followed by the methods used. Then the results of the ethnographic research are detailed for the insights relating to acquisition of toilets and the results of participatory photography are detailed for insights relating to the toilet user experience. The chapter culminates with an analysis of the collective findings and a Summary including next steps in the research.

3.1 Need for the Research

Referring to the research question and the first objective, we require knowledge of the motivations for purchasing a toilet, to understand what currently makes a toilet aspirational and tacit pain points involved in using them, to understand the user experience. The universal needs that many people share will help inform the value proposition of the new concept that will then be explored in the following chapter.

Expected Learnings

By the end of this chapter, the lead users appropriate for eliciting latent needs for an aspirational toilet will be identified as well as the lead users appropriate for eliciting needs for user experience. The expectations from this chapter are to gain insight from both of the two lead user groups to inform the design of the new aspirational toilet in a concise form. Upon completion of this chapter, success would be:

- Respondents chosen
- In-depth insights collected and analysed

3.2 Research Approach

For insights related to acquisition the choice of the lead users for adoption will be to look at developing world users. In the same way lead users with arthritic hands can inform the design of ergonomically fitted handles, lead users from low-income environments may teach us about the motivations for acquisition of toilets (von Hippel, 1986; Ideo, 2014; Judge, Hölttä-Otto and Winter, 2015).

The study respondents chosen, come from the country with a majority of search engine searches from https://trends.google.co.uk related to faeces and urine shown in Figure 3-1. The majority are from West Africa where there are significantly higher searches in Nigeria and Ghana. There are also high numbers in South Africa, Singapore and the Philippines, however people in Nigeria and Ghana use a wider range of toilet user experiences from open defecation to a flushing toilet (UNICEF and WHO, 2008). Ethnography has been chosen for acquisition as the method shown in Table 3-1.

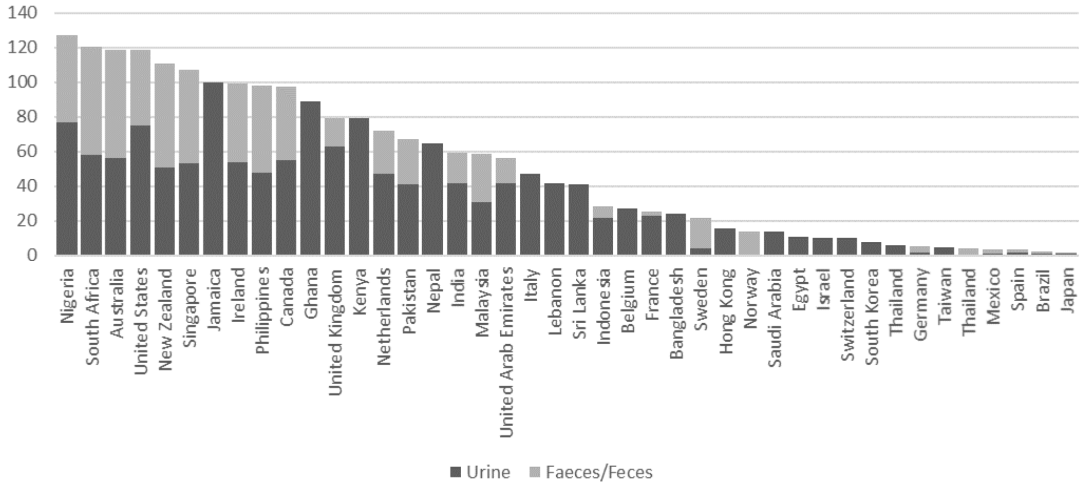


Figure 3-1 Google searches for *faeces* and *urine*.

Graph to show normalised Google searches as a proportion of other Google searches, for faeces and urine for different countries. Source: Adapted from https://trends.google.co.uk (accessed 16/05/2017).

For user experience, direct observation of toilet user experience is not possible because of dignity, for this reason, the techniques for insight gathering are limited.

Norman and Verganti (2012) believe more innovation comes from observing the *'workarounds'* and individual creativity that people use to solve their unmet problems. A user made *'hack'* speaks of the underlying needs that users may have, but may not express (Fulton Suri, 2005). Participatory photography combined with Netnograpy has been chosen for acquisition as the method shown in Table 3-1.

Table 3-1 Methodologies and reasons for rejection.

Research Option	Method	Principle Reasons for Rejection
Option 1:	*Questionnaire*	Researcher bias, priming, answering on future products.
Option 2:	*Focus Group*	Socially acceptable answers.
Option 3:	*Ethnographic Research*	Subjective analysis.
Option 4:	*Repertory Grid*	Confusing protocol for respondents.
Option 5:	*Netnography*	New and lacking in rigour.
Option 6:	*Participatory Photography*	Reliability of respondent participation and understanding of method.
Selected Option[6]	**Method**	**Principle Reasons for Selection**
Option 2:	*Ethnographic Research*	Held in context of use.
Option 5:	*Nethnography*	The limits of observations or participatory photography with respect to dignity.
Option 6:	*Participatory Photography*	Hacks indicate latent needs.

The hacks indicate unspoken problems people may have during the use of toilets (Hahn, Marconnet and Reid, 2016). A quick and simple way to find user hacks is to search for the hacks that people have shared on the internet. The ideal method

---

[6] The repertory grid technique was also chosen for triangulation, however it was rejected after seven participants because of difficulties in translation. This is explained further in Appendix A.

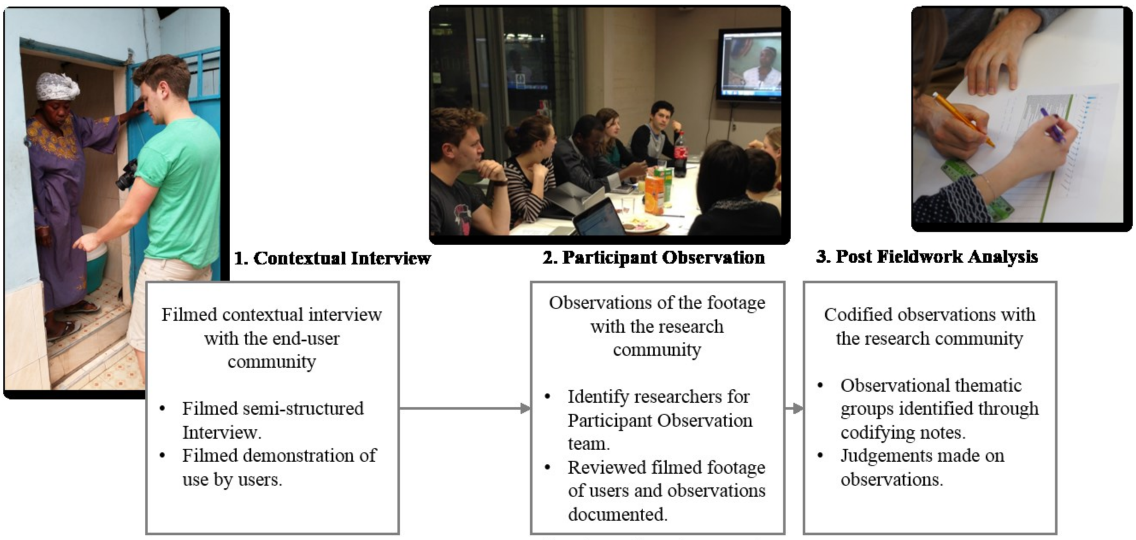
would be a combination of participatory photography and Netnography to indicate people's frustrations through the hacks or adaptions they make to their toilets.

3.3 Ethnographic Research

Ethnographic research on low-income individuals is the chosen method with a focus on those that have pursued purchasing a household toilet – *who may find toilet user experiences aspirational* - and those that have not. Out of the countries of interest, Ghana has been chosen as the most interesting since a new Container-Based Sanitation (CBS) toilet have been launched that aims to reach the poorest and most needy for a small weekly fee for three, four or five collections a week depending on household size (Huberts et al., 2016; Ideo, 2014).

Method

The ethnographic research method used follows a three step process shown in Figure 3-2; the *Contextual Interview* and *Participant Observation* is a common element in past projects and a third step of post fieldwork Analysis has been added to this project since a number of studies have lacked detail in the post fieldwork analysis (Bosch-Sijtsema and Bosch, 2014; Goffin et al., 2012; Rosenthal and Capper, 2006; Skaggs, 2010).



Respondent and end-user refers to the interviewees in Ghana.

Translator A refers to the translator supporting the researchers conducting the interviews.

Demonstration of use is denoted by the phrase as Participant Observation for the purpose of this research.

Translator B refers to the translator that supports in the participant observations, who is not part of the Contextual Interview.

The observation of interest identified in the filmed footage is informed by previous hidden needs projects.

Judgements are considered reliable since individual bias is minimised by agreeing with a large research community.

Figure 3-2 The process of the ethnographic research.

The process and resources needed for each stage of the ethnographic research.

The study involves participants from Ghana's second largest city, Kumasi. The urban areas of Ghana account for 26.4% of the total population. Across Ghana's urban areas 38.7% of people use public toilets, compared to the 54.0% of households who have sanitation available within the home such as W.C., pit latrine or KVIP whereas 7.4% have no access to any sanitation facilities (Ye et al., 2014). This research focuses on those that have a new CBS system in their house and those that do not have access to any sanitation or use public facilities.

The researchers conducting the contextual interview and demonstration of use were two PhD researchers with a translator equipped with video recording. The video of the participant observation was systematically coded later by ten trained researchers with an additional translator to minimise personal bias following the COnsolidated criteria for Reporting Qualitative Research (COREQ) guidelines (Tong, Sainsbury and Craig, 2007). The contextual interview was conducted on 49 owners of the CBS followed by a demonstration of use while a contextual interview and walkthrough of the domicile was conducted with 28 people who did not have household sanitation. The interviewees were selected at random by selecting a different region across the city for each day and arranging up to ten interviews from the chosen area from a list of participants. Translator A was present for each interview since many of the respondents had no English proficiency and Translator B was available for the *Participant Observation* during the analysis of the footage back in the UK. The post fieldwork analysis included 1,441 observations from the *Contextual Interview* and *Participant Observation*. Presented here are the contradictions, workarounds and intangible observations.

Table 3-2 IBM-WASH framework (Dreibelbis et al., 2013).

	Contextual Factors	*Psychosocial Factors*	*Technology Factors*
Societal	Policy, climate & geography	Advocacy & cultural identity	Manufacturing & distribution of product
Community	Access to markets and resources	Shared values & stigma	Location, access & maintenance
Interpersonal	Roles, responsibilities & space	Injunctive norms, aspirations & shame	Sharing access
Individual	Wealth, age & employment	Disgust & perceived threat	Perceived cost, value & convenience
Habitual	Favourable environment	Outcomes & expectations	Ease of routine and use of product

Contextual Interview

Respondents are encouraged to talk freely about topics that are important to them, however a degree of prompting is required by the translator in Ghana. The interviewers adhered to COREQ guidelines to minimise researcher influence on the respondents and ensure their behaviour and responses were authentic and candid. The semi-structured interview was based on the 15 factors identified as influential in the Integrated Behavioural Model for WAter, Sanitation and Hygiene (IBM-WASH) developed in the systematic review by Dreibelbis et al. (2013), shown in

Table 3-2. The IBM-WASH framework was used as a prompt for the interviewers to ensure questions where comprehensive whilst keeping the interview versatile and allowing respondents to freely expand and go as in-depth as they felt on topics that were important to them. After the semi-structured interview, a demonstration of use and of cleaning was then done ensuring the entire environment was captured with locations of paraphernalia. The purpose was to identify when and how participants were acting in a contradictory way to how they claimed they acted. Whether consciously acting differently to how they state or unconsciously behaving differently to how they perceive, the contradictions indicate latent needs or held beliefs like the example given in Figure 3-3 (Goffin, Lemke and Koners, 2010). The research received ethical approval from Cranfield University's Research Ethics System (CURES) to ask questions about and record people's sanitary behaviour and a mock demonstration of use shown in Appendix H.

Figure 3-3: Example contextual interview.

Example of a contextual interview with Interviewer A; respondent not shown for anonymity. Source: J Larsson.

Participant Observation

Upon return to the UK, a trained *Observation Team* of 11 - *ten researchers including the two interviewers and Translator B* - were assembled. The Observation Team were split into pairs and were tasked with identifying observation categories that had been used in previous latent needs analyses, focusing on contradictions, workarounds and intangible observations indicating latent needs (Norman and Verganti, 2012).

Table 3-3 Demographics of respondents for owners of container-based sanitation and non-owners of container-based sanitation.

	Owners of CBS (%)	**Non-owners of CBS (%)**	**Total (%)**
Respondent Male	17 (25)	7 (10)	24 (35)
Respondent Female	30 (44)	14 (21)	44 (65)
Total	**47 (69)**	**21 (31)**	**68 (100)**
DMU Male	14 (21)	3	Inconclusive
DMU Female	29 (43)	2	Inconclusive
DMU Collective	4 (6)	1	Inconclusive
DMU Landlord	0 (0)	5	Inconclusive
Total	**47 (69)**	**11**	**Inconclusive**

*Decision Making Unit (DMU)

Contradictions are defined as disjunctures of when actions do not fit with respondent explanations and over-generalisations or glossing over actions or claims of idiosyncrasy - like *"no-one else would do it this way…"* (Goffin, Lemke and Koners, 2010). The importance of the Contextual Interview is therefore to compare it to the *Participant Observations* to identify these contradictions and identify answers that may be for social desirability – *how people think they act or should act compared to how they truly act*. Workarounds are defined as the hacks or intuitive ways we adapt or exploit a product or the environment to meet respondent needs (Brown, 2008; Fulton Suri, 2005). Intangible observations are defined as fears, frustrations, displays of humour, non-verbal cues, linguistic cues or animated displays of emotion

(Goffin, Lemke and Koners, 2010). Each of these observations were recorded with the time on the video with a detailed description of what is observed and what the respondent said.

77 interviews were conducted, nine were considered inappropriate due to video quality or because an interview was disrupted before all 15 factors of the IBM-WASH framework were covered resulting in 47 CBS customers and 21 non-customers included in the final analysis. Table 3-3 shows the demographic variety of the respondents.

Post Fieldwork Analysis

Upon completion of observing the footage and compiling the notes on the observations, the Observation team clustered reoccurring observations into themes after codifying the notes made on the observations. Table 3-4 shows how judgements on the themes and problems observed were arrived at and established why this observation had occurred and the underlying problem is assumed from this judgement - *e.g. why has the respondent done this? We agree it may be because it makes them feel that.*

Table 3-4 Description of method to identify the underlying problem associated with the observed themes

Theme	Judgement	Underlying Problem
T1 **T2** **...** **Tn**	Why the researchers think the observation has occurred.	What the underlying problem the respondent is facing.

Results

In this section, the focus is on the idiosyncratic behaviours, analysing the contradictions and workarounds. There is an analysis of the contradictions and workarounds in the qualitative survey to establish unspoken problems. 36 unique codes were identified in the notes made on the 1,441 observations from the 67 respondents and are detailed in the Chapter 4. The code for *Use* was the most frequently occurring code with 358 counts followed by 343 for *Cleaning*, 333 for *Others in the House*, 207 for the *Location* of the toilet, 164 for the *Space* available and 160 for the *Acquisition* of the CBS toilet. *'Theoretical saturation'* is the point at which enough data has been collected to learn something new. Constant comparison throughout coding assumes theoretical saturation and is demonstrated by Pareto Analysis. 80% of the total codes identified are contributed by 20% of the top occurring codes, which suggests if more respondents were interviewed no new themes in the notes would be codified displayed in Figure 3-4. Cumulatively 1,691 (57%) out of the 2,952 codes collected were observed in first seven (19%) of the 36 codes.

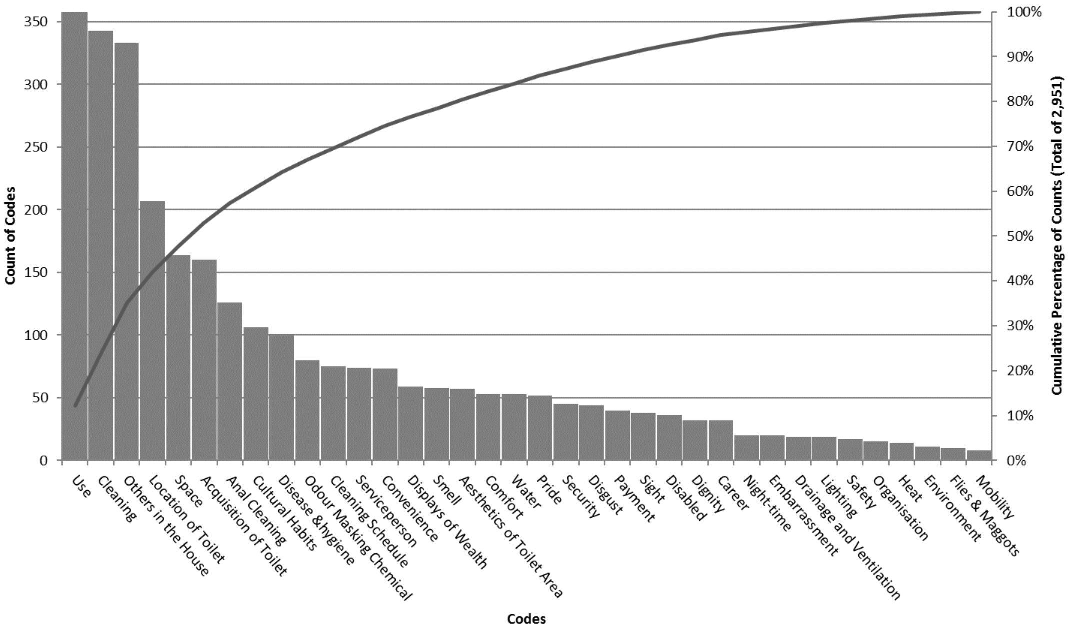


Figure 3-4 Theoretical saturation of codes.

Graph to show Pareto analysis that confirms theoretical saturation of codes.

Contradictions

The Observation Team made a note of a contradiction if the respondent was observed doing a behaviour that appeared to contradict what they claimed they did in the contextual interview from the collective perspective of the Observation Team. Several respondents commented that *"the toilet is perfect"* however several workarounds were spotted implying the respondent is trying to meet a need of theirs that perhaps is not conscious to them. Summaries of the variety of contradictions are shown in Table 3-5.

There were many contradictions referring to cleaning of the CBS, two of which are shown in Figure 3-5. For example, respondents claiming they clean their toilet often, but would be seen struggling to open the detergent bottle indicating they do not clean their toilet very often. Some respondents would say they clean it every day, however their CBS appeared to not have been cleaned in days or even weeks, while some respondents did not even know where the cleaning paraphernalia was kept. When asked to demonstrate cleaning, one respondent shown in Figure 3-5b, began by saying *"I simply..."* describing dismantling the toilet, shortly after saying this, the CBS fell apart on him. The surprise of it falling apart on him indicates this is perhaps not as regular or simple an act.

One respondent complained about flies in chamber pots that were used for the young children, however flies were also present in the CBS toilet when he lifted the lid. Flies are not uncommon in and around Kumasi and he did not state that he was bothered by the flies that came out of the CBS toilet, therefore the team considered this a contradiction.

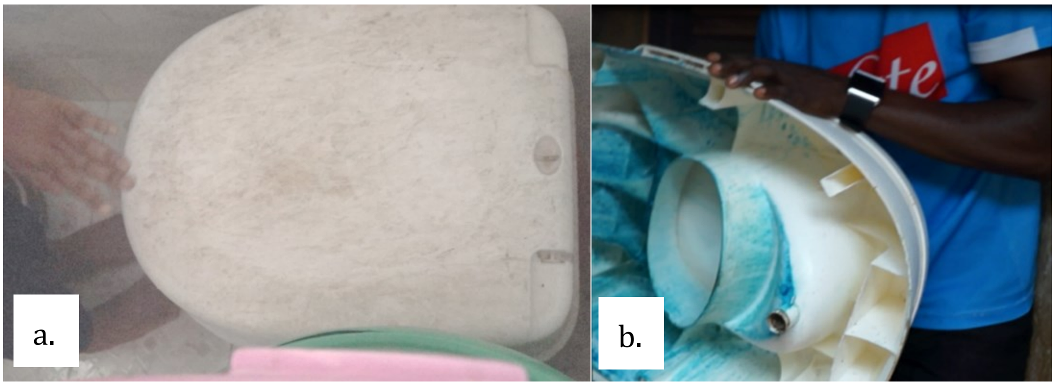


Figure 3-5 Contradictions of cleaning.

(a) Photograph of dusty toilet-lid. (b) Photograph of dismantled toilet. Source: J Larsson.

One respondent claimed he signed up to the service because the *"public toilet is messy"*, however his CBS appeared to be very messy, according to the Observation Team and again his interpretation of *messy* is could be different to the researchers. A typical contradiction was the fear of disease that public toilets presented, however several respondents did not know how public toilets transfer disease or how severe the disease would be once contracted. This contradiction does not imply their fear is invalid or exaggerated, instead it points to the source of their fear.

One respondent said the CBS is affordable, but when asked later in the interview he claimed he would like it to be cheaper. Several households did however make the young males continue to use the public toilet, payment required or open defecate, since the collection rate is dependent on the filling rate of the toilet, it is related to how many people use it. Subsequently, the fit and able who can travel down the dusty road and pay for the public toilets are sent out while the ones who stay at home - *like the elderly, sick or vulnerable* - take priority in using the toilet. One young male claimed he preferred open defecation and would *"always try to find a virgin space"*, however later in the interview he said he would not use a torch when going out at night, which contradicts how he may find a *"virgin space"*.

Figure 3-6 Contradictions of location.

(a) Available space in the veranda at front of house. (b) Curtain for privacy. (c) and (d) Outhouses with locks on. Source: J Larsson.

A respondent who frequented the public toilets said she does not have space despite having a veranda, which the Observation Team collectively agreed was filled with junk, such as a chair shown in Figure 3-6a, which from the researchers' perspective, could house a CBS. When asked about this option, the respondent simply said that was not where toilets would go.

Another respondent claimed she did not mind people being in the room with her while she used the CBS in her Mori, but she has a curtain covering the opening for dignity shown in Figure 3-6b. Again, the researchers do not dispute the validity of her claim that indeed she may not mind having people in the room as she uses the CBS, but the contradiction indicates her conceptualisation of privacy and dignity is different to the researchers' interpretation of privacy and dignity.

One mother claimed the toilet is beneficial for when someone is ill, particularly to save night-time trips to the public toilet. She said the CBS is good because it can be near the children when they are ill, however the respondent later claimed it is always kept in the outhouse and was not moved during the *Participant Observation*. Another respondent claimed the toilet *"Never moves"* just to observe later in the video that she moves it backwards and forwards to clean it.

Several respondents said anyone can use their CBS, but also said later in the interview that the outhouse was kept locked. Conversely, some other respondents claimed it was always locked, but during the demonstration of use the padlock on the door appeared to be unlocked like in Figure 3-6c and Figure 3-6d.

Table 3-5 shows the collection of the variety of contradictions observed in the footage. Each contradiction noted by the Observation Team illuminates the respondent's conceptualisation of particular constructs or indeed highlights problems that are unmet to the user that may not be consciously voiced according to Construct Theory as stated by Kelly (1955). The researchers have made judgements that point to an underlying problem that has given rise to the observation in Table 3-6.

Table 3-5 Contradictions with the contextual interview.

	Statement from Respondent	Contradiction
C1	Toilet cleaned once a day or every three days.	Toilet covered in more than a day or three days' worth of dust or dirt or the respondent has difficulties when cleaning it – *like it is their first time*.
C2	Disgusted by mess in public toilet and flies that are there.	Their toilet is equally as messy, or flies are present.
C3	Concerned contracting disease from toilets.	No or little knowledge of disease transfer of severity.
C4	Claim the CBS is affordable.	Respondent then says CBS could be cheaper.
C5	Toilets are for everybody.	Young male relieves himself outside.
C6	There is no space for a toilet.	There space for a toilet in the living room or front porch.
C7	Does not mind people in the room while using the CBS.	Has a curtain to the door of the Mori.
C8	Mobility is a desirable feature of the CBS.	The CBS is never moved.
C9	Anyone can use the toilet or only selective people can use the toilet.	Padlocks on outhouse or no padlocks respectively.

Table 3-6 Judgements made on the contradictions with the contextual interview.

	Judgement	Underlying Problem
C1	Respondent wants to believe they are more hygienic than the norm.	Serviceperson prompts cleaning the toilet because of ease and shame.
C2	Being clean is being neat and dust is accepted and it is not the flies that are the problem, the number of them implies how unclean it is.	Feedback needed of how clean and hygienic the toilet is.
C3	There is fear in the unknown of disease.	The intangibility of disease.
C4	Do not want to have to worry about using it more for whatever reason.	Payment linked to amount of use.
C5	Because the fit and young are made to go outside there is shame if one does use the 'sick and elderly toilet'.	Removing stigma of toilet for sick and elderly.
C6	No space refers to no 'toilet space' e.g. outhouse or Mori.	Toilets do not belong in living areas.
C7	Does not want people to see her on the toilet.	Toilet needs to be used without people seeing you.
C8	Mobility refers to moving the toilet for cleaning purposes.	Toilet fixed in place, but easy to clean.
C9	Anyone in the family unit is free to use the toilet, but locked to keep outsides away from outhouse.	Toilet for the family unit.

Figure 3-7 Workarounds of use.

(a) Step at the front of the CBS. (b) Chamber pots for the young. Source: J Larsson.

Figure 3-8 Workaround getting off toilet.

Elderly lady using the wall to stabilise her while getting off toilet. Source: J Larsson.

Figure 3-9 Workarounds of location.

(a) Wood under toilet to stop floor getting dirty. (b) Light used to help see while using toilet. Source: J Larsson.

Workarounds

Many CBSs are bought for the convenience of the disabled, elderly, sick and pregnant. The adolescences in the families of the respondents did not want to use the household toilet systems because of the image it portrayed or the embarrassment of using it around the family. Although many of the respondents purchased the CBS toilet for convenience, workarounds were observed to increase the comfort in use or ease of getting on and off the toilet, implying that there could be improvements made in comfort and ergonomics.

Several CBSs had a brick or piece of wood placed at the front to raise the feet in the act of defecation like Figure 3-7a. Some respondents, namely the young children, are too short to use the CBS and used chamber pots to defecate in, then the mother or father would empty the pot into the CBS seen in Figure 3-7b. One respondent said the serviceperson would leave extra chemical for him to put into the chamber pot before the child used it.

One elderly respondent said she needed the CBS because it was more comfortable than the existing squatting toilet that existed in the compound and it was easier on the knees. Figure 3-8 shows the elderly lady using the wall in front of her as support to help her get off the toilet.

One family put a piece of wood on the floor to stop the floor getting dirty, however the urine tank at the base of the toilet was placed upside down shown in Figure 3-9a. The neck to urine tank is at floor level and thus will not fill up the full volume of the bottle and if it overflows, urine will spill on the floor.

A few respondents used a lamp when using or cleaning the CBS like Figure 3-9b. The respondent balances the lamp up high on the wall of the Mori, using the height of the wall to give her the best spread of light while in the Mori. This is a co-opting workaround to allow her to have both hands free to do what she needs to when using or cleaning the CBS.

Figure 3-10 Workarounds of cleaning and organisation.

(a) Floor soaked with detergent (b) Drying CBS outside (c) Chalkboard in communal area to keep track of how much each family owes for bills. Source: J Larsson.

Figure 3-11 Workarounds of paper disposal.

(a) Paper kept on the back of the door for anal cleansing (b) Used paper kept in a bin by the toilet (c) Disposed toilet paper by burning out the front of the household. Source: J Larsson.

Figure 3-12 Workarounds of ancillary actions.

(a) Plastic sheet to keep toilet dry while it is raining (b) Bucket used to flush public toilet. Source: J Larsson.

In the act of cleaning one respondent said she uses a detergent to wash the floor and leaves it for a prolonged period to let it soak in and then rinsed it away after some time seen in Figure 3-10a. Several respondents washed the CBS outside over the gutter to allow the wastewater to flow away easily like Figure 3-10b. The respondents usually left the CBS out to dry in the sun. This can be seen by the yellow taint the toilet lid now has from sun stains.

Anal cleansing is often done by wiping with paper or by washing with water and soap, the CBS toilet cannot accept paper waste. Many wipers kept their paper behind the door as an exploiting workaround to save carrying paper with them each time they visited the CBS like in Figure 3-11a. Respondents often needed a bin by the toilet to hold this dirty paper seen in Figure 3-11b. A few respondents declared they burn the toilet paper outside their houses on the street to get rid of it and avoid paying disposal charges at the rubbish dump and run the risk of getting fined for having faeces in their rubbish seen in Figure 3-11c.

Table 3-7 The themes from the observed Workarounds of use.

Theme	Workaround
W1	Step at front of toilet.
W2	Chamber pot.
W3	Leaning on wall getting off toilet.
W4	Wood Under toilet.
W5	Lamp for use and cleaning.
W6	Leave cleaning detergent on floor.
W7	Chalkboard of bills.
W8	Paper on shelf.
W9	Paper bin.
W10	Burning paper.
W11	Plastic cover.
W12	Tipping bucket of water down toilet.

The CBS toilet of one respondent is kept exposed on the roof of the household seen in Figure 3-12a. He uses a plastic sheet to cover the toilet during the rainy season. In the public toilets, the attendants often resort to using buckets of water to flush when it is messy since the cistern does not fill like in Figure 3-12b. They have containers of water at the front of the public toilet ready for this reason and other cleaning duties. The commune in Figure 3-10c, uses a chalk board to communicate who has and has not paid for CBS toilet usage. Table 3-7 shows the collective variety of the workarounds observed from the footage. The Observation Team have made judgements that point to an underlying problem that has given rise to the observation in Table 3-8.

Table 3-8 Judgements made on the workarounds of use

Theme	Judgement	Underlying Problem
W1	To raise the legs.	Sitting is not comfortable for defecation.
W2	For children to use.	Children too short to use toilet.
W3	To give support.	Getting up is hard on the knees.
W4	Stop floor getting dirty.	Toilet not containing the waste properly.
W5	Using lamp to see.	Isolated rooms for the toilet (Outhouse or Mori) are not ventilated and thus have no light.
W6	Leaving detergent to let it soak.	Harsh stains and comfort in knowing it is hygienic by exposure over time.
W7	Chalk board to track who owes what.	Shared community, difficult to know who owes what and who.
W8	Always have accessible paper when visiting toilet.	Need paper when visiting toilet, not practical to bring with you.
W9	CBS cannot take paper.	People need to clean themselves after defecating and do not have adequate means of disposing of paper.
W10	Dispose of waste paper.	Cannot throw paper away with receiving charge or fine.
W11	Tarpaulin to keep toilet dry when it rains to stop it overflowing.	The toilet is kept outside. Presumably for smell or hygiene reasons.
W12	Using bucket of water to flush away waste.	Cistern or plumbing does not work.

Intangibles

There were many displays of humour or laughter for many of the questions asked born out of embarrassment. For instance, many respondents laughed when asked whether they liked the toilet:

Aesthetics

> *"[Laughter] I do not care about colour scheme compared to the room"*
>
> Respondent 01
>
> *"[Laughter] The toilet is nice. The toilet is beautiful"*
>
> Respondent 02
>
> *"[Laughter] I campaign for others to buy the toilet"*
>
> Respondent 34
>
> *"[Laughter] it makes me more special"*
>
> Respondent 77

Respondents articulated the benefit of owning a toilet and in some cases, were somewhat emotive and displayed non-verbal responses of how proud they were about owning a toilet. For example, Respondent 02 was visibly animated and very eager to show off their toilet:

Ownership

> *"[Animated] You can't eat without a toilet"*
>
> Respondent 5
>
> *"[Animated] I am proud that I have a [CBS] toilet, so proud, I wish I could send one to my hometown"*
>
> Respondent 12
>
> *"[Animated] Only my family use the [CBS] toilet"*
>
> Respondent 33

The reasons respondents gave for owning a toilet often was for the convenience of not having to walk to the public toilet:

Convenience

Laughs when asked how long it takes to get to the public toilet

Respondent 25

"[Laughter] If it's [CBS] closer to you its more convenient"

Respondent 43

"[Animated] Jogging from this place to that place to answer nature's call"

Respondent 48

"[Animated] Because I am aging I do not like to walk to the public toilet"

Respondent 51

The emphasis on convenience of having a toilet at home was not just because of the disabled or the elderly however, there was also a fear of thieves at night-time and general safety for the family members with concern for the safety of the women of the household:

Safety

"I am fearful of thieves at night"

Respondent 14

"I am fearful of crossing the busy road to access public toilet"

Respondent 17

"There are thieves when using the public toilet … I am concerned about the safety of my kids and my husband from thieves"

Respondent 18

"I am scared that someone could attack me [Going to the public toilet at night]"

Respondent 22

"It is risky for my children to use public toilet… The hole is too big for their feet"

Respondent 49

"I find it scary to go to public toilet at night"

Respondent 54

Another issue that the females of the household expressed was a toilet for privacy and dignity. Respondent 43 was asked *"do you mind going to the [CBS] toilet with your husband in the room?" and she responded with "No [Laughter]"*:

Dignity

"[Laughter] The kids don't use the toilet [CBS] because they are shy"

Respondent 04

"If I am using it [CBS] and someone else is in the room, some people won't know what I am doing [followed by laughter]"

Respondent 45

"People would be embarrassed to use a toilet there because it's too exposed"

Respondent 63

[How long has it been since you removed the toilet paper?] "Two days, but there is lots of paper [Laughter]"

Respondent 68

Another reason for owning a toilet was through the fear of disease, where a fear of others' waste drove them to purchase their own CBS toilet:

Disease

"[Laughter] Big boys don't use [CBS] toilets… [Open defecation] Is good because you need a virgin space"

Respondent 03

"[Animated] Disease transfers from other people using the public toilet"

Respondent 07

"[Laughter] I am the only one who uses it"

Respondent 31

"I do not let other people use the toilet because I feel that I need it"

Respondent 40

"You don't get infections with the [CBS] toilet like you get from public toilets"

Respondent 45

"I am afraid of getting an infection from the seat"

Respondent 47

"You don't get diseases from [CBS] toilet, only the public toilet … [Animated] You get disease from using a toilet right after someone else uses it"

Respondent 50

"Fear of getting diseases from public toilet"

Respondent 54

"[Laughter] You can catch diseases from others"

Respondent 63

"I do not want to touch the wood that is used as a lid"

Respondent 68

"You get diseases from other people, but [CBS] toilet uses chemicals"

Respondent 71

"[Animated] It's only me who uses the [CBS] toilet so I can't get an STI from the [CBS] toilet"

Respondent 74

Respondents also associated and were fearful of the heat from faeces with disease:

Heat

"[Animated] If you don't cover your nose you might get sick [because of the chemicals] ... [Laughing] We're all going to die"

Respondent 17

"You get diseases from the heat"

Respondent 45

"You can get disease from the heat"

Respondent 54

"I am fearful of disease because of the heat"

Respondent 56

"Heat causes disease"

Respondent 59

"[Animated] You are able to fear heat not see it"

Respondent 62

"I am worried about the heat coming out of the hole of the [non-flushing] public toilet. It may transfer diseases. That's why we only go there at night"

Respondent 63

It is suspected that the problem is not necessarily the heat, but instead the miasma from the faeces including the smell and the shimmer.

Miasma

“I am scared of the chemical splashing on me… I had a bad past-experience and I still have the image in my head"

Respondent 03

“[Animated] I am worried that splash from chemical may have an effect on my anus”

Respondent 31

“My husband was worried the smell of the chemical would be all over the room"

Respondent 43

“I don’t like sitting on the cold [with respect to the wooden seat]”

Respondent 73

Nearly all respondents knew the necessity of cleaning the toilet and upkeeping a good standard of hygiene:

Cleaning

“The [CBS] toilet must be clean to keep out animals”

Respondent 01

“[Disgust] People spit everywhere in public toilet [They do this because they do not want to swallow due to smell]”

Respondent 08

“Being clean is being neat”

Respondent 18

“[Fear] if they don't clean the toilet they would attract mosquitos and spread malaria”

Respondent 21

“My [CBS] toilet is cleaner [than the family toilet], but that is because I am the only person who uses it”

Respondent 31

"[Pride] when you clean the toilet it lasts longer"

Respondent 34

“[Animated] I do not want to clean it because I have just run out of gloves”

Respondent 47

> *"[Animated] You have to take care of the toilet so that it lasts longer"*
>
> Respondent 49
>
> *"We were worried by flies in the sawdust [CBS toilet], so chose to switch back to the chemical [CBS toilet]"*
>
> Respondent 51
>
> *"[Laughter] You eat with the right hand and use the left hand for dirty things"*
>
> Respondent 52

Despite the fear of disease and the consensus of keeping their CBS toilet to a high standard of hygiene, often males would not clean the toilet:

Male Responsibilities

> *"[Laughter] Others clean the toilet, but I do it sometimes because I am responsible for the [CBS] toilet being well cleaned"*
>
> *Respondent 34*

Additionally, several respondents showed a frustration towards children making a mess of their toilets since cleanliness was a high priority:

Children making a mess

> *[Who does the cleaning?] "[Laughter] Not the kids"*
>
> Respondent 04
>
> *"I tell the children off if they do not wash their hands [Laughter]"*
>
> Respondent 45
>
> *"The children are unable to use saw dust [CBS toilet] because they spill it everywhere"*
>
> Respondent 56
>
> *"[Frustrated] I do not like the children playing with the [CBS] toilet"*
>
> Respondent 62

Despite the importance of cleanliness however, the main reason for respondents not to own a CBS or household toilet was because they claimed there was not enough space to house a toilet:

Not enough space

> *"[Frustration] We do not have enough space for a toilet"*
>
> Respondent 25
>
> *"Queueing at public toilet is frustrating"*
>
> Respondent 54

Even if respondents had space for a CBS toilet, there were many who showed frustration with the payment of the toilet:

Payment

> *"I do not like when visitors come because it [CBS toilet] gets filled up too quickly"*
>
> Respondent 01
>
> *"[Frustration] I would prefer to pay weekly rather than monthly"*
>
> Respondent 12
>
> *"[Laughter] I sneak kids in the public toilet"*
>
> Respondent 22
>
> *"I cannot afford for everyone to use the toilet. The oldest son must use the public toilet because he is 'Strong'"*
>
> Respondent 49
>
> *"I would have a toilet if [CBS company] would pay for it"*
>
> Respondent 63
>
> *"[Frustration] I always have to give my children money to go to public toilet"*
>
> Respondent 67

Table 3-9 Themes of the intangible observations.

Theme	Intangible Topic
I1	Hilarity in finding toilet aesthetically pleasing
I2	Pride in owning a toilet
I3	Convenience of not walking to public toilet
I4	Fear of thieves
I5	Privacy and dignity for females
I6	Fear of disease from others
I7	Fear of disease from miasma
I8	Children make a mess
I9	Males do not clean
I10	Not enough space for a toilet
I11	Frustration with payment

The variety of the themes from the intangibles, are declared in Table 3-9. The table shows the collective variety of the intangible observations from the footage of which, there were 11 themes, labelled I1 to I11.

Like the contradictions and the workarounds, the intangible responses to questions are because the respondents are passionate about something or are hiding how they really feel about an unmet or unconscious problem. There are judgements made that point to underlying problems in Table 3-10.

The Collection of the Results

Figure 3-13 shows the different varieties of the user journey, whether it is the CBS with chemical or CBS with sawdust or a male that still frequents the public toilet. Each of the themes identified – *the contradictions C1 to C9, the workarounds W1 to W12 and the intangibles I1 to I11* – are overlaid showing where the pains and or underlying problems exist. The majority of themes occur in the acquisition of the toilet and the cleaning of the toilet with a few others appearing in the use of the toilet.

Table 3-10 Judgements made on the intangible themes.

Theme	Judgement	Underlying Problem
I1	Hilarious because toilets are disgusting products.	Toilets are shut away in outhouses or Moris and not aesthetically pleasing products.
I2	Pride in providing for the needy and vulnerable in the family.	Providing makes you the protector.
I3	Public toilets are quite far or the terrain en route is challenging.	Some family members are disabled, elderly or pregnant and cannot walk the distance.
I4	Thieves are present particularly at night-time.	It is dangerous to go to the toilet alone, but you have to often go to the toilet alone as a private act.
I5	No-one likes being watched while defecating.	There is not adequate space to house a private toilet.
I6	The mess of the unknown from others is fearful.	Public toilets are left messy because there is no ownership of the mess.
I7	The fear of disease is attributed to smell and heat.	The invisibility of disease is attributed to the tangible features of faeces (smell and heat).
I8	Children do not know how to use the sawdust CBS toilets properly and make a mess.	Any prior knowledge of how to use a toilet presents problems for children.
I9	Females are the house keepers and men earn the money at work.	Traditional gender roles mean men are not expected to clean.
I10	The disgusting nature of toilets means people do not want them in their home.	Toilets are shut outside and people may not have surplus space to build an outhouse or Mori.
I11	Public toilets are cheap per visit and the CBS seems expensive as a monthly payment.	The perception of how much is spent on sanitation is little on pay per visit basis, but expensive in monthly instalments.

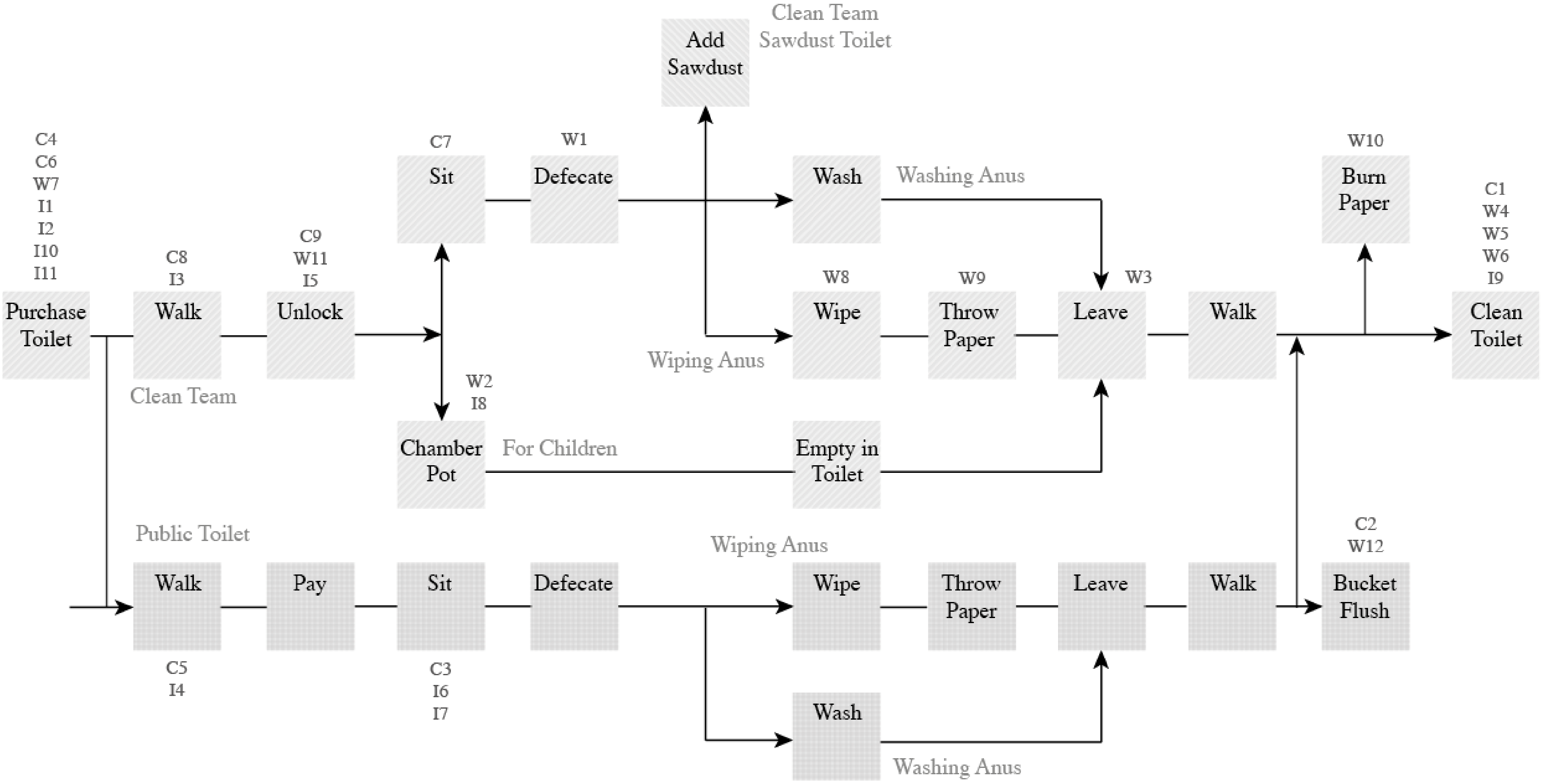


Figure 3-13 User Journey Map.

User Journey Map of different uses of the CBS or decision to go to the public toilet with observation themes overlaid on top. Source: J Larsson.

Figure 3-14 Workarounds and hacks shared on internet forums.

Workarounds and hacks shared in internet forums. Source: https://www.instructables.com and https://www.hackaday.io

3.4 Participatory Photography

Looking more closely at the toilet user experience, the photos that innovators share online has been chosen with particular focus on user hacks and workarounds to identify user unmet needs.

Method

Due to the sensitivity of the subject, observing the use of toilets is not possible. With a view on lead users, an investigation into the workaround that hackers develop for toilets can indicate frustrations in the use of the toilet (Norman, 2008). This study uses participatory photography where participants are found by the solutions they share on the internet and focuses solely on the workarounds people have shared on sharing sites or blogs.

A structured search on hacker and Do It Yourself (DIY) websites *https://www.instructables.com* and *https://www.hackaday.io* for workarounds using the search terms: *toilet, bathroom, hack, workaround.* Traditional filtering could not then be undertaken, instead a review of the posts from highest to lowest relevance was done. Duplicates of the type of workaround were removed.

Table 3-11 The hacks and the proposed underlying problems.

	Workaround	Judgement	Underlying Problem
a.	Musical Toilet	Plays music when toilet is flushed, mostly for comic effect.	Visiting the toilet/bathroom is a dull and uninspiring part of the day.
b.	Toilet Brush	Leaving toilet brush to drip dry because of mess it makes in holder when wet.	Wet toilet brushes cultivate bacteria if left wet in holder.
c.	Socks on Seat	Socks on toilet seat for warmth.	Toilet seat can be cold if sat on in the middle of the night/morning.
d.	Wrist Handle	Wrist handle alternative instead of hand operated handle.	The fear of the spread of germs on hand operated handles.

e.	Splash Guard	For young children – *mostly boys* – learning to use the toilet.	Young children – *boys* – that have little control over *aim.*
f.	Basin Cistern	Hand washing above cistern to recycle grey water as flush.	Toilet flushes waste litres of clean water.
g.	Odour Warning	A timer unit to warn the next user when last person visited for comic effect.	The bathroom often smells if visiting straight after someone else has used it.
h.	Endless Toilet Paper	A wire dispenser of toilet paper for 10-12 rolls.	Running out of toilet paper is problematic.
i.	Paper on Water	Helps eliminate Worthington Jets[7].	The splash that comes from a Worthing Jet is embarrassing if in public and concerning hygienically.
j.	Foot Handle	A foot handle instead of a hand operated handle.	The fear of the spread of germs on hand operated handles.
k.	iPad Holder	A holder to rest an iPad on to watch or play while on the toilet.	Visiting the toilet can be boring and sometimes lengthy.
l.	Plants on Cistern	The water sat in the cistern is used to water plants.	Bathrooms are cold and clinical and the presence of plants helps soften the room.
m.	Fragrance Paper	Adding flower essence to toilet paper.	The fragrance from the essence masks the smell of faeces and is inconspicuous.
n.	Coca Cola	Adding Coca Cola to clean the toilet bowl.	The acidity and carbonation of the Coca Cola helps remove stains.
o.	In-Tank Toilet Cleaner	Upturned water bottle to dispense detergent upon flush.	Toilets would be nicer if they were cleaned and deodorised on each use.
p.	Drill Brush	Using a hand drill with a toilet brush on the end to clean the toilet.	The speed and rotation of the drill helps remove stains.

---

[7] The impact of the faeces on the water deforms the surface of the water and then the water rebounds into a jet that protrudes from the centre of the impact.

q.	Automatic Toilet Lid	Motor on toilet lid to automatically lift and lower the toilet seat before and after use for comic effect.	Men and women use the toilet differently and notably argue over how it is left for the next user.
r.	Detachable Toilet Seat	For a disabled person to use the varying heights of toilets while out.	Toilets are not standard and come in many shapes and sizes that can be problematic for those who cannot sit low or jump up high.
s.	Automatic Paper Folder	Automatic toilet paper folder for comic effect.	Toilet paper is rarely used in single sheets and many people fold paper for wiping, which is apparently effort.

Findings

There were many and varied hacks and workarounds found on DIY and hacking sites. There were 19 workarounds that were considered unique seen in Figure 3-14 and judgements were made on these hacks seen in Table 3-11 . A few of which had been shared for comic effect, however these were not ignored, but instead examined closer since there is truth in comedy. From the 19 workarounds selected there were six themes codified: *Cleaning, Odour Control, Disease, Entertainment, Ease of Use* and *Comfort in Use*, shown in Table 3-12. To summarise, the bathroom is clinical and lacks entertainment. However, it remains clinical because of concerns about hygiene. The commitment to hygiene has overridden comfort for the users including ergonomically, environmentally and audibly.

Table 3-12: The themes of the hacks and the proposed underlying problems.

Theme	Hack topic	Underlying Problem
H1	*Cleaning*	The hacks such as the Drill Brush and the Coca Cola to help remove stains or the In-Tank Toilet Cleaner to reduce the chance of stains.
H2	*Odour Control*	The hacks such as Fragrance Paper and In-Tank Toilet Cleaner to mask toilet odours with the Odour Warning preventing the next user to face bad smells.
H3	*Disease*	The hacks such as Foot Handle and Toilet Brush that avoid the spread of hygiene.

H4	*Entertainment*	The iPad Holder and Musical Toilet to make the experience more enjoyable.
H5	*Ease of Use*	The hacks such as Detachable Toilet Seat and Automatic Toilet Lid to make the use easier with respect to actively and ergonomically using the toilet.
H6	*Comfort in Use*	The hacks such as Socks on Seat and Plants on Cistern to make the use and the surrounding environment more enjoyable.

3.5 Analysis of Findings

Ethnographic research was used to uncover latent needs in the acquisition of toilets to understand what it means for a toilet to be aspirational while the participatory photography method was used to elicit the latent needs for user experience. Over the collection of individual nuances, there are several duplicating themes shown in Table 3-13.

From the individual cases of contradictions, workarounds and intangible observations from the ethnographic research, there were 31 themes identified; nine contradictions, twelve workarounds and ten intangibles and an additional six from the participatory photography. Certainly both observations together paint a rich picture of the problems faced by the users and the context in which the product is used (Goffin, Lemke and Koners, 2010). Each observation made, whether it was contradiction, workaround, intangible or hack indicate problems or even opportunities for future products (Norman, 2008). Often the best solution may not directly be the workaround or hack made by the respondent, but instead a more creative solution may exist that should be explored by the design team (Brown, 2008; Fulton Suri, 2005; Ideo, 2014).

There were several motivations for adopting the CBS toilet from the ethnographic research. Primarily, the pride of owning a toilet (I2), convenience to avoid walking (I3), safety from thieves (I4) and safety from disease (C2, C3, I6 ad I7). However, the intangible observations finding the thought of an aesthetically pleasing toilet amusing (I1) support the hacks to make the experience more enjoyable (H4). Fear of disease is a more complex factor that is discussed in more detail below (I6 and I7).

Table 3-13 Elicited insights from ethnographic research and participatory photography for acquisition and user experience.

Ethnographic Research – Acquisition	Participatory Photography – User Experience
Comfort in Use	Comfort in Use
Cleaning	Cleaning
Disease	Disease
Cost Model	Entertainment
Ancillary Action	Ease of Use
Aesthetics	Odour
Safety and Convenience	
Location	
Space	
Shame of Use	

Reviewing similar qualitative studies in a low-income context the study by Jenkins and Curtis (2005) found two main motivations for latrine adoption centred around prestige: to affiliate with the urban elite, and to express new experiences and lifestyle. They also found that there were two main drivers centred around wellbeing: the family's health and safety, and convenience and comfort. The main interest in constructing latrines was for male heads to provide for their female family members for privacy and convenience (Routray et al., 2015). The qualitative study by O'Reilly and Louiss' (2014) on the other hand, found that there was a pressure to be *"civilized"* in owning a toilet. One respondent said, *"Toilets are a necessity. There was a wave when everybody was getting a toilet built, so I also built it"*, and another who said *"When everyone started to be clean, the environment started to be clean and civilized. Then we built a toilet. When everyone started building toilets we felt embarrassed [because we did not have one]"*. A survey on the uptake of the same CBS found only that the CBS was adopted for young children (Huberts et al.,

2016) and other surveys in low-income contexts again only found that the most important features for a good toilet were how close the toilet is to the household and accessibility during day and night-time and acknowledges that cleanliness is important (Jenkins and Scott, 2007; Tumwebaze et al., 2012). In short, the findings were that the motivations to buy toilets had more to do with societal shame rather than aspirational drive (O'Reilly and Louiss', 2014). A qualitative study of barriers to accessing water, sanitation and hygiene for disabled people in Malawi also found that the barriers to sanitation adoption were long distances and uneven ground to toilets and problems squatting (White et al., 2016).

This research also found that payment is an issue (C4) and the ethnographic research found that often family members were not allowed to use the CBS toilet because increased filling rate, meant increase cost (I11). Organising payments in a low-income setting is pressing issue as found in the workarounds (W7), but is not so much with flushing toilets since they are one off payments and why no hacks were identified around payment. Space and wealth were the determining factors whether people had a toilet or not; Respondent 63 claimed *"I would have a toilet if [CBS company] would pay for it"*.

Ramani, SadreGhazi and Duysters (2012) claim that individuals in low-income countries do not have the money to pay for toilets or there is no infrastructure. When more subtly, lack of value of ownership of toilets is the main cause for slow uptake. Mulinge (2015) as well as Prahalad and Hart (2008) claim that money dictates how much people spend not on what or why. For instance, the findings of the Systematic Review by Seymour and Hughes (2014) on the user preferences and motivations for sanitation in developing countries, found that there were five factors; comfort, cleanliness, convenience, prestige and health benefits. They found that research that studied the motivational factors prestige and health benefits were lacking in information where more work is necessary in understanding these as drivers for adoption.

Contradictions regarding cleanliness were observed, the Observation Team noted that there could be variations in definitions of cleanliness. The toilet may be dusty and dirty (C1) as this is an everyday occurrence that arguably, does not consciously bother them; however, neatness and order is more important. A few respondents claimed, *"Being clean is being neat"*. Leaving detergent on the floor (W6) may give the user confidence that the toilet space is clean; this observation is suspected to satisfy people's fear of the invisibility of disease and may be why people find strangers' mess in public toilets so disgusting (C2, C3, I6 and I7). The additions people make to mask or avoid the malodour of toilets, speaks of their frustrations with the smell (H2). The hacks that were made allow users to avoid touching surfaces indicate to people's fear of disease (H3). This view was held by respondents in Malawi, who mentioned there was a risk of contagion from people with epilepsy and albinism that could potentially be transmitted through sharing water (White et al., 2016). The feeling of disgust towards strangers is more pronounced than close loved ones, for instance sharing a toothbrush with the postman causes more disgust than the thought of sharing it with a family member (Rosenquist, 2005).

From the contextual interviews of CBS owners, the toilets were nearly always in an existing toilet space - *e.g. outhouse or Mori* – while there were several contradictions relating to non-CBS customers and the space available for a CBS collection toilet (C6, C8 and I10). Those without these spaces perceive that toilets are not possible for them although practically there was space available, according to the Observation Team.

The seemingly meaningless daily routine of going to the toilet has a negative stigma attached to it that opposes other habitual rituals that we all have during the day (Leone, 2012). Keeping a physical distance from the negative attributes of toilets and away from homes, contributes to the reason CBS are nearly always kept in outhouses or Moris (Chun, 2002). Breaking the held belief *'that toilets belong in this space'* comes from the meaning attributed to toilets as a boundary object that separates between nature, that is disordered and cleansing, and culture, which is ordered and sterile. Putting this boundary object in the middle of the house and making it pleasant enough to use is the biggest challenge for the future (Gramigna, 2013; Leone, 2012). These findings are coherent with the qualitative study by Routray et al. (2015), who found that low-income individuals believed they never had health problems from open defecation:

> *"Containing faeces in the latrine pit inside the compound is perceived to be 'impure' and considered to be 'disrespectful' for the worship shrine at home. People feel latrine pits are the breeding grounds for mosquitoes. With open defecation, they believe faeces (impurities) are left outside, away from homes and mosquitoes can't breed."*
>
> (Routray et al., 2015)

Putting a block of wood in front of the toilet to raise the legs (W1) is a sign of adaption according to Fulton Suri (2005) that describes how respondents may not be as comfortable on the CBS as they claim they are. There is difficult confliction with this assumption; the toilet is too high for the comfortable position of the legs while defecating (W1) and too high for young children to use (W2), however, it is too low down for the elderly to comfortably get on and off from (W3). This is particularly important since many people bought the CBS for the sick, elderly, pregnant and vulnerable (I3). Promoting the posture of squatting is physically more comfortable for defecation and better for general health according to literature (Rane and Iyer, 2014; Sakakibara et al., 2010; Sikirov, 2003).

3.6 Summary

The insights gathered from the ethnographic research and the participatory photography show there are common themes that indicate universal needs regarding motivations for purchasing toilets and the toilet user experience. Namely, fear of disease inspiring people to purchase a CBS and contributing to confusions around cleaning, the negative stigma around toilets that are shut away in toilet spaces and the convenience, safety and comfort for the sick and elderly. The results from this chapter are considered met:

- Respondents chosen

Eliciting latent needs favours qualitative techniques since they can delve deeper into people's motivations and emotions. A lead user approach of purposefully selecting users with idiosyncratic or exceptional circumstances favoured ethnographic research on 77 respondents in Kumasi Ghana. Finally, because a true participant observation was not possible because of dignity issues with toilet user experiences, participatory photography on hackers found on the internet was chosen to find the unspoken needs through analysing their workarounds. There are clear limitations with the generalisability of the findings and the transferability to other audiences and these are discussed in more detail in the Conclusion of this thesis.

- In-depth insights collected and analysed.

This research was the first known of its kind and the findings – *nine contradictions, twelve workarounds and eleven intangible observations* - are beneficial for designers, sanitation experts and social scientists alike. The findings from the ethnographic research and participatory photography indicated the importance of changing stigma and meaning of toilets since currently toilets are kept in toilet spaces and adolescents do not use them. There were similarly several workarounds observed around the comfort in use of the toilet. Lastly the fear around the intangibility of disease and the confusion around cleaning indicates that a reassurance of hygiene and disease is necessary. As a divergent process the findings have been left open for other researchers to make their own judgements. The next chapter will converge on the findings to reframe the problem focusing on the most important insights.

Key Findings:

- Cost or accessibility is not the only determining factors in whether a product is aspirational to own, the other factors include; convenience, disease, space and location available.
- The user experience is limited by factors like odour, cleanliness of the environment, the comfort and the entertainment while in use.

- The restricted access to a product’s low-income audience can provide insight into motivations for acquisition acting as lead users.
- Internet sharing sites or social media allow easy and no cost access to innovators and hacks that can give an indication of unmet needs in the user experience.

Next Steps

The Chapter 4 is intended to meet Objective 2 and reframe the problem. The common latent needs revolve around comfort in use and cleanliness. Stigma will be investigated and the need to change the negative stigma that people associate with disease and disability as this indicates that people shut toilets away in outhouses that many do not have. Comfort and cleaning are also considered issues that will be addressed.

“Brainstorming, ironically, is a structured way of breaking out of structure.”

Tim Brown

4 TRANSLATING INSIGHTS

Objective 2: Translate latent needs and reframe the problem.

This chapter is dedicated to meeting Objective 2; translating the insights from Chapter 3 into a new user value proposition. The section begins with a review of methods for ideation followed by the idea generation methods used. Then an investigation into what new value proposition should be pursued. Finishing with a summary of the research and a proposed value proposition for the experimental plan to meet Objective 5.

4.1 Need for the Research

Finding the correct problem is the most important step in any design activity (Design Council, 2010; Norman, 2013). Most of the innovation from latent needs analysis comes from reframing the problem (Madsberg and Rasmessen, 2014). Starting with the brief of *"Design an aspirational toilet"*, the collection of features that one associates with a toilet is in the mind of the designer before starting (Harni, 2010). Therefore, the scope of innovation is limited - *for example you always sit on a toilet, so this is an essential feature*. By reframing the problem, the possibilities are more open - *like you may not have to sit on the toilet* (Dorst, 2011; Dorst and Cross, 2001).

The synthesis of the insights is said to rely heavily on the intuition of the designer, but there are a plethora of Design Thinking tools to aid the designer (Brown, 2008; Ideo, 2014; Norman and Verganti, 2012). Both analytic and empathic methods are explored here to provide a balanced realisation of the insights. Some of the creative methods for idea generation require the participation of users, however the lead users featured in Chapter 3 are not available.

Table 4-1 Methodologies considered and reasons for rejection.

Research Option	Method	Principle Reasons for Rejection
Option 1:	*Concept Mapping*	Relies on intuition of designer.
Option 2:	*Creative Toolkit*	Cannot incorporate lead users.
Option 3:	*Design Workshops*	Cannot incorporate lead users.
Option 4:	*Elito Method*	Structured with little room for blue-sky creativity.
Option 5:	*Generative Research*	Cannot incorporate lead users.
Option 6:	*Personas*	No emphasis on idea generation.
Selected Option	**Method**	**Principle Reasons for Selection**
Option 1:	*Concept Mapping*	Can be used systematically to find novel opportunities.
Option 4:	*Elito Method*	Investigates the root problem.
Option 6:	*Personas*	Humanise the concepts with other methods.

Expected Outcomes

The new toilet solution should be revolutionary to maximise the perceived newness and added value (Adhiutama, Shinozaki and Yoshikubo, 2009; Rogers, 1995). The new meaning provided by revolutionary innovations *"often do not address a recognized demand but instead create a demand previously unrecognized by the consumer"* (Garcia and Calantone, 2002) and should begin to satisfy the insights found from the previous chapter. Success in this chapter will be defined as:

- A toilet user experience value proposition from the insights.

4.2 Research Approach

The methods used are concept mapping, Elito method and personas. The concept mapping uses correspondence mapping on the 36 codes from the ethnographic research to visually represent the code interdependency. The Elito method is used alongside this to create a *'logic line'* from the observations made to concepts generated by the Observation Team. Finally, personas generated by the Observation Team are also used to ensure that the human element remains in concepts generation.

4.3 Concept Mapping

The Observation Team having reviewed 18.5 hours of footage from the ethnographic research, understand the emergent themes. Looking for a structured approach to the communication of the emergent themes, correspondence mapping has been identified as a repeatable method that quantifies the qualitative insights. The interdependency between codes – *the themes in the notes from the observations* - is of interest to form an objective understanding of the people interviewed. The definition of codes that were agreed upon by the Observation Team are detailed in Table 4-2. Correspondence mapping, a form of principle component analysis, was undertaken to quantify the relationship between the codes to minimise researcher bias. Plotting the interdependency between the codes visually, builds a concept map. correspondence mapping creates orthogonal components for each item in a matrix, sometimes called factor scores that account for the variance between the items in the matrix[8]. In this case the items in the matrix are the number of occurrences each code has with one another. For instance, the code for the *Odour Making Chemical* occurred in 27 observations with the code of *Cleaning,* but the code for *Odour Making Chemical* did not occur once with the observations relating to the respondent's *Career* from Table 4-2.

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[8] Of course, there are probably more than two factors of interest in the notes taken in the ethnographic research – *there may even be 36 unique themes* – however this technique is used to cluster and observe patterns in the results.

Table 4-2 The statements made of the emergent themes of each code.

	Top Codes	Definition of Codes
T1	*Use*	There are workarounds for more comfort on the toilet - *lifting legs* - and getting off – *support* - and people still use chamber pots for children and elderly.
T2	*Cleaning*	The trigger for cleaning is often prompted by the service person, usually a woman who cleans.
T3	*Others in the House*	The trigger for acquisition is usually for others in the house, namely the sick, disabled, elderly, vulnerable and pregnant often because they can't use the public toilet. Relatives often make the decision for acquisition when the toilet is for the vulnerable.
T4	*Location of Toilet*	The physical layout for the toilet is nearly always in its own allocated space - *Outhouse or Mori*.
T5	*Space*	The environmental interactions are usually with the paper bin situated next to the toilet. There are little or no places to keep cleaning products. The toilet is often located in an existing outhouse.
T6	*Trigger for Acquisition*	The trigger for acquisition is often for the convenience of a closely located toilet for the sick, disabled, elderly, vulnerable and pregnant and permission often comes from the husband.
T7	*Anal Cleaning*	There are a mix between paper wipers and anal cleansers with water. Those that use paper keep it by the toilet and leave it to over flow to either burn or dispose of.
T8	*Cultural Habits*	The women of the house do the cleaning with regular utensils and usually with the left hand.
T9	*Disease & Hygiene*	There is a fear that disease transfers through touching the toilet seat when others have used it and through heat
T10	*Odour Masking Chemical*	There are frustrations with the chemical because the scent of the chemical is strong. The sawdust smells in the heat of the sun.
T11	*Cleaning Scheduling*	Some respondents clean on a schedule every day to every three days when the service person comes to change the cartridge; usually the mother's job to clean.
T12	*Serviceperson*	The service acts as a trigger for acquisition because people don't often know how or where to purchase the toilet and wait for the service person to come around or often stop the service person in the street to ask.

T13	*Convenience*	The trigger for acquisition is for the convenience of the sick, disabled, elderly, vulnerable and pregnant so they don't have to walk and queue for the public toilet and for ease, simplicity and comfort.
T14	*Displays of Wealth*	It's not uncommon for people have running water for showers. People often lack space to house items such as fridges, cookers, luggage.
T15	*Smell*	The most frustration about smell comes from the strong and bad scent of the chemical.
T16	*Aesthetics of Toilet Area*	Often people have blue lights in their homes and toilet spaces. Some have installed ceramic floors for better cleaning also. The CBS has marked some walls from opening the lid.
T17	*Comfort*	There are several workarounds that help people get the right position or posture for defecating, like a step in-front of the toilet.
T18	*Water*	People have to collect water to wash himself or herself or the toilet from a water source away from the toilet.
T19	*Pride*	Lots of displays of emotion with respect to be the first to own a toilet or providing a toilet to their family.
T20	*Security*	There are several environmental interactions with locks that face outwards not inwards
T21	*Disgust*	Frustrations about cleaning the mess people make and it gets on their hands. Namely children and squatters and the mess attracting flies.
T22	*Payment*	Most comments about pay are about how convenient is for members of the house and the time it saves.
T23	*Sight*	The look of cleanliness is nearly always a contradiction about how messy respondents truly leave the CBS toilet.
T24	*Disabled*	When the disabled, elderly or pregnant are mentioned, the highest occurring theme was how they are bought for their needs.
T25	*Dignity*	People often have curtains, doors and locks for their toilet areas.
T26	*Career*	Only sometimes are CBSs bought to assist them in their profession - *store owner or priest.*
T27	*Night-time*	People often talk of their fear for safety at night, from thieves and attackers.

T28	*Embarrassment*	There are signs of humour when talking about the use of CBSs for both adults and children.
T29	*Drainage and Ventilation*	Because of the space the CBSs are in, the urine drains at their feet and there are rarely windows.
T30	*Lighting*	People often bring torches with them to use the toilet and blue lights often illuminate them.
T31	*Safety and Convenience*	Respondents are usually fearful of the risks at night or letting children cross the road to use the public toilets.
T32	*Organisation*	Tenants of compounds often write on the walls keeping track of who owes whom for utilities.
T33	*Heat*	Most respondents are fearful of the disease that heat brings.
T34	*Environment*	People use different paraphernalia to overcome the different challenges the seasons bring - *rain and dust*.
T35	*Flies and Maggots*	There are fears of disease that flies and maggots bring.
T36	*Mobility*	People contradict themselves when talking about the mobility of the toilet. It stays in one location as they say, but they move it for cleaning.

Correspondence mapping is performed on the matrix Table 4-3, the two highest factor scores F1 and F2, make up the two orthogonal dimensions for a biplot to represent the relationship between the codes. The biplot of two principle components F1 and F2 describe 15.13% of the variance between the codes with F1 on the horizontal axis and F2 on the vertical axis. The Euclidean distances in the biplot Figure 4-1 represents the correlation between codes.

Table 4-3 Frequency of occurrence when each code occurs with another.

Codes	*Acquisition*	*Aesthetics of Toilet Area*	*Cleaning*	*Career*	*Odour Making Chemical*	…	*Count of Code n*
Acquisition	160	1	3	8	6	…	4
Aesthetics of Toilet Area	1	57	5	0	5	…	1
Cleaning	3	5	343	2	27	…	4
Career	8	0	2	32	0	…	0
Odour Making Chemical	6	5	27	0	80	…	1
…	…	…	…	…	…	…	…
Count of Code n	4	1	4	0	1	…	53

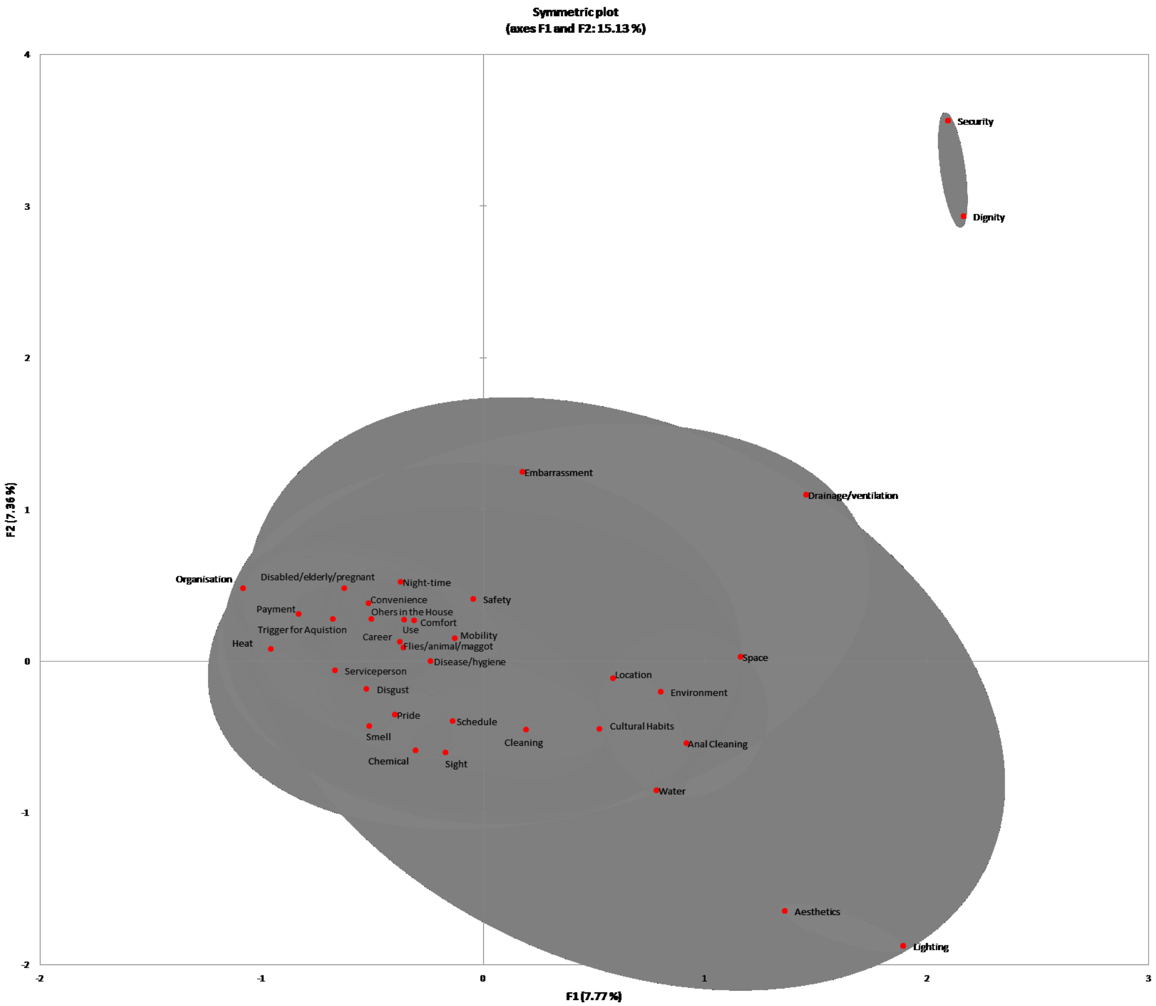


Figure 4-1 Full biplot of correspondence mapping.

Graph to show the full biplot of correspondence mapping of codes to create an objective Concept Map.

There are three apparent clusters; the location of the toilet – *Location*, *Environment and Space* - the comfort and use of the toilet – *Comfort, Others in the House, Convenience and Disease* - and finally the disgust and fear of disease – *Smell, Disgust, Cleaning and Schedule*.

Table 4-4 First 15 steps of Ward's Method of clustering analysis of the codes and data categories.

Stage	Codes	Codes	Coefficient
1	*Career*	*Flies/Maggots*	0.04
2	*Comfort*	*Use*	0.05
3	*Others in the House*	*Convenience*	0.11
4	*Chemical*	*Sight*	0.14
5	*Pride*	*Smell*	0.14
6	*Comfort*	*Flies/Maggots*	0.14
7	*Convenience*	*Disabled*	0.15
8	*Others in the House*	*Comfort*	0.15
9	*Career*	*Disease*	0.16
10	*Trigger for Acquisition*	*Others in the House*	0.17
11	*Disease*	*Mobility*	0.19
12	*Disgust*	*Serviceperson*	0.19
13	*Trigger for Acquisition*	*Payment*	0.19
14	*Convenience*	*Night-time*	0.20
15	*Disgust*	*Pride*	0.21
…			

To avoid subjectively clustering the codes, clustering analysis was undertaken following Ward's Method; agglomeration hierarchical schedule. The first 15 steps of 59 from the Ward's Method are shown in Table 4-4 where coefficients are Euclidean distances between the nodes. Traditionally, this method is represented in a Dendrogram diagram, instead each step of the Ward's Method has been used to create a density map shown in Figure 4-2, for an unbiased interpretation of clustering.

There are clearly two distinct clusters, with a weaker third cluster. Firstly, the intangible data categories of *Fear*, *Frustration*, *Confusion* and others are closely related to the codes of *Disease*, *Use*, *Comfort*, *Others in the House*, *Convenience*, *Night-time, Safety* and importantly *Trigger for Acquisition*. Implying the observations regarding the acquisition of the CBS were closely related to emotive topics involving the family or disease. The next cluster, involves the data categories of contradictions and workarounds including the codes of *Pride, Smell*, *Cleaning Schedule* and *Disgust*. Implying there are unconscious or unspoken issues regarding the presentation and cleaning of the CBS. The last and more separate cluster of codes contains *Space*, *Location*, *Environment, Culture* and *Anal Cleaning*. This is somewhat distant to the intangible observations indicating that they are not such emotive factors. There are several codes that sit noticeably far from the central cluster; *Security, Dignity, Lighting, Aesthetics* and *Drainage and Ventilation.*

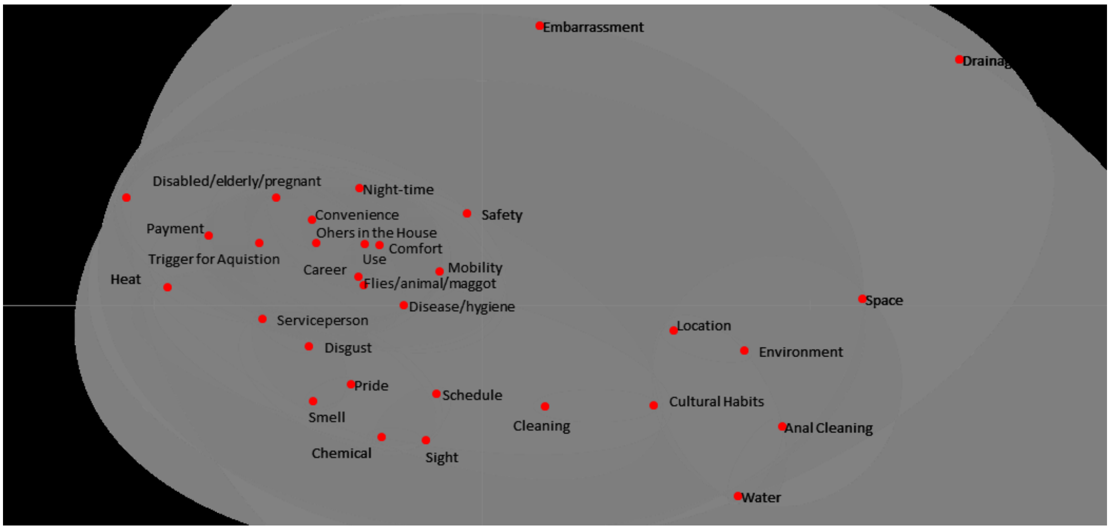


Figure 4-2 Correspondence mapping of codes.

Graph to show correspondence mapping of codes against two principle components superimposed with Ward's Method of clustering analysis. The full biplot is shown in Figure 4-1.

The codes in Table 4-2 are focused on the functional and less so on the emotive. Figure 4-3 shows a biplot of only the intangible observations from the ethnographic research to identify the emotive responses of the respondents to further understand the motivations and attitudes of respondents with respect to the adoption of a CBS toilet.

The factors F1 and F2 this time account for 100% of the variance of the codes in the biplot. We see clusters of codes around the observations associated with frustration and codes associated with fear along the horizontal axis of F1 (81.21%). We can postulate that this may indicate that codes are closely related to a dimension that we can describe as *'confusion'*, where one end of the spectrum is *'frustration'* with the unknown and *'fear'* of the unknown at the other end of the spectrum.

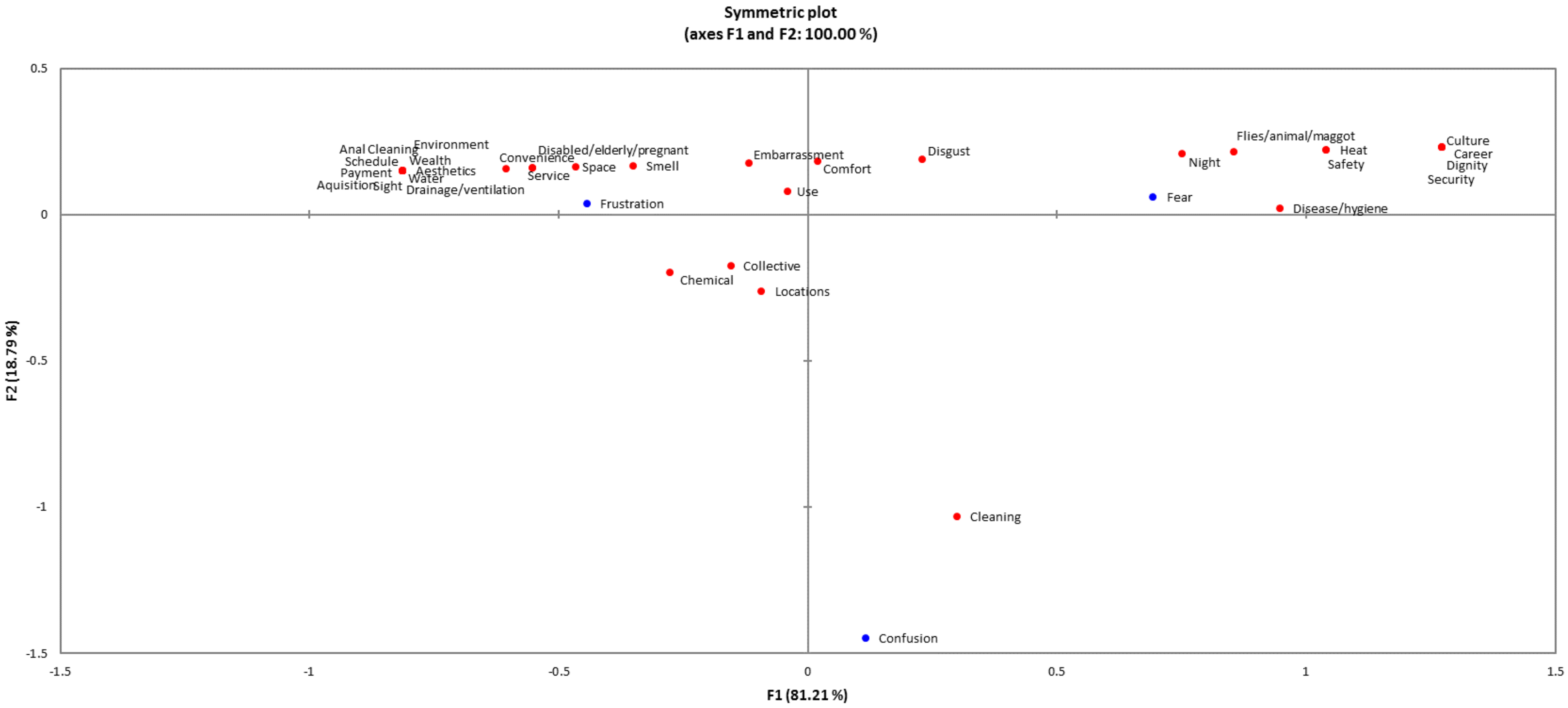


Figure 4-3 Biplot of ‘intangible observations’ correspondence mapping.

Graph to show the biplot of correspondence mapping of codes from the intangible observations to create an objective Concept Map.

4.4 Elito Method

In addition to the clustering, to interrogate the codes and to make sense of the clustered codes, the Elito Method was used on the emergent themes from each of the codes. The Observation Team reviewed all observations associated with each code to create judgements and the underlying problem that gave rise to the codes, to avoid subjectivity, the eleven-person Observation Team discussed each code fully and the interpretations. The Elito method helps structure the wealth of perspectives of the Observation Team by displaying the codes in the structured spreadsheets; these are shown in Table 4-5. Instead of discussing each observation – *of which there were 1,441* – the team discussed each code and the collective observations that were associated with them.

Table 4-5 The judgements and proposed motivations for the statements made on each of the codes. Adapted from the Elito Method (Martin, Hanington and Hanington, 2012).

	Judgements	Underlying Problem
T1	Sitting is easier on the knees, however raised knees are easier for defecating.	Comfort in the use of the toilet is not the same as comfort in the act of defecation.
T2	People clean when someone else takes away the waste. Women cleaning tradition.	More convenient to clean when serviceperson dismantles toilet. It is the women's responsibility to clean.
T3	Toilet provides convenience for family members in need.	Purchasing a toilet is an act of providing help for health and safety.
T4	The toilet is isolated in outhouse or Mori because these are toilet spaces.	Toilets bring and cultivate disease, so they are shut away from living spaces.
T5	Toilets require ancillary actions and other consumables.	The space needed for the toilet extends beyond the physical footprint.
T6	Walking to the public toilets is difficult for the disabled and dangerous for the vulnerable.	There is peace of mind to provide convenience for the family to have their own safe independence.
T7	Two distinct categories of wipers and washers.	There exist different methods of self-cleaning is locally depending on cultural habits.

T8	Cleaning is the woman’s job. And there are certain artefacts are for cleaning.	Traditional values towards family members and human waste. Conformity of sanitary behaviour and individual roles.
T9	The miasma of heat is a way of understanding the invisibility of disease.	Rationalising disease transfer by projecting fears onto tangible aspects of the toilet.
T10	The smell of chemicals is strong and unnerving, smell of faeces is unpleasant.	There is discomfort in extreme smells both faeces and chemical.
T11	People clean when someone else takes away the waste.	There is shame in others seeing you're untidy.
T12	Word of mouth is particularly important and they have to see it to believe it, usually through serviceperson.	Strong community interaction and trust in peer referral.
T13	Certain people struggle with travelling to public sanitation facilities because of disabilities, terrain or safety from others.	Convenience means saving distance, time and increasing comfort.
T14	There are many gifts and signs of wealth from weddings that clutters up houses reducing space.	No perceived feasibly because of the lack of space or difficulties in installing the infrastructure.
T15	The smell of chemicals is strong in enclosed spaces and unsettling.	Discomfort in unfamiliar and extreme smells.
T16	People have tried to improve the surrounding aesthetics of the toilet space.	There is pride and aspiration in owning toilet and comfort in use also comes from the state of the surrounding environment.
T17	The posture of sitting is comfortable, but the number of workarounds suggests people could be more comfortable.	The experience of going to the toilet should be relaxing, but the posture should promote the squatting position.
T18	There are sources of water for individual households, but they are not necessarily always located near the toilet.	Washing hands and cleaning the toilet is made less convenient by having to travel to collect water.
T19	Owning a toilet brings pride to the provider of the household because of the convenience and safety it brings.	Allowing household member’s freedom to do as they wish makes the heads of house feel as though everyone is catered for.

T20	Locks are not for privacy while on the toilet, but to keep people out when you are away.	The toilets are often situated away from the house and locks are needed to stop others using and misusing their toilet.
T21	There is little ownership over toilets that are not yours, but a lot of emphasis in keeping your personal toilet tidy.	The fear around others' mess means people actively avoid cleaning publicly used toilets, while toilets for the family are fine to clean.
T22	If it provides for family members who are in need then people find a way to pay without complaint.	The benefits of having a toilet in the home are not immediately obvious if lack of mobility is not the main reason for owning one and the costs are salient in owner's mind if it is not obvious that it is cheaper than the alternative.
T23	People's idea of clean may not be exclusively making the CBS look brand new.	The presence of dust everywhere in the dry season and similarly dirty rainwater in the wet season becomes invisible to individual over time.
T24	The need for a household toilet is most strongly felt by the elderly, disabled or pregnant.	There is obvious advantage to having a household toilet for those that cannot or should not travel to the public toilet, particularly at night.
T25	People do not like to be seen on using the toilet.	Going to the toilet is a private act and people feel the need to conceal themselves from sight.
T26	People need toilets at home and at their shop that are often separated.	Toilets are not just needed at home. Particularly for men who are away from home most of the day.
T27	If at night you need to visit the public toilet, there is a risk of being attacked on route.	There can be attackers or robbers that are around under the cover of darkness.
T28	The thought of others seeing you use the toilet is embarrassing.	People's dignity should be preserved when using the toilet.
T29	Toilets are kept in closed areas to keep out of sight/smell.	The need to keep the toilet in its own space is because of the unpleasantness and often is not ventilated so smell cannot escape.
T30	The closed spaces the toilets are kept in do not have light.	The lack of ventilation in toilet spaces thus makes the spaces dark.
T31	The public toilets are sometimes a distance away from the home	In dense urban areas the ability to have public toilets near every

	and require navigating many dangers on the way.	household means some have to walk for some distance and are then exposed to attackers.
T32	It is a sharing community and writing on the walls helps keep track of who owes what.	The communities are no strangers to sharing products or utilities and often record who owes what publicly to keep track and signify.
T33	People make the connection between diseases and heat because disease is invisible and so too is the heat produced from faeces.	The invisibility of disease makes it hard to understand how it is transferred and the correlation of the unpleasant miasma from long drop toilets is believed to be the cause.
T34	The seasons are extreme and it is impractical to protect against dust and rain all year round when plastic bags will make do.	There is little point erecting a structure to protect from the rains or dust when they are present intermittently throughout the year.
T35	The more disgusting something is, the more flies and maggots there are.	The presence of maggots and flies indicates something disgusting.
T36	People want to keep their toilets in a fixed place, but like to easily move it to clean around it.	It is practical to keep the toilet in one place to permanently contain the disgusting smell and mess associated with it.

The concepts suggested by the Observation Team to meet some of the underlying problems to the codes are:

- Visually indicating the presence of disease.
- Personalised profile toilet seats to reduce the perception of others' disease.
- Squatting bars to help the users use the toilet and off the toilet. These bars can dispense hand sanitiser.
- Lockable toilet with RFID access to know who uses it.
- Aperture opening on toilet seat to make it smaller for children.
- Pay via phone or SMS rather than a serviceperson.

The metaphors for the solutions are given as:

- Visually indicating the presence of disease concept is like shining a spotlight on the vermin that you are trying to catch.
- Personalised profile toilet seats would be like multiple detachable heads for the one family electronic toothbrush.
- Hand sanitising squatting bars to help you up would be akin to a tooth fairy taking away the disease tooth and leaving the clean surprise.
- An RFID accessing toilet is similar to the London Underground Oyster card.
- An aperture toilet seat would be like an adjustable car driver's seat.
- Pay via phone allows for an uber-like peer-to-peer toilet sharing service.

The Observation Team did not create concepts for each of the underlying problems, but each concept meets multiple underlying problems. The emergent themes that unite the solutions are disease, inclusivity and comfort of use and organisation of ownership including payment.

4.5 Personas

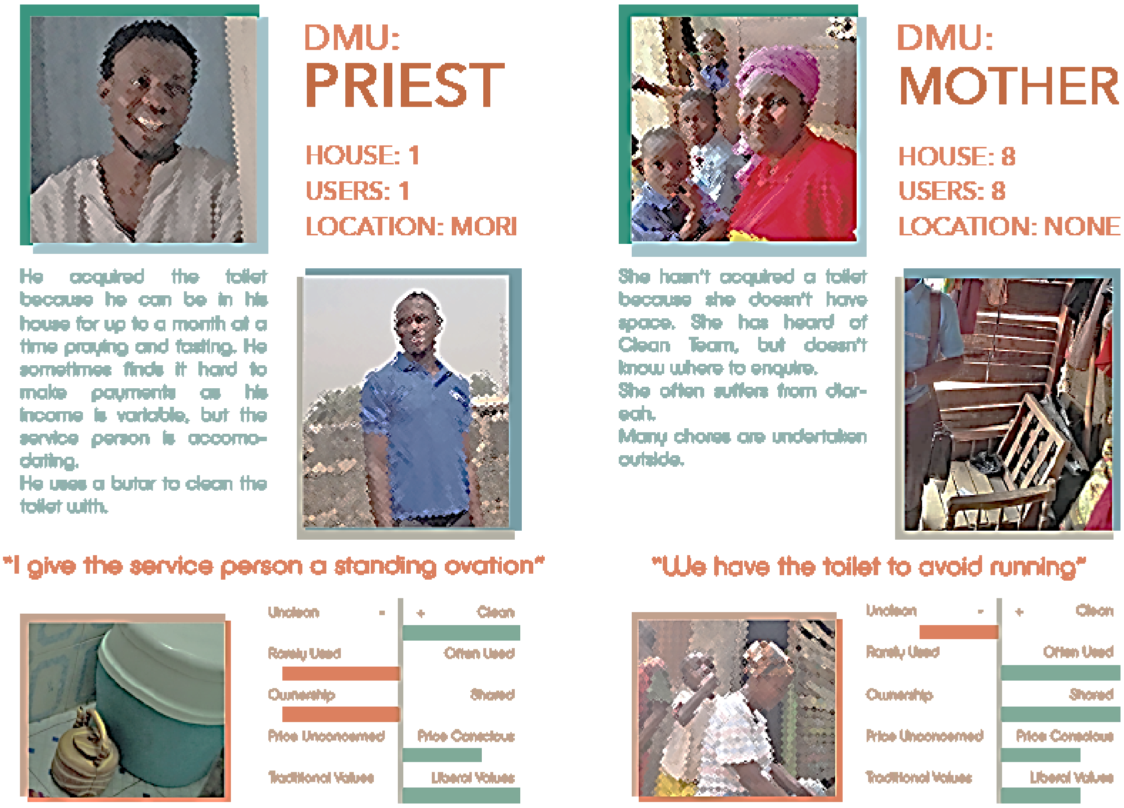
To remain empathic and not detach from the human element of the research, the Observation Team generated personas that represent character summaries of individuals that represented the emergent trends or idiosyncratic behaviours observed in the ethnographic research. Importantly, the Observation Team identified that traditional personas of a user would not suffice, since the Decision-Making Unit (DMU) in the purchase of the CBS, was often not the user of the toilet. The persona character summaries take into account household dynamics.

The Priest

There is only one in the house of the Priest who has bought his CBS for religious reasons. He stays in his abode for weeks or sometimes months at a time praying and fasting as seen in Figure 4-4. Because of his variable income, he finds making payments difficult and appreciates the flexibility the serviceperson gives him to make up missed payments at some other date. As a religious man, he keeps his CBS clean because of fasting it is less used than others. He perceives the CBS to be totally his. He is sensitive to price and holds traditional values.

The Mother

The Mother is the DMU of the large house of eight in Figure 4-4. Due to diarrhoea, a common occurrence for the household, her family often must make trips in the night to the public toilet. She does not currently own a CBS and does not know where it would fit in her already cramped home. Having many household members means that the house is often messy where chores are usually undertaken outside. She is somewhat liberal and if she were to own a CBS, it would be a purchase for sharing, but cost is an issue.



He acquired the toilet because he can be in his house for up to a month at a time praying and fasting. He sometimes finds it hard to make payments as his income is variable, but the service person is accomodating.
He uses a butar to clean the toilet with.

"I give the service person a standing ovation"

She hasn't acquired a toilet because she doesn't have space. She has heard of Clean Team, but doesn't know where to enquire.
She often suffers from diareah.
Many chores are undertaken outside.

"We have the toilet to avoid running"

Figure 4-4 Personas of the Priest and Mother.

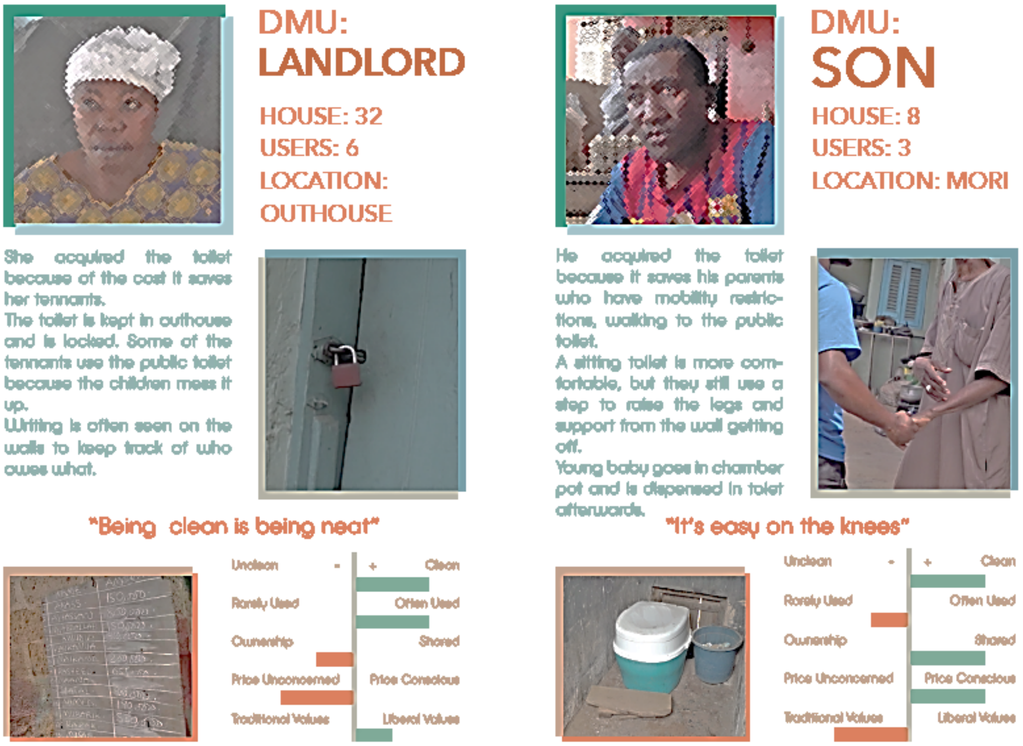
Personas of the households of the Decision-Making Unit (DMU) of the Priest (Left) and the Mother (Right). Source: J Larsson

The Landlord

The Landlord owns a complex where multiple families live, approximately 32 people as shown in Figure 4-5. She has purchased a CBS and keeps it in an outhouse. Previously, tenants were free to use it and chalk would often be seen on the wall as a means of accounting. Now the outhouse is locked because children made a mess when they used it and it is now exclusively for her. Cleanliness is important to her. She is not price conscious and is fairly liberal in her views.

The Son

The Son bought a CBS for his elderly parents and keeps it in a Mori to save them from having to walk to the public toilets as seen in Figure 4-5. He keeps a wooden block in-front of the CBS to raise their legs while defecating and they often need support or help getting off the CBS. He also has a young baby who uses a chamber pot and that is disposed of in the CBS. The CBS is clean and not often used and as such he is sensitive to price. He is a traditional man who purchased the CBS for sharing because he sees it as his duty to look after his parents.



She acquired the toilet because of the cost it saves her tennants.
The toilet is kept in outhouse and is locked. Some of the tennants use the public toilet because the children mess it up.
Writing is often seen on the walls to keep track of who owes what.

He acquired the toilet because it saves his parents who have mobility restrictions, walking to the public toilet.
A sitting toilet is more comfortable, but they still use a step to raise the legs and support from the wall getting off.
Young baby goes in chamber pot and is dispensed in toilet afterwards.

Figure 4-5 Personas of Landlord and Son.

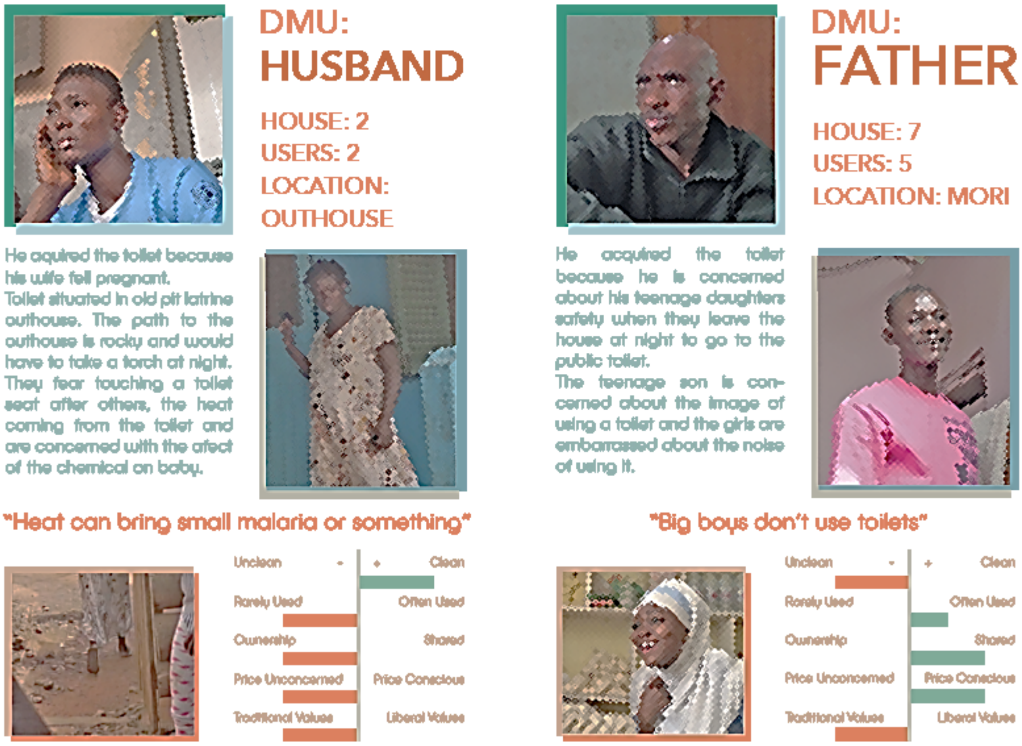
Personas of the households of the Decision-Making Unit (DMU) of the Landlord (Left) and the Son (Right). Source: J Larsson

The Husband

Similar to the Son, the Husband bought the CBS for his pregnant wife to avoid her having to walk to the public toilets and protect from the heat and disease from public toilets as shown in Figure 4-6. They keep the CBS in an outhouse and the walk is rocky at night and requires a torch. They keep the CBS clean as it is rarely used and they do not want others to use it. Money is not an issue to the husband because looking after his wife is of upmost importance.

The Father

The Father bought the CBS for his family, primarily to save the females in the house from venturing out at night that as can be seen in Figure 4-6. He is fairly price conscious and continues to defecate outside to reduce the filling rates. His adolescent son also defecates outside, but this is done out of pride of being a man. The CBS is not particularly clean since it is shared and he believes it is not the man's job to clean.



He aquired the toilet because his wife fell pregnant.
Toilet situated in old pit latrine outhouse. The path to the outhouse is rocky and would have to take a torch at night. They fear touching a toilet seat after others, the heat coming from the toilet and are concerned with the afect of the chemical on baby.

"Heat can bring small malaria or something"

He acquired the toilet because he is concerned about his teenage daughters safety when they leave the house at night to go to the public toilet.
The teenage son is concerned about the image of using a toilet and the girls are embarrassed about the noise of using it.

"Big boys don't use toilets"

Figure 4-6 Personas of Husband and Father.

Personas of the households of the Decision-Making Unit (DMU) of the Husband (Left) and the Father (Right). Source: J Larsson

The metaphor for the reasons many people would invest in a CBS toilet arrived at by the Observation Team, would be the father who buys a mobile phone for his daughter. This metaphorical father purchases a phone for his daughter to appear liberal, allowing her to run free while he has piece of mind that she can call if she is in danger. Instead of being the annoying father who restricts her freedom in fear of those outside the home for her own good. The sense of fulfilment and identity associated that this metaphorical father would receive is the driver for many in the acquisition of a CBS. Whether it is a father for his daughters or husband for his pregnant wife, a son buying it for his elderly parents.

4.6 Analysis of Findings

Following on from the summary of Chapter 3, the main themes were fear of disease, negative stigma and the convenience, safety and comfort for the sick and elderly. From this stage of the research, many of the emotive codes in the correspondence mapping in Figure 4-2 are close to the codes associated with *Disease* (T9) such as *Smell* (T15), *Heat* (T33) and *Flies and Maggots* (T35) and less so with codes like *Dignity* (T30) as one would expect. *Disgust* (T21) of *Disease* (T9) is associated with *Smell* (T15) and *Heat* (T33) is the main contrbutor to this stigma that afftects the *Location* (T4) toilets are kept in. This is what respondents who do not have *Space* (T5) mean when they do not have toilets; that they do not have space to shut toiets away from living areas. These themes informed the judgments made in the Elito method that led to several concepts shown in Table 4-2 and Table 4-5. There are many assumed underlying problems around how toilets are perceived and the fears of disease. This is reflected in the personas, where we see the DMUs of the *Mother*, *Father*, *Husband* and *Son* are all driven by the care and wellbeing of their family members. The care for *Others in the House* (T3) is often the *Trigger for Acquistion* (T6) and is for *Safety and Convenience* (T31) of the vulnerable and *Disabled* (T24).

The concept mapping shows a variety of reasons respondents may have acquired a CBS toilet; *Disease & Hygiene* (T9), *Comfort* (T17), *Others in the House* (T3), *Convenience* (T13), *Night-time* (T27) or *Safety* (T31). The reoccurring theme that appears to unify the cluster in the concept mapping is the care for *Others in the House* (T3). The main reason for respondents not to adopt a CBS toilet was because of the perceived lack of space which is suspected to be because of the need to distance toilets from living areas because of the risk contagion (T4) from smell (T15), heat (T33) or others in public toilets (T9). This presents an apparent confliction that CBS toilets are purchased to help the distance the vulnerable away from the disease-ridden public toilets, but the main reason for not adopting a CBS toilet is because of the lack of space available to distance the disease-ridden toilets away from living areas. This confliction presents creative tension where fear of disease is at the core that is an interesting avenue for exploration. The attribution of positive wellbeing may bring a new dimension of meaning to toilets dampening the fears of disease.

The evidence suggests that the fear of disease is a barrier for many people's perceptions of toilets. The research implies that the polluting perception of toilets may prevent them from being seen as aspirational. Intuitively, a user experience that helps monitor or reassure the head of a house about the household health or wellbeing would somewhat satisfy the underlying fear of disease from toilets. Aspiration from the Definition of Terms Section 2.6, is defined as *'the desirability of a product or it's attributes and features that express virtues one associates with contentment'* where contentment with respect from toilets may come from knowing that everyone in the household is healthy and well. The knowledge of a family member's health or wellbeing may benefit the personas of the *Mother, Son, Father* and *Husband* since their rationale in investing in a toilet is to provide for and protect the family. A device that could indicate if a child's health would be far more valuable from their perspective than a toilet for defecation.

The evidence detailed in Chapter 3 and this chapter, indicate a value proposition that begins to satisfy the fear of disease, which can then change the stigma of toilets. The research started with the problem *"How to create an aspirational toilet"*, but the direction of development of what makes an aspirational toilet was not clear. The synthesis of the insights is summarised in Figure 4-7 suggests that the reframed problem "*How to reverse the stigma of toilets by reducing people's fear of disease"* would create a more aspirational toilet user experience.

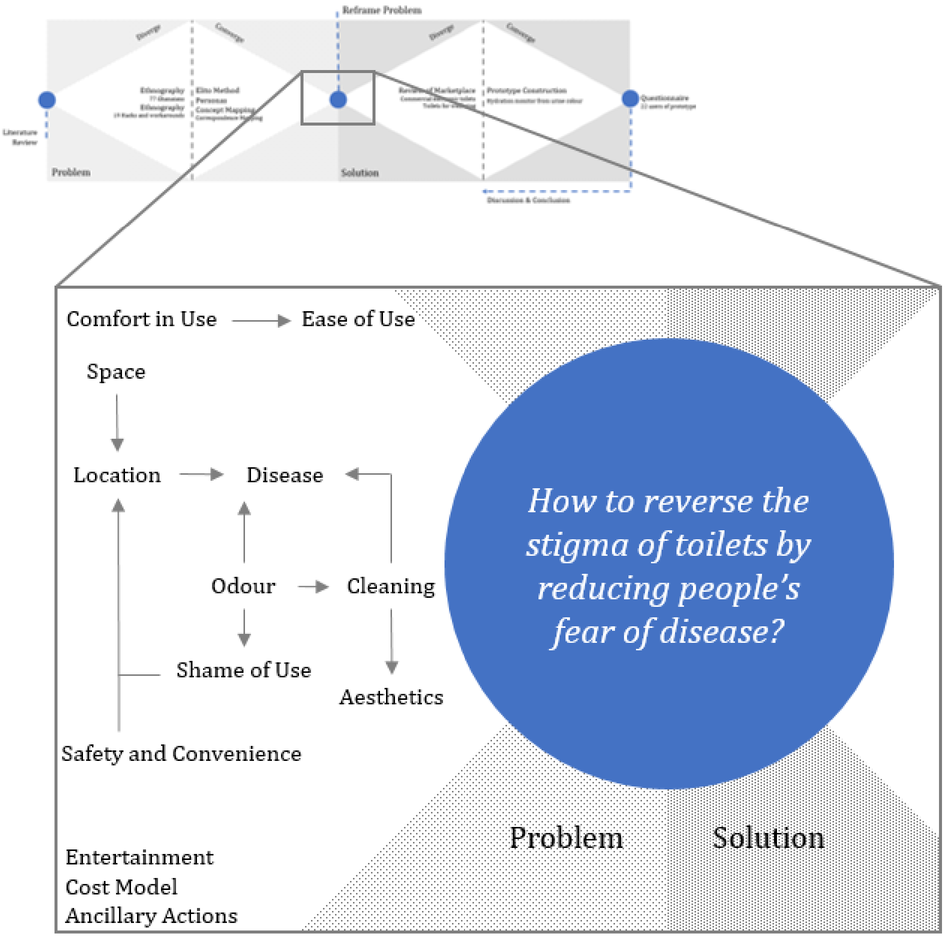


Figure 4-7 Reframing the Problem.

Magnified image of the reframed problem in the middle of Figure 1-6, informed by the insights gathered. Source: J Larsson

Themes and issues that were observed in relation to comfort and ease of use are considered periphery issues that is secondary to the need to change stigma[9]. As previously mentioned, the seated posture of a toilet user experience can change if the core of the concept has been explored first. In other words, a new seated position on the toilet may not create a revolutionary innovation, but a toilet concept centred around health and wellbeing that could have a new seated position may be considered a revolutionary innovation.

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[9] A brief investigation into seated positions has been explored in Appendix E, but was considered out of scope for the main body of the thesis.

4.7 Summary

This chapter converges on the reframing of the problem to find the value proposition. The research motivation was to understand how to make toilet user experiences aspirational to increase the uptake of toilet acquisition. Several methods were used to synthesise the insights from Chapter 3. Concept mapping demonstrates there is a clustering of emotive codes around the disease associated with toilets. The Elito Method reinforces the concept mapping by delving deeper into the underlying reasons for many of the observations. The personas generated from the ethnographic research, suggest that CBS toilets are purchased for the safety and wellbeing of others in the household. Therefore, the dominant emerging theme from this research so far suggests that there is a need to reverse the stigma created by the fear of disease and to clarify the benefits of ownership.

> *"The most "utilitarian" objects in the home, such as running water, toilets, electrical appliances, and the like, were all introduced into general use… Thus it is extremely difficult to disentangle the use-related function from the symbolic meanings in even the most practical objects. Even purely functional things serve to socialize a person to a certain habit or way of life and are representative signs of that way of life."*
>
> (Csikszentmihalyi & Rochberg-Halton, 1981)

The quote above by Csikszentmihalyi & Rochberg-Halton (1981), shows how challenging making a utilitarian product like a toilet, aspirational. However, since this quote, water has been turned into an aspirational product with multiple brands selling different designed water bottles marketed for vitality and wellbeing. The variety of designs are shown in Figure 4-8. The lead users from the previous chapter have indicated that the fear of disease is an important issue when it comes to toilet adoption and a reinforcement of a positive angle of wellbeing may be an effective method of disassociation with the contagious. Toilets and water are similarly aligned where hydration could potentially play the role of reinforcing wellbeing; toilets may be perceived as aspirational if they are associated with wellbeing much like water bottles are now.

Figure 4-8 Variety of design differences in the utility product of water.
Water has been transformed into an aspirational product by association with vitality and aspiration. Source: https://www.google.co.uk (accessed 20/04/2018).

Referring to the affordances of toilet user experiences in the Introduction of this thesis, the avenues for revolutionary innovation were source of water, source of fertiliser, source of energy and monitor of health and wellbeing. The intuitive step taken from the evidence, led to a value proposition that begins to satisfy the universal fear of disease by utilising the opportunity to monitor the user's wellbeing. Other issues identified from the insights are considered periphery issues. The following measures for success have been met:

- A toilet user experience value proposition from the insights.

The convergence of the findings are a valuable contribution to designers, sanitation experts and social scientists again and may benefit others looking to improve toilet user experiences. Admittedly there are infinite new directions a toilet may take, but the process presented here, indicates a wellbeing monitor may the most promising for revolutionary innovation. The process has limitations - *that are discussed in more detail in the Conclusion* - and may not be exhaustive, but a wellbeing monitor is an exciting direction to begin to satisfy the fears of disease while changing the stigma of toilets enough to reimagine toilet user experiences for revolutionary innovation.

Key Findings:

- Reframed problem is focused on resolving the stigma and the associations of disease with toilets.

- The compliment of analytic methods used together with empathic methods can contribute to understanding of latent needs.
- Hunches and intuition of the designer is encouraged in the synthesis of data in human-centred design, this chapter provides more rigorous methods.

Next Steps

Objective 2 has been met and the decision has been made to create a wellbeing monitor. The next chapter shall be dedicated to meeting Objective 3; reviewing what exists in the marketplace that relates to wellbeing monitors for toilets. This shall involve a survey of current technologies with embedded sensing and sensors available in the marketplace to inform the design of prototype for the experimental plan.

"If we refrain from questioning the status quo, it is… primarily because we associate what is popular with what is right."

Alain de Botton

5 REVIEW OF THE MARKETPLACE

Objective 3: Review the marketplace and horizon scan current solutions.

This chapter is dedicated to finding the gaps in the marketplace, to see if the needs identified have already been met. It begins with a review of the marketplace for intelligent toilets, followed by a review of sensors for measuring wellbeing, culminating with a discussion on how the Proof-of-Concept (PoC) prototype shall manifest in the next chapter for the experimental plan.

5.1 Need for the Research

The previous chapter identified a toilet for wellbeing monitoring as a viable value proposition. The hacks identified in the participatory photography indicates that there is a space in the market for low-cost solutions to user experience needs. This chapter will horizon scan for current technologies integrated with toilets and other health prognosticators from urine to benchmark the complexity and price point for the development of a new concept used in the experimental plan in the following chapter.

This chapter will explore what is available in the market, if they meet the insights from Chapter 3 and 4 and how successful the existing concepts are. The dead-ends and successful products will allude to the future direction of the concept and create a more resolved specification for the PoC prototype.

Expected Outcomes

The expected outcome will be a realisation for a concept that is informed by any opportunity spaces identified by a review of the marketplace. Ultimately the goal is to create an asirational user experience that will make people want to revisit it above traditional toilets because of the superior user experience. The delivery of this chapter will be a concise rationale for the prototyping of a new toilet concept. The definition of success for this chapter will be:

- A review of new and innovative toilets.
- A review of wellbeing monitoring toilets.

- Identification of opportunity space.
- Comparison with insights found.

5.2 Research Approach

Different search databases and search methods were considered. Mostly web searches on the search engine https\\www.google.com because it would give a representation of the toilets currently available. This chapter first focuses on commercially available toilets, then lab-based prototype health and wellbeing toilets then finally different sensors or sensing techniques to measure wellbeing.

5.3 Review of the Marketplace of Toilets

Looking at commercially available toilets in a wider context, displayed in Table 5-1. Interestingly, the leader in toilet innovation is Japan where we see many concepts focused on comfort while on the toilet, with few concept from the regions of the lead users in previous chapters. Nearly all the concepts identified in Table 5-1 follow an automatic bidet cleaning functionality with some more novel features such as playing music or illuminating the toilet bowl. the lead users from the previous chapters, A few targeted at the elderly that aid getting on and off the toilet or monitor frequency of use for a third party. Nearly all the commercially available toilets are *'add-ons'* to regular toilets, whether it is the toilet seat or a unit that attaches to the side. Only the Gael Force (2016) toilet is entirely different to regular W.C toilets as its electronics and sensors are used to incinerate the waste. The price of the commercially available toilets is relatively expensive and can be seen in Table 5-1.

Table 5-1 Commercially available electronic toilet technologies

Name	Description	Cost	Source
Neorest AC Washlet – Toto	Automatic bidet cleaning Automatic bidet drying Air extraction Heated seat Self-closing seat	*£11,390*	(Toto, 2017)
VIS7000 Bidet Toilet	Automatic bidet cleaning Automatic bidet drying	*£1,298*	(USPA, 2017a)

	Deodorising Heated seat		
Comfort Electric Toilet – Cinderella	Waste incineration Climate control	*£3,936*	(Gael Force, 2016)
Auto Electronic Toilet Seat	Automatic bidet cleaning Automatic bidet drying Self-closing seat	*£461*	(Mano Mano, 2016)
Automatic Seat LED Light	Automatically lit bowl	*£49*	(Wish, 2016)
CCP-7035 – USPA	Automatic bidet cleaning Automatic bidet drying Heated seat	*£1,195*	(USPA, 2017b)
Solo Powered Toilet Lift – Mountway	Seat raiser lift	*£1,250*	(Mountway, 2017)
Supreme BB 1000 – Bio Bidet	Automatic bidet cleaning Automatic bidet drying Deodoriser Heated seat	*£635*	(Bio Bidet, 2017)
AquaClean 8000 – Geberit	Automatic bidet cleaning Automatic bidet drying Deodorising	*£4,136*	(Geberit, 2017)
SFE-7035	Automatic bidet cleaning Automatic bidet drying Heated seat Deodoriser	*£1,178*	(Shower Toilet, 2017)
Safety 1st Smart Rewards Potty	Music playing Sticker dispenser for potty training reward	*£30*	(PreciousLittleOne, 2017)
Numi – Kohler	Auto-flush Automatic bidet cleaning Self-closing seat Heated seat MP3 Player	*$6,400USD*	(Caswell, 2011)

Smart Caregiver Tidy Toilet Sensor Pad	Pressure sensor detecting when a user is present measuring frequency	*$14.95USD*	(Val-U-Care, 2017)

Of these toilet sensing technologies, it is only Japan that have truly embraced *"exotic"* toilet technologies where Europe and the USA still predominantly remain with passive cistern systems (Brooke, 2002). With respect to wellbeing and diagnosing health, there are no examples in the marketplace except the Smart Caregiver Tidy Toilet Sensor Pad that measures arrivals to monitor the frequency of toilet trips for elderly users.

5.4 Review of Lab-based Wellbeing Monitoring Toilets

There are a few examples of toilets that prognosticate health or wellbeing, most of which are in PoC form, shown in Table 5-2. They range from an unobtrusive health screening toilet system for the treatment of diabetes and chronic heart failure, measuring ElectroCardioGram (ECG), blood pressure, body weight, body temperature, bio-impedance for total body water and urine analysis for glucose using indicator test strips, even a gigometer for detecting radioactive material (Horan, 1996; Rogers, 2016; Schlebusch, 2011; Schlebusch et al., 2015; Tsukamura et al., 1992).

Table 5-2 Top health monitoring technologies for toilets.

Sensing	Source
Measuring frequency of arrivals.	(Telehealth Sensors, 2015)
ECG, weight, temperature bio-impedance, urinalysis.	(Schlebusch, 2011; Schlebusch et al., 2015)
Urine specific gravity.	(Hydralert, 2016; Wynch, 2015)
Urinalysis, weight, blood pressure.	(Tsukamura et al., 1992)
Blood pressure, frequency of bowel movements.	(Rogers, 2016)
Radio activity of urine.	(Horan, 1996)
Reagent strips, specific gravity, electrical conductivity.	(Drury, 2013; Song, Boga and Wei, 2014; Wakefield, 2013; Wynch, 2015)

Observing the lab-based concepts and prototypes shown in Table 5-2, there is a trend for toilets to be used as health screening devices in future. The prototypes are presented for the elderly or clinically sick and measure for things such as blood pressure, except the concept of Rogers (2016) which is proposed to be used with a host of other connected devices that uses personal data to improve one's wellbeing holistically. The Hydralert (2016) product focuses on the health of industrial operatives using heavy machinery to ensure their concentration is not compromised by dehydration. What the prototypes and lab-based concepts do not do is explore the information that can be gained from human waste itself. What can be learnt from urine has been presented here and diet, hydration, renal function and even cardiovascular disease can be inferred from the components of urine (Brunzel, 2013; Premasiri, Clarke and Womble, 2001).

5.5 Review of Marketplace of Sensors

Human waste contains a lot of information about an individual's gastrointestinal track and renal function (Brunzel, 2013). Moreover, it may infer other determinants such as muscle metabolism and diet. Of the existing electronic toilets, none are health or wellbeing centric. However, the health determinants from human waste is well known and it is quite common to see hydration charts in shared toilet facilities similar to Figure 5-1.

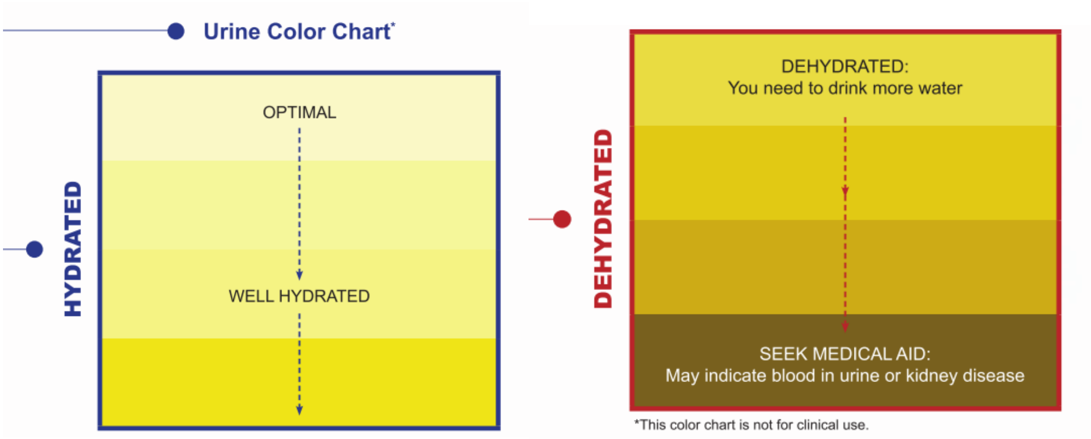

Figure 5-1 Urine colour chart.

Hydration and urine colour chart. Source: (U.S. Army Public Health Command, 2010).

Beginning with urine, the Specific Gravity (SG), osmolality and Electrical Conductivity (EC) indicate renal function - *how well the kidneys filter the solutes that passes through our system* (Brunzel, 2013). More simply, urine colour is universally known as an indicator of hydration, however SG is used above colour. The colour of urine also can tell a lot more about health as shown in Table 5-3. Further analysis of urine can be used as a non-invasive method of diagnosis of the kidney, measuring nitrogen compounds in urine can not only indicate renal and liver function, but also muscle metabolism from creatine and indicate risk of cardiovascular disease and hypertension from elevated levels of uric acid (Brunzel, 2013; Premasiri, Clarke and Womble, 2001).

Table 5-3 Simplified examples of the health determinants indicated by the colour of urine adapted from Strasinger & Schaub Di Lorenzo (2008) and Brunzel (2013).

Colour	Cause
Colourless	Recent fluid intake
Pale Yellow	Diabetes
Dark Yellow	Dehydration
Orange-Yellow	Phenazopyridine - Indicates Hypotension
Yellow-Green	Bilirubin oxidised to bilverdin - Indicating haemolytic anaemia
Green	Pseudomonas infection
Blue-green	Indican - Indicating renal failure
Pink	Red blood cells
Red	Myoglobin - Indicates heart attack
Port wine	Porphyrins - Indicates liver cancer
Red-Brown	Red blood cells oxidised to methemoglobin - Presence of blood
Brown	Homogentistic acid - Black urine disease
Black	Malignant melanoma

Faeces is far more complex and can tell one a lot more about the person. There are many factors that can be learnt from faeces, from diet to the function of each of the organs along the gastrointestinal track as well as bacteria, virus and parasite levels. The current tests to identify peculiarities range from macroscopic screening of form and colour, microscopic screening, odour, frequency, volume and chemical analysis for a large variety of proteins, fats, carbohydrates, enzymes (Brunzel, 2013). Stools can give an indication into a person's diet, whether they are eating enough fibre, but faeces can tell you a lot about the digestive tract of a person including the presence of viruses or cancer. In short, a great deal can be learnt from a person's urine or faeces.

When sat on the toilet, an individual's weight could also be measured and skin temperature, even heart rate if there are electrodes in the toilet seat. The combination of different measures may indicate an uncountable number of health determinants. To begin the research will focus on what can be learnt from urine and put what can be learnt from faeces to one side to save complexity. A unit that only analyses urine will be much easier both in terms of implementation and development.

Volume and Frequency of Urinations

Volume and frequency of urinations is a simple metric. Normal frequencies are six *urinations/cap/day* and volume varies from 600 to 1,800 *mL/cap/day*, with normal visits considered to be approximately 30-300 *mL/h* (Brunzel, 2013; European Hydration Institute, 2016; Rose et al., 2015). Volume and frequency are affected by how much you drink, but is also skewed by Cystitis or renal failure, both of which is very important for general health and wellbeing. Measuring how much someone expels can indicate how much they are drinking whether they have problems with their kidneys or bladder; for instance, when an individual excretes more than 500 *mL* of urine at night, the condition is termed nocturia and is a feature associated with chronic progressive renal failure (Brunzel, 2013).

> *"A person's diet, health, and exercise directly affect daily urine volume. The kidneys maintain a balance between fluid intake and excretion; however, their control is one-sided. Any excess fluid ingested but not needed can be excreted as urine, but the kidneys have a limited ability to compensate for lack of adequate fluid intake. As the quantity of metabolic solutes that need elimination from the body increases, so does the volume of water required to*

> *excrete them. If the body lacks adequate hydration, these solutes saccumulate in the body despite the best efforts of the kidneys to eliminate them."*
>
> (Brunzel, 2013)

There exist some sensors in the market for measuring the arrivals of toilet visits by use of pressure sensors pads (Telehealth Sensors, 2015). There seems to be no volume sensors for toilets on the market, although measuring liquid levels is common in other industries, for instance float sensors in car fuel tanks, capacitance probes for the food and beverage industry or ultrasonic range finders for water levels (Agrawal and Singhal, 2015). A fuel sender for a scooter fuel tank costs approximately £10. The cheapest ultrasonic range finders cost approximately £15.

Specific Gravity of Urine

Specific Gravity (SG) of urine is a measure of its density, in other words, the concentration of other molecules in urine. It is affected by hydration, renal function and abnormalities in antidiuretic hormone – *the hormone that makes one want to urinate*. The SG of urine ranges from 1.007 kgm^{-3} to 1.010 kgm^{-3}, any measurement below this range indicates hydration where the concentration of molecules in urine is diluted and any measurement above 1.010 kgm^{-3} indicates dehydration (Brunzel, 2013; Riebl and Davy, 2013).

Clinically a refractometer, urinometer or Harmonic Oscillation Densitometry (HOD) is used to measure the SG of urine. A refractometer measures the refractive index of the urine, implying the more refraction the denser the liquid (Armstrong, 2007; Strasinger and Schaub Di Lorenzo, 2008). A urinometer is a float that sinks more if the liquid is less dense. An HOD records the time taken for a sound wave to travel through the liquid (Strasinger and Schaub Di Lorenzo, 2008). Density of a liquid is affected by the temperature of the liquid, so ensuring samples are measured at the same temperature is also important. Refractometers and urinometers require verification by eye and are not electronic sensors that can be used digitally and HODs are far too expensive to explore.

Osmolarity of Urine

The osmolarity of urine is the concentration of solute particles per kilogram in the liquid and the level of renal concentration (Brunzel, 2013). It differs to SG since the weight of different molecules, primarily sodium and chloride, are nearly half the weight as the molecule of urea (Strasinger and Schaub Di Lorenzo, 2008).

> *"Specific gravity depends on the number of particles present in a solution and the density of these particles, whereas osmolarity is affected only by the number of particles present."*
>
> (Strasinger and Schaub Di Lorenzo, 2008)

Similar to SG, osmolality is affected by hydration, renal function and abnormalities in antidiuretic hormone where normal ranges for people are between 300-1200 *mosm/kg* (European Hydration Institute, 2016). As SG, the measurement of osmolarity is dependent on the temperature of the sample. Osmometers are very expensive and complex machines that cost approximately £1,000 for one unit.

Electrical Conductivity of Urine

EC of urine is affected by the presence of salts, the more saline urine is, the less resistance because conductivity, in general, is a non-linear function of electrolyte concentration in solutions (Kavukcu et al., 1998). The normal ranges of urine are between 1.1 *mS* and 33.9 *mS* and EC again is skewed by temperature (Fazil Marickar, 2010).

> *"Conductivity is more reliable in determining the electrolyte concentration and is more practical. While urine osmolality and specific gravity are effected by solutes other than electrolytes, conductivity is only found to be related to sodium and uric acid."*
>
> (Kavukcu et al., 1998)

The resistance of the liquid is measured by use of a conductivity probe – *a cathode and anode*. The approximate costs found online are around £100, however this can be achieved through conductive probes and opensource electronics.

Colour of Urine

The characteristic 'yellowness' colour of urine is primarily due to the pigment of urochrome and the more yellow urine is implies the concentration of urochrome is higher – *i.e. the SG is higher* (Brunzel, 2013). Colour variations from yellow can indicate the presence of a disease, a metabolic abnormality, food or drugs that have been ingested or from excessive physical activity or stress. Table 5-3 outlines how the colour of urine differs for different causes.

The chart from the U.S. Army Public Health Command (2010) in Figure 5-1, shows that different colours of urine relate to hydration, however it states that colour is not for clinical use. Colour is not recognised as a clinical method for evaluating hydration because it is a subjective guide as it is determined by non-repeatable means (Riebl and Davy, 2013). Despite this, colour is as effective as SG as a hydration indicator and can indicate many more issues (Armstrong et al., 1998; Fletcher et al., 1999; Strasinger and Schaub Di Lorenzo, 2008).

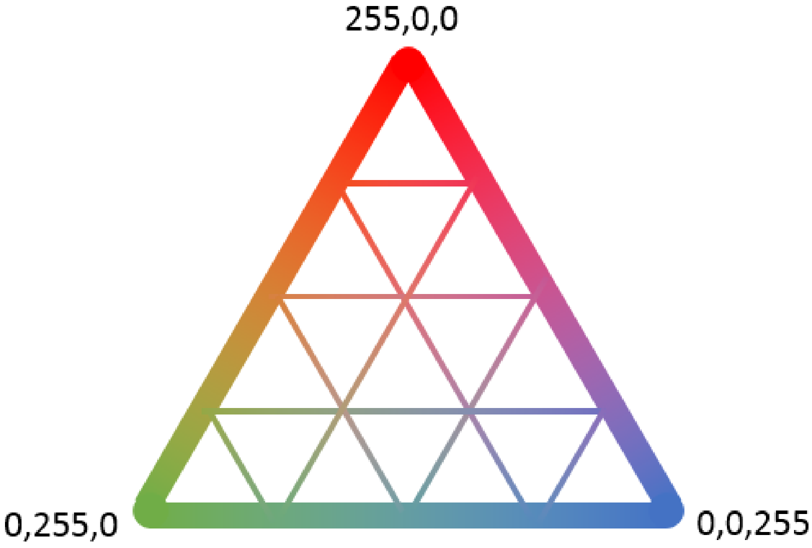

Figure 5-2 Colour spectrum of RGB combinations.

Ternary plot to show the colour spectrum according to RGB combinations from 0-255 for Red (R), Green (G) and Blue (B). Source: J Larsson.

Previous studies have classified colour subjectively, although sensors do exist for colour. Based on an additive colour sensing of Red, Green and Blue (RGB)[10], sensors for colour costs approximately £8.00 per sensor. Sensing colour using the same theory, using a photoresistor, photodiode or phototransistor measuring absorption with red, green and blue filters or reflectance with red, green or blue illumination, the theory of additive colour can be seen in Figure 5-2. The approximate cost of this concept is just pennies.

Table 5-4 Colour hydrations from (U.S. Army Public Health Command, 2010).

Colour	R	G	B	
⬜	249	243	207	
🟨	247	244	173	
🟨	247	239	154	
🟨	245	224	43	Hydrated
🟨	240	219	94	Dehydrated
🟨	231	202	38	
🟨	212	174	41	
🟫	128	102	41	

Inferring hydration is the exciting avenue to explore, where colour has not been utilised as a quantifiable method for sensing. Colour is universally known to indicate one's hydration, but because of the difficulties in quantifying colour, it is not used in a clinical context (Armstrong, 2007; Brunzel, 2013; European Hydration Institute, 2016). The proposal made here, is that if one could measure the colour of urine then it would be a contribution to people wishing to assess their hydration. A person's hydration is inferred clinically from measuring several factors of urine including osmolarity, EC, frequency of urinations, volume, colour and SG (European Hydration Institute, 2016). There seems to be a great

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[10] How additive RGB colour combinations make up the colour spectrum is shown in Figure 5-2.

opportunity to reliably quantify the colour of urine to determine hydration repeatedly that then allows further determinants to be discovered on future calibration.

Though generally accepted as a vital source of life, water is often overlooked in terms of nutrient intake and the lack of which serves several critical functions, After 1-2% of body mass loss of water, one's cognitive and motor skills are impaired, after all the body is 50-65% water (European Hydration Institute, 2016; Hillyer, Menon and Singh, 2015). The performance of cognitive function such as concentration, vigilance, memory, and critical thinking has been observed to decline; or more simply if you're dehydrated you make more mistakes (Riebl and Davy, 2013). The long-term consequences and severity of dehydration on cognitive ability are unknown (Popkin and Rosenberg, 2011).

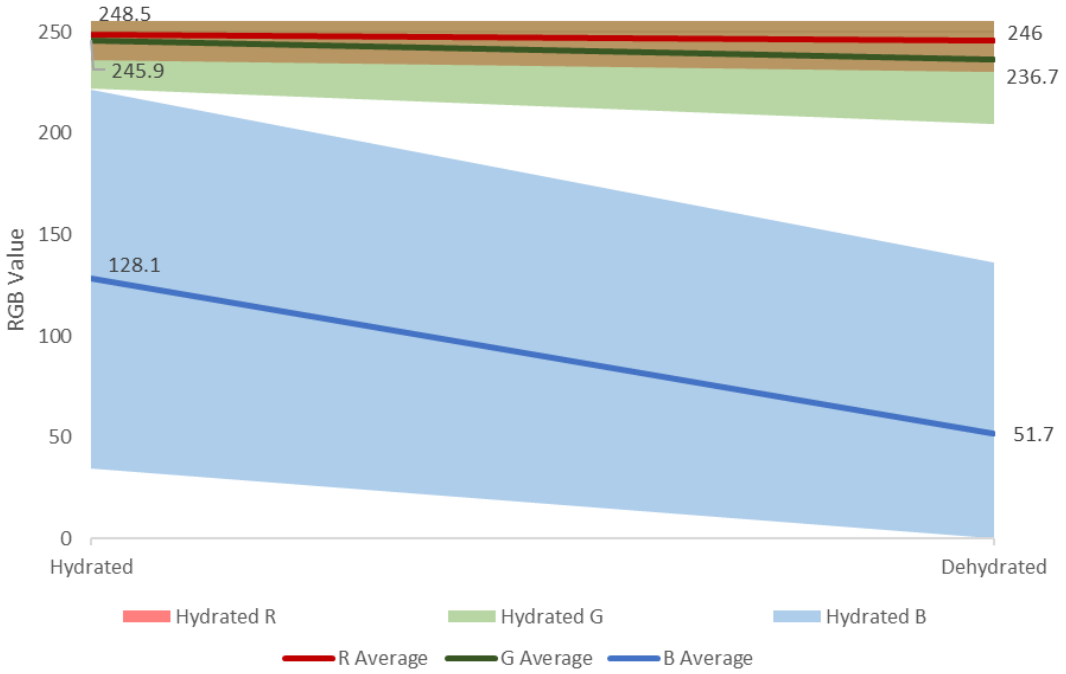


Figure 5-3 Dehydration threshold for RGB colours of urine.

Graph to show dehydration threshold for urine colour charts from a search on https://www.google.co.uk/ (06/12/2016).

Comparing ten different hydration charts from the search engine https://www.google.com/images shown in Table 5-4, slight variations between hydrated thresholds and dehydrated thresholds of RGB values can be seen. Hydration levels are most dependent on blue level from RGB, an average hydration level of 128 and dehydration of 52. Average drops across red green blue values of 2.5, 9.2 and 76.4 respectively as seen in Figure 5-3.

5.6 Analysis of Findings

From a broad search of commercial toilets, there are lots of electronic toilets that use electronic sensors to improve personal hygiene and the overall comfort of the experience of defecation. The commercially available electronic toilets are relatively expensive and are unobtainable for most people - *certainly out of reach of those in Kumasi Ghana* (Ye et al., 2014). Japan is the leading country for innovation in the world of toilets, there are a *"flourishing industry of sanitary fixtures"* (Leone, 2012).

> *"Japan makes the most advanced, remarkable toilets in the world. Japanese toilets can, variously, check your blood pressure, play you music, wash and dry your anus and 'front-parts' by means of an in-toilet nozzle that sprays water and warm air, suck smelly ions from the air, switch on a light for you as you stumble into the bathroom at night, put the seat lid down for you (a function known as the 'marriage-saver') and flush away your excreta without requiring anything as old-fashioned as a tank."*
>
> (George, 2008)

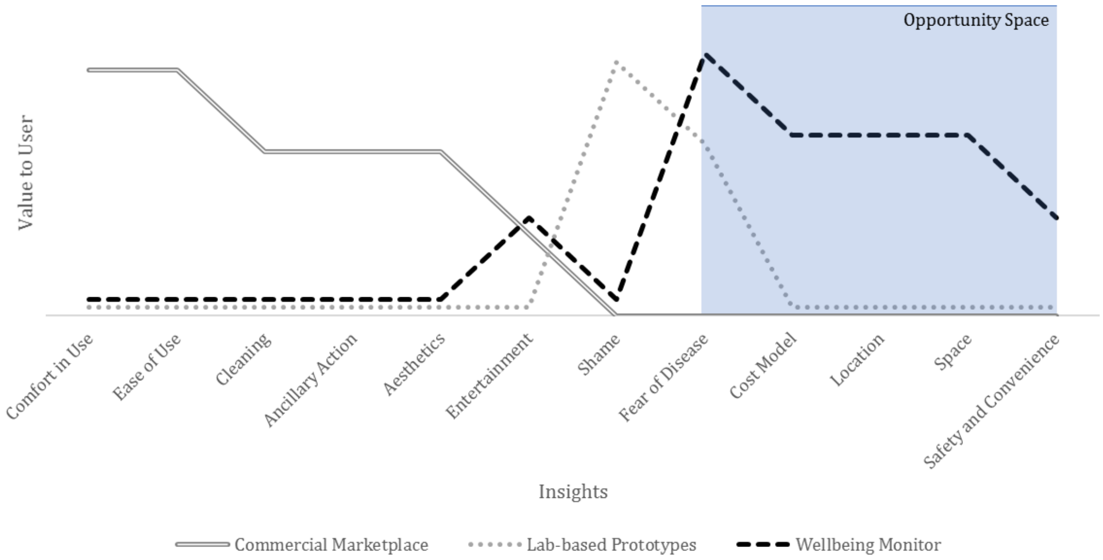


Figure 5-4 Value curve of Wellbeing Monitor versus marketplace.

Graph to show Value Curve and opportunity space of commercial toilets in the marketplace, lab-based prototypes and potential of a wellbeing monitoring toilet versus the insights gathered based on the Value Curve by (Chan and Mauborgne, 2015). Source: J Larsson

Figure 5-5 (Left) Angular toilet (Right) Black toilet.

Examples of creeping featurism by Norman (2013) for differentiation (Left) Changing smooth freeform to angular (Right) Making toilets black from white. Source: Kohler Intelligent Toilet.

The gaps in market are identified by plotting the insights found in Chapter 3 and 4 against the concept of a wellbeing monitor versus the marketplace toilets in a value curve in Figure 5-4 (Chan and Mauborgne, 2015; Kim and Mauborgne, 1997). This demonstrates that there is space for an affordable wellbeing monitoring toilet concept, that may meet the underlying fear of disease. We can see that the toilets in the marketplace meet a selection of latent needs, namely; *Comfort in use, Ease of Use, Cleaning, Ancillary Actions, Aesthetics, Entertainment and Shame* from Table 3-13. However, there is opportunity space for a wellbeing monitor concept to meet the needs of *Fear of Disease*, *Cost Model*, *Location*, *Space* and *Safety and Convenience*. The health focused lab-based prototypes are for chronic illnesses like cardiovascular disease or diabetes and ultimately reinforce a negative connotation with toilets; a toilet that promotes positive wellbeing may alleviate user's underlying concern with the invisibility of disease. Hydration appears to be a promising avenue to investigate to indicate a user's wellbeing. Additionally, the review of the marketplace of sensors available for measuring hydration, suggests that a low-cost colour sensor is achievable.

The commercially available *'high-functioning'* toilets are an example of what Norman (2013) calls *"featurism"*; a by-product of incremental innovation. A company may add new features to differentiate from the competition or because the offering has been adapted to accommodate multiple viewpoints. A change of meaning to a wellbeing monitoring toilet will differentiate from the commercially available toilets in the marketplace that are examples of creeping featurism like the toilets shown in Figure 5-5.

5.7 Summary

The findings of the insight gathering in Chapter 3 and the translation of the insights in Chapter 4 indicate a toilet for wellbeing monitoring would be an avenue to explore in producing an aspirational toilet user experience. This chapter explores the options and sets out a rationale for how a toilet that monitors the user's hydration would provide more value based on the findings from the ethnographic research, current literature and the current and future marketplace of toilets. Hydration is a complicated determinant to measure since it is inferred by numerous parameters. Of the six that can be measured from urine; SG, EC, colour, volume, frequency and osmolality; colour and conductivity seem the most viable for a low-cost concept. Colour has not been quantitively measured in literature, but low-cost sensors have been found that can repeatedly measure colour, where increases in yellow colour implies an increase in concentration of urobilinogen and thus water content of the body (Strasinger and Schaub Di Lorenzo, 2008). The following measures for success have been met:

- A review of new and innovative toilets.

There are several electronic toilets that focus primarily on anal cleaning or comfort and are relatively expensive. The research shows there are a few lab-based or prototype toilets that investigate toilets as prognosticators of health, but are for specific needs and not proposed as aspirational products.

- A review of wellbeing monitoring toilets.

There has not been much investigation into what can be learnt from one's waste to promote wellbeing. The existing health monitoriing toilets are still in prototype or lab form and are comprehensive health screening devices that appear to be expensive.

- Identification of opportunity space.

The findings of this chapter are valuable contributions for designers, sanitation experts and health professionals who are interested in the using toilets as health and wellbeing monitors of users. There are few wellbeing focused electronic toilets, with the majority focusing on comfort and ease of use. They are marketed for the higher end of the earning spectrum with little at a low-cost price-point. The techniques for inferring hydration from urine are influenced by other diseases or renal complications. Currently no one device measures multiple parameters at once for an affordable price. A wellbeing monitor toilet using colour as the primary parameter with some of the other parameters to measure hydration for confidence may be a low-cost and unique product for measuring wellbeing.

- Comparison with insights found.

The insights from Chapter 3 and 4 show the stigma and the fear of disease are the biggest problems facing the adoption and user expereince of toilets.

Key Findings:

- The user experience of the toilets that are centred on comfort are a novel experience and are intriguing, but their price-point makes them inaccessible for many people.
- Few concepts are focused on health and wellbeing; the lab-based concepts that do are comprehensive health screens.
- Colour maybe a low-cost method of inferring user hydration.
- The concept of the wellbeing monitor is inherently different from the rest of the marketplace.
- Others using a latent needs approach may also benefit from the avoidance of *"featurism"* in an attempt to produce aspirational user experiences.

Next Steps

This chapter meets Objective 3 to review the marketplace of what currently exists and presents the rationale for a toilet that measures hydration. The next chapter will aim to meet Objective 4 to create the hydration monitor device, the chapter shall:

- Provide a rationale for using low-cost prototyping equipment and detail why it is appropriate to integrate sensors. This will be supported with examples of other research projects using similar technologies.
- Prove the concepts principle by simulating the technology of simulant and urine.
- Discuss recommendations for advancing the complexity of the concept.

Chapter 6 will show the value of using rapid prototyping techniques with low-energy and low-cost electronics, whilst demonstrating the lessons learned from proving the principle of operation.

"Humans are the reproductive organs of technology. We multiply manufactured artefacts and spread ideas and memes."

Kevin Kelly

6 PROOF OF CONCEPT FEASIBILITY

Objective 4: Develop a toilet for the experimental plan based on the gaps identified by insights and marketplace.

This chapter is dedicated to completing Objective 4, the development of a prototype for the experiemental plan; a low cost hydration monitoring technology for the user's urine. It begins with the method considered and a rationale for the technology chosen, followed by the development of the Proof-of-Concept (PoC) prototype.

6.1 Need for the Research

The review of the marketplace indicated that there are currently no toilets commercial or otherwise that may meet the latent needs of changing the stigma and fear of disease at an affordable price-point. The PoC prototype is being constructed to enrich the user experience by providing them with data from monitoring wellbeing. To develop a prototype that is suitable for user testing, to determine whether the data that indicates wellbeing will be aspirational, the technology principle must first be proven. For these reasons, it is vitally important that no other variables influence the user experience. In meeting the aim of the research, one crucial objective is to create and build a functional prototype that is suitable for evaluation and testing.

The PoC will be made to identify the colour of urine and thus indicate the user's hydration. Theoretically the user can implement this technology to track and monitor their results over time. This chapter will investigate how the colour of urine may determine hydration. The theory according to literature is increase in the yellow colour of urine implies an increase in the concentration of urobilinogen in the urine, indicating body water levels are low and thus hydration levels are low (Strasinger and Schaub Di Lorenzo, 2008).

Expected Outcomes

By the end of this chapter, a unit that reliably measures hydration is made to use for user testing in the following chapter. The unit shall remain visually similar to normal toilets or urinals so its form does not affect the outcome of the test in a setup like Figure 6-1. The focus is on the data and information captured and whether it is aspirational and therefore the technology will be designed to be compact, discrete and low-cost to meet the needs from the marketplace analysis. The intention is to show the feasibility of the PoC in indicating a user's hydration through colour.

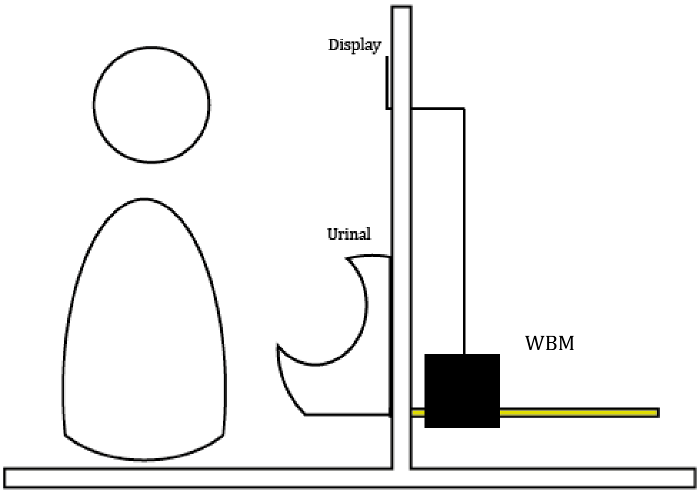


Figure 6-1 Proposed test setup.

Proposed experimental test setup for human user testing. Source J Larsson

The accuracy of the prototype will be the focus of this chapter and success will be defined by:

- The ability to identify colour and how correlated colour is to other parameters of urine that infer hydration status.
- The technical limitations of the prototype.
- Minimisation of external variables on user experience.

An aspirational user experience is not necessarily a new product, but the previous chapters have indicated that a wellbeing monitoring toilet may make an aspirational user experience. For this reason, an emphasis on the wellbeing data is the focus and so the prototype and environment must and should be as least distracting as possible.

6.2 Research Approach

An alternative approach to constructing a working prototype could be a questionnaire of whether people would like a toilet that detects hydration. As stated in the Literature Review, people may not envisage the future and may not know explicitly why they like or dislike certain products (Bertrand and Mullainathan, 2001; Cooper and Evans, 2006; Fellman, 1999b; Goffin et al., 2012; Vianna e Silva et al., 2011). The survey approach was rejected since a prototype that people can see and understand will give far more reliable information. Another method may be to create a mock device that randomly told a user whether they were hydrated or not. This method would have been quicker, but was rejected because of the ethical implications of fabricating hydration and how they may act with the false information. Therefore, a functional prototype that measures the participant's hydration was selected as the most appropriate method to capture authentic feedback from users.

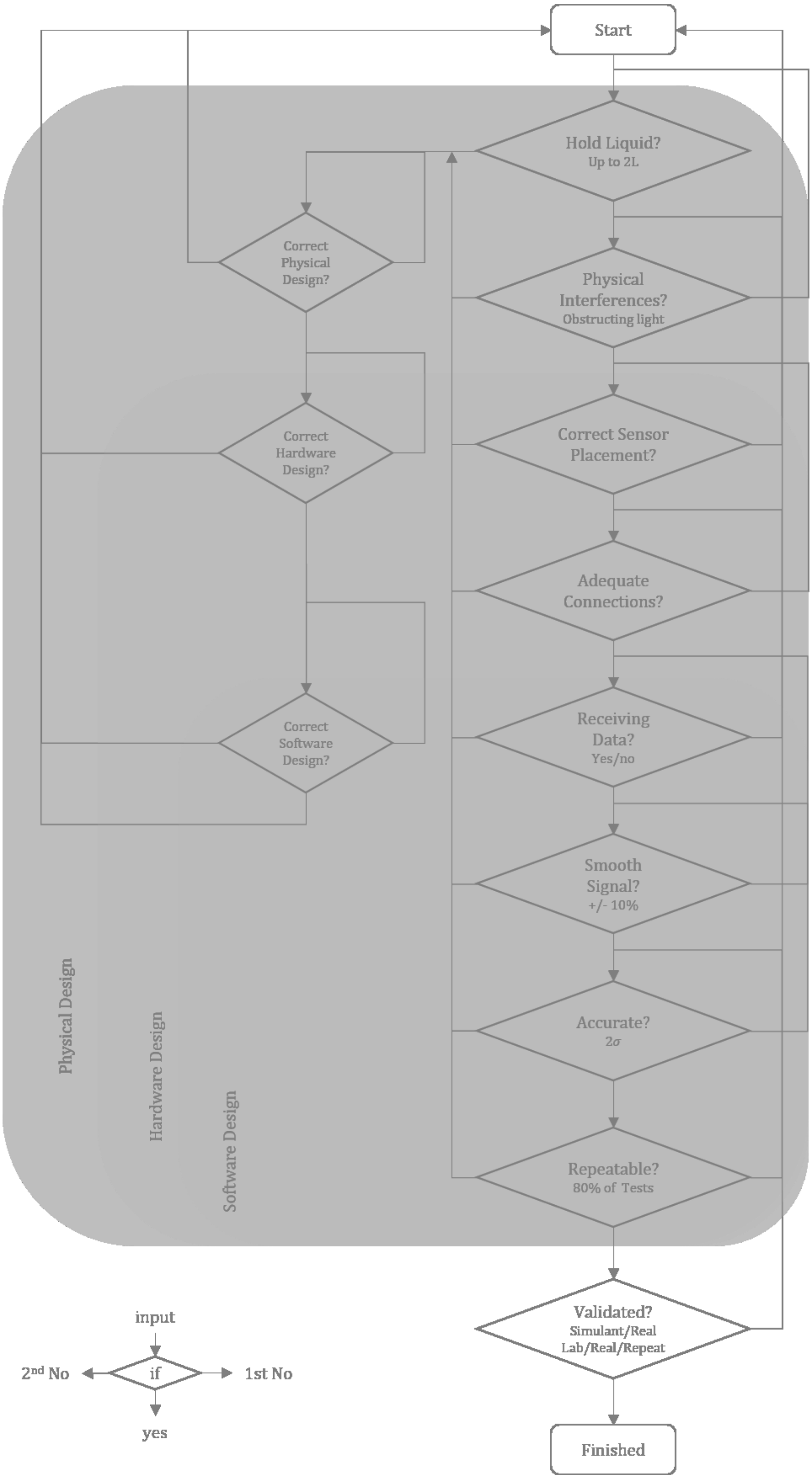
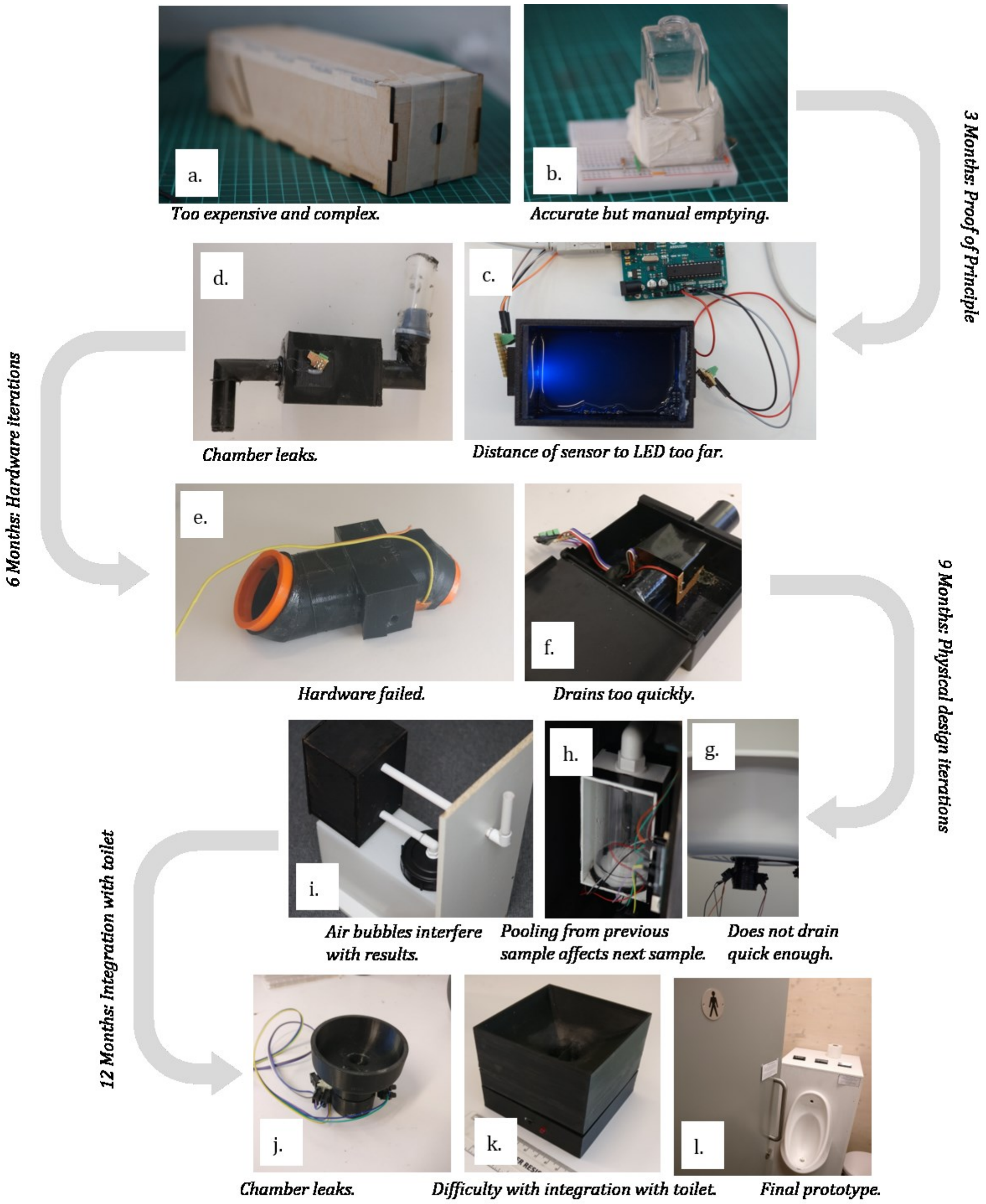


Figure 6-2 Flow chart of tests used to prove the principle.

Flow chart of tests to prove the principle. Source: J Larsson.



Too expensive and complex.
Accurate but manual emptying.
Chamber leaks.
Distance of sensor to LED too far.
Hardware failed.
Drains too quickly.
Air bubbles interfere with results.
Pooling from previous sample affects next sample.
Does not drain quick enough.
Chamber leaks.
Difficulty with integration with toilet.
Final prototype.

Figure 6-3 A selection of 12 prototypes of the Wellbeing Monitor.

A selection of 12 of the different physical design prototypes of the Wellbeing Monitor. Source J Larsson.

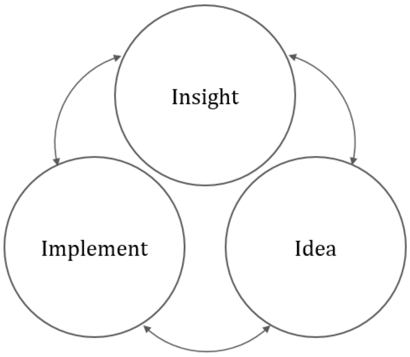


Figure 6-4 The Design Thinking process.

The Design Thinking process. Source: Adapted from (Brown, 2008).

The development of the WellBeing Monitor (WBM) followed the process flow chart shown in Figure 6-2, a systematic process of covering the physical design, the choice of hardware and the design of the firmware. This flowchart identifies problems and provides avenues for investigation to increase reliability and accuracy of the WBM. An update to each prototype, new piece of hardware or version of firmware is verified by running through the flow chart first checking whether modifications have affected the ability to hold liquid, that there are no interferences with the sensors and that the signal received is smooth and repeatable. If for instance the signal is not smooth, a check on the physical design and any interference with sensors before the firmware is interrogated. Figure 6-3 shows 12 of the different adaptions made to the physical design of the WBM over a period of approximately 12 months when problems were found and physical adaptations were needed. Over the same period, over 20 versions of the firmware were also made to minimise noise and increase repeatability. More detail of the WBM prototype build can be found in the Appendix C.

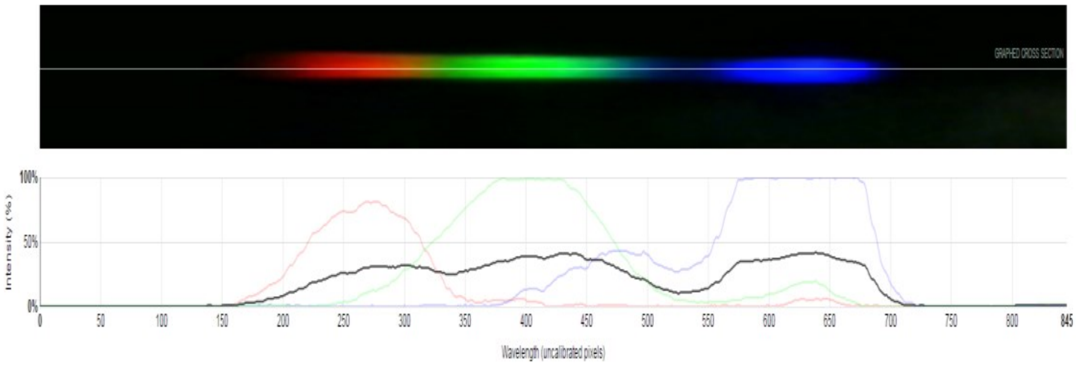


Figure 6-5 Spectrometer results from sample.

Received spectrum of sample (Top). Graph to show light intensity versus wavelength (Bottom). Source: J Larsson

First the colour capturing capabilities of the WBM are tested and the results displayed. Progressing on from this, a comparison of colour absorbed of simulant urine will be tested against the Specific Gravity (SG) of simulant. Then a comparison of colour of urine against its corresponding SG. The details of the development can be found in the Appendix C and urine was collected with ethical approval from Cranfield University's Ethics board.

The creation of solutions is a non-linear process of gaining insight by observation, generating ideas and implementing those ideas through various means of prototyping, shown in Figure 6-4. As more and more problems are identified and resolved, the fidelity of the prototype increases. Once the prototype is at an adequate standard and it is confident that many problems have been identified and resolved, then optimisation of the concept can take place. An example of the evolution of the concept of triggering the analysis of the urine using the Design Thinking Process shown in Figure 6-4:

***Idea**: hold urine, analyse then flush with solenoid valve.*

***Implement** and observe*

***Insight**: Next result is diluted if user does not flush after use.*

***Idea**: flush after ten seconds.*

***Implement** and observe*

***Insight**: Unit does not know if urine present.*

***Idea**: Contact probes to make and break switch using urine.*

***Implement** and observe*

***Insight**: Solenoid valve is not necessary.*

***Idea**: Allow urine to backup and control the trickle out until empty.*

***Implement** and observe*

***Insight**: Contact probes can measure electrical conductivity.*

***Idea**: Measuring electrical conductivity of urine is also an indicator of hydration.*

***Implement** and observe*

***Insight**: The time until vessel is empty indicates the volume.*

***Idea**: Measuring volume of urine and frequency of visits are also indicators of hydration.*

The final concept then becomes a urine hydration monitor measuring colour through the absorption of RGB light, specific gravity from the diffusion of light, electrical conductivity by the conductivity across two contact probes and finally volume and frequency from timing the contact between the probes.

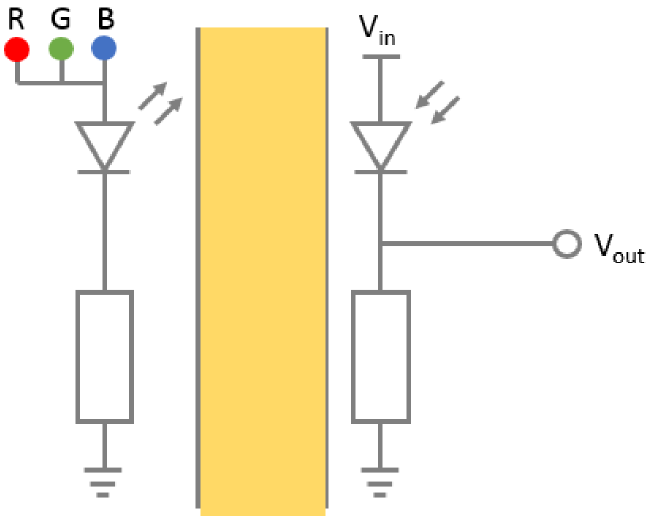


Figure 6-6 Assessing the colour of urine schematic.

The simplified schematic of how the configuration of RGB LED and photoresistor may classify the absorption of colour using a potential divider. Source: J Larsson.

To remain agile and progress the design further, tests have been chosen to be done on relatively small samples since the progression of the concept may be slowed by the collecting of and storing of urine samples. Once the concept is refined to a higher resolution prototype then more accurate tests are undertaken.

6.3 Prototype Construction

Originally, a spectrometer was constructed to break apart the light spectrum to understand components of urine to a high resolution shown in Figure 6-3 (a) and the results on simulant are shown in Figure 6-5. This was built from a webcam, two razor blades, a laser cut wooded box and controlled by a Raspberry Pi; a pocket sized personal computer with a Linux operating system installed on it.

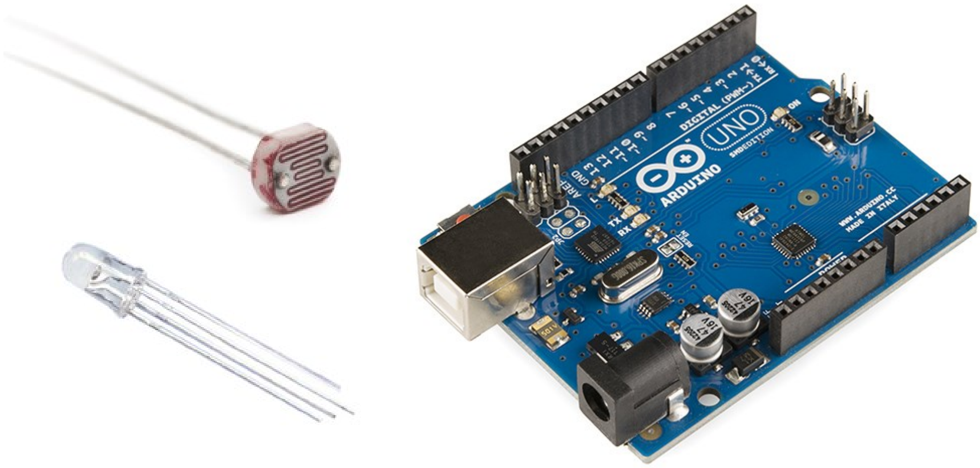


Figure 6-7 Low-cost wellbeing monitor components.

RGB LED, photoresistor and Arduino micro controller used in low-cost wellbeing monitor solution based on colour. Source: https://www.google.co.uk/images.

With a view to reduce the complexity and cost of the unit, measuring the receiving intensities of light of a photoresistor of each colour Red, Green and Blue (RGB) from a Light Emitting Diode (LED), one can determine the colour from the absorption and the light for each colour as a type of *'naïve spectrometer'* shown in Figure 6-6. The RGB LED is located on the opposing side to the photoresistor in the container; the container is sealed and black to reduce noise in the data readings that is captured by an Arduino. These components are shown in Figure 6-7.

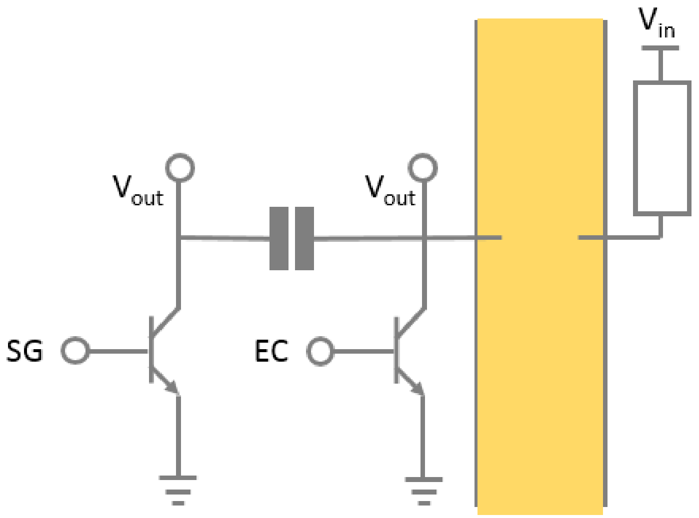


Figure 6-8 Assessing the electrical conductivity and specific gravity of urine. *The simplified schematic of how the configuration of a potential divider and RC circuit maybe used to classify the electrical conductivity and capacitance of the urine. Source J Larsson.*

The principle functionality of the WBM is the identification of RGB value of the urine through the absorption of colour from an RGB LED as shown in Figure 6-9. The device also infers hydration through four of the remaining five parameters; Specific Gravity (SG), Electrical Conductivity (EC), Volume and Frequency from European Hydration Institute (2016) that are detailed in Table 6-1 and can be seen in Figure 6-8.

Table 6-1 The final Wellbeing Monitor concept's functionality.

Urine Parameter	Sensor
Colour	RGB absorption – RGB LED and photoresistor A.
Specific Gravity	Capacitance.
Electrical Conductivity	Contact probes.
Osmolality	N/A
Volume	Contact probes and time.
Frequency	Contact probes and time.

Figure 6-9 shows the process of sweeping through the colour spectrum while the photoresistor measures the collected intensities of light graphically 100 times a second. This is the equivalent of transferring from blue to red through magenta. This sketch occurs again two more times for each of the primary colours from red through yellow to green then again through cyan back to blue. Figure 6-10 shows there too is a strong correlation between the amount of blue light and red light being absorbed by the urine and the urine's SG.

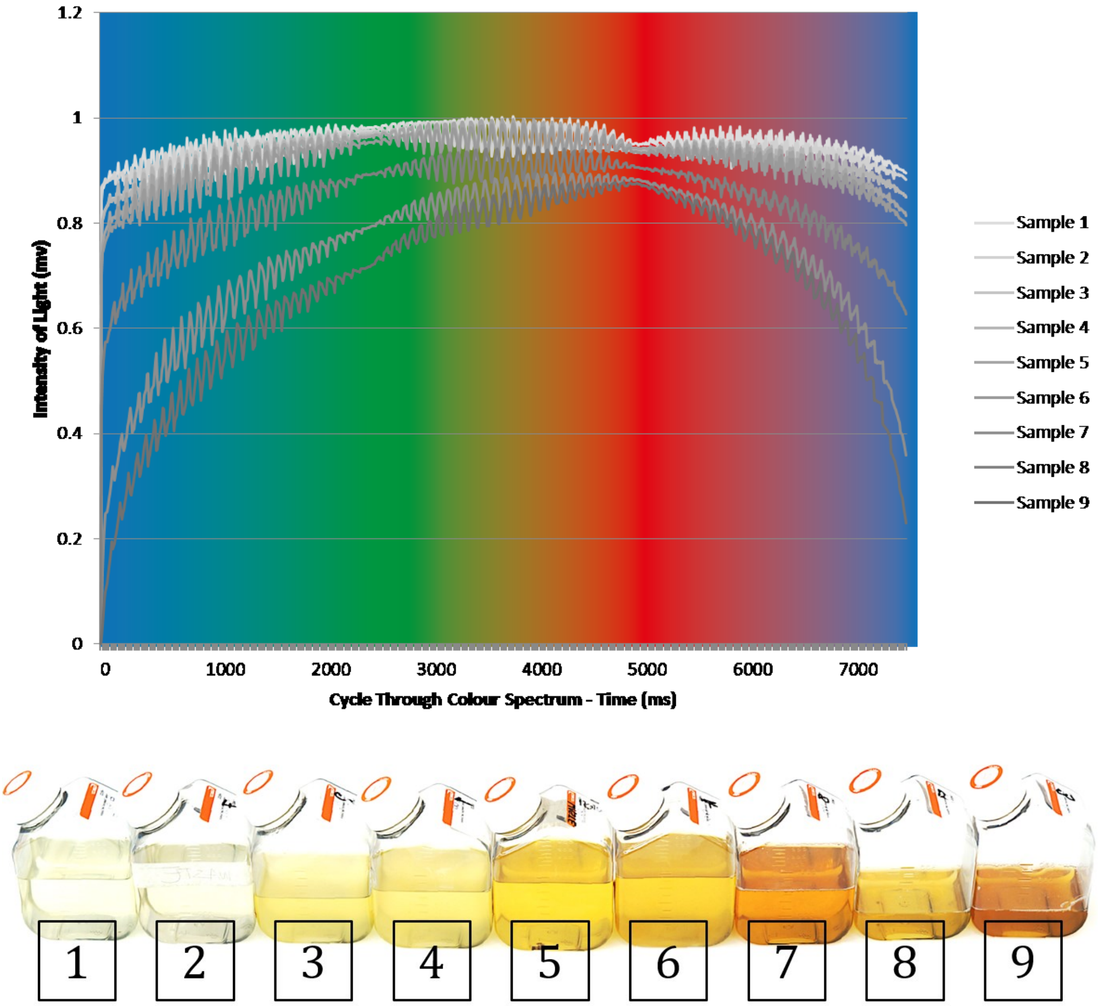


Figure 6-9 Light absorbed by urine samples.

Graph to show the light received by photoresistor throughout the changing colour spectrum for nine samples of urine. The nine samples of urine varying in specific gravity from 1.001 (Sample 1 far left) to 1.025 (Sample 9 far right). Source: J Larsson.

Figure 6-11 shows the received values of RGB colours from the WBM for 64 different samples of coloured liquid made by using different combinations of food colouring – *combinations of increments of four drops for red dye, blue dye and yellow* *dye*. The results show there are strong correlations to the amount of RGB detcted across all the samples and the ability to identify the liquid colour is achievable.

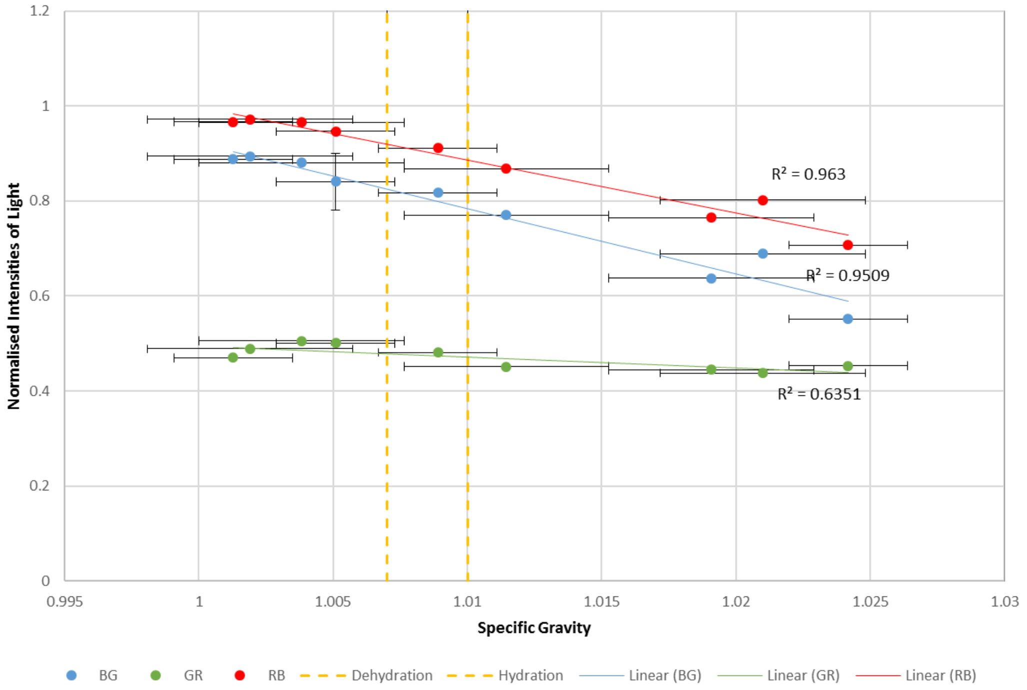


Figure 6-10 Specific gravity versus light absorbed.

Graph to show the relationship between specific gravity of urine and the integral amount of light received for blue to green, green to red and red to blue light. Source: J Larsson.

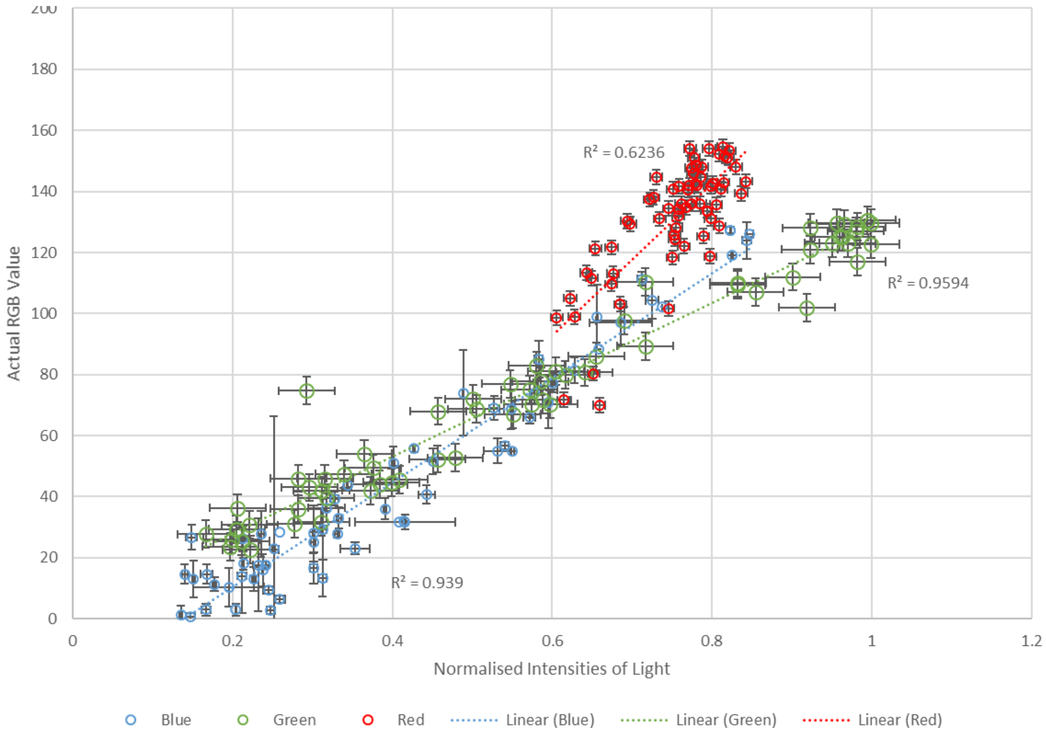


Figure 6-11 Assessing the colour of samples.

Graph to show the regression to colour swatches using RGB signatures from photos of coloured water. Source: J Larsson.

The equations given by the regression curves are given in (6-1), (6-2) and (6-3) where the RGB values can be calculated from the intensities of received light of red I_r, green I_g and blue I_b. From which, the RGB values of the samples in Figure 6-9 can be recalculated from the results of Figure 6-10 and are shown in Table 6-2.

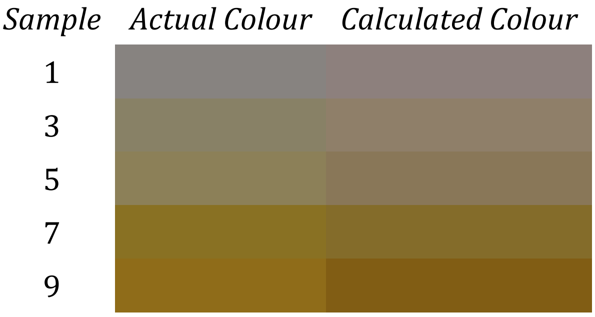
$$\mathrm{R} = -0.1859\mathrm{I_r}^2 + 19.918\mathrm{I_r} - 380.38 \qquad \textbf{(6-1)}$$

$$\mathrm{G} = 0.0018\mathrm{I_g}^2 + 2.0355\mathrm{I_g} + 5.0277 \qquad \textbf{(6-2)}$$

$$\mathrm{B} = 0.0298\mathrm{I_b}^2 + 1.3858\mathrm{I_b} - 6.8028 \qquad \textbf{(6-3)}$$

The calculated RGB colour swatches were obtained by taking the average RGB values from the eye dropper tool from Microsoft PowerPoint.

Table 6-2 Actual colours of urine versus calculated colours.



Sample	*Actual Colour*	*Calculated Colour*
1	🟫	🟫
3	🟫	🟫
5	🟫	🟫
7	🟫	🟫
9	🟫	🟫

As with the colour of urine, the EC of samples were tested using the conductivity probe configuration shown in Figure 6-8. The readings from the Arduino were well correlated, but repeatability was much harder to achieve as shown by Figure 6-12.

Minimising Noise

Solutions to noise in the results may come from changes to the physical design, hardware and firmware. The noise itself will be from external interference so the priority is to minimise interference in the physical design and hardware. For instance, air bubbles interrupt the path of light between the RGB LED and the photoresistor and one may observe a lot of changes made to the physical design to address this in Appendix C. Other sources of noise were choice of hardware components, such as the power source. Figure 6-13 shows the noise measured on the photoresistor with different power sources; USB, power-bank and 9v battery.

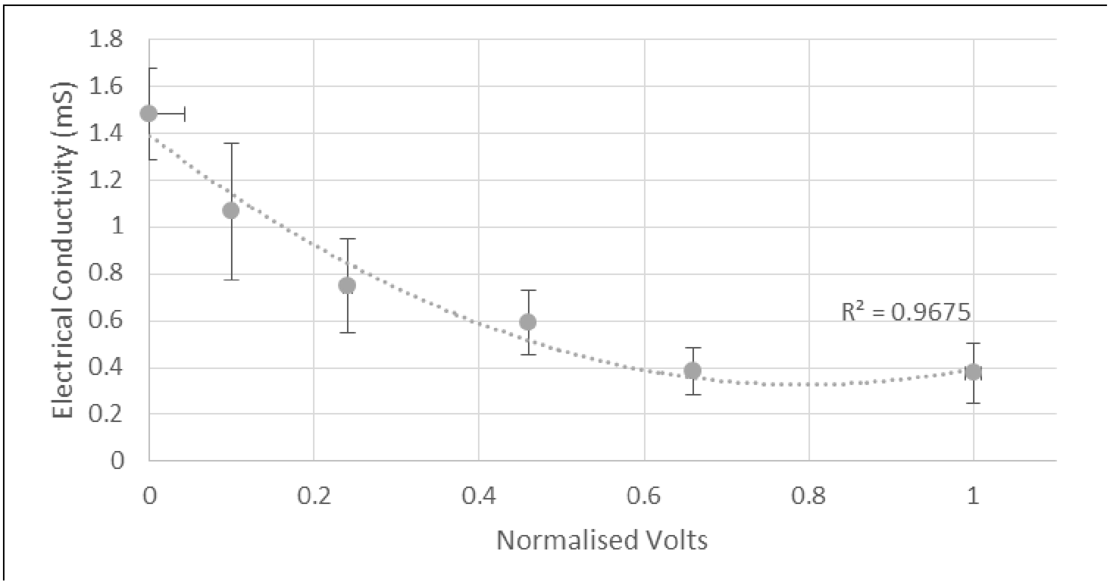


Figure 6-12 Electrical conductivity of samples.

Graph to show normalised sensor readings versus electrical conductivity of six samples. Source: J Larsson.

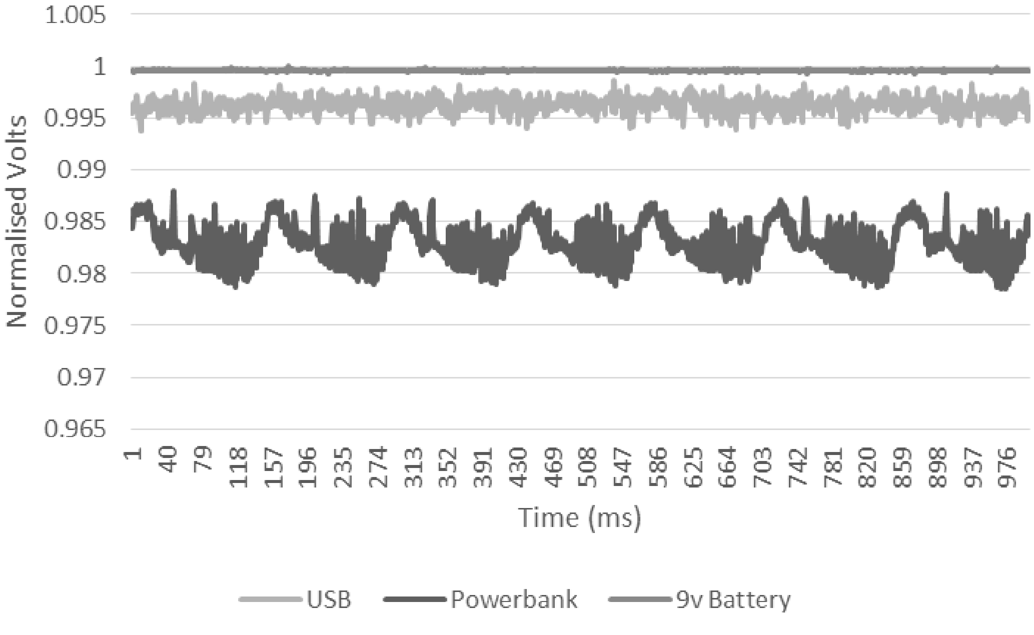


Figure 6-13 Noise of different power sources.

Graph to show normalised analogue readings powered by USB, power-bank and 9v battery. Source: J Larsson.

Physical design parameters of interest are dimensions like the distance between the photoresistor and the RGB LED and the thickness of the acrylic windows that separate them. For instance, as the distance between the light source and receiver increases, the maximum intensity decreases, but the amount of absorption increases, Figure 6-14 shows how as concentrations of simulant increases the range of intensities of blue light absorbed the optimum distance between the RGB LED and photoresistor is found to be approximately 35-55 *mm*.

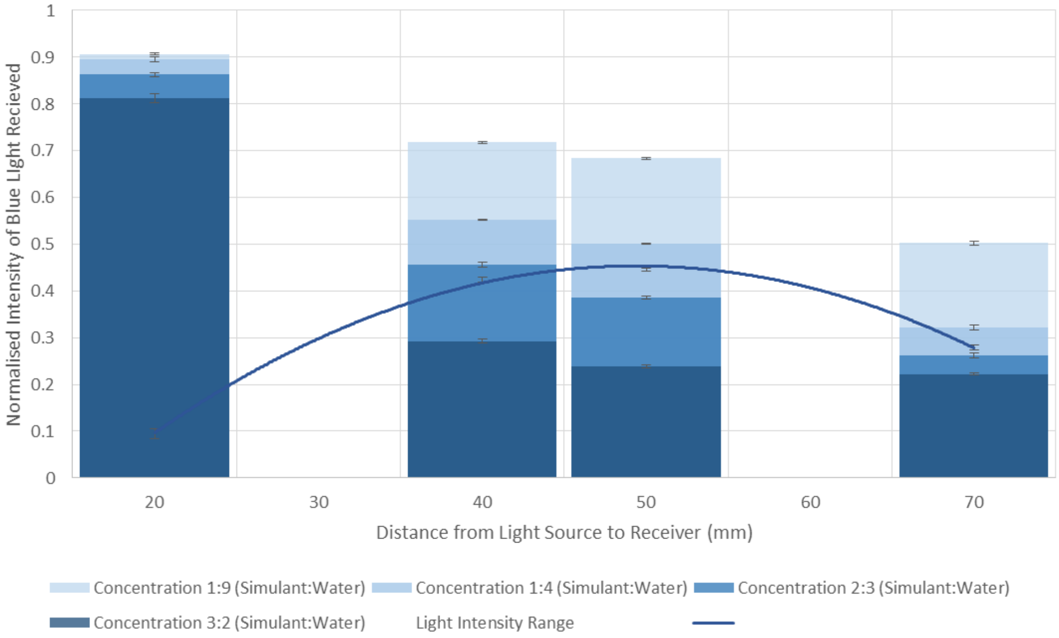


Figure 6-14 Optimal width of chamber.

Different intensities of blue light received for different concentrations of simulant urine for different distances of absorption. Source: J Larsson.

After the identification and reduction of sources of noise was made with the physical design and hardware, the design of the firmware incorporated methods to obtain more accurate results, following the flow chart in Figure 6-2.

Figure 6-15 shows the raw data over 100 *ms* from photoresistor with a smoothing function overlaid versus the mean of the results and how there is 40 *ms* ramping up of the values – *perhaps a grounding issue, but the source of the problem could not be found*. The firmware solution to this problem was a smoothing function; a form of running average that prioritises new data over previous; for example,

$Smooth = 0.8Data_n + 0.2Data_{n-1}$. The mean of all the results over 100ms on the other hand, returns a result that is has is approximately 96% of the true value in this example.

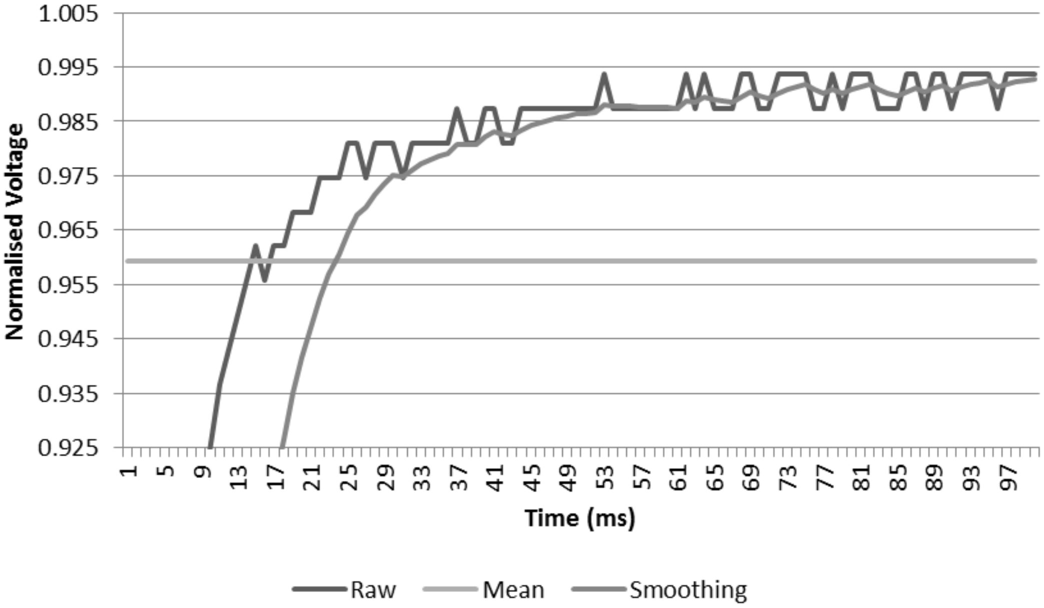


Figure 6-15 The firmware smoothing function.

Graph to show how the mean average of all readings is not representative whereas a smoothing function is more accurate. Source: J Larsson.

Triggering Analysis

The physical design of the WBM was made so that the outlet hole diameter was smaller than the inlet hole diameter such that urine would fill the analysis chamber for analysis then drain out automatically. Observing Bernoulli's equations in (6-4) and (6-5) to find appropriate radii of the spiralling inlet hole r_{in}, the transparent chamber for the RGB LED and photoresistor r_{ch} and the and outlet spiralling hole r_{out} we have:

$$P_{in} + \frac{1}{2}\rho v_{in}^2 + \rho g h_{in} = P_{ch} + \frac{1}{2}\rho v_{ch}^2 + \rho g h_{ch} \tag{6-4}$$

$$P_{ch} + \frac{1}{2}\rho v_{ch}^2 + \rho g h_{ch} = P_{out} + \frac{1}{2}\rho v_{out}^2 + \rho g h_{out} \tag{6-5}$$

The details of solving these equations and further development can be found in Appendix C and an example is shown in Figure 6-16, but the resultant entry holes for a chamber that falls in the optimum range of 30 to 50 mm in diameter, from Figure 6-14, r_{ch} = 16 mm radius acrylic tube with a wall thickness of 3 mm, resulting in the RGB LED and photoresistor being 38 mm apart, with an outlet hole 1.5 $mm < r_{out} <$ 5.2 mm. Figure 6-16 shows how this is not always a straightforward process however were the physical design needed altering to allow air bubbles to escape the chamber smoothly. These were later found to introduce noise into the analysis.

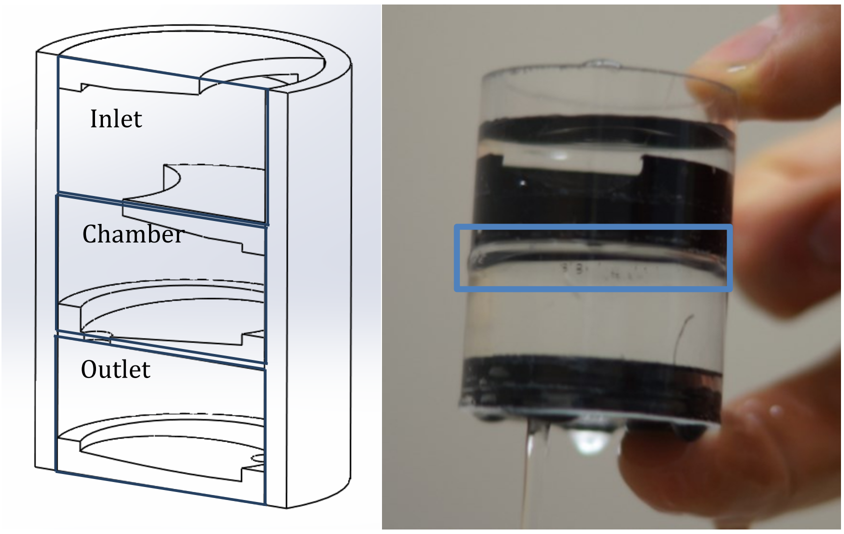


Figure 6-16 Chamber design.

Analysis chamber design (Left). Trapped air bubble in chamber bound by surface tension of water in inlet hole requiring further development (Right). Source: J Larsson.

Any detected drop change in resistance from the contact probes will indicate something has entered the chamber and analysis of the liquid can be undertaken until the reading returns to the initial point where nothing is between the contact probes, that can be seen in Figure 6-17. We then may measure the time taken for the urine to empty from the chamber giving us the volume of the urine after calibrating how long it will take one litre of liquid to empty the chamber given in sample code shown in Figure 6-18.

After this function, then we have values for the start time of liquid entering the chamber *Time[0]*, RGB, EC and end time values *Time[1]*. From this we may extrapolate the volume of liquid by dividing by the time taken for 1L of water to pass through.

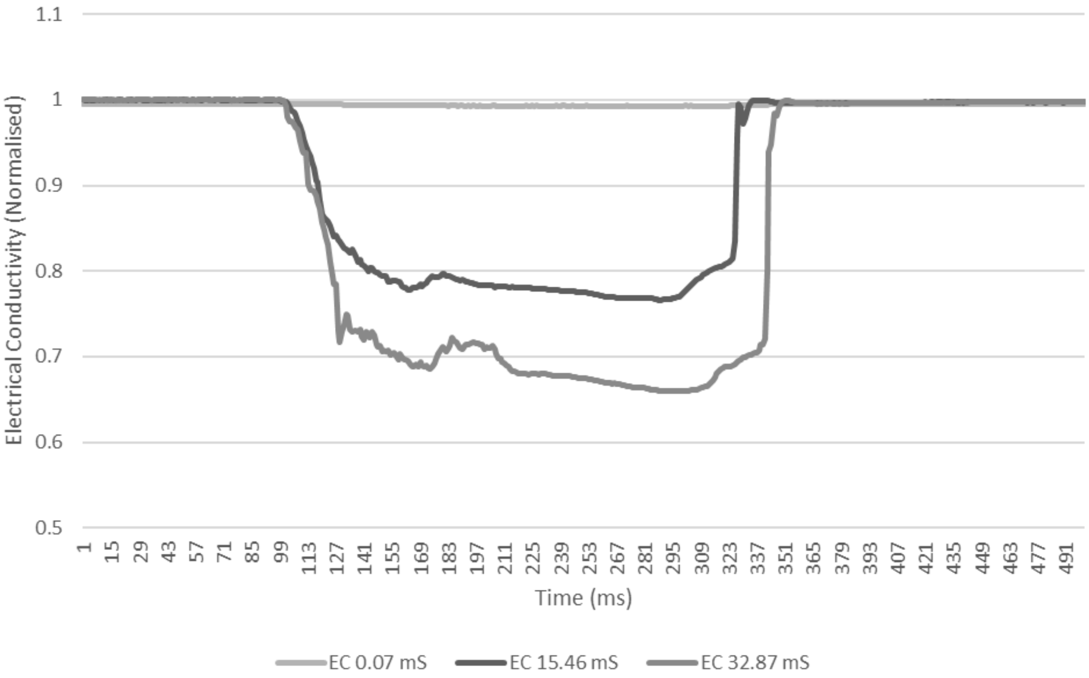


Figure 6-17 Resistance change as urine enters chamber.

Graph to show changes in resistance in voltage divider versus time for three samples of varying electrical conductivities. Source: J Larsson.

```
#define threshold 50                    //Obtained EC from calibration

if( EC < EC_previous – threshold ){     //If increase in conductivity
        if( calibrate_state == 0 ){
                Time[0] = millis();                    //Start time recorded
                calibrate_state = calibrate_state + 1;
        }

        RGB_EC();                                      //Run analysis
        Time[1] = millis();                            //Record end time
}

EC_previous = EC;
```

Figure 6-18 Example code of the triggering of analysis.

Example code of the triggering pf analysis. Source: J Larsson.

Displaying the Data

A survey of display methods has provided three clear avenues to display the hydration data in a manner that tests how aspirational the data is without influence from a radically different toilet design. Of course, one could use audio feedback as well as or instead of visual, the choice comes down to what is most natural for the user. The point of view or the choice of feedback signifier comes down to the culture of the user and since the test is conducted in the UK, visual feedback is the most intuitive (Norman, 2013). The three display methods of a traffic light system, Liquid Crystal Display (LCD) screen and a mobile application were prototyped and are discussed in more detail in the Appendix D. The traffic light system was chosen for the final prototype and uses red, amber and green to illuminated acrylic signs that display *"dehydrated"*, *"intermediate"* and *"hydrated"* respectively on the front of the urinal prototype Figure 6-19 and Figure 6-20. The text is laser etched onto acrylic and LEDs are positioned to shine internally into the acrylic, illuminating the edge of the text in the chosen colour.

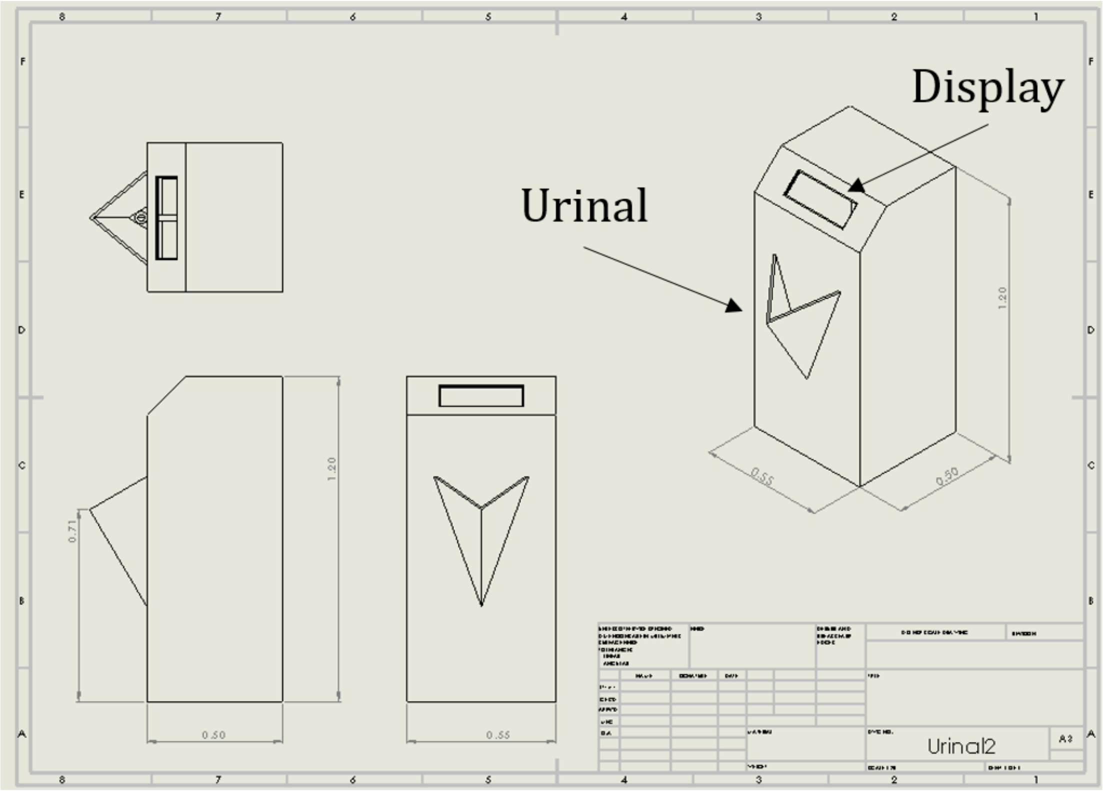


Figure 6-19 **Urinal prototype dimensions.**

Approximate dimensions of urinal prototype – A commercial urinal will be attached to the front not the open pyramid shown here. Source: J Larsson.

Figure 6-20 Experimental test prototype with traffic light signals.

Toilet urinal with traffic light signals for hydration. Source: J Larsson.

Repeatability

To ensure that the unit performs for the duration of the user testing, repeat testing has been undertaken. 117 donated samples of urine were collected and tested over a three-day period without cleaning of the unit between each test. Hydration is inferred by measuring the sample's EC and SG using a conductivity probe and refractometer for each metric respectively, both calibrated on deionised water.

Over the 117 samples, 18 *(15%)* are identified as dehydrated by EC and 51 *(35%)* by SG, however only 18 *(15%)* are considered dehydrated for both of the parameters; the WBM identified 15 *(13%)* samples that are dehydrated. Three *(3%)* hydrated samples were incorrectly detected as dehydrated and six *(5%)* dehydrated samples were incorrectly detected as hydrated, meaning over the three-day intensive testing, the WBM was accurate 92% of the time. The WBM was not as accurate as the conductivity probe, but was more effective than the refractometer by itself; they were effective 100% and 72% of the time respectively.

Over the 117 tests, the unit reliably calculated hydration, however the unit needed regular recalibration. After investigating the cause of the fluctuating results, the cause seems to be in how the hardware was assembled. After prototyping the

WBM numerous times, the decision was taken to proceed to user testing since the prototype correctly inferred hydration 92% of the samples. To ensure the WBM was accurate and repeatable each time it is used by a participant, code in C# has been written to automatically recalibrate the WBM after each and is shown in Figure 6-21.

```
unsigned int RGB_Array[3];

                    //Map the calibrated RGB values in lookup table from 0 - 255
RGB_Array[0] = map( R, Lookup_R [0], Lookup_R [1], 0, 255 );
RGB_Array[1] = map( G, Lookup_G [0], Lookup_G [1], 0, 255 );
RGB_Array[2] = map( B, Lookup_B [0], Lookup_B [1], 0, 255 );

if ( R < Lookup_R[0] ) { RGB_Array[0] = 0; }
if ( R > Lookup_R[1] ) { RGB_Array[0] = 255; }
if ( G < Lookup_G[0] ) { RGB_Array[1] = 0; }
if ( G > Lookup_G[1] ) { RGB_Array[1] = 255; }
if ( B < Lookup_B[0] ) { RGB_Array[2] = 0; }
if ( B > Lookup_B[1] ) { RGB_Array[2] = 255; }
```

Figure 6-21 Example code of the automatic calibration.

Example code of the automatic calibration. Source: J Larsson.

From the lab experiments on simulant to the real urine tests, the WBM has shown great repeatability and correlation to urine SG which is a good indicator of hydration that can be seen in Figure 6-9 (Armstrong, 2007; Brunzel, 2013; European Hydration Institute, 2016).

First lab based tests on simulant urine show that the absorption of red, green and blue light has a regression of 0.996, 0.85 and 0.999 respectively. Blue light appears to be more reliable because the more the more *yellow* the liquid becomes – *the more red and green light is reflected* – and the more blue light is absorbed.

Each test was repeated with the SGs of each urine sample using a calibrated refractometer at room temperature since the SG of a liquid is also dependant on its temperature. The WBM performed accurately even in a real scenario on 17 urine samples with σ from 8.0×10^{-4} to 4.2×10^{-3}. It is suspected that colour and SG are not perfectly correlated or fluctuations in temperature affect the correlation since the WBM has proven to be very repeatable under calibrated conditions. Nonetheless, SG is still well correlated and this uncertainty can be accounted for.

6.4 Analysis of Findings

An Arduino is an electronics based open-source hardware and firmware microcontroller designed for simple low cost embedded projects (Teli and Mani, 2015). The board accepts the inputs from various sensors and can control a variety of other devices based on the inputs; objects built with an Arduino can be made to respond to sound, temperature, light, pressure, and movement to name a few (Agrawal and Singhal, 2015). The Arduino software environment has been designed for beginners so it is easy to understand, but it is best suited for its hardware capabilities (Rao et al., 2013). The software is open-source and many projects are available with an active online community and the hardware is also inexpensive. Similar examples of Arduinos being used for sensor applications with water including data loggers for tests or automatic watering plant systems (Agrawal and Singhal, 2015; Rao et al., 2013; Teli and Mani, 2015).

Interestingly, although the WBM has been shown to be repeatable with low standard deviations from the lab-based experiments with urine, the regression suggests that colour is not perfectly correlated with SG. Sample 8 appears to be lighter in colour than Samples 7 and 9, however their SGs show they are quite different – *Sample 7 (1.019), Sample 8 (1.021) and Sample 9 (1.025)* – although the results of Sample 8 deviate somewhat from the regression curve, the values of blue to green, green to red and red to blue indicate dehydration. Reflections on this indicate either colour itself is not an indicator of SG – *since urine is not dilutions of one substance and is instead is a composition of many molecules* (Rose et al., 2015) - or the measurements of SG in this case were not accurate or repeatable enough, presumably the effect of different temperature of urines or accuracy of calibrated scales used.

It is interesting to note that Samples 3 and 4 from Figure 6-9 have different SGs – *1.004 and 1.005 respectively* – however they are indistinguishable to the eye based on their colour. Figure 6-9 shows that the WBM detects an average drop in blue-green by 0.040, green-red 0.005 and red-blue by 0.019 while $\sigma < 5.97\text{x}10^{-2}$, showing that the setup is appropriately accurate and repeatable to detect this change in SG better than the human eye.

Given these results, the latest prototype apparatus will be accurate, but not precise, implying that colour is not a perfectly correlated indicator of SG. If one observes the urines in Figure 6-9 , samples seven has a lower SG than sample eight, however the colour, to the eye and to the apparatus, indicates the SG is more. This implies one of two things, firstly that colour is not a perfect indicator of hydration, which is logical since the turbidity of urine affects the results, the colour is determined by an array of components influenced by diet (Brunzel, 2013; Rose et al., 2015). Secondly that SG is not a perfect indicator of hydration. SG has been shown to be very accurate, provided there is no presence of water imbalances. This can only be accounted for by measuring fluctuations exceeding 1% from the person's baseline body weight (Riebl and Davy, 2013). This is no cause for concern, instead it is cause for further investigation; the combination of sensors and factors can detect further variables such as the presence of blood in urine.

The results of light absorbed by the liquid versus the SG of urine in real-life conditions, show that the WBM is adequate to indicate SG with linear regressions of 0.87, 0.83 and 0.84 for the absorption of red, green and blue light respectively. Urine is not simply darker shades of one colour; it may appear yellow/green on average, but it ranges from clear to even black across the spectrum. Future advancements of this concept will have to be focused on plotting the varieties of colours of urine and how that varies in SG across the spectrum.

The total cost of the WBM added to a urinal is approximately £20 and the open-source coding language makes the ability to develop the concept far easier and economical. Of course, the resolution of the results will be far less than a spectrometer, but the WBM solution presents an interesting, low-cost opportunity for the purpose of determining whether people will find hydration and other health parameters like diabetes or renal disease, aspirational as a new toilet proposition. To broaden the initial success criteria of the use of colour to infer hydration, further components have been added such as a capacitor, two transistors shown in Figure 6-8 that detect other hydration parameters and give a more comprehensive overview of wellbeing than solely the prototype based on colour.

6.5 Summary

Clinically, hydration is inferred by several parameters of urine; SG, EC, osmolality, volume and frequency of visits, but by itself, SG is the best indicator of hydration (European Hydration Institute, 2016). The colour of urine is universally known to indicate how hydrated someone is though methods of classifying colour are subjective and not appropriate for clinical use (Fletcher et al., 1999; Riebl and Davy, 2013; U.S. Army Public Health Command, 2010). An indication of a user's wellbeing and the knowledge of a user's hydration may bring associations of positivity to the toilet while dampening fears of disease. The WBM is a valuable contribution to designers and sanitation experts as well as health professionals because of the new approach to inferring hydration. The results presented in this chapter show that colour can be quantified and repeatable and presents a novel method for reliably and repeatedly determining the colour of urine. The development of the WBM prototype presented opportunities to measure more than just colour in the inference of hydration making the unit reliable 92% of the time. The success criteria are as follows and are considered met:

- The ability to identify colour and how correlated colour is to other parameters of urine that infer hydration status.
- The technical limitations of the prototype.
- Minimisation of external variables on user experience.

The WBM developed appears like a normal urinal so the aesthetics will not influence the perceived user experience from the data. The WBM shows great promise as a low-cost solution that may add increased value to users of toilets by indicating levels of hydration. Whether the data and information a user receives from the WBM is aspirational is still up for debate, but the concept has been shown to be feasible in the current chapter.

Key Findings:

- The experimental test prototype is focused on improving the user experience through the data not the product.
- Simple parameters such as SG, EC, volume, frequency and colour can provide a comprehensive view of user wellbeing – *particularly hydration*.

Next Steps

The next chapter will focus on the remaining objective; to assess the change in aspiration of the user experience. A questionnaire will be constructed to gauge the aspiration, value and meaning users receive from the data of the WBM in comparison to normal toilet user experiences. Upon successful analysis of the questionnaire on the data, the chapter will end with future manifestations of the concept and how the design of the unit may convey aspiration to users.

"The value of an idea lies in the using of it"

Thomas Edison

7 HUMAN USER TESTING

Objective 5: Assess the change in aspiration and user experience of the revolutionary innovation.

This chapter is dedicated to meeting Objective 5 and assesses whether the value proposition of the WBM is aspirational. The chapter begins with a review of methods for assessment followed by the composition of the questionnaire. Then the results of the questionnaire followed by manifestations of the WBM for different markets.

7.1 Need for the Research

Now the WellBeing Monitor (WBM) has been developed, this chapter presents the results of a post-user experience questionnaire, focused on perception of aspiration and user experience. The purpose of the research is firstly to determine whether the WBM has increased value, meaning and is aspirational and secondly whether the findings from Chapter 3 were indeed universal latent needs.

Table 7-1 Methodologies and reasons for rejection.

Research Option	Method	Principle Reasons for Rejection
Option 1:	*Questionnaire*	Researcher bias and priming
Option 2:	*Focus Group*	Socially desirable answers.
Option 3:	*Kano Analysis*	Testing satisfaction of multiple features.
Option 4:	*Usability Report*	Pre-launch method.
Option 5:	*Ethnographic Research*	Ethically cannot observe product in use.
Selected Option	**Method**	**Principle Reasons for Selection**
Option 1:	*Questionnaire*	Testing hypothesis.

Ethnographic research and focus groups are rejected for not being able to observe the use of the WBM and Kano Method was rejected because only one feature of the product is being tested; the data received from the WBM experimental test. A questionnaire is chosen in Table 7-1, as appropriate for the final test after use of the prototype.

Expected Outcomes

This chapter looks to identify a change the aspirational value proposition of toilet user experiences to the user. An additional focal point is whether the data from the WBM begins to satisfy user fears of disease and changes perceptions of the spaces toilets are kept in. Success for this chapter is defined by:

- If the data from the WBM is considered aspirational by participants.
- If the developments begin to address user concerns with disease.
- If conceptualisation of the WBM and a review of the intended audience.

7.2 Research Approach

In the formulation of a questionnaire, a hypothesis should be tested and Independent Variables (IV) and Dependant Variables (DV) should be identified to test (Feldman and Lynch, 1988). The hypothesis is:

H1: The data from a wellbeing monitoring toilet is aspirational.

Therefore, the DVs of interested in this questionnaire are *aspiration* and *value* of the user experience as detailed in the Definition of Terms Section 2.6. When investigating *aspiration*, the evidence from the research suggest toilet user experiences are not aspirational because they are meaningless, habitual visits to relieve oneself. The data generated from the WBM attached to the toilet may bring new purpose to visiting the toilet and developments can begin to satisfy fears of disease. The IV that will be tested are taken from the definitions in Table 2-5, namely, contentment and meaning. The assumptions that influence the questionnaire formulation are:

A1.0: Toilet user experiences are not aspirational because they are perceived as meaningless utility products.

A1.1: Wellbeing monitoring data from a toilet may provide an aspirational user experience because it brings new, enhanced meaning that users associate with contentment.

When investigating *value*, the findings from Chapter 3 suggests that toilets are not valued because they are perceived as utility products and are shut away in bathrooms and outhouses. The Definition of Terms Section 2.6 implies that the IV for *value* are aligned with Maslow's Hierarchy of needs. The assumptions that influence the questionnaire formulation are:

A2.0: The value of toilets comes from its function, meeting basic physiological needs.

A2.1: Wellbeing monitoring data from a toilet may bring increased value to toilet user experiences by meeting higher needs.

When investigating revolutionary innovations, literature suggests that the stigma of toilets becomes associated with current features of toilets – *white and ceramic*. Following this, the IV for perceived innovation is features associated with products. The assumptions that influence the questionnaire formulation are:

A3.0: Toilets are not considered aspirational because stigma is associated with the current features of toilets.

A3.1: A disassociation with toilet features will achieve the attribution of new meaning for an aspirational toilet user experience.

Following the method used by Judge et al. (2015), a questionnaire will be given to participants before using the WBM equipped toilet to gauge their current perception of *value*, *meaning* and *aspiration* of normal toilets and after a week of use with the WBM another questionnaire will be given to them to verify whether these parameters have increased to answer the original research aims. The design of the questionnaire has been made to answer the hypothesise and the choice of questions, wording and sequence is informed by the DVs and IVs.

The variables of interest, aspiration and value are subjective constructs that are difficult to measure in a repeatable fashion. These variables are influenced by the Definition of Terms Section 2.6. For this reason, a questionnaire with both quantitative and qualitative measures are included to understand why participants give certain answers. Where possible the questions are quantitative, Likert scale questions that quantify how much participants agree with the statements in Table 7-2 and Table 7-3 that follow a scale of '*strongly disagree', 'disagree', 'neither agree nor disagree', 'agree'* and '*strongly agree'* according to Robson & McCartan (2015). Questions regarding *value* and *aspiration* are accompanied by an open '*why?'* to provide a qualitative response to these personal and subjective constructs (Goffin, Lemke and Koners, 2010; Robson and McCartan, 2015). A word cloud is then generated on the collection of the words used to describe '*why?'*, where the frequency of occurrences is directly proportional to the word's size in the cloud, which visualises the collective responses in an easily digestible format.

Participants were asked to complete the pre-questionnaire before using the WBM equipped to a normal urinal. Then participants used the urinal over the course of a week before being given the post-user experience questionnaire to complete.

Table 7-2 Table showing the question wording from the dependent variables from each assumption and hypothesis.

	Dependant Variable	Question Wording	Answer Type	Wording Source
A1.0	Aspiration	*Toilet or urinals are aspirational to own.*	Closed Likert	(Park, Macinnis and Priester, 2006)
		The features and attributes of toilets bring me content.	Closed Likert	(De Botton, 2007) (Vigneron and Johnson, 1999)
A1.1	Aspiration	*Do you regard the wellbeing monitor to be more or less aspirational than a normal urinal specifically to you?*	Closed Binary	(Park, Macinnis and Priester, 2006) (De Botton, 2007) (Vigneron and Johnson, 1999)
A2.0	Value	*Toilets or urinals are valuable to me.*	Closed Likert	(Verganti, 2009)
A2.1	Value	*Do you regard the wellbeing monitor to be more or less valuable than a normal urinal specifically to you?*	Closed Binary	(Verganti, 2009)
A3.0	Aspiration	*Please indicate the categories of aspirational products*	Closed Likert	Categories dictated from results of the features listed in the pre-questionnaire.
A3.1	Aspiration	*Please indicate the categories of aspirational products*		Categories dictated from results of the features listed in the pre-questionnaire.

Table 7-3 Table showing the question wording from the independent variables from each assumption and hypothesis.

	Independent Variable	Question Wording	Answer Type	Wording Source
A1.0	Meaning	*What statements do toilets or urinals express?*	Closed Categorised	(Csikszentmihalyi and Rochberg-Halton, 1981) (Verganti, 2009) (Harni, 2010)
A1.1	Meaning	*What statements do the wellbeing monitor express?*	Closed Categorised	(Csikszentmihalyi and Rochberg-Halton, 1981) (Verganti, 2009) (Harni, 2010)
A2.0	Needs	*Which of the following needs are met by toilets or urinals?*	Closed Categorised	(Norman, 2004; Yalch and Brand, 1996)
A2.1	Needs	*Which of the following needs are met by the wellbeing monitor?*	Closed Categorised	(Norman, 2004; Yalch and Brand, 1996)
A3.0	Features of toilets	*Please describe a toilet by listing it's features and attributes*	Open List	
A3.1	Category of Products	*Please indicate the category toilet or urinal/wellbeing monitor/aspirational products would belong to.*	Closed Categorised*	Categories dictated from results of the features listed in the pre-questionnaire.

**Categories are images of selections of products that share features with toilets determined by participants. See Figure 7-1.*

The sequence of questions and wording is important to avoid priming the participants as discussed in the Literature Review. The sequence of questions is informed by the choice of DVs and IVs. The DV should be determined first before determining the IVs (Feldman and Lynch, 1988). The IVs are the hierarchy of needs and dimensions of meaning, detailed further in the Definitions of Terms Section 2.6. The wording of the questionnaires, similarly is taken directly from the definitions of the DVs. Control variables such as nationality and age were also recorded to monitor the effects. The full questionnaire can be seen in Appendix G.

The final questions require participants to observe photos of products that belong to different categories selected from product features in the pre-user experience questionnaire shown in Figure 7-1. These categories are determined by selecting the highest occurring features listed by participants in the pre-questionnaire. The questionnaire shows images of products that share the features for each category – *like the seating category displays images of chairs*. The questionnaire then asks participants to indicate the aspirational categories, categories one associates with health and wellbeing and categories that belong in the bathroom to test whether participants' existing biases affect how they perceive the WBM equipped toilet.

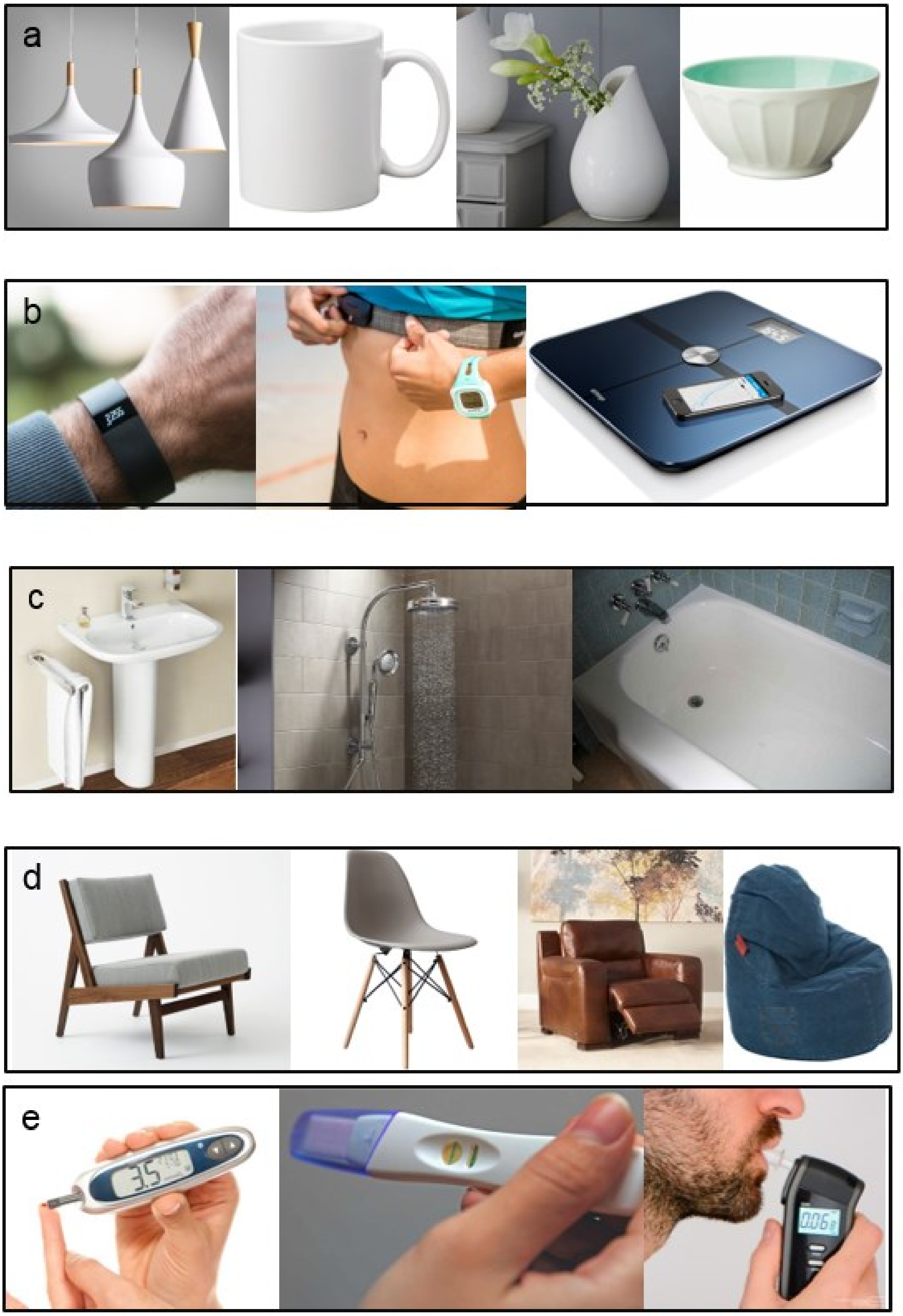


Figure 7-1: Categories of products in questionnaire.

Collection of product categories identified in the pre-user experience questionnaire, See Figure 7-10. Water (a), Wearables (b), Water (c), Seating (d) and Health Prognosticators (e). Source J Larsson.

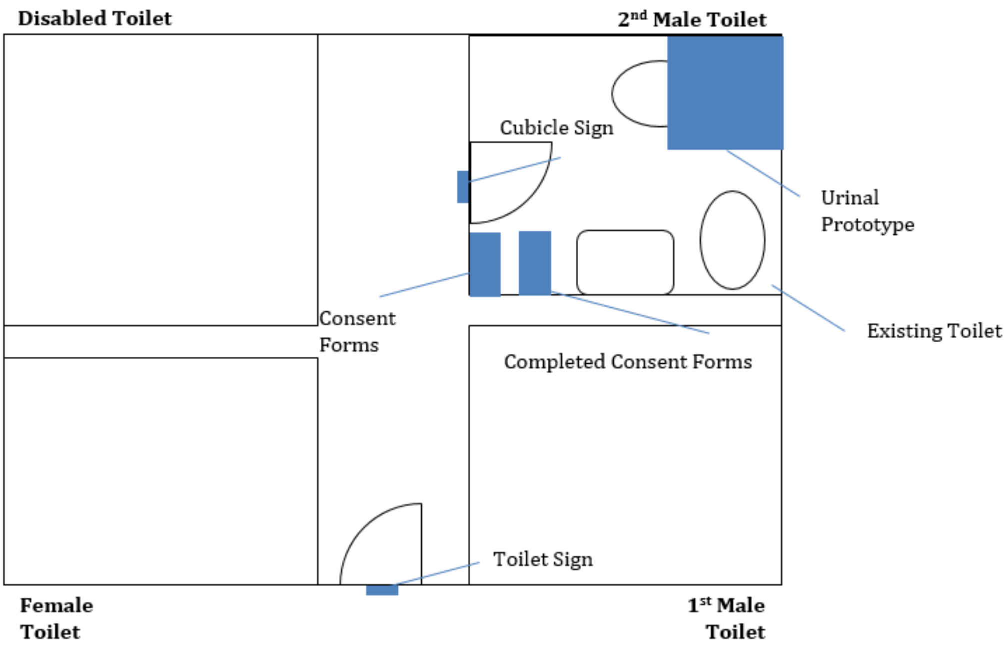


Figure 7-2 Floorplan for user testing.

Floorplan of the user testing and the toilet environment the test is held in. Source: J Larsson

Figure 7-3 Using the experimental test prototype.

Image depicts use of the urinal experimental test prototype displaying inferred hydration status. Source: J Larsson

The sample size of the questionnaire will be determined by observing the chi-squared, goodness of fit score comparing the numbers of people choosing '*strongly disagree', 'disagree'*, etc for toilets versus the WBM for each question to see when the results are statistically significant. A representative sample of the population is not possible and instead the difference between the pre and post-user experience questionnaires is of interest (Bernard; H. Russell, 2006). The test is conducted on male staff and students of the Centre for Design in Cranfield University, an example is shown in Figure 7-3. The participants are recruited by email and in person and are given consent forms to fill out and are briefed before conducting the test. They are shown the location of the prototype, that is in the floorplan in Figure 7-2 and it is explained that it is to be used as a normal urinal would be and their honest experience is required for the pre and post-user experience questionnaires.

The rear right male toilet is used for the experiment leaving the other male toilet at front right, the front left female toilet and the rear left disabled toilet free for other users who are not partaking in the study. The staff and students are made aware of the date, time, and location of the test over email and any new visitor outside the building is informed of the test as they arrive. For any person who is unaware of the test that enters, there are three signs to warn them; first on the toilet door, second on the cubicle door and third on the urinal. If by chance someone has used the toilet and wishes to opt-out of the study, there is an opt-out form on the back of the toilet door warning them data has been collected and allowing them to anonymously opt-out.

7.3 Results

There were 22 male participants from a variety of countries including Britain, France, Kenya and Mexico. The average age of participants was 31 with a range from 22 to 48. By the tests nature, the population were all men and no women could participate.

The majority of participants *neither agree nor disagree* that toilets or urinals are *aspirational (DV)* to own *(45%)* as shown in Figure 7-4. The WBM on the other hand, has a large majority of those that *agree* the WBM is *aspirational* to own *(55%)*. Chi-Squared score *(<0.01)* indicate that there is a statistically significant difference between how *aspirational* participants perceive toilets compared to the WBM equipped urinal.

When asked whether the *features and attributes (IV)* of toilets bring the participants *contentment (DV)*, according to chi-squared goodness of fit *(<0.01)*, there is a statistically noticeable rise in those that *agree* that *features and attributes* bring them *contentment* for the WBM equipped urinal *(68%)* over toilets or urinals *(36%)* shown in Figure 7-5.

Though many participants *agree* or *strongly agree* that toilets and urinals are *valuable (DV) (77%)*, Figure 7-6 shows the WBM equipped urinal has a perceived increase in *value*, where nearly all participants *agree* or *strongly agree* that the WBM is *valuable (95%)*. The increase in *value* was not statistically significant however, observing the chi-squared score *(0.22)*.

The reasons participants gave for *why* the WBM equipped urinal is *valuable* and *aspirational*, the reoccurring words used are; *health, wellbeing, feedback, monitor, hydration, useful, data, conscious, knowing* and *reassuring* to name a few. This was because many participants claim it is the knowledge of having information concerning hydration and how this can inform them of their water intake, shown in the word cloud in Figure 7-9b.

Observing the hierarchy of *needs (IV)* in Figure 7-7, the majority of participants *(95%)* said toilets and urinals meet physiological needs where participants feel the WBM meets higher *needs (48% physiological, 38% psychological and 38% self-esteem)*. Once again, observing the chi-squared score, we see that the higher needs are statistically significant *(<0.01)* for the needs met by WBM compared to the needs met by toilets.

With respect to *meaning (IV)*, many participants believe toilets express *none of the above (59%)* or *qualities of the self (27%).* The data from the WBM expresses *reminders for self-improvement (95%)* or *qualities of the self (55%)* that can be seen in Figure 7-8 and is reflected in the word clouds Figure 7-9b. The reasons given *why* participants find toilets *valuable (DV)* and *aspirational (DV)* are; *physiological, needs, functional, essential, everyday* and *convenience* to name a few. This is because of toilet's function and how it meets physiological needs as well as the importance of cleanliness and the necessity of having a toilet within the home for convenience shown in word cloud in Figure 7-9a.

Toilets are defined by the participants as a collection of 28 different features and attributes from a *seat* and *lid* to *white* and *unpleasant,* the highest occurring of which seem to be existing and most familiar features and attributes of toilets. As one expects, there is a bias towards the most visually and audibly obvious features the user encounters in the toilet user experience and the highest occurring features and attributes. The categories for comparison are chosen from the highest occurring features of toilet *(Water, Seating and White)* shown in Figure 7-10 with a *Wearables* category and a *Health Prognostication* category added for the WBM. Toilets and urinals are considered to be in the *Water* category by nearly the entirety of participants *(95%)* and the WBM was identified to be part of the *Wearables* category *(82%)* that can be seen in Table 7-4. Figure 7-11 shows that participants found that the *Wearables* and *Seating* categories to be aspirational *(86% and 55% respectively),* the *Wearables* and *Health Prognosticators* satisfies *health concerns (77% and 91% respectively)* while *Water* category *belongs in bathrooms (95%),* observing Figure 7-11.

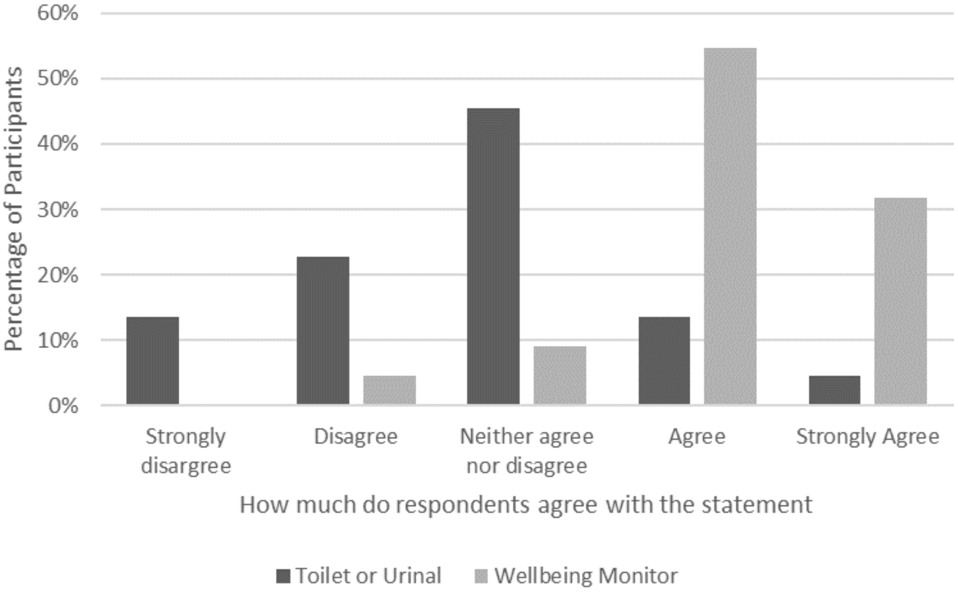


Figure 7-4 How aspirational toilets and the Wellbeing Monitor are.

Graph to show the agreement with the statements "Toilets/Wellbeing Monitor is aspirational to own" versus the percentage of participants. Source: J Larsson.

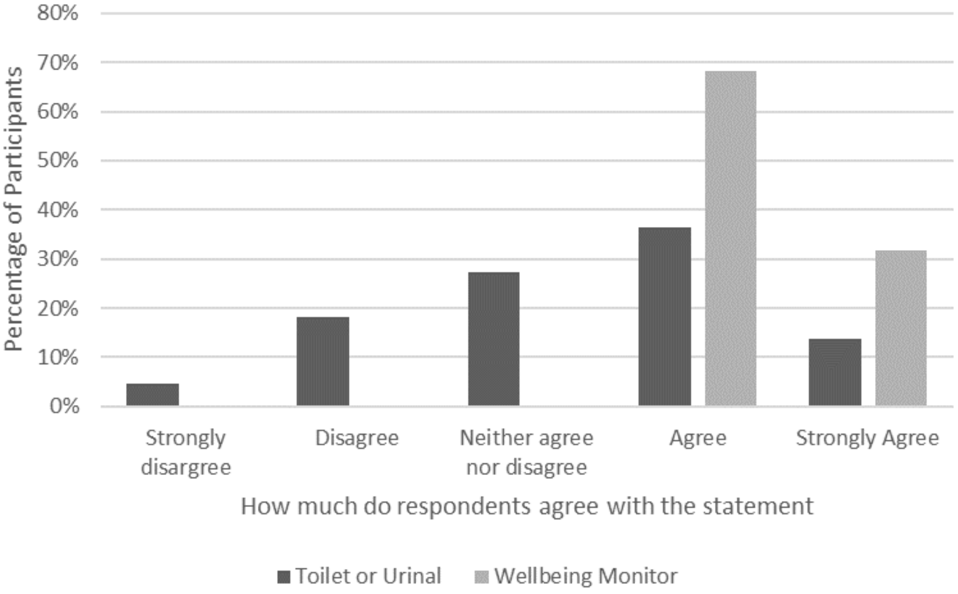


Figure 7-5 Contentment with toilets and Wellbeing Monitor.

Graph to show the agreement with the statements "The features and attributes of toilet or urinals/wellbeing monitor bring me contentment" versus the percentage of participants. Source: J Larsson.

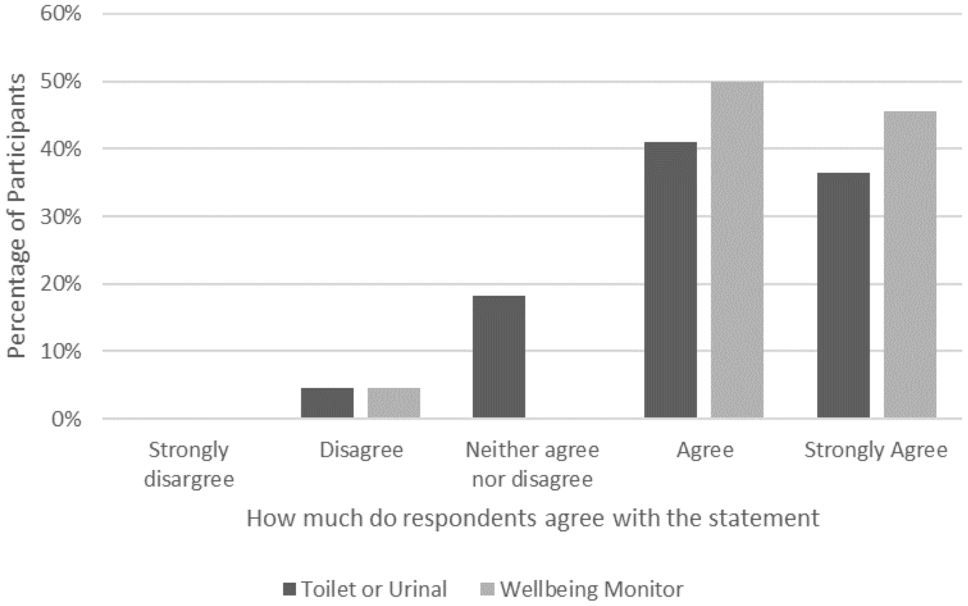


Figure 7-6 The value of toilets and Wellbeing Monitor.

Graph to show the agreement with the statements "Toilets/Wellbeing Monitor is valuable to me " versus the percentage of participants. Source: J Larsson.

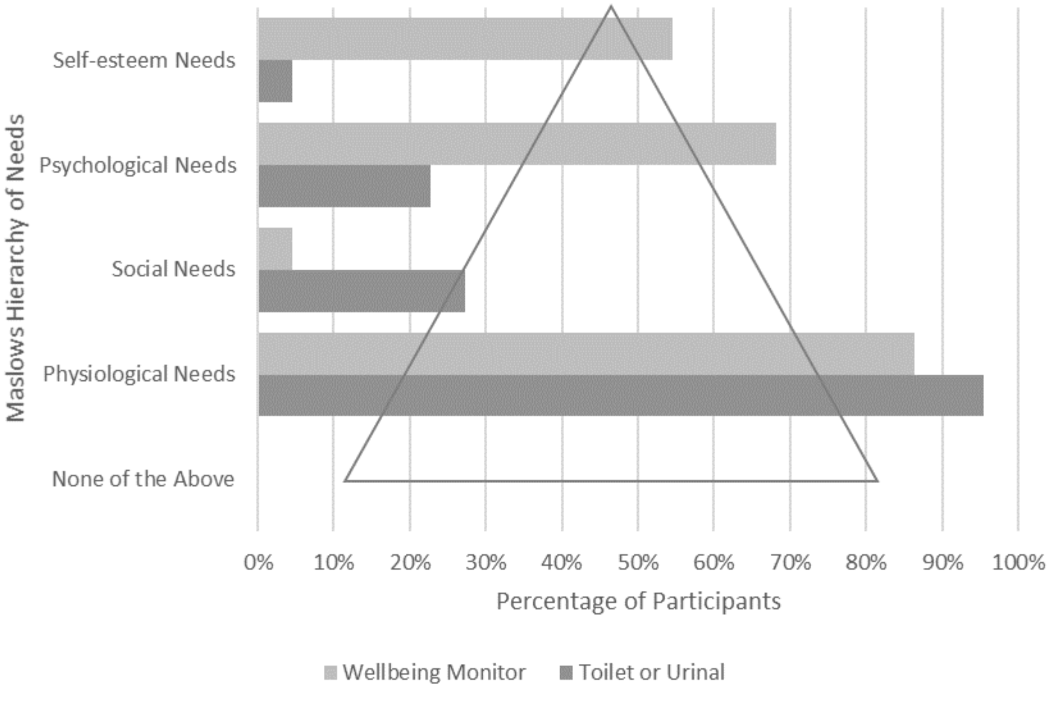


Figure 7-7 The needs toilets and the Wellbeing Monitor meets.

Graph to show the positioning of toilets versus Wellbeing Monitor on the hierarchy of needs see Figure 2-5. Source: J Larsson.

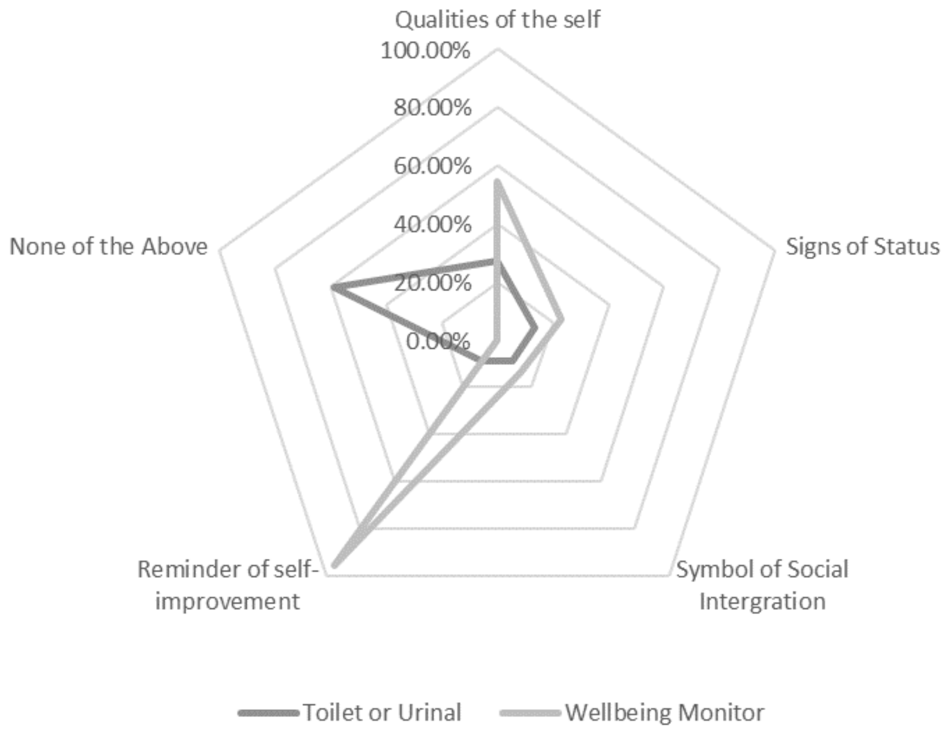


Figure 7-8 What toilets and the Wellbeing Monitor mean.

Graph to show the percentages of participants answers for dimensions of meaning of toilets versus Wellbeing Monitor. Source: J Larsson.

Table 7-4 Association of toilets or urinals and the wellbeing monitor with the five different categories. See Figure 7-1.

Category	**Toilets or Urinals (%)**	**Wellbeing Monitor (%)**
White	0	0
Wearables	0	82
Water	95	0
Seating	0	0
Health Prognostication	5	18

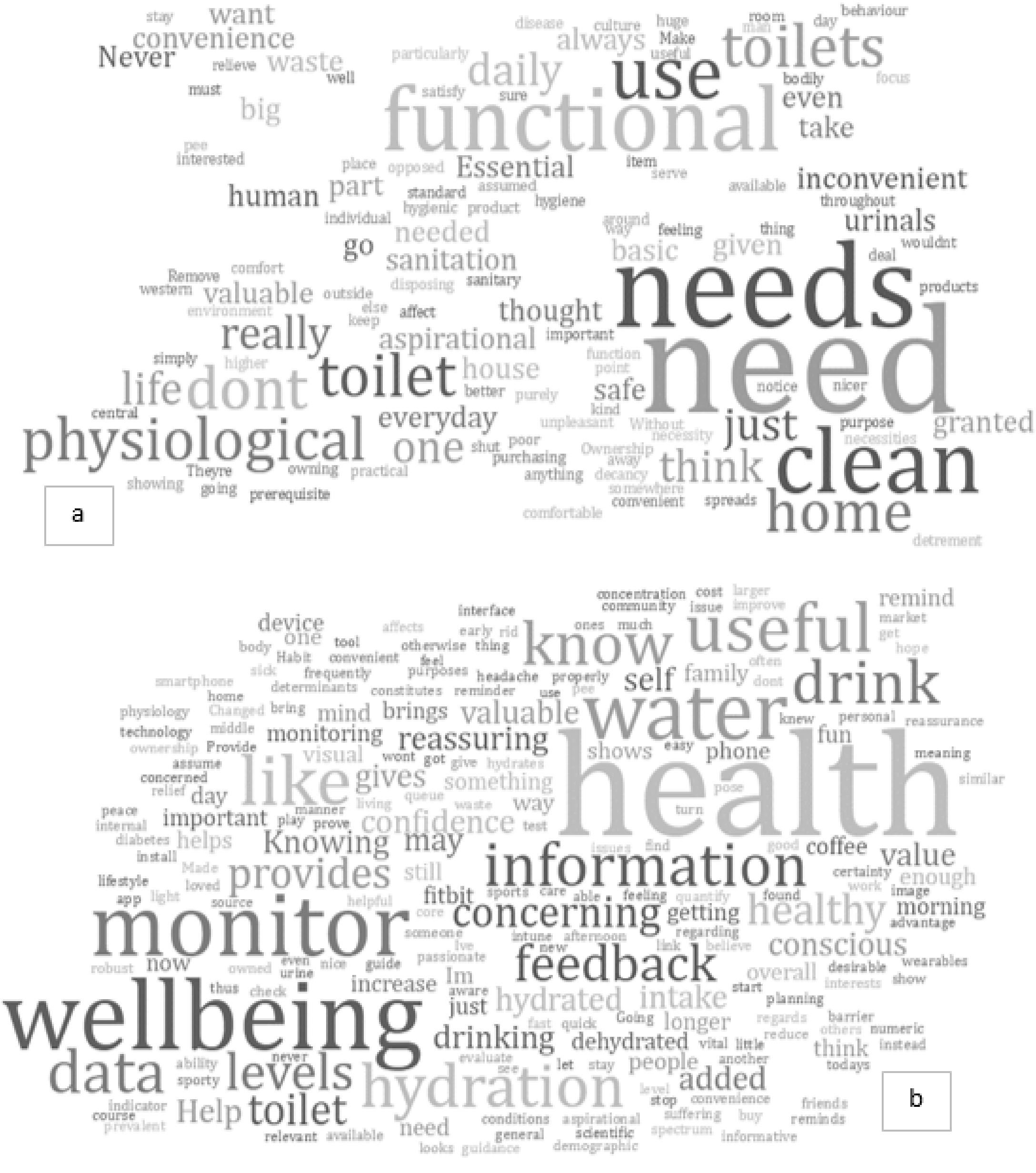


Figure 7-9 Word clouds of what toilets and the Wellbeing Monitor mean.

Word clouds of all the terms used to describe what toilets or urinals (Top) and the Wellbeing Monitor (Bottom) meant to participants. Source: J Larsson.

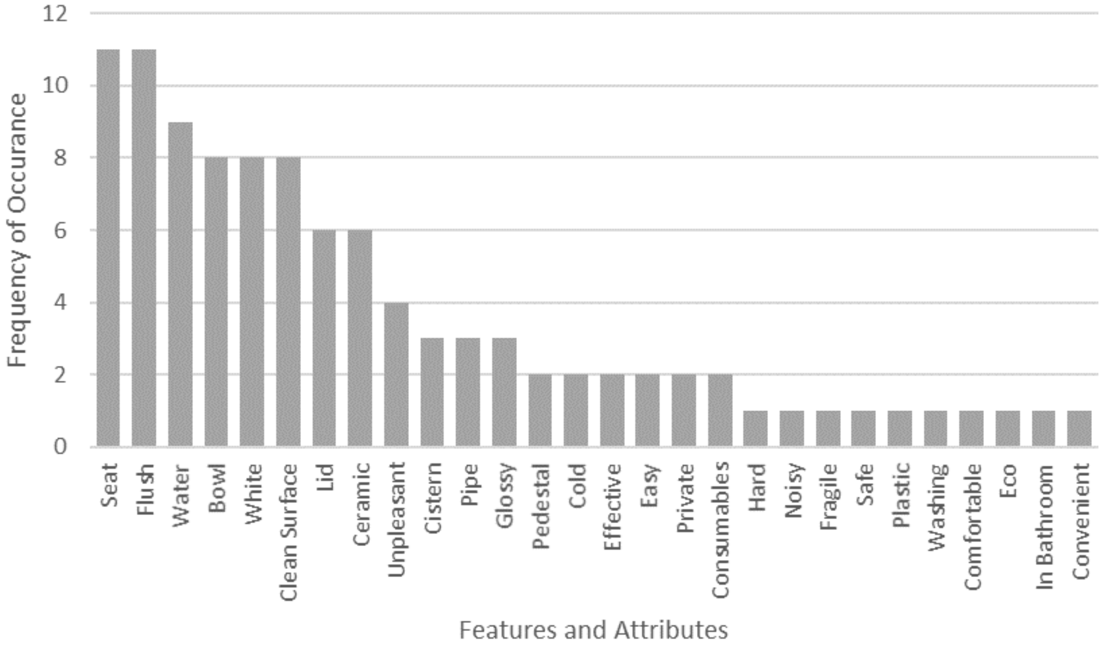


Figure 7-10 Features and attributes of toilets.

Graph to show frequency of mentions of features and attributes associated with toilets. Source: J Larsson.

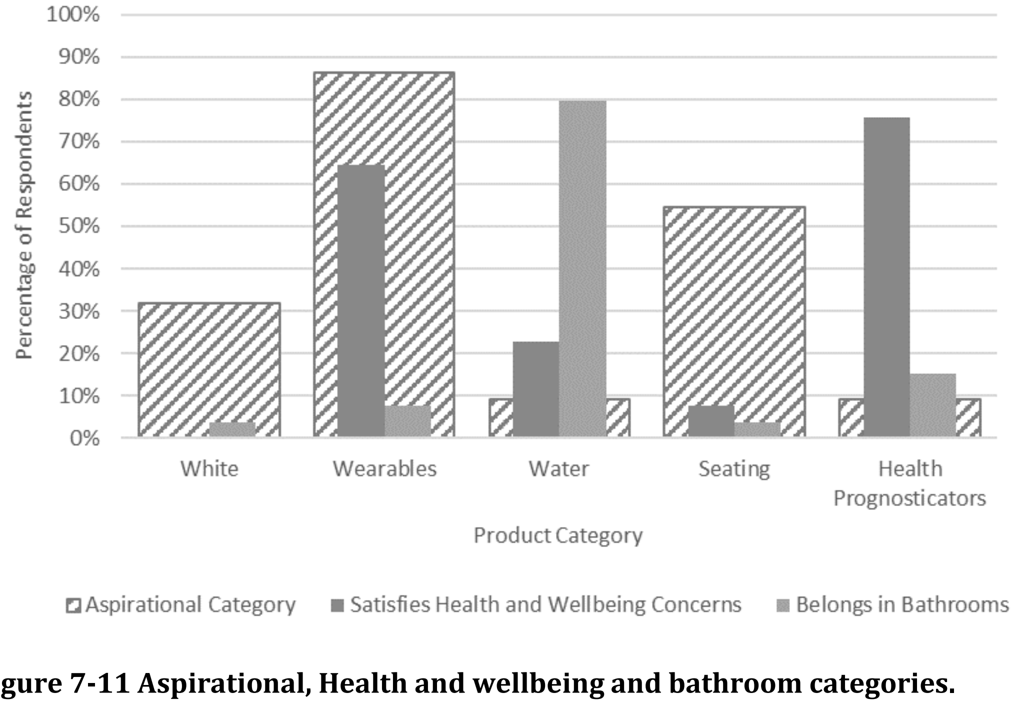


Figure 7-11 Aspirational, Health and wellbeing and bathroom categories.

Graph to show people's category associations with aspirational products, products that satisfy health and wellbeing concerns and products that belong in bathrooms. See Figure 7-1. Source: J Larsson.

7.4 Analysis of Findings

Participants *agree* or *strongly agree* that the WBM is *aspirational (DV) (87%)* compared to those that *agree* or *strongly agree* that a toilet or urinal is *(19%)* seen in Figure 7-4. More participants *agree* that the data from the WBM brings them *contentment (68% for WBM versus 36% for toilets)*, shown in Figure 7-5. The language used to describe the *value* of toilets and urinals from the word cloud in Figure 7-9a, shows a reoccurrence of utility focused words, such as *need*, *physiological* and *functional*. The dimensions of *meaning (IV)* in Figure 7-8, show toilets and urinals meet *none of the above* by many of the participants *(59%)* while the majority of participants *(95%)* feel that the meaning of the data from the WBM is for *reminders for self-improvement*. In the variety of language used to describe why the data from the WBM is aspirational, the most occurring answers are words like *knowledge* and *wellbeing* and *hydration*, *information* and *health*. The lack of health, wellbeing or hydration phrases suggests this attribute was not considered when users think of or use toilets. The positive questionnaire results to the WBM and the positive 'surprise' comments from users after use of the device, indicates that technology has provided users with a truly novel experience with information and feedback that is useful. The increase in *value, aspiration*, *meaning* and *contentment* may be because of the ability to prognosticate wellbeing in part or it may be because there is new technology and participants are curious; however either of these outcomes still suggest the WBM is aspirational to users. The statistical significance of each of the results supports the assumptions A1.0 and A1.1 to become the following propositions:

P1: Toilets are not aspirational because they are meaningless utility products

P2: Wellbeing monitoring data from a toilet may provide an aspirational user experience because it brings new, enhanced meaning that users associate with contentment.

Observing the results for *value (DV)* and *needs (IV)* from assumptions A2.0 and A2.1, more participants *agree* or *strongly agree* that the WBM has more *value* than toilets *(95% versus 77% respectively)* seen in Figure 7-6, although not statistically significant. Figure 7-7 shows that a majority of participants (*95%*) said that toilets meet their *physiological needs*, however there are several participants that believe toilets also meet higher needs (*27% for social needs, 23%% for psychological needs and 5% for self-esteem needs*). Overwhelmingly, the data from the WBM meet higher needs (*5% for social needs, 68% for psychological needs and 55% for self-esteem needs*). The results suggest that toilets are valuable in meeting physiological needs and the value of the WBM comes from meeting higher needs. The results shown in Figure 7-6 and Figure 7-7 support the assumptions A2.0 and A2.1 to become the following propositions:

P3: The value of toilets comes from its function, meeting basic physiological needs.

P4: Wellbeing monitoring data from a toilet may bring increased value to toilet user experiences by meeting higher needs.

The categories of products are created by selecting products that have the same features as the top occurring features of toilets in the pre-questionnaire, namely *Seat*, *Water* and *White* categories shown in Figure 7-10. Two others are added for the data of the WBM of *Wearables* and *Health Prognosticators*. Toilets and urinals are considered to be in the *Water* category by nearly the entirety of participants *(95%)* and the *Water* category is considered *aspirational* by only a few participants *(9%)*. The WBM is identified to be part of the *Wearables* category *(82%),* which is considered the most *aspirational* category by participants *(86%).* However, some participants associate the WBM with the *Health Prognostication* category *(18%)* and the *Health Prognostication* category is not seen as aspirational *(9%)*. These percentages can be seen in Table 7-4 and Figure 7-11*.* The strong association of the WBM data to the *Wearables* category *(82%)* and the association again to *aspirational products (86%)* suggests that if the features of a WBM were coherent with these products, then participants would consider them aspirational. Collectively the results shown in Figure 7-11, Figure 7-10 and Figure 7-5 support the assumptions A3.0 and A3.1 to become the following propositions:

P5: Toilets are not considered aspirational because stigma is associated with the current features of toilets.

P6: A disassociation with toilet features will achieve the attribution of new meaning for an aspirational toilet user experience.

There is however a caveat to proposition P6. The test was constructed on a normal urinal to test whether the data of the WBM would be the driver of aspiration. The results suggest that if the features of the WBM resemble features in the *Water* or *Health Prognostication* categories, the WBM may not be considered aspirational. Following this, hypothesis H1 is supported by the evidence to become the following proposition:

P7: The data from a wellbeing monitoring toilet is aspirational.

Since health and wellbeing are not features mentioned by participants when describing *why* toilets are valuable, seen in word cloud Figure 7-9a, the value from the data from the WBM is associated with health and wellbeing by most of the participants, seen in word cloud Figure 7-9b. Additionally, the WBM is considered aspirational by participants whereas the toilet is less so, seen in Figure 7-4. Therefore, health and wellbeing is aspirational, but not met by toilets. Since this value proposition was born out of the insights regarding fear of disease in Chapter 3 and 4, the latent needs from Chapter 3 and 4 are considered significant and achievable and could be met by further development of the WBM.

7.5 Implications of the Wellbeing Monitor

The WBM was presented to an Innovation Lead Manager at a Blue-chip company that develops health and wellbeing devices for medical and daily use purposes. The WBM was also presented at the IWRA World Water Congress conference. The feedback was that there are clear benefits in the WBM's ability to diagnose hydration, implement quickly, mobility, real-time analysis and application at large scale. Moreover, the WBM was celebrated for the ability to indicate diabetes or other health anomalies with further research and development.

Table 7-5 The benefits of the wellbeing monitor and how they may be appropriate to different markets.

Market	**Monitor hydration**	**Implement quickly**	**Mobile**	**Real-time analysis**	**Large Scale**	**Average**
Athletes	3	2	3	3	1	**2.4**
Military	3	3	3	3	3	**3**
Industrial operatives	2	1	2	3	2	**2**
Parents/babies	3	1	3	3	2	**2.4**
Elderly	3	1	1	3	2	**2.0**
Disaster relief	2	3	3	3	3	**2.8**
Developed world masses	2	1	1	2	3	**1.8**
Developing world masses	2	1	1	2	3	**1.8**

The WBM is a simple and low-cost sensor array that is highly transferable. An investigation in Table 7-5 demonstrates how the benefits identified may serve different markets. A review of markets include; athletes, whether they are professional or not; the military, particularly infantry in dry places or on long excursions; operatives of industrial machinery, like mining; parents of babies and toddlers; those looking after the elderly; those affected by disaster stricken regions or refugees; and finally the general populous in the developed and developing world.

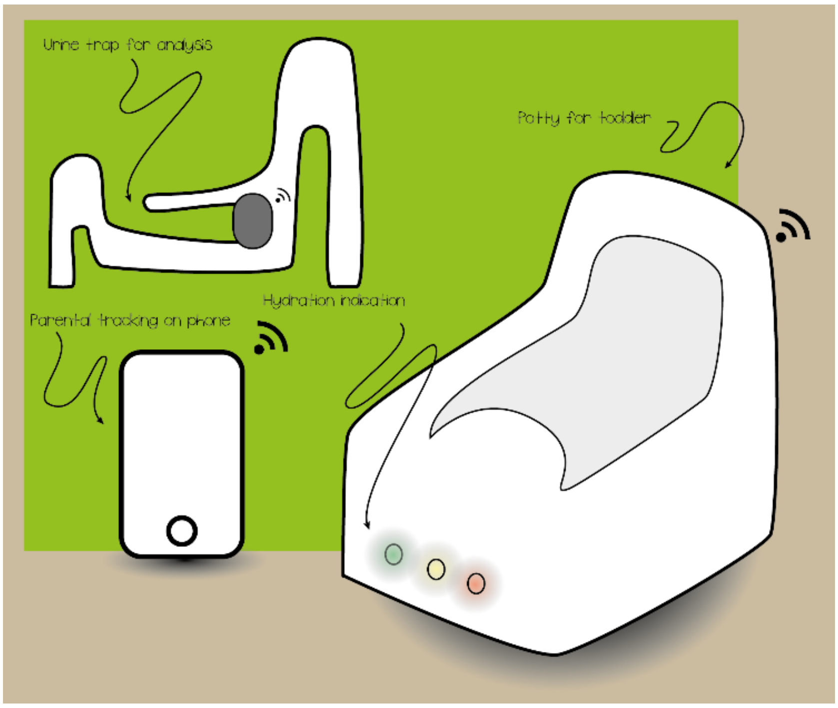


Figure 7-12 Wellbeing monitoring potty.

Sketch of wellbeing monitoring potty for mothers to monitor the wellbeing of their children. Source: J Larsson.

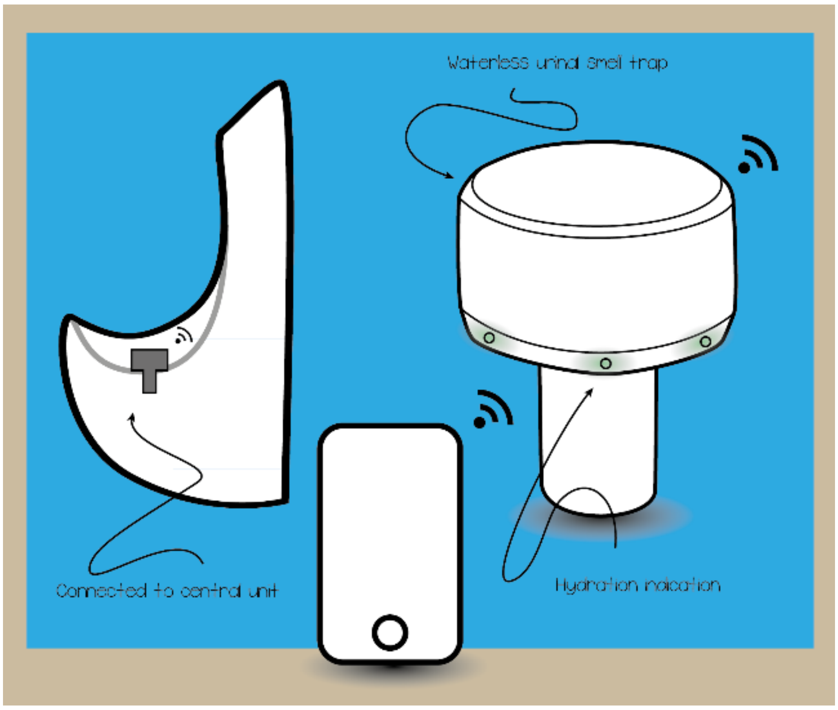


Figure 7-13 Wellbeing monitoring urinal.

Sketch of wellbeing monitoring urinal for the elderly, industrial operatives and general populous. Source: J Larsson.

Babies and infants are one of the most at risk when dehydrated (NHS Choices, 2017). For mothers wanting to monitor their babies, the WBM may be very desirable. The market for baby and nursery equipment is worth approximately £85 million where safety and monitoring devices is 11% of that figure in the UK alone (Maurya, 2014). An intelligent potty that tracks a child's wellbeing and communicates it to the parents may be very aspirational to own, a sketch of the concept is shown in Figure 7-12.

Observing the elderly market, one in ten hospitalisations of patients over 65 are considered to be due to dehydration and the economic burden of dehydration of elderly patients is a difficult number to estimate, but is reported to be $1.14 billion at aggregate level for USA in 1999 (Frangeskou, Lopez-Valcarcel and Serra-Majem, 2015). A solution similar to Figure 7-13, would help alleviate these problems, but is functionally focused and is not particularly aspirational to own and has been progressed into a model shown in Figure 7-14.

The average colour of your urine is pale yellow, your urine is currently normal. Good job!

The average volume of urine is 1.4L/day, you are currently excreting 1.2L/day. Keep it up!

The average urinations a day is 6, you are currently on 3. Are you drinking enough?

The average specific gravity of urine is 1.01 kg/m3, you are currently at 1.003kg/m3. Are you drinking enough?

The average conductivity of urine is 11mS, you are currently at 12.2mS. Are you drinking enough?

Figure 7-14 Image of final prototype of Wellbeing Monitor.

Image of final prototype of Wellbeing Monitor. Source: J Larsson.

The WBM may be beneficial to monitor hydration levels in disaster stricken areas and used as a tool for disaster relief to monitor and allocate water efficiently. For instance, in 2010, Haiti suffered a 7.0 magnitude earthquake and over 3 million bottles of water were donated. Also, Nestlé Waters Canada donated $58,743 worth of bottled water to Project Water, an organisation that distributes bottled water to dehydrated individuals in the summer months in Toronto (Nestle Waters, 2017). Again, this is functionally beneficial and not aspirational to own, but may manifest as a concept similar to Figure 7-15.

From Table 7-5, the military appears to benefit the most from the WBM where hydration is a health factor of great importance (Maintenance and Operations, 2008; Smith, 2017; Spitler et al., 2016). Within the UK there have been several fatalities simply on training missions due to over-heating and dehydration in recent years (Morris, Brooks and Weaver, 2016). The WBM could manifest as a handheld device shown in Figure 7-16. Once again, the military benefits functionally from the WBM, but may not an aspirational product to own.

Grand Prix drivers lose $2L/h$ of water through perspiration and remaining hydrated is important for both cognitive and physical reasons that clearly benefits athletes of all creeds (Watkins, 2006). A loss of water of 1-2% of one's body mass causes one's cognitive and motor skills to be impaired (Hillyer, Menon and Singh, 2015). Much as wearables - *such as Fitbits, Garmin watches or Apple watches* - have been marketed towards fitness conscious people and have since become aspirational to own, so too the WBM may be positioned as a fitness aiding product. Observing the market data from Ballaben (2016), health and wellness monitoring is the most popular reason for investing in wearable technologies and is a growing sector.

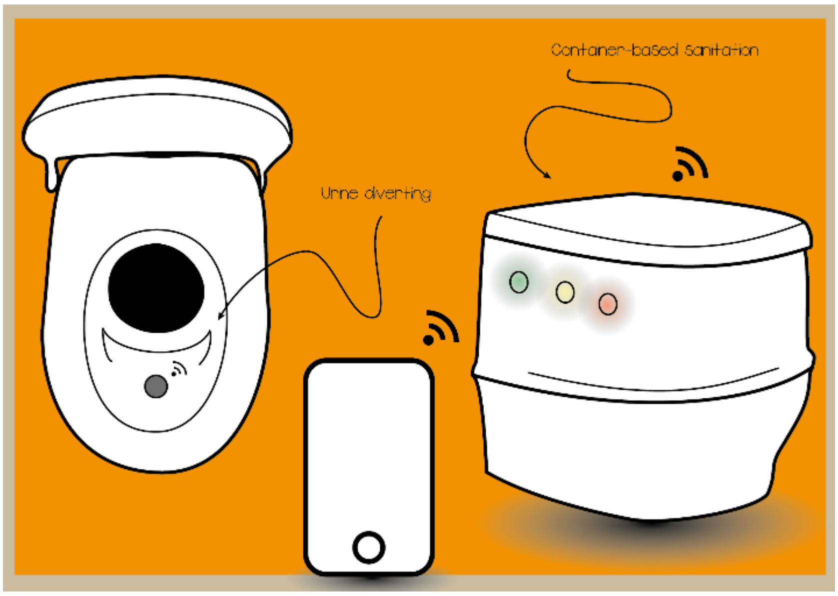


Figure 7-15 Wellbeing monitoring container-based sanitation toilet.

Sketch of wellbeing monitoring, urine diverting, container-based sanitation toilet for disaster relief or developing world contexts. Source: J Larsson.

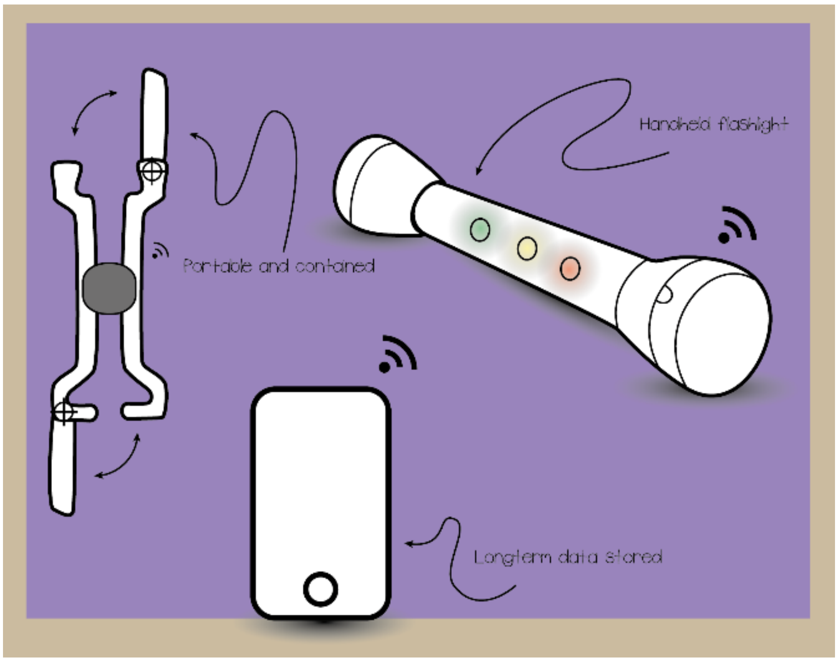


Figure 7-16 Wellbeing monitor for athletes or military.

Sketch of a 'flashlight' handheld wellbeing monitor for athletes or the military concept. Source: J Larsson.

If the WBM were to be made as an aspirational product for the general masses, 35% of people find health and wellness monitoring - *e.g. heart rate throughout the day, sleep monitoring* - as a feature or application that they would be interested in if purchasing a wearable device and 25% of people find sports applications a benefit of wearables (Coen, 2017). Admittedly, the WBM would not exist as a wearable technology and the handheld concept in Figure 7-16 may be considered unappealing. The trend of connected personal devices and health monitoring is clear and a solution similar to Figure 7-17 may be more appropriate. The market worth is unknown, but if wearables and connected devices is a growing market, we can assume there is space (Ballaben, 2015).

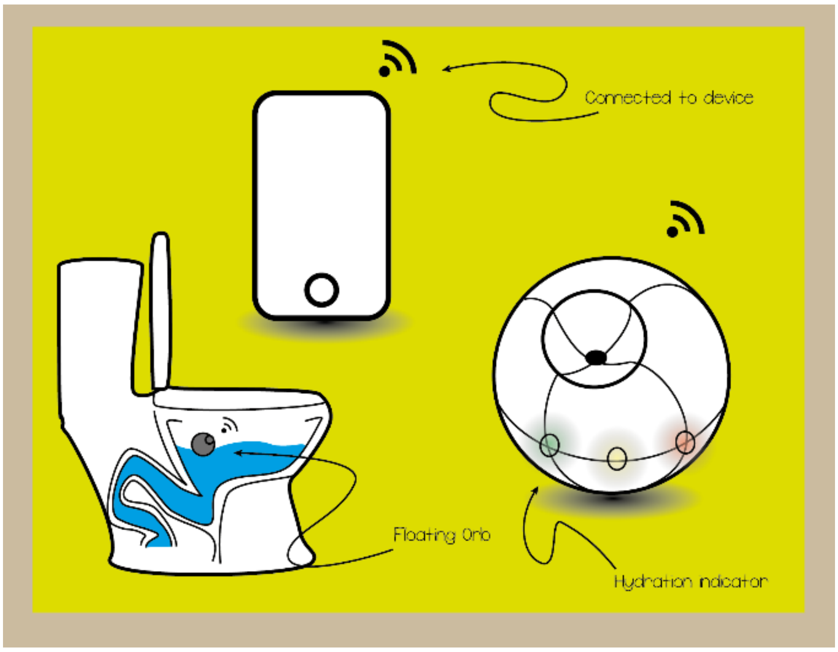


Figure 7-17 Wellbeing monitoring floating orb.

Sketch of wellbeing monitoring floating orb for flushing toilets in developed countries. Source: J Larsson.

The 2.4 million in the developing world that do not have adequate sanitation that inspired much of this research, may benefit from the changed in value proposition the most, especially if the WBM were developed to identify if a user has contracted water-borne pathogens. Adhiutama, Shinozaki and Yoshikubo (2009) observed in the diffusion of a particular toilet and state, *"the more customer understand the benefit of the product, the more opportunity customer to adopt the product"* and the

WBM may inspire individuals to adopt toilets in these regions more because of the feedback of health data showing them how beneficial the WBM is. A concept similar to the one presented in Figure 7-15 is particularly beneficial for women in south Africa for example, who do not use public toilet facilities in fear of being raped or women who work in Kenya and Tanzania avoid drinking during the day to avoid going to the toilets at work because they are disgusting (Rosenquist, 2005). If the WBM were considered aspirational, over time it may help overcome the identified stigma.

7.6 Summary

This chapter shows how aspirational a WBM equipped toilet is for participants by completing a questionnaire before using the WBM prototype, allowing them to use the WBM for an extended period and completing another questionnaire afterwards for comparison. Both qualitative and quantitative questions were asked since the questionnaires were structured to understand the participants change in perception of aspiration and value of the user experience. The chapter was considered successful. Testing the core concept of the WBM, the value proposition is considered aspirational by the questionnaire results and it has been validated with industry experts. The form and manifestation of the concept is important however and a product that resonates health prognostication is not considered aspirational.

- If the data from the WBM is considered aspirational.

This chapter shows that the core value proposition of a toilet that begins to satisfy disease concerns by diagnosing a user’s wellbeing can be aspirational. The findings in this chapter are valuable contributions for designers and sanitation experts that indicate the importance of wellbeing in how toilets are perceived. The hypothesis that the data from the WBM is aspirational is supported since value, aspiration and contentment increased. The WBM met higher than physiological needs and has new meaning that is aligned with reminders for self-improvement where toilets were confirmed to be meaningless. Despite this however, 23% of participants believed the WBM belonged to the health prognostication category, which only 9% believed was aspirational. This suggests that the image of the future concept should have features that users associate with other aspirational products.

- If the developments begin to address user concerns with disease.

The different markets that the WBM could exist in offer may different manifestations. Whether the WBM is for the general populus or it is for particular users such as athletes or recipients of disaster relief, the form of the device may be interchangable. Arguably, if a WBM did not look like a toilet, the user does not interact with it in the same way as a toilet and the value they receive from it is disassociated from a toilet. The aspiration to own a household toilet – *even call it by another name* – would mean that it will be adopted more widely.

- If a conceptualisation of the WBM and a review of the intended audience.

The concepts presented and the assesment of how they best meet the different audiences suggest that there are a variety of audiences that may benefit from the WBM such as athletes or parents of young children. However, these audiences may not find he WBM concept aspirational. For a wider general populus audience, the concept sketches of the WBM challenges the typology of toilets.

Key Findings:

- The majority of participants believe the data from the WBM makes the user experience more aspirational.
- The value participants receive from toilets comes from the physiological needs toilets satisfy, whereas the value of the WBM comes from meeting higher needs.
- The data from the WBM makes the user experience more aspirational, but crucially only when users associate the WBM with a category of wearables and not health prognosticators.
- The data from the WBM may serve many different potential markets.

- Other projects looking to produce aspirational user experiences may also benefit from the association of products with certain categories and the associated materials and features.

Next Steps

Following this chapter, a discussion of the research is given and the implications for future researchers.

“Consumption has been increased by crafting artificial needs, weakening the quality and durability of utility objects, making objects irreparable, and by marketing short-lived novelties and bric-a-brac.”

Pekka Harni

8 DISCUSSION

The findings from this research intends to contribute knowledge through each of the objectives: to understand how one may implement latent needs research, to reframe the problem from the insights from latent needs, to inform the design of aspirational product user experiences. The thesis has thereby provided at least some answers to the question of *'how may aspirational toilet user experiences manifest?'.* The evidence from each chapter's key findings is discussed in relation to literature in terms of; theoretical contributions, the transferable learnings for other Design Thinkers; practical contributions, for the implications on the design of toilets. The knowledge contributions are several themes that emerge from the key findings of the research that are discussed and compared with the perspectives from current literature.

- An aspirational toilet user-experience: defining what it looks like.
- Perceptions: public and private spaces and the sanitation-health gulf.
- Toilets as wellbeing prognosticators.
- Identifying lead users: user-experience and aspirations for acquisition.
- Reframing the problem: focusing on user needs.

8.1 An aspirational toilet user-experience: defining what it looks like.

The questionnaire from the Human User Testing was designed to test the IVs – *need and meaning* – of toilets and WBM equipped toilet affected the DVs – *value and aspiration.* Norman (2004) states the value of a product comes from how the product satisfies a user's physiological, social, psychological or self-fulfilment and self-esteem needs. Figure 7-6 shows there were more participants that perceive the data from the WBM equipped toilet as more valuable than toilets by themselves *(77% of participants agree or strongly agree versus 95% agree or strongly agree)* and participants feel the WBM equipped toilet meets higher needs like psychological *(23% versus 68%)* and self-esteem needs *(5% versus 55%),* shown in Figure 7-7. Csikszentmihalyi and Rochberg-Halton (1981) state products are a reflection of one's self-image for different meanings; for qualities of the self, signs of status, symbols of social integration or reminders for self-improvement. Reviewing the results of the questionnaire that test toilets against a WBM fitted urinal, we see that more participants agree the WBM is more aspirational *(87%)* than toilets *(19%)* shown from the distributions of in Figure 7-4. The majority of participants believed the WBM expressed a meaning of *reminder of self-improvement (98%)* where the majority believed toilets by themselves express no meaning at all *(59%)* seen in Figure 7-8 because the WBM meets higher needs on Maslow's Hierarchy of Needs Figure 7-7. More participants agree the WBM brings them contentment *(100%)* compared to toilets *(50%)* as shown in Figure 7-5. The evidence here indicates the data of the WBM equipped toilet is aspirational to participants and this may be because features, namely the data, brings participants contentment.

The WBM equipped toilet is designed to appear like a normal urinal so the form did not influence the results as seen in Figure 6-20. Csikszentmihalyi and Rochberg-Halton (1981) suggest that the negative connotations we have with toilets then become associated with features and attributes we see and interact with. The insights from the ethnographic research show that there is a current stigma surrounding toilets that is compounded by respondents fear of disease shown by the quotes from the intangible observations – *indicating emotive subjects*:

> *"I am worried about the heat coming out of the hole of the [non-flushing] public toilet. It may transfer diseases. That's why we only go there at night"*
>
> Respondent 63

Gramigna (2013) argues that features of sitting or flushing become inseparable from the stigma of a toilet, the flush for example, visually and audibly signifies to the user that the filthy and profane has been deleted. We see there is a repetition of certain features as listed in Figure 7-10; people define toilets as a white, ceramic, water flushing, generally unpleasant seated products. The association of disease with these features may explain the 5% of participants that disagree that the WBM is valuable and 5% of participants that disagree that the WBM is aspirational from Figure 7-6 and Figure 7-7 respectively. This evidence suggests that the form is also important in creating aspirational user experiences.

The results from the questionnaire showed that 82% of participants associate the WBM with a *wearables* category and 18% of participants associate the WBM with *health prognosticators* in Table 7-4. Interestingly, *wearables* and *health prognosticators* are considered aspirational by 86% and 9% of participants respectively in Figure 7-11. Comparing this with toilets that are considered to be in a *water* category by 95% of participants, we see that only 9% of participants consider the *water* category aspirational. This evidence suggests that though the physical appearance of toilets may anchor the stigma of disease and stop the product from being perceived as aspirational, the WBM may not be considered an aspirational user experience if the form resembles a product considered to be in a *water* category or *health prognosticator* category.

Figure 1-4 shows that the affordances of toilet user experiences provide avenues for revolutionary innovation, that are toilets as a source of water, source of fertiliser, source of energy and monitoring health and wellbeing. Several authors in literature claim that what people say is not what they do and as such, results from surveys may not elicit tacit needs (Bertrand and Mullainathan, 2001; Fellman, 1999a; Goffin, Lemke and Koners, 2010). Not one respondent from the ethnographic research or participatory photography mentioned that health could be monitored from the toilet shown in Table 3-13 and similarly health was not mentioned in the pre-user experience questionnaire shown in Figure 7-10. The premise to Design-Driven Innovation and a latent needs approach to design is that *'people do not know what they want'* (Cooper and Evans, 2006; Verganti, 2009). This implies that that the explicit needs of users would not produce an innovative user experience and the latent needs – *around fear of disease* – did produce an innovative user experience not previously realised by the user. The current commercially available toilets shown in Table 5-1, indicate toilets do not appear to be extending into the health and wellbeing space. A black toilet or angular toilet depicted in Figure 5-5, may be considered novel or unconventional from what a user expects, referring to the features listed by participants in Figure 7-10. There are examples of what Norman (2004) deems *"creeping featurism"* for the sake of differentiation from competitors that may not yield innovative or aspirational toilet user experiences. The evidence indicates that the change of stigma to satisfy health was not imagined by users and the perceived increase in value indicates that the WBM meets user latent desires where the current marketplace does not.

The WBM is an aspirational user experience, but other innovations could equally be pursued. There were other needs identified in the ethnographic research and participatory photography in Table 3-13 - *such as comfort in use or entertainment while on the toilet* – but these were not pursued because they were deemed to be peripheral. Design problems should not simply focus on the newness of a technology, it is vital to reframe the problem to include the value to the end user (Castillo, Diehl and Brezet, 2012; Norman and Verganti, 2012). Several authors in literature claim one misconception about innovation is not all innovations require novel technologies and instead the wider spread innovations are those that mean more to the users or provide more value (Garcia and Calantone, 2002; Rogers, 1995; Verganti, 2009; Weigel and Goffin, 2015). Table 3-13 shows that price is also a determining factor in the adoption of toilets. Space for example was another salient issue for Respondent 25 who said, *"[Frustration] We do not have enough space for a toilet"* and the dignified solitude of the environment toilets are kept in is important, as shown in the correspondence mapping in Figure 4-2. New technology could have been developed to meet these needs. The word clouds in Figure 7-9 confirm that health and wellbeing was not a value that participants receive from the user of toilets, but health, wellbeing and feedback appeared many times as a value of the WBM that is aligned with the insights from Table 3-13. The many new manifestations of the WBM concept are shown in sketches like Figure 7-16, that are arguably new and innovative manifestations of toilets not previously realised. The evidence here suggests that additional technology or add-on features to toilets, like those seen in the participatory photography, would not make toilets aspirational since they would remain in a non-aspirational category. The concept of the WBM – *using the data from user's waste to interrogate their* *health and wellbeing to reinforce a positive indication of their wellbeing* - is the most promising direction for an aspirational toilet user experience.

8.2 Perceptions: public and private spaces and the sanitation-health gulf.

The ethnographic research found that the main driver for purchasing a toilet is related to a fear of disease seen in Table 3-13. The hacks that allow users to avoid touching door handles from the participatory photography in Figure 3-14, is aligned with this universal fear.

Disease transfer is an emotive issue as shown by the evidence in the grouping of codes from the ethnographic research around disease in the correspondence mapping in Figure 4-2, the frequency of disease centric judgements made on the contradictions observed in Table 3-6, the workarounds observed in Table 3-8 and the displays of intangible emotion in Table 3-10. This is encapsulated by several quotes throughout Section 3.3 such as the one given below:

> *"[Animated] Disease transfers from other people using the public toilet"*
>
> Respondent 07

This evidence demonstrates that respondents in the ethnographic research did not always understand disease transfer with respect to toilets and would attribute disease to tangible things like smell, heat or other people.

> *"You can get disease from the heat"*
>
> Respondent 54

The attribution of disease to heat and smell is supported by other authors Leone (2012) and Rosenquist (2005) and is the core of the Miasma Theory found in pre-Victorian attitudes towards human waste (Horan, 1996). Disease being an emotive driver for the adoption of toilets is a finding that is shared by many authors (Chun, 2002; Jenkins and Curtis, 2005; O'Reilly and Louiss', 2014; Routray et al., 2015; Tumwebaze et al., 2012). The hacks such as avoiding touching door handles in Figure 3-14, indicate the universality of this insight. The evidence and the literature suggest that even if disease transfer is understood, the invisibility of disease is a constant fear for most users. As such, toilets are shut away in toilet spaces - *whether they are outhouses in low-income countries or bathrooms in more affluent countries* - to separate the negative associations with disease. This excludes the availability of toilets for those without separate spaces or limits how aspirational the toilet user experience may be for those that do. From the ethnographic research, the respondents that did not have household toilets claimed that the lack of space was the main reason for not acquiring a CBS toilet, as seen in the judgments made in the Elito method in Table 4-5. The results suggest that it is not necessarily space that is the issue, but the need to shut toilets away from living areas. The literature suggests the space in which the toilet is kept reaffirms the sense of public to private and reminds us of the polluting sense of defecation (Chun, 2002). Gramigna (2013) claims that currently *"toilets transcode exterior space into interior space, public into private"* and so the space they are kept in represents this. Therefore, issues expressed about space are fundamentally about location, related to concerns about disease and proximity to private living areas. In other words, the root cause of the issues with space is actually about the universal fear of disease. Combatting stigma around disease may in turn tacitly address perceptions of the lack of space. The WBM value shown in the word cloud Figure 7-9b indicates that the WBM may be one avenue that can begin to alleviate the issues surrounding the universal fear of disease by providing a sanitised view into the user's health – *meeting the benefits of illness inspection associated with a German toilet design while remaining clean and modern like the Japanese toilet design* (George, 2008; Žižek, 1997).

The reoccurrence of particular features and attributes to toilets – *namely seat, water, flush, bowl, white etc.* – suggest users may not be able to dissociate the universal stigma of disease with toilet[11]. This supports the need to disassociate

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[11] The association of attributing certain properties of disgust to similar products forms the concept deemed 'Sympathetic Magic' or 'Magical Contagion' from psychology (Herz, 2012).

new toilet concepts from current toilet and the need to reframe and breakaway from current norms – like lifting the legs whilst defecating. Again, this supports the need for revolutionary innovation in the sanitation space. The interesting question this research presents is, *'how and to what degree a concept such as the WBM may alleviate and manifest in different cultures such as Ghana, Japan, Germany, France or UK to meet the universal fear of disease?'*.

8.3 Toilets as wellbeing prognosticators

The other health prognosticator prototypes shown in Table 5-2, are more comprehensive health screening toilets that diagnose diabetes and cardiovascular disease. Using negative disincentives such as reinforcing the dangers of disease or societal shame to motivate the uptake of toilets may not be an effective method for increased toilet adoption as mentioned by O'Reilly and Louiss' (2014) and Jenkins and Curtis (2005). The WBM has been shown to be valued and considered aspirational by users in Figure 7-6 and Figure 7-4. The WBM has positive practical contributions as a monitor of users' health where the effects of improved sanitation can be tracked, the first low-cost solution of its kind shown by the review of the marketplace in Table 5-1. This is not so much an issue for affluent countries where sanitation is nearly ubiquitous, but the improved desirability and affordability of the WBM may benefit low-income users who lack sanitation and suffer dehydration from diarrheal diseases from water-borne pathogens (Bill & Melinda Gates Foundation, 2015; Prahalad and Hart, 2008; UNICEF and World Health Organization, 2015). Authors acknowledge improved infrastructure – *infrastructure like water pipes or soft infrastructure like personnel for CBS services* - to enable the diffusion of toilets is needed, but greater work needs to be done on increasing the desire and aspiration of owning household sanitation (Dreibelbis et al., 2013; Ramani, SadreGhazi and Duysters, 2012; Routray et al., 2015; White et al., 2016). Table 7-5 shows the WBM is aspirational for many audiences; for disaster relief, the elderly, parents and their babies or even developing world users and one example of how it may be appropriate is shown in Figure 7-15. The evidence throughout the Proof of Concept Feasibility in Chapter 6 shows that the WBM technology is novel because of the methods used to infer hydration and adopts methods for evaluating hydration at an affordable price, but the measured parameters can infer other health indicators and may be able to notify a user whether they have contracted water-borne pathogens, an example of this has been explored in Appendix F. The word clouds in Figure 7-9 indicate that it is the value the data provides the user that is beyond the utility centric view that users currently have of toilets and this innovative perspective shift may influence the uptake of toilets for a variety of users, particularly in contexts that drastically need them[12].

8.4 Identifying lead users: user-experience and aspirations for acquisition.

The final WBM was developed from the latent needs elicited from low-income lead users and hackers. The final solution has an increase in perceived value and aspiration of ownership after a period of use shown in Figure 7-6 and Figure 7-4. Literature shows that observations and contextual interviews provide deep consumer insight and can lead to innovative product concepts (Madsberg and Rasmessen, 2014; Prasetio and Dhewanto, 2011; Price and Wrigley, 2016; Rosenthal and Capper, 2006; Skaggs, 2010). Authors have stated anomalous behaviour leads to deep consumer insight (Norman, 2008; Skaggs, 2010). Literature supports the use of latent needs methods and suggests that the approach leads to revolutionary innovation (Prasetio and Dhewanto, 2011; Price and Wrigley, 2016). Another qualitative study on disabled people and sanitation in Malawi found:

> *"The research methods employed in this study helped generate data that would not have been achieved through in-depth interviews alone"*
>
> (White et al., 2016)

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[12] Verganti (2009) himself recognises that new technology has the ability to introduce new meaning not before envisioned, but the uniqueness of the WBM as a case study is how changing meaning was the core of the value proposition as opposed to changing technology.

Only two examples of using developing world users as lead users have been found; a wheelchair that was designed for the rough terrains in Africa by Judge, Hölttä-Otto, & Winter (2015) and a dishwasher that was designed observing old order Mennonites who exercise low resource consumption lifestyles by Govindarajan & Trimble (2012)[13]. The contradictions observed in the ethnographic research, shown in Table 3-5, show respondents would claim they did not like the mess in public toilets though their CBS toilet appeared to be equally as messy. In the case of the workarounds, shown in Table 3-7, the respondent would not mention they had an issue with comfort when the workaround would suggest otherwise. The contradictions in Table 3-5 and Table 3-6 suggest a construct is defined as one thing to the respondent and something else to the researchers, which requires more probing to understand the underlying problem. Literature supports this and suggests the use of observation techniques like ethnographic research and participatory photography to find latent needs, particularly suits a topic of a sensitive nature such as visiting the toilet. Just as the elderly can teach us about ergonomic handles, disabled users can teach us about mobility, so too can developing world users teach us about barriers to the acquisition of products.

8.5 Reframing the problem: focusing on user needs.

The research started with the question *"how may aspirational toilet user experiences manifest?"* and the Translating the Insights methods used in Chapter 4 – *concept mapping, Elito method and personas* – reframed the problem to indicate that many of the user barriers were a result of the stigma associated with the fear of disease. The need to investigate the underlying problem in greater depth also indicates that the reframing of the problem is the critical step in any user focused design problem (Design Council, 2010; Ideo, 2014; Norman, 2013). Reframing the problem, can yield far more innovative and aspirational product user experiences

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[13] There are other examples however, known as *'reverse innovation';* the typical perspective is that innovation comes from high quality products designed for affluent countries that is then simplified to cheaper versions for low-income users, where reverse innovation is the reverse of this (Govindarajan and Trimble, 2012; Hadengue, de Marcellis-Warin and Warin, 2017; Kuhr, Otto and Sosa, 2013).

as demonstrated by this research. As an example, approaching the brief *'reinvent the chair'* conjures up images of chairs with different number of legs, but still look like chairs. To set the brief as *'reinvent the way to elevate a user's posterior'* may not even include legs and be hung from the ceiling or may not even be a sitting posture at all. The point of this analogy is aspiration and meaning is as much a part of design as is marketing and branding, where reframing the design problem to focus on the user allows more innovative solutions may be achieved than simply starting from a technology focus.

8.6 Summary

The evidence called upon in this chapter, contributes practically by bridging the user understanding of sanitation hygiene to the health effects by making the toilet user experience more aspirational. The faeco-oral pathways diagram in Figure 1-3, shows how important toilet usage is, however the findings indicate to dominant underlying and universal concern of the invisibility of disease transfer negatively impacting on the image of toilets, the toilet user experience and the acquisition of toilets in the developing world. The data from the WBM that has been developed from this, has shown to bridge the gap in to begin to satisfy users' concern of disease by informing users of their hydration, improving the user experience through reminders for self-improvement. A latent needs approach lends itself well to elicit user needs and reframe the problem to incorporate the user's needs. The WBM is one answer to the research question, *'how may aspirational toilet user experiences manifest?'* following this methodology and the evidence discussed in this chapter contributes theoretically and builds on the belief of current literature that meaning change and technology change can lead to revolutionary innovations and aspirational product user experiences.

8.7 Contributions to Knowledge

The following are the key contributions to knowledge from this research:

- The novelty of the identification and elicitation of significant latent needs from the 77 lead users in Kumasi Ghana.

- Defining the gap in the marketplace for toilet user experience to contribute to the knowledge of health and wellbeing. This gap demonstrates the universality of the unmet latent need.
- The construction and test of the WBM concept to infer hydration in real-time is novel and has been validated as aspirational.
- New and innovative forms of future toilets challenges the typology of toilets.

“Any sufficiently advanced technology is indistinguishable from magic.”

Arthur C. Clarke

9 CONCLUSION

Toilets have not fundamentally changed in 200 years and as a topic of discussion is considered taboo. There are lessons to be learnt for other practitioners undertaking latent needs research or design of innovative and aspirational products by assessing the implementation of latent needs research in the design of an aspirational toilet user experience. The research was driven by the question:

How may aspirational toilet user experiences manifest?

The research aim was *'to assess the implementation of latent needs to design an innovative aspirational product user experience'* which was achieved by reflecting on the taboo and ambitious subject of re-designing a new toilet user experience. The first Objective sought to elicit latent needs, indicating the dominating themes to be a universal fear in disease, a stigma of toilets and the convenience, safety and comfort for the vulnerable. The translation of the insights - *Objective 2* – found that alleviating the fear of disease may produce an aspirational user experience. Objective 3, a review of the marketplace, presented a gap for low-cost connected wellbeing monitoring concept. Objective 4, the design and development of the proof-of-concept, showed that colour can identify hydration repeatedly and has not been used before. The final Objective 5 tested the final concept on users and showed that the data received from this technology presents an aspirational value proposition for a new toilet user experience.

The insights from the ethnographic research and the participatory photography show that the fear of disease, the convenience for the sick and elderly and the safety of the women and children was a motivator for acquisition. The negative stigma that toilets have, mean they are often kept in outhouses or Moris. The resultant effect is that those without space for an outhouse or Mori do not perceive it practical to own a toilet.

After use of several ideation techniques, a WBM was arrived at as a concept that may begin to satisfy the underlying fear of disease. The ability to give real-time feedback of the household’s wellbeing provides improved value to the user experience.

A review of the marketplace shows that electronic toilets, at present are relatively expensive and are made to improve the comfort while on the toilet. Any health centric electronic toilets are either still in laboratories or are in prototype form and are very much health focused to diagnose chronic diseases particularly for the elderly. The review shows that there is an opportunity space for a low-cost unit that can feedback general wellbeing data that may benefit everyday users. The WBM was then prototyped and tested to measure hydration of users correctly 92% of the time. The novel method for inferring hydration meets the requirements from the marketplace by costing approximately £20 and as such is relatively affordable.

A questionnaire was distributed to 22 male participants to gauge how they feel towards toilet user experience. The participants then used the WBM prototype for an extended period and completed another questionnaire on their experience. Firstly, the WBM is a new technology and was not envisioned by the participants previously, indicating the novelty of the product. The participants nearly unanimously found the data from the WBM more valuable and aspirational than a normal toilet or urinal, indicating that the WBM is indeed a novel concept. The findings from the questionnaire indicate that the manifestation of the WBM is important for the product to be perceived as aspirational. The findings of the questionnaire and supporting literature suggest that the form the final product should take, should break away from existing toilet forms to become a revolutionary innovation.

9.1 Impact of the Research

The lessons from the implementation of latent needs to the design of an innovative aspirational toilet user experience, indicates the development of a toilet that monitors wellbeing can begin to satisfy users’ universal fears of disease. The innovative shift in the value proposition of toilets is an important dimension of innovation that designers should focus on equal to technology change when creating any aspirational product user experience.

9.2 Limitations

The study has several limitations in contributing to the design of toilet user experiences and as a case study for the wider body of knowledge in designing aspirational product user experiences. There were a multitude of insights collected from the ethnographic research and participatory photography and the research focused on changing the value proposition of the toilet since the issues surround fear of disease and negative stigma associated with toilets were identified as the dominant problems for users. The WBM is essentially a toilet with more functionality and one would expect it to naturally be more aspirational because it has more functionality that a normal toilet, so any addition to a normal toilet would be more aspirational than a normal toilet user experience. On the other hand, cleaning routines and sitting posture also presented itself as universal problems, but was not pursued in this research. Extending this point, assuming the insights were of most importance, there may have been more aspirational concepts that one could have chosen; the process of selecting ideas was presented in a logical structed form, but there is still a degree of researcher intuition that influenced the decision to proceed with the WBM. The limitations of each chapter are discussed where alternative methods or alternative explanation of results are offered.

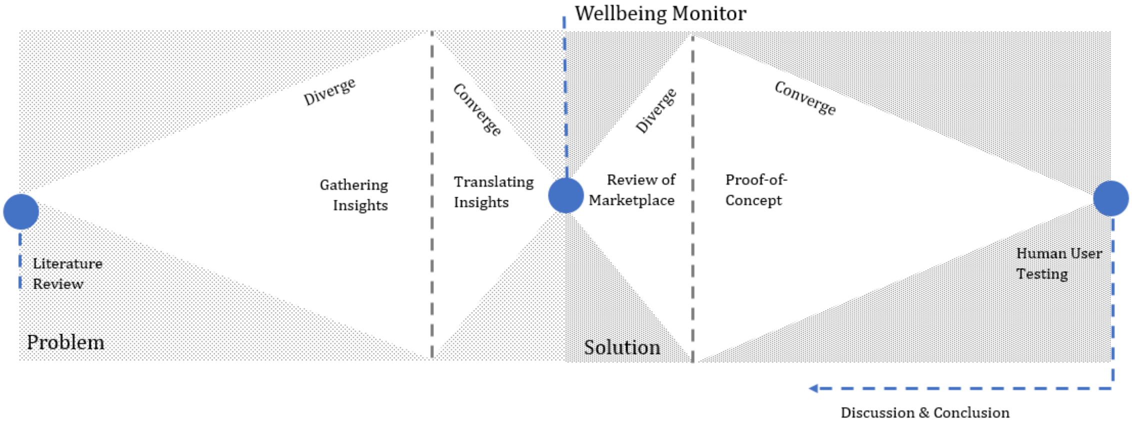

Figure 9-1 Process of research reflecting time spent.

Process of research reflecting time spent. Source: J Larsson.

Reflecting on the process over the three years, the majority of time was spent on gathering insights and on Proof-of-Concept (PoC) development represented in Figure 9-1. The time spent on making the PoC although necessary, did not contribute to the better understanding of implementing latent needs and given the opportunity and resources, it would be more beneficial to subcontracted so more time may be spent on refining solutions to the user's needs or delving deeper into their true latent needs with further qualitative studies on the use of new prototypes. However, the development process was invaluable and a thorough understanding of what was achievable through use of low-cost and open-source electronics presented a new and innovative concept that was relatively inexpensive.

Reflections on Objective 1

The objective of Chapter 3 was to uncover the latent needs of the lead users identified. Ethnographic research and participatory photography research is qualitative in nature and the question regarding the reliability of the results is that would the same results be found if another researcher undertook the research or another method was used? On the whole, ethnographic research has been shown to be more effective at deep insight about the use of a product than other traditional methods such as surveys and interviews, but one criticism of qualitative research, is that it does not allow for widespread generalisation (Bosch-Sijtsema and Bosch, 2014; Goffin and Koners, 2011; Rosenthal and Capper, 2006; Skaggs, 2010). Although the qualitative study in Malawi shows that it is coherent with quantitative surveys (Wood, Foster and Kols, 2012). The justification for using the methods and the rejection of structured-questionnaires and surveys was made in Chapter 3. COREQ guidelines and the IBM-WASH framework were followed and multiple researchers and translators were used in the ethnographic research to avoid bias (Dreibelbis et al., 2013; Tong, Sainsbury and Craig, 2007). The IBM-Wash framework has limitations in the context of this research. With respect to the formulation of the IBM-WASH framework, many of the search terms used in the systematic review were comprised of theories of explicit and conscious decision making, not encompassing latent or tacit levels of cognition. E.g. the *"theory of reasoned action"*, *"theory of planned behaviour"*, *"self-*

efficacy" and *"decision making"* to name a few. If the semi-structure interview were based on a framework that is incorporates latent and tacit mental processes, perhaps more in-depth insights could have been elicited.

The diagram by Silva et al. (2012) in Figure 2-3, suggests Generative Sessions uncover more significant and deeper consumer insight eliciting feelings and beliefs. It was not used on the lead users identified in Kumasi Ghana because of the time restraints of the project and the ability to systematically record and anylse data in a foreign setting with language and environmental barriers, but could have produced deeper insights regarding their emotions. Relationships between household members became clear as an import factor in the adoption of household toilets in the generation of the personas, but unfortunately the opportunity to investigate this further was not available.

The ethnographic research was time and resource intensive. It took a long time to gather the data, but nearly three times longer to analyse the data. Though the ability for deep insight is less, a questionnaire or survey on the other hand, would take nearly no time at all to analyse if the questions are selected appropriately. The participatory photography was far quicker than the ethnographic research, but was limited since an interview with the hacker was not possible to probe deeper into their motivations.

> *"These methods are very time consuming, so designers typically only examine small numbers of people, often numbering in the tens."*
>
> (Norman, 2013)

The ethnographic research did not need to be on 77 respondents and instead, 20-30 may have been adequate. Though the developing world users are themselves lead users, more targeted selection of respondents – *instead of randomised slection* – could have produced more insight. This brings into question the topic of significance in quantitative studies versus qualitative studies. Qualitative studies are more interested in the idiosyncratic behaviours, as is design research (Brown, 2008; Ideo, 2014; Norman and Verganti, 2012). Quantitative studies are interested in painting a representative picture of the majority. Significance therefore in quantitative studies is a measure of confidence of the representation whereas significance in qualitative studies is about the depth of the insight. Therefore the number of respondents is less important than the purposefulness of the selection in a qualitative study and as such, although respondents of Kumasi Ghana were already chosen as lead users, more purposeful selection of 20-30 respondents may have been more beneficial.

The use of video cameras and audio recordings was necessary in effective analysis of the Contextual Interview and Demonstration of Use because of the complexity of the changing environments and has shown to be a great addition to latent needs research (Goffin, Lemke and Koners, 2010). Similarly, upon return to the UK, the Translator B during the analysis recognised several times that Translator A during the interview had not translated directly what the respondents had said because of the embarrassment of the topic. The ability to revisit interviews made the process more valuable.

A demonstration of use was crucial in identifying contradictions and workarounds that show the nuances in respondents' use of the CBS toilet and indicate respondent's latent needs. However a true participant observation is recommended (Norman, 2008; Norman and Verganti, 2012). Given the sensitivity of the topic however, it was not appropriate to have a true demonstration of use and this was the main reason for selecting participatory photography to compensate for the ethnographic research's shortcomings.

Reflections on Objective 2

The objective of Chapter 4 was to translate latent needs and reframe the problem. The reframed problem from the insights was to change stigma from the fear of disease and promote positive wellbeing inspired by authors Norman (2004) and Verganti (2009). Verganti (2014a, 2014b) himself uses another Bill & Melinda Gates Foundation (BMGF) funded project as an example of innovating meaning; the Next Generation Condom. As a mission to fight HIV, the BMGF launched a challenge for ideas to reinvent the condom, however this proposition attracts engineers and scientist to create new technological solutions to this problem, when the current solution is perfectly adequate in preventing HIV technologically speaking. A revolutionary innovation solution to this project would be an improved condom user experience not necessarily a new technology.

Chapter 4 arguably is a pivotal decision-making stage where insights gathered are used to influence the ideas that make up the final concept. If at this stage, more designers were used in brainstorming activities, more or better concepts may have been generated (Martin, Hanington and Hanington, 2012). The techniques used for idea generation were varied and suited the mind of the researcher and as such were a combination of analytic and empathic methods for creative exploration. However another researcher may resonate more with different methods. This stage requires more of researcher intuition than other stages and is limited, but a variety of methods used may minimise these shortcomings. The correspondence mapping in Figure 4-1 did not map concept ideas on the same biplot for instance and the User Journey map in Figure 3-13, did not include the steps, thoughts or relationships that ocurred before the purchase of the CBS.

The correspondence mapping factors F1 and F2 only accounted for 15.13% of the variance. This is an exceptually low value for orthoganol components. After removing some 'outlying' codes, the variance between orthoganol components increases, however it does not paint a full picture of the codes captured in the ethnographic research and for this reason, the correspondence mapping with variance of 15.13% remained. The Elito method traditionally creates a *'logic line'* from observation to concept, however there were many observations and instead only concepts that emerged from interesting observations were pursued. The purpose of creating the logic line is to trace whether the new concepts and the metaphors are directly associated with the observations. The steps in the Elito method - *making judgements and assuming underlying problems* - followed here, has been spread out over Chapters 2 and 3 and the logic line therefore is hard to follow, perhaps defeating the core purpose of the technique. Personas were generated from the Observations Teams experience of 18.5 hours of analysing the footage, not from quatitative data. For this reason the personas may not seem as relaible or may be perceived as subject to bias, but because they were generated by the Obervation Team as a collective, researcher bias is pressumed to not be present.

Reflections on Objective 3

The objective of Chapter 5 was to review the marketplace and horizon scan current solutions. The purpose was to assess the feasibility and viability of the WBM by assessing what else exists to meet the needs identified and at what price. Without a doubt Japan is the leading country for innovation in the world of toilets, there are a *"flourishing industry of sanitary fixtures"* (Leone, 2012). The findings however, were that most electronic or connected toilets had additional features that improve the comfort of the experience rather than innovate the meaning or the value proposition.

> *"The probl*em is that after the pr*oduct has been available for a while, a number of factors inevitably appear, pushing the company toward the addition of new features—toward creeping featurism"*
>
> (Norman, 2013)

The WBM is not a concept that would compete with the Japanese toilets adding more features, but instead using current technology to meet a 'true need'. The findings from Chapter 3 and 4 suggests the WBM is a good direction to head in, but there are currently no products that are tailored to health and wellbeing. The lack of toilets that meet health and wellbeing concerns may be because it is not a need from the marketplace. The feedback from the results in Chapter 7 and the prototype and lab-based concepts suggest there is a future in toilets for health monitoring. Literature suggests that sometimes innovations may take decades to be accepted; technology changes rapidly, but people and culture change slowly (Norman, 2013; Rogers, 1995).

Reflections on Objective 4

The objective of Chapter 6 was to develop a new prototype for user testing based on insights and gaps in the marketplace. To solely test the effectiveness of the data received by the WBM the prototype was purposefully designed to resemble a normal urinal so the form of the prototype does not influence how aspirational the data is perceived.

The technology has shown to be promising, but future analysis on a larger sample of urine is necessary to show a significant correlation between RGB colour of urine and hydration. One approach would have been to fabricate the hydration results of an individual user and gauge the users' receptiveness of a mock concept before committing to months of work on the development of the electronics. Instead, for ethical reasons, the decision was made to not fabricate the results, but to produce a reliable and accurate device for testing user hydration.

The flow chart of development in Figure 6-2, briefly communicates how problems were solved, but does not give any detail about how to generate ideas. The Design Thinking process in Figure 6-4 is a better methodology for ideation (Brown, 2008; Design Council, 2010; Norman, 2013). The layout of the chapter does not reflect the chronological process taken, as the refinement of hardware and firmware was not a linear process. New unforeseen problems or opportunities arose that required attention; the flow chart that has been offered best demonstrates the path taken, but not the inspiration in ideas. Unfortunately, a degree of designer intuition is needed when problems present themselves, regardless of how systematic the development process is (Micheli et al., 2012).

Reflections on Objective 5

The objective of Chapter 7 was to assess the change in aspiration of the user experience. Arguably, innovations can only be judged after ten years or so after they have been released into the marketplace, since innovation is defined by how well it is received (Norman, 2013). Comparing the results from Chapter 7 to insights in Chapter 3 however, the WBM begins to meets many of the users' latent needs and is therefore considered to be innovative.

Admittedly, the questionnaire in Chapter 7 is not an exhaustive study since there were 22 participants and the construction of the test meant that all participants were male; there may be other drivers and priorities for a female audience. Also, only 22 participants were available to test the prototype and the generalisability of the results is difficult to assess. As discussed in the Literature Review, questionnaires themselves are not always reliable and many participants may have been giving answers to questions they believed the researcher wanted to see rather than what they truly felt; known as the social desirability bias. Further research needs to be conducted on a female audience to see whether a female audience may react differently to the ability to capture their data. Issues around dignity and sharing of personal information whilst on the toilet are suspected to be more prevalent with a female audience. Similarly, the environment where the test is conducted is suspected to be important and a test of whether the same results would be seen in a domestic environment rather than a public or institutional setting.

The dimensions of meaning in Figure 7-8 and indeed constructs of value and aspiration may be very different from one participant to the next and may need additional clarification. The method of questionnaire suggests the WBM is valuable and aspirational and is because of the addition of wellbeing feedback from the word clouds in Figure 7-9, but the nuances of the participants responses may need further explanation. For instance, the differences between the definitions of aspiration and value for the low-income audience – *lead users in the ethnographic research* – may be different to the definitions of a high-income audience – *participants of the final questionnaire* - the inclusion of these definitions would have been beneficial to incorporate in the initial research group for reference.

82% of participants considered the WBM to be in the Wearables category and 86% of participants found the Wearables category aspirational. The assumption is that if the WBM were to resemble products in the Wearables category, for example a FitBit watch, then the WBM would also be considered aspirational. However, to change the form of a toilet concept sufficiently to have its aspiration equal to that of a wearable, is a challenge indeed. Nevertheless, the participants responded positively to the WBM.

Acting reflexively about the qualitative research and external influences from literature, it is worth questioning whether the definitions of aspiration correct or even helpful. Self-esteem is prioritised highly in Maslow's hierarchy of needs and where the researcher is from in an individualist society (Yalch and Brand, 1996). As such the researcher views are more than likely idiocentric where aspiration is defined by individual success and standing out from the crowd. An individual from a collectivist culture, such as Ghana, would likely hold allocentric views (Triandis, 1989). In general, allocentrics subordinate their personal needs for the good of the collective and self-actualisation is achieved by serving the needs of others (Subrahmanyan and Gomez-Arias, 2008). Creating product user experiences that project an image of an ideal self that differentiate the owner from everybody else may be useful in the diffusion of pro-social innovations in individualistic societies.

9.3 Future Research

The insights gathered in the ethnographic research and participatory photography are considered significant because of the idiosyncratic behaviours observed. Further research into the universality of the findings would be advised to see if the problems in Kumasi Ghana are shared for the people in other cities or other countries.

The WBM can infer hydration by correlating the results of the colour of urine to parameters such as specific gravity or electrical conductivity of urine, both of which can be skewed by other factors or diseases. For instance, those with diabetes have unusually high specific gravity because of glucose in their urine and they may be considered more dehydrated than they truly are because of unreliable results. The WBM can indicate when one parameter is unusually high or low for their predicted hydration level and may act as a first warning for diabetes, renal disease, dietary issues or indeed whether users have contracted water-borne pathogens given more rigorous laboratory testing.

A WBM may benefit several different types of people within the UK and a *'one size fits all'* product may serve no needs at all. Further prototyping and user testing is needed to find who values the data the most. The literature suggests that features and attributes of products that others associate with contentment or project an image to others that is admirable. If this is the case, an additional investigation would be what features, materials or attributes are aspirational to the target audience. The concept shown in Figure 7-17 has been identified as a strong concept and the progression of this concept may need further user validation with prototypes that test the feasibility – *the wireless data aspect with a smart phone* - acceptability– *models testing aesthetics* – usability – *models that test the user experience with app*. Further investigation into where, when and how users may interact with this concept; whether preferred use is at home, the data is shared and what the user the data for.

The implementation of latent needs in the design of aspirational product user experiences needs further research into the validity of methods. There are many methods for reinventing technology, but the research and supporting literature suggests that the dimension of meaning is equally, if not more important in the generation of revolutionary innovations. This thesis has shown the potential for revolutionary innovation using a latent needs approach and has identified the need for further research into the role of intuition of the designer in the synthesis of insights.

A latent needs approach to create aspirational user experiences shown in this thesis would also be beneficial on products that are valued purely for their utility. There is an exciting opportunity to further the research on other utility product user experiences. Wind turbines, water recovery, recycling or adoption of electric vehicles would benefit from aspirational revolutionary innovation of their user experience to encourage greater diffusion. Additionally, a benefit of a latent needs approach to understand the aspects of aspirational user experiences of anti-social products would be beneficial. For instance, realigning the aspirational aspects of smoking, fast food packaging or overuse of games consoles. The application of the methodology in both instances would further the knowledge of the techniques used as well as the role of aspirational user experiences in revolutionary innovations.

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Appendix A. Four Avenues for Innovation

There were four avenues for innovation identified when observing the affordances of toilet user experiences. They are source of water, source of fertiliser, source of energy and body function.

Source of Water: Urine is 95% water where the remaining is made up from mostly nitrogen, phosphorous and potassium (NPK) compounds (Rose et al., 2015; Steinfeld, 2004). Provided the compounds can be filtered out, the toilet can provide the user with a source of water for drinking, cleaning, or plant watering. The concept is undeniably an interesting option that will a solution for the future with increasing water scarcity (Lemonick, 2013; Woo, 2016); *will a toilet that produces clean water be aspirational?*

Several water purification techniques already exist for waste water seen in Table A-1. The Janicki water treatment is a centralised system that toilets are plumbed into and operates using the same principle as the Slingshot product. They can purify all water including effluent by distillation and as such are not directly connected to toilets (Gates, 2015; Goodier, 2012).

Table A-1 Top five water producing technologies for toilets.

Process	Source
Distilling of urine using heat from the combustion of faeces.	(Gates, 2015)
Distilling of all waste water.	(Goodier, 2012)
Membrane filtration of urine.	(Parker, 2014)
Membrane filtration of waste water.	(Van Den Heuvel and Jowitt, 2007)
Biofiltration of urine using MBBR (Moving Bed Biofilm Filtration).	(Udert, 2002)

It is important to note, that the perception of *'clean water'* is a huge barrier and a toilet that produces fresh water will be unlikely to enhance the user experience.

Rozin et al. (2015) conducted a study on 2,000 Americans and found that on the acceptability of trying wastewater, 48% were unwilling to try recycled wastewater, 28% were uncertain about trying wastewater, only 19% were willing to try recycled water. Rather than distrust in the technology involved in purification, a user no longer associates water with wastewater when the water is reintroduced into natural systems; the natural system perceptually purifies the water *"spiritually".* This view is almost universally held, even in developing countries as summarised by the following quote:

> *"running water may be most acceptable for drinking because it is exposed to the sunlight; it is considered to be "alive" and therefore "pure""*
>
> (Franceys, Pickford and Reed, 1992)

Franceys, Pickford and Reed (1992) argue that using technologies to purify the urine as a source of water would also require the plants or sunlight to give the recycled water the required sense of *"purity"*.

Source of Fertiliser: Interestingly, approximately 5% of urine that is not water, contains useful fertiliser compounds – *notably Nitrogen, Phosphorous and Potassium (NKP)* - suitable for plants and there is more so in faeces (Rose et al., 2015; Steinfeld, 2004). Fertiliser for plants can be extracted from urine or faeces by bio-filtration processes or by worms (Anand and Apul, 2014); *Will a toilet that produces fertiliser be aspirational?*

Fertiliser extracted from urine or faeces could be used directly onto plants such as the examples in Table A-2. Having plants in the house for decorative or fragrance purposes is very commonplace, plants are often gifted as an appreciation for beauty and life (Csikszentmihalyi and Rochberg-Halton, 1981). Plants frequently exist in the home, situated on windowsills and balconies and act as a tie to the natural world, particularly in urban dwellings.

Table A-2 Top technologies for producing fertiliser from toilets.

Technology	Source
Reed filter of urine for bamboo plants.	(Hyphae Design Laboratory, 2008)
Anaerobic composting.	(Anand and Apul, 2014)
Urine dilution and applied straight to plants.	(Steinfeld, 2004)
Biofiltration using MBBR.	(Udert, 2002)
Microbial fuel cell using urine.	(Kuntke et al., 2012)

Fertiliser can help the growth of plants for aesthetics or even food. Having food grown at home could save money and the burden of carrying food back to the home. This concept is not simple and requires constant maintenance that would be difficult with previous horticultural knowledge. The time it takes to decompose and the smell from composting also presents problems for this concept to be a more enjoyable user experience.

Source of Energy: The calorific value of faeces is approximately 132 *kcal/cap/day* that is more energy than wood (Onabanjo et al., 2016; Rose et al., 2015). Similarly the calorific value of urine is 1701 *kcal/cap/day*. Harnessing this engergy for heat or electricity could be useful for any household; *Will a toilet that produces energy be aspirational?*

The energy in faeces maybe captured using an incinerating toilet or a combustor or simply the combustion of the biogas emmitted from the sludge as in the concepts in Table A-3 (Gómez et al., 2010; Onabanjo et al., 2016). The heat energy potentially could convert to kinetic energy and then to electrical energy - *by a sterling engine or dynamo*. Urine has also been used to produce electricity by microbial fuel cells or anaerobic digestion (You et al., 2015).

Table A-3 Top energy producing technologies for toilets

Process	Source
Combustion of faeces.	(Onabanjo et al., 2016)
Microbial fuel cell using urine.	(Kuntke et al., 2012)
Anaerobic digestion of sludge.	(Gómez et al., 2010)

Wellbeing Monitoring: The analysis of lab-based wellbeing monitoring toilet concepts has been moved to the man thesis in Review of the Marketplace Section 4.4.

Summary: Clean water from toilets has the potential to enhance the user experience by bringing fresh water to users. Unfortunately, the concept of filtering urine for fresh water at source, presents the problem because it is not *spiritually purified* by introducing the water back into natural systems and this may not motivate people to revisit the toilet and it may not make them aspirational (Rozin et al., 2015). Fertiliser from waste can enhance the toilet user experience because plants grown from the fertiliser can improve the aesthetics of toilet spaces. A toilet that creates energy from either urine or faeces or both is an interesting concept because of the calorific value of human waste, however does not enhance the user experience. Human waste affords a toilet concept that interrogates a users' health (Brunzel, 2013; Strasinger and Schaub Di Lorenzo, 2008). The negative connotations with disease may not motivate people to revisit a toilet, but instead using the information for positive reinforcement would.

Appendix B. Repertory Grid Method

The researchers intended to use the repertory grid technique on the 77 respondents who were chosen in the ethnography to triangulate the data and obtain deeper insights. The repertory grid method involves selecting six elements to compare and contrast that have some commonality. The approach was to choose elements that serve other basic needs to identify perceptions about need and perceptions about desire, namely; soap for washing, water for drinking, bed for sleeping, food for eating, toilet for defecation and the ideal toilet. After these were explained fully to the respondent the respondent then was given three of the six and asked to find a commonality between two of the elements that contrasted the third. This construct was probed using laddering techniques, to obtain a single word or short phrase to represent it. Then they were asked which of the two constructs they preferred – *using the language they used, avoiding putting words in the respondent's mouth*. Then the respondent would line all six elements on a five-point spectrum from one representing the positive construct and five representing the negative construct. Finally, the respondent would then rank all six elements according to the amount of pride they get when each element is don't well and amount of fear if it is done badly to understand the aspirations associated with each element. An example comparison of elements is shown below:

Water for Drinking and Current Toilet are similar and the Bed for Sleeping is different.

How are they different?

You don't really need the bed, but you do need water and the toilet.

So, you don't really need the bed, but can you explain what you mean by 'need' water and the toilet?

Water and Toilets are a necessity to live.

Can you then rank all six elements from one being a 'necessity to live' to five 'don't really need it'?

The translator was not able to effectively translate and differentiate the concept of comparing and contrasting elements and when the things were used. Even when the technique was trailed on English speaking, university educated Ghanaians, the respondents would struggle and explain how, when and where they used to do each activity forgetting to compare or contrast the three presented to them.

The technique was abandoned after seven were completed firstly because of the respondents available; the ones that could understand the technique had a higher standard of living and most had access to flushing toilets. Secondly a few of the respondents would become frustrated after the first few questions and would give exaggerated or even untruthful responses to answers in order to hurry the process along; an example is given in Table B-1.

Table B-1: Example repertory grid, notice how the respondent has lost interest by the third comparison and has answered ones or fives for the remainder of the grid.

Positive Construct	Water	Toilet	Bed	Soap	Food	Ideal Toilet	Negative Construct
Uses water	1*	1*	5*	3	4	2	Does not use water
Kills germs	4	4	5	1*	2*	3*	Does not kill germs
Goes to your stomach (heavy)	2*	5*	5	5	1*	5	Goes away (don't swallow)
Full (strong)	1*	1	5*	1	1*	1	Not full (not strong)
Contains water for body to function	1*	5	1	1*	1	1*	Doesn't contain water
Made from tree	1	5*	1*	5	1*	5	Not made from tree

Has a smell	5	5	5*	1*	1	1*	**No smell**
Carry with you	1*	5	5	1	1*	5*	**Can’t carry it**
Sitting	5	1*	1	5*	5	1*	**Not sitting**
Comfort for relaxing	1	5	1*	1	1*	1*	**Not comfortable**
Pride if done well	1	5	5	3	2	4	**Least pride**
Least fear if done badly	5	5	5	5	5	5	**Most fear if done badly**

*Compared and contrasted elements

Summary: To conclude the technique is very insightful if done correctly, but because of language barriers – *whether it is limitations of the language or misunderstanding of the translator* – the results are not reliable. The author recommends that future practitioners working with populations that use another language fully brief the translator in the technique in the method and also in the process to avoid biasing the respondents’ answers. Extra time should be considered to practise the technique on the population to make sure the process is fluent and not as overly lengthy.

Appendix C. Prototype Construction

Hardware

The choice and design of the components and container for the concept will be explored below and the dependent variables will be justified. This section is broken into the following sections; Controller, LED, Photoresistor, Container, Triggering Analysis and Battery.

Controller: The Arduino board can control and responds to electrical signals up to 5 V from sensors that respond to the real world. The sensors may be photoresistors, thermistors, accelerometers, switches or ultrasonic distance sensors. The Arduino board consists of a USB connector for power and connectivity to the board for uploading the firmware and displaying the data over serial. The board operates on 7V to 20V external supply.

The ATmega328 has a flash memory of 32 KB. The 14 digital pins can be used as input or outputs at 5 V and have direct current of 40 mA each with an internal pull-up resistor of about 20-50 kΩ. Six of the pins provide Pulse Width Modulation (PWM) output. It also has six analogue inputs, each input provides 1024 different values or 10 bits of resolution measuring from 0 to 5 V with a clock speed of about 16 MHz (Teli and Mani, 2015).

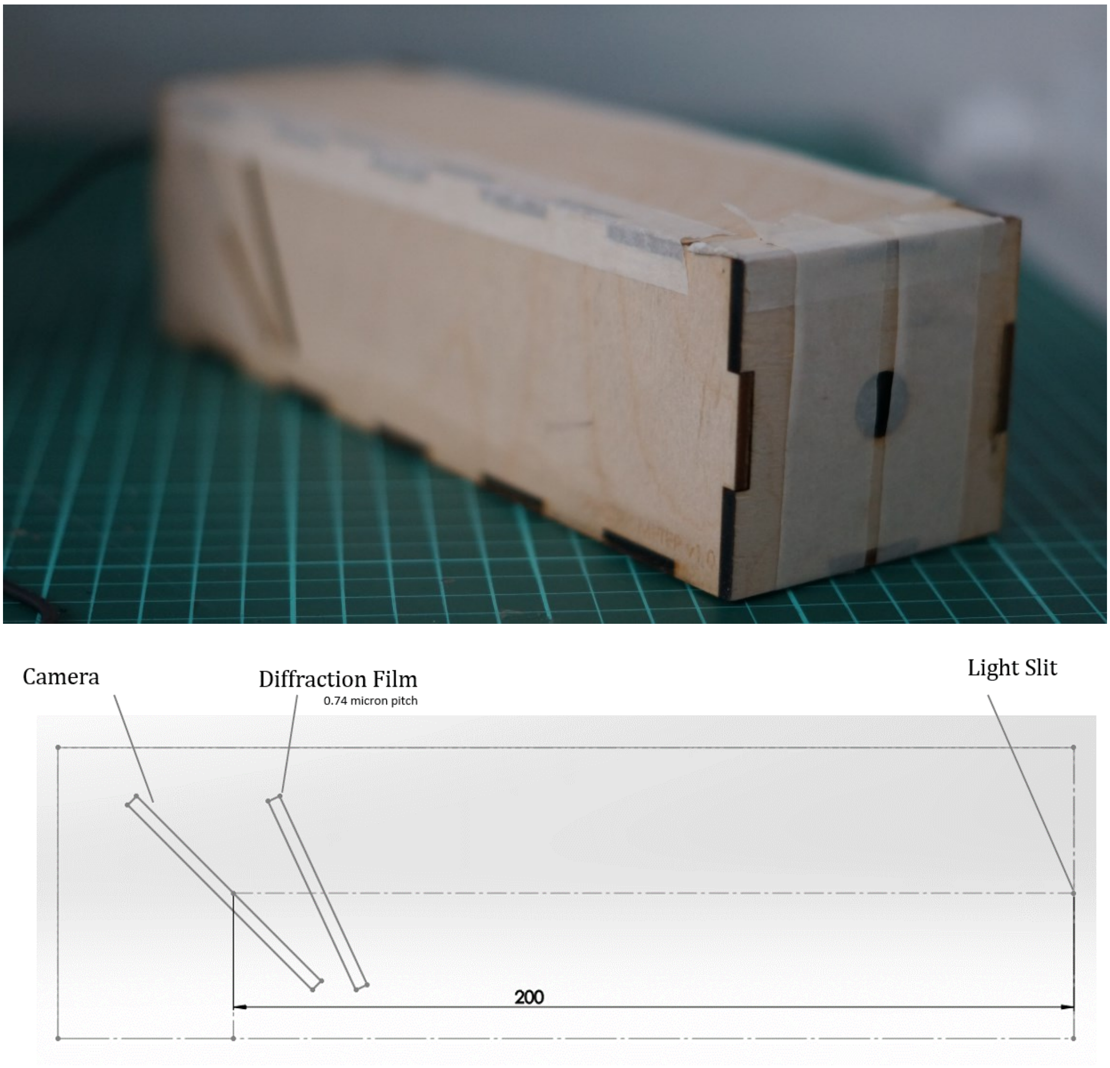


Figure C-1: Low cost spectrometer.

Low cost spectrometer from DVD-R diffraction grating, two razors and webcam. Source: J Larsson.

LED and Photoresistor: The previous Chapter used an off the shelf RGB LED and photoresistor and the results were more than accurate enough. Continuing with these components, the questions that need to be answered to progress the concept onto user testing are; Reliability of components, Distance of gap between the sensor and light source and Choice of materials for the chamber.

The various components include (Agrawal and Singhal, 2015):

- A Broadcom BCM2835 System on a Chip (SoC) that's made up of an ARM central processing unit (CPU) and a Videocore 4 Graphics Processing Unit (GPU).
- GPIO pins for general purpose input/output connection points.
- RCA to allow connection with an analog TV or monitor.
- Audio Out to connect with audio devices such as speakers or headphones.
- LED for indicating function.
- USB connection port for peripheral devices like mouse and keyboard.
- HDMI to connect with HD compatible devices.
- Power over 5 V USB micro connector.
- SD card slot to hold the LINUX operating system.
- Ethernet for wired networks.

The Arduino board includes:

- Atmega328 microcontroller chip.
- 14 digital input/output pins.
- Analog input pins for sensors.
- ICSP header.
- Power over jack socket.
- A 16 MHz oscillating crystal.
- USB connection for uploading sketches.
- Reset button.

The resistance of the photoresistor increases as the level of light increases; specifically, from 500 Ω to 10 $M\Omega$. The circuit was constructed using a potential divider where increasing intensities of light translate to reducing resistances across the photoresistor at Z_1.

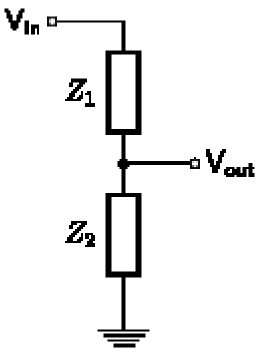


Figure C-2: Voltage divider.

Voltage divider. Source www.google.com.

Where V_{in} is $5V$, Z_1 is the phototresistor and V_{out} can range from 0 to $5V$. $10k\Omega$ resistor is an appropriate value for resistor Z_2 since it produces voltages at V_{out} between approximately $0.26V$ and $4.76V$ that can be seen from the equation below.

$$V_{out} = \frac{Z_2}{Z_1 + Z_2} V_{in}$$

The data sheet of the photoresistor shown in Figure C-3 states that the relationship between luminance and photoresistor resistance, is logarithmic also the resistance responds differently for different wavelengths for a given intensity of light. On top of this, the photoresistor deviates by approximately 5% relative resistance for 20˚C above and below room temperature.

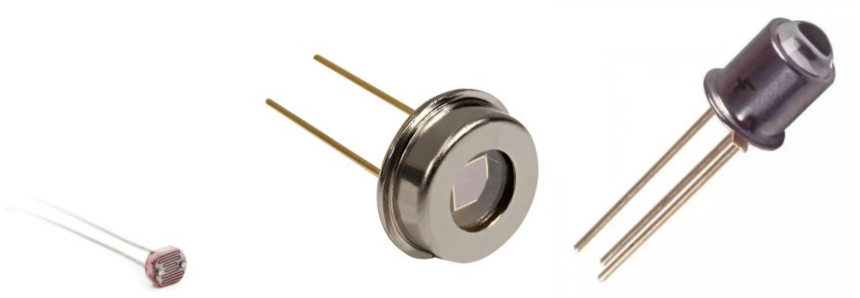


Figure C-3: Photoresistor, photodiode and phototransistor.

Images of photoresistor, photodiode and phototransistor costs approximately £0.10. Source https://www.google.co.uk/. Source: J Larsson.

As the distance between RGB LED and photoresistor increases the intensity of light received decreases exponentially; twice the distance means four times less light. As one can imagine, the closer the sensor to the light source the larger the sensor range and the more sensitive the readings.

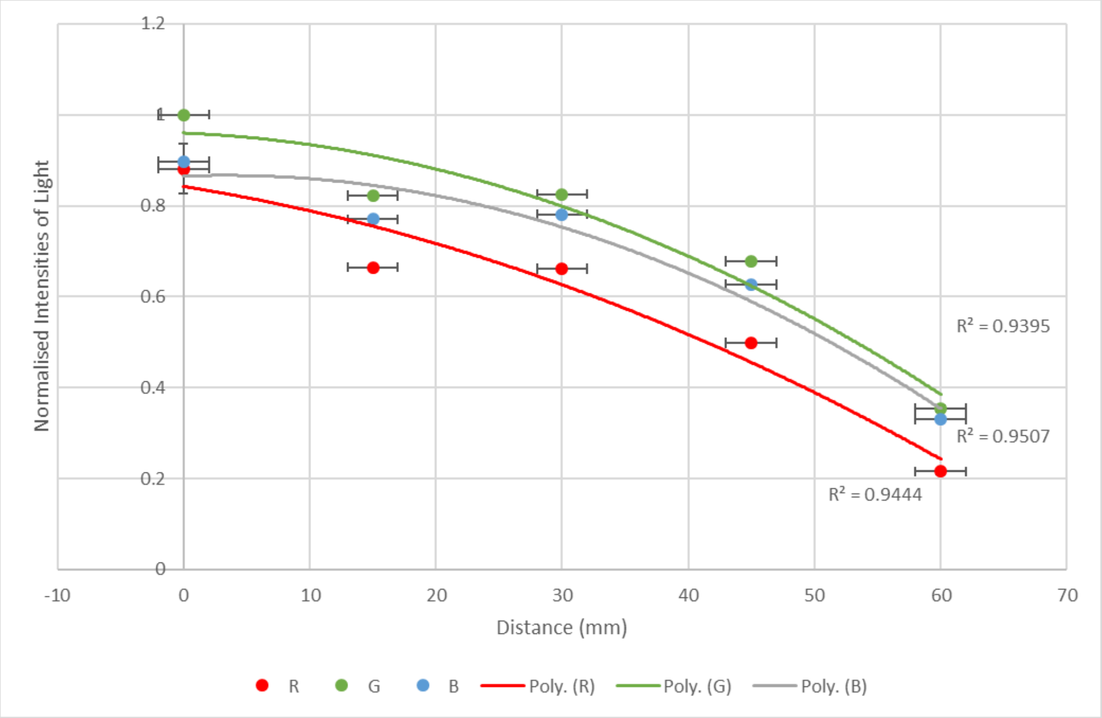


Figure C-4: Intensities of light received.

Graph to show normalised intensities of light received by photoresistor versus different distances of RBG LED from photoresistor. Source: J Larsson.

On the other hand, the more distance between the sensor and the light source, the more light is absorbed in the liquid. When recording the light absorbed for different concentrations of simulant in vessels with different widths we see the greatest range of blue light absorbed between the concentrations of simulant appears to be around 50 *mm* apart.

As you can see the apparatus is very repeatable but not always accurate. Perhaps the positioning of the chamber affects the reading; for instance, the thickness of the chamber walls. There is little correlation between the thickness of the transparent tube that separates the RGB LED and photoresistor and the intensity of light of light received, the readings are not the same however suggesting there is another variable interfering, like the angle the acrylic is place at.

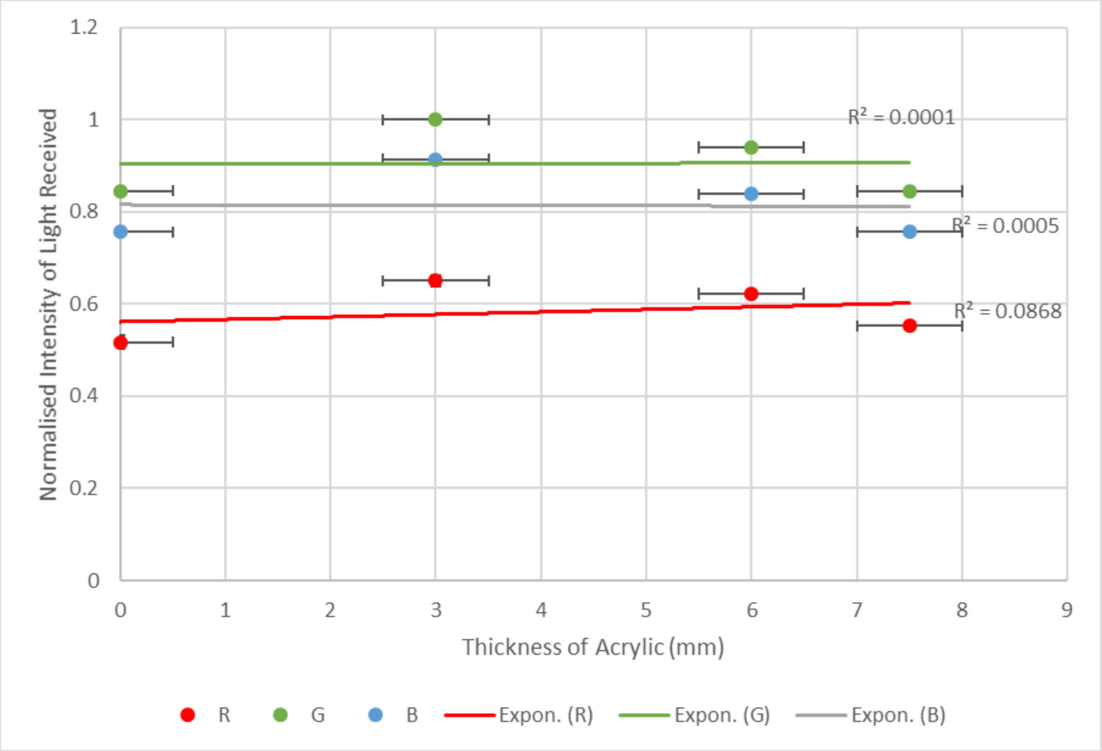


Figure C-5: Intensities of light received.

Graph to show changes in intensities of light received by photoresistor versus varying thicknesses of acrylic between RGB LED and photoresistor. Source: J Larsson.

Containing Urine: Lots of prototyping uncovered requirements for the final concept. Know constraints were factors like minimising light noise, but additional factors across such as pooling from previous samples shown in Figure C-6, or the effect of air bubbles on the received light intensities.

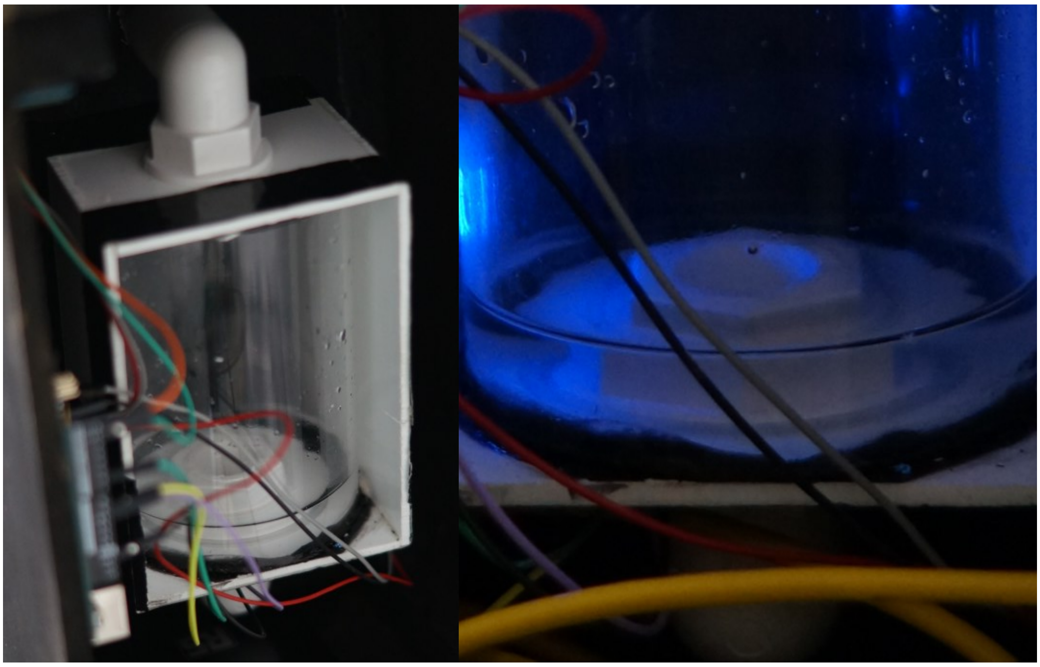


Figure C-6: Light refraction and dilution pooling.

Light refraction and dilution pooling. Source: J Larsson.

The way this prototype was constructed meant that there was always a pool of liquid at the base of the container and hence the sample that enters the container then is diluted with the liquid from the previous test, that can be seen in difference in the *full* regions of Figure C-7.

As discussed above, initially a solenoid valve was chosen so analysis could be done on a sample then flushed out, but after a series of prototyping, a backup of urine to then ‘trickle’ out was decided to be more appropriate for cost and complexity reasons. To reducing external light noise, a baffle design was made to be inserted into the acrylic tube. The gaps between baffles needs to be large enough to allow the air in the test chamber to escape.

Air is getting trapped in the analysis chamber because the surface tension of water is blocking the inlet hole, however the size of the inlet and outlet holes are crucial in order to ensure the chamber is full with urine for the duration of analysis.

From the tests shown above, it is known that the optimal tube diameter is between 30*mm* and 50*mm*, however this is for fully filled chambers. As liquid enters the chamber, fills the chamber then drains has different received intensities of light because of the refraction of light. Figure C-7 demonstrates this by recording the changing intensity of light received by the photoresistor changing as 200ml and 500ml of water slowly empties out of the container. This indicates that ensuring the analysis is repeatable, the chamber must be fully filled.

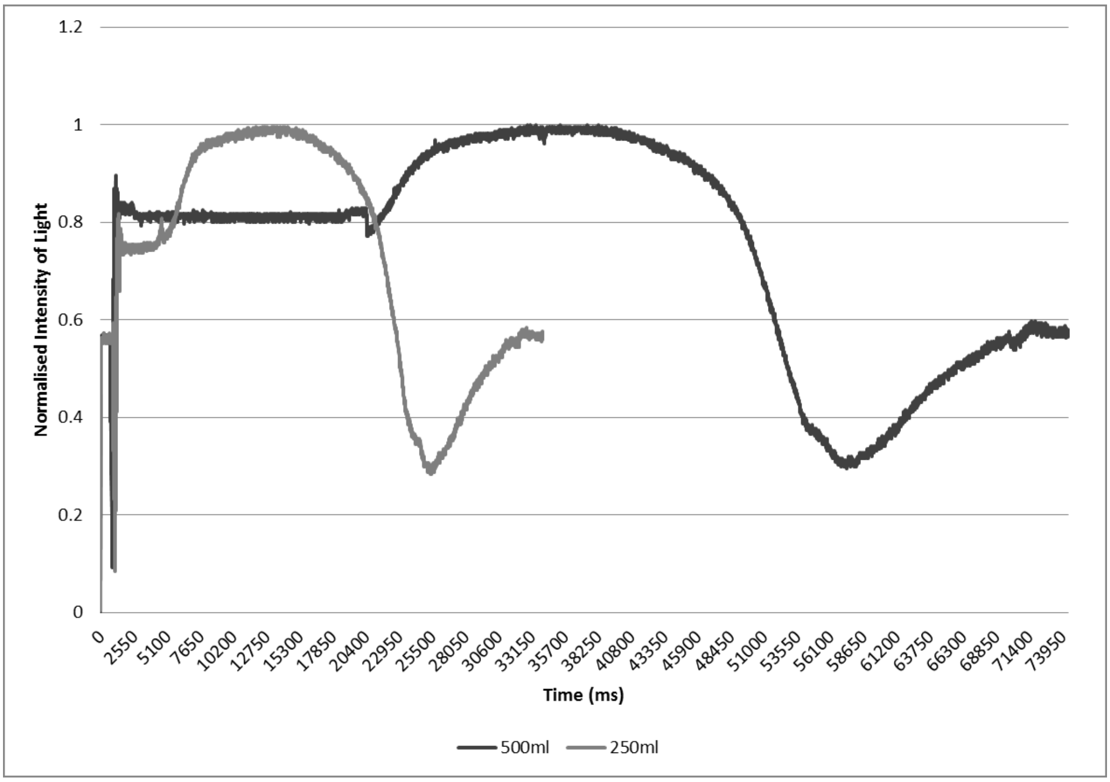


Figure C-7: Time for chamber to fill and empty.

Graph to show normalised received intensities of blue light versus time for a chamber that fills and empties with simulant. Source: J Larsson.

Observing Bernoulli's equation to find appropriate radii of the spiralling inlet hole r_{in}, the transparent chamber for the RGB LED and photoresistor r_{ch} and the and outlet spiralling hole r_{out} we have:

$$P_{in} + \frac{1}{2}\rho v_{in}^2 + \rho g h_{in} = P_{ch} + \frac{1}{2}\rho v_{ch}^2 + \rho g h_{ch} = P_{out} + \frac{1}{2}\rho v_{out}^2 + \rho g h_{out}$$

Where P_{in}, P_{ch} and P_{out} is the pressure from at the inlet, the analysis chamber and outlet hole respectfully, v_{in} , v_{ch} and v_{out} are flow velocities at the inlet, the chamber and outlet, ρ represents fluid density and h_{in}, h_{ch} and h_{out} are the heights of the inlet, chamber and outlet holes respectfully.

Since urine is incompressible we can also assume for the areas of the inlet, chamber and outlet mouths that the velocities are as follows:

$$A_{in}v_{in} = A_{ch}v_{ch} = A_{out}v_{out}$$

Focusing just on the radii for the chamber and the outlet holes where v_c needs to be less than the user's urine flow velocity, we get:

$$\pi r_{in}^2 v_{in} = \pi r_{ch}^2 v_{ch} = \pi r_{out}^2 v_{out}$$

Rearranging for v_o we then have:

$$v_{ch}\frac{r_{ch}^2}{r_{out}^2} > v_{out}$$

Substituting in v_{out}, considering $P_{in} = P_{ch} = P_{out} = P_{atmos}$, cancelling for urine density ρ and setting $h_{out} = 0$, we get:

$$\frac{1}{2}v_{ch}^2 + gh_{ch} = \frac{1}{2}v_{ch}^2\frac{r_{ch}^4}{r_{out}^4}$$

Rearranging for r_c we get:

$$2gh_{ch} = v_{ch}^2\left(\frac{r_{ch}^4}{r_{out}^4} - 1\right)$$

$$\frac{2gh_{ch}}{v_{ch}^2} + 1 = \frac{r_{ch}^4}{r_{out}^4}$$

Substituting in the values for acceleration due to gravity - *9.8m/s²* - and the minimum velocity flow of urine - *2.35m/s* (Nürnberger, 1985)- we a minimum value r_{ch} of:

$$r_{ch}^4 \ > r_{out}^4(8.34h_{ch} + 1)$$

$$r_{ch} > r_{out}(8.34h_{ch} + 1)^{1/4}$$

Repeating the process again for r_{in}, we then have:

$$v_{in}\frac{r_{in}^2}{r_{ch}^2} > v_{ch}$$

Substituting in v_{ch} , considering $P_{in} = P_{ch} = P_{out} = P_{atmos}$ and cancelling for urine density ρ, we get:

$$\frac{1}{2}v_{in}^2 + gh_{in} = \frac{1}{2}v_{in}^2\frac{r_{in}^4}{r_{ch}^4} + gh_{ch}$$

Rearranging for r_{ch} we get:

$$2g(h_{in} - h_{ch}) = v_{in}^2\left(\frac{r_{in}^4}{r_{ch}^4} - 1\right)$$

$$\frac{2g}{v_{ch}^2}(h_{in} - h_{ch}) + 1 = \frac{r_{in}^4}{r_{ch}^4}$$

Again, substituting in the values for acceleration due to gravity - *9.8 m/s²* - and this time the maximum velocity flow of urine – *3.25 m/s* (Nürnberger, 1985)- we a minimum value r_{in} of:

$$r_{in}^4 > r_{ch}^4[6.03(h_{in} - h_{ch}) + 1]$$

We get the minimum radius r_{in} and the following dimensions as:

$$r_{in} > r_{ch}[6.03(h_{in} - h_{ch}) + 1]^{1/4}$$

$$r_{in} > r_{out}[8.34h_{ch} + 1]^{1/4}[6.03(h_{in} - h_{ch}) + 1]^{1/4}$$

It has been observed that holes with small radii do not allow all the urine in the chamber to drain out because of the urine's surface tension. Finding the minimum radius r_o for given surface tension γ, we have the change in pressure to be:

$$\Delta P = \frac{2\gamma}{r_{out}}$$

No water will drain from the chamber when the pressure difference between the hole and atmospheric pressure is zero or where $P = \rho g h$. Where both equations equal one another, we have:

$$\rho g h_{out} = \frac{2\gamma}{r_{out}}$$

For water with surface tension $\gamma = 7.3 \times 10^{-2}\ N/m$, the minimum radius r_{out} of the outlet hole, leaving us with the final ratios of:

$$r_{out} > \frac{14.6 \times 10^{-2}}{9.8 h_{out}}$$

$$r_{ch} > r_{out}(8.34 h_{ch} + 1)^{1/4}$$

$$r_{in} > r_{ch}[6.03(h_{in} - h_{ch}) + 1]^{1/4}$$

Assuming the chamber height is approximately $10mm$, for a chamber that falls in the optimum range of 30 to 50 mm in diameter, discussed above, a $16mm$ radius acrylic tube has been chosen with a wall thickness of $3mm$, resulting in the RGB LED and photoresistor being 38 mm apart, requires an outlet hole of less than 5.2 mm radius, but greater than 1.5 mm. For sufficient filling rate of the chamber, the inlet is two helical holes with the same diameter as the outlet. Figure C-8, below shows how the manifestation of these calculations has resulted in an appropriately sized chamber with spiralling inlets and outlets eliminate external light while accounting for appropriate ratios for filling. Two spiral holes of the same radius as the outlet hole has been chosen so it fills the chamber quicker than the chamber drains and sufficiently quick enough so it does not back up too much.

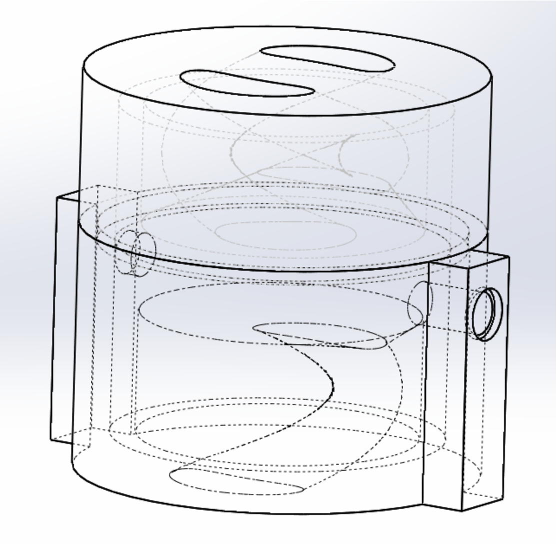


Figure C-8: Inlet and outlet spiralling holes.

Diagram of redesigned analysis chamber with 16mm radius analysis chamber, 1 x 4mm outlet and 2 x 4mm inlet spiralling holes.Source: J Larsson.

The minimum outlet hole radius and the subsequent ratios for the inlet and chamber radii are consistent with rudimentary tests performed in prototyping and show filling and draining are adequate.

Contact Probes: Measuring the resistance across the contact probes has two functions; to trigger analysis and measure the EC of the urine. The factors that need to be addressed are:

- Component choice
- Distance across contact probes
- Time taken

From literature urine ranges from 1.1 to 33.9 mS with an average of 21.5 mS and so the contact probes must reliably detect liquid with EC of 1.1 mS. EC of urine is measured in Siemens - *the inverse of resistance*. In the prototype, another voltage divider is created using the conductivity of the urine as resistor Z_2. Minimal amperes of the Arduino require the choice of Z_2 to be approximately $560\,\Omega$, unfortunately the change in V_{out} is between $3.09V$ and $0.25V$.

$$V_{out} = \frac{Z_2}{Z_1 + Z_2} V_{in}$$

$$V_{out} = \frac{5Z_2}{560 + Z_2}; 909 < Z_2 < 29$$

Testing simulant with varying values of EC across a normal range, the triggering of analysis is more than detectable. Albeit minimal – *an average of 0.13% of a normalised signal* - the change in EC is detectable for samples with as little conductivity as 0.07 mS.

As one may observe, since EC is an indicator of hydration we may also use the contact probes to not only trigger analysis, but also calculate the urine's EC strengthening the inference of hydration. Unfortunately, determining the truth EC of the sample is not as reliable as detecting a sample is present. Notice the rate of change of the sample's EC over time as the water leaves the unit.

Using sodium chloride, different samples of liquid with varying EC were made. For 200ml of ultrapure water with increments of 1.00g of sodium chloride, there are clear and measurable differences that the unit detects as shown in the main thesis.

The distance between the probes is determined by the height of the chamber; the analysis can only begin once the chamber is full. By placing the contact probes in the outlet and inlet holes at approximately 10mm apart, then the chamber is presumed to be full.

Battery: The reliability and repeatability of the voltage dividers discussed above are very much dependant on the supplied voltage of d V_{out}. The Arduino has a built in voltage regulator to keep the voltage stable, but from an AC mains power source, there are fluctuations in voltage despite voltage regulator smoothing. Additionally, power over USB may also have interference on top of this.

The variance is not large by any means 0.08%, 0.21% and 0.01% standard deviation for USB to the laptop and Bluetooth powered by a 1024 mA power-bank and Bluetooth powered by a $9V$ battery respectively. Strangely, Bluetooth powered by a power-bank has more noise and less overall voltage. The difficulty of using a $9V$ battery to power the Arduino is then observing and interrogating the data received from the unit for further development[1].

Firmware

The development of the firmware is not as straight forward as the development of the hardware. Problems that arise are not as easily identifiable as mechanical or physical problems. Below are the details of the process taken to develop the firmware that accompanies the hardware.

- Reducing Noise
- Calculating RGB and EC
- Triggering Analysis
- Displaying the Data

The Arduino board is programmed by its own Arduino IDE programmed on a computer. The IDE converts the code into logic instructions that is uploaded and understood by the hardware as physical inputs or outputs (Teli and Mani, 2015).

Reducing Noise: Much of the prototyping to reduce noise using firmware was conducted on an online and open-source emulator to simulate the electronics using *www.circuits.io*. Most notably, one fundamental change with the firmware is that the method of analysis has changed. The colours of the RGB LED are created by digital PWM as opposed to varying the voltage received. Figure C-9 below shows a reading every ten milliseconds versus an average of ten readings every ten milliseconds, minimising the noise that may interfere.

---

[1] See Appendix B for how to transfer data over serial using Bluetooth.

```
RGB_EC(){
        for( int i = 0; i < 10 ; i += 1 ){                       //For 10 readings
                sensorValuea0 = analogRead(A0);
                sensorValuea1 = analogRead( A1 );
                sensorValueA0 = sensorValuea0/10 + sensorValueA0;
                sensorValueA1 = sensorValuea1/10 + sensorValueA1;
                delay(1);                                        //Take average for 10ms
        }
}
```

Using this strategy, the standard deviation of the results is reduced by 53.4% (from 6.04 x 10^{-3} to 3.23 x 10^{-3}) without overloading the data sent over serial.

The noise is reduced significantly by this method, but by taking the average over time can produce more accurate results. The graph below shows the results with the reduction in noise function overlaid with the mean calculated for the time period and a smoothing function.

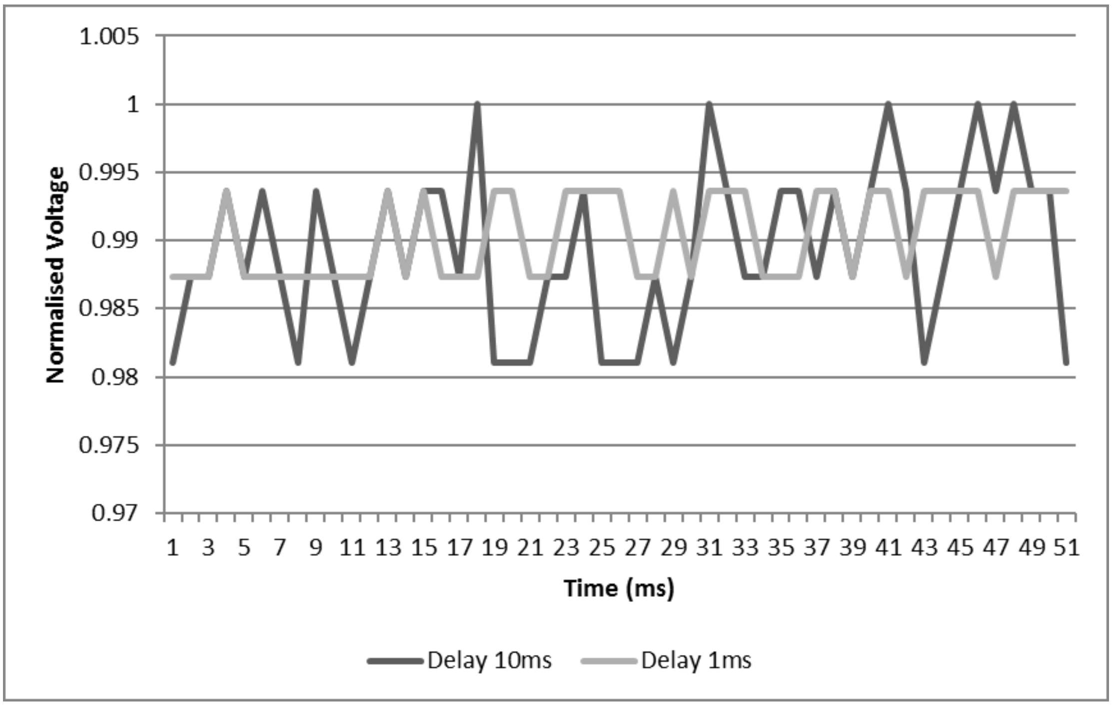


Figure C-9: Reducing noise.

Graph to show less noise from taking average of 10 every readings 100 times a second than taking 100 readings a second. Source: J Larsson.

Nearly all tests begin with a ramp up from near zero when reading the voltage dividers for both sensors. Taking the mean of the results over a period skews the true result as shown in the main thesis. A smoothing function that is a simplified moving average without using much memory instead was introduced. For a new reading *sensorValuea0*, the smoothing function *sensorValueA0* is plotted in the main thesis.

```
R = 0.8*sensorValueA0 + 0.2*R;      //Repeat for G & B
EC = 0.8*sensorValueA1 + 0.8*EC;
delay(1);                           //Smooth new reading against previous
```

Given the smoothing function had enough time, this method then returned results accurately each time they were taken.

Calculation: The calculation in the previous chapter was based on sweeping the LED through the spectrum mimicking a spectrometer, however the same data can be received from an evaluating the amount of light absorbed from simply red, blue and green by themselves.

Using the *analogRead()* function of the Arduino IDE, the resulting value is between zero and 1024 representing 1024 steps between zero and $5V$. The more readings over time produce a more reliable technique, over time the raw reading from the Arduino vary somewhat for several reasons, however a reading every millisecond is a large amount of data to send over serial to a laptop to record. Taking a reading regularly every ten milliseconds produces 100 readings a second and is manageable for the recording of data using the code below:

```
#define RED 6;                          // Red LED to pin 6
#define GREEN 9;                        // Green LED to pin 9
#define BLUE 10;                        // Blue LED to pin 10

RGB_EC(){
        digitalWrite( RED , HIGH );
        digitalWrite( GREEN , LOW );
        digitalWrite( BLUE , LOW );

        //Read photoresistor & EC probes
        int sensorValuea0 = analogRead( A0 );
        int sensorValuea1 = analogRead( A1 );
        delay(10);                              // Wait 10ms
}

int R = sensorValuea0;                  //Repeat for G & B
int EC = sensorValuea1;
```

As one may see the slight decline on the EC measurement as the sample drains from the chamber. This may be to do with particulates sedimenting in the liquid or from some other variable, but nonetheless the smoothing function described above will continually adjust. Also the mean value across the period the chamber is full may not be the true EC of the sample.

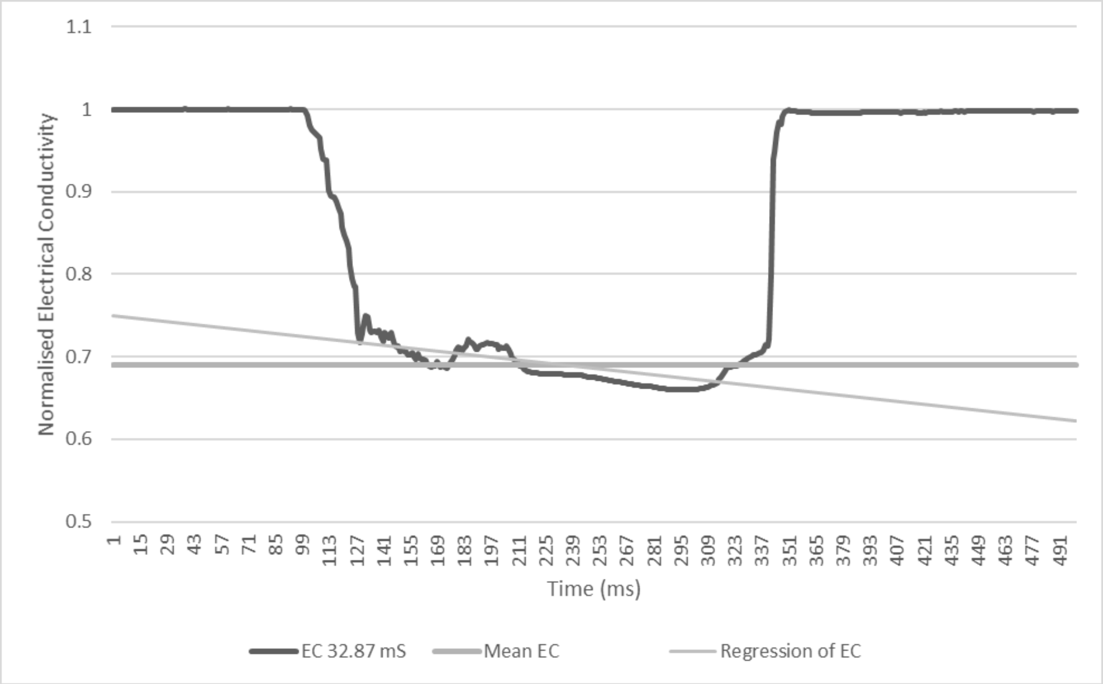


Figure C-10: Water entering unit.

Graph to show water entering unit and nromalised electrical conductivity from apparatus. Source: J Larsson.

From observation, the decline seems linear and regular for each sample, so the smoothing function is taken for a set amount of time. Across different samples, the apparatus is able to reliably detect the EC of the samples and differentiate small increments comfortably, as shown in Figure C-11.

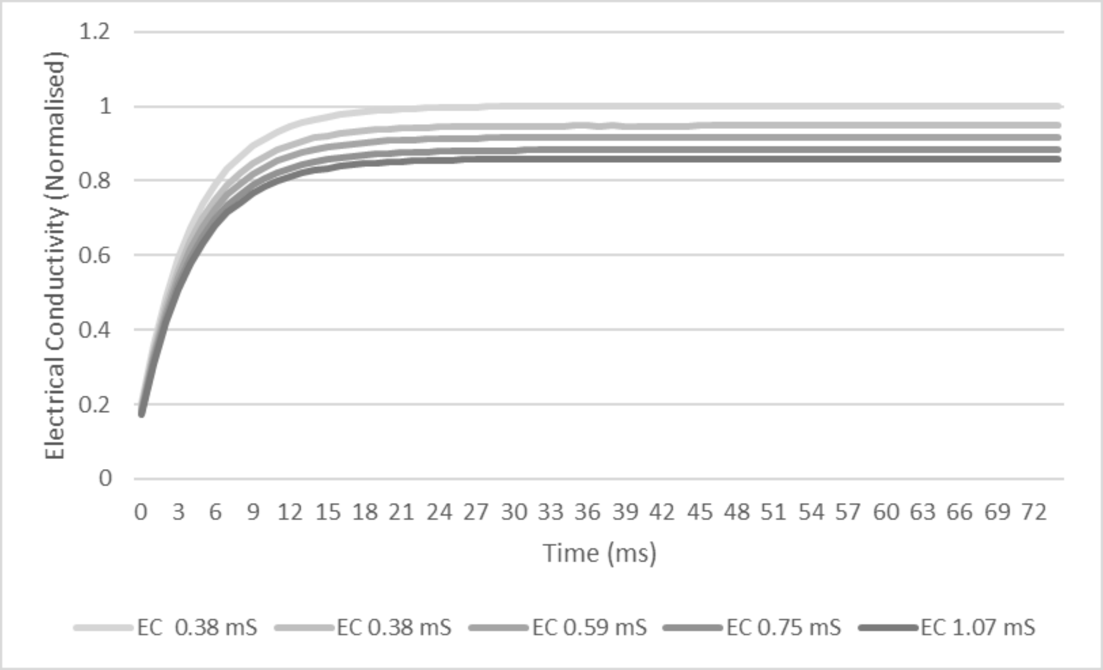


Figure C-11: Electrical conductivity of liquid.

Graph to show normalise electrical conductivity from the apparatus for different conductivities of liquid. Source: J Larsson.

For a known time taken for $1L$ to empty out of the unit T_0, the volume of a sample in millilitres would be calculated by:

$$Vol = 1000 \times \frac{Time[1] - Time[0]}{T_0}$$

Of course the filling rate of the unit until connection has been made between the contact probes is dependent on the incoming flowrate of urine and may skew the results. For a significantly small camber this is presumed to be insignificant. However, the drainage hole must be appropriately sized; small enough to allow the unit to fill with urine, but not too small so it takes too long to drain.

Calculating Hydration

Urine colour is recognised as an indicator of hydration along with SG, EC, osmolality, colour, volume and frequency – *discussed in detail in Chapter 3* - although the blue value threshold for dehydration is less defined than the other methods. Urine colour hydration charts, shown in Chapter 3 indicate that a threshold for dehydration is approximately below blue value is less than 51.

Informing the user whether they are hydrated, intermediate or dehydrated is best communicated by a traffic-light display based on the values stated by European Hydration Institute (2016), i.e. when blue light is below 51 and EC is above 13 *mS*:

Table C-1: The thresholds for determining scores for appropriate display of hydration status.

Threshold	**Blue < 51**	**Blue > 51**
EC > 13mS	Dehydrated	Intermediate
EC < 13mS	Intermediate	Hydrated

If the result of the blue value shows the user is dehydrated and the EC result is above the threshold, then the user is certainly dehydrated and a red light flashes. If the colour shows the user is dehydrated, but the EC result is below the threshold then the result is intermediate and the light flashes amber for example. Only when the blue value and the EC result indicate the user is hydrated does the light flash green. The following code that enables the function described above is as follows:

```
#define Dehydrated 3                            //Red LED to pin 3
#define Intermediate 4                          //Amber LED to pin 4
#define Hydrated 5                              //Green LED to pin 5

if( B < 51 && EC > 13 ){ int LED = Dehydrated;  }
if( B < 51 && EC < 13 ){ int LED = Intermediate;  }
if( B > 51 && EC < 13 ){ int LED = Intermediate;  }
if( B > 51 && EC > 13 ){ int LED = Dehydrated;  }

for( int i ; i < 5 ; i += 1 ){                  //Pulsing LED Function
        for( int j ; j < 255 ; j += 1 ){
                digitalWrite( LED , j );
                delay(1);
        }
        for( int j ; j < 255 ; j += 1 ){
                digitalWrite( LED , 255 - j );
                delay(1);
        }
        delay(100);
}
```

This may not be an accurate representation of one’s hydration, but over time the daily volumes and inter-arrival times will paint a richer picture of an individual’s hydration that can be compared to their baseline. This will be discussed more in detail in the next Chapter – *because of techniques of identification* – and can be more complex with better computing power and an updating database, over the cloud for example.

```
int Volume[100];                    //Each Volume is stored for each arrival
int Frequency = 0;
int Volume;                         //Total volume of urine for a day

for( int n ; n < 100 ; n += 1 ){
        R[n] = R;                   //Storing all values throughout the day
        G[n] = G;
        B[n] = B;
        EC[n] = EC;
        Volume[n] = ( Time[1] – Time[0] ) / T0;
        Arrival_Time[n] = Time[0];
}

if( millis() > 24*60*60*1000 ){                         //After 24 hours
        for( int n ; n < 100 ; n += 1 ){
                if( Volume[n] > 0 ){
                        Frequency = Frequency + 1;
                        Volume = Volume[n] + Volume;
                }
        }
}
```

Unfortunately, this has not been implemented into the firmware because of memory restrictions and will be explored with computation on the cloud.

Preparation for User Testing

Now the hardware and firmware have been progressed to a satisfactory level, the integration of the unit in a toilet cubicle is needed for use on participants. Below are the steps taken to ensure the physical design is appropriate; Integration with Toilet, Triggering Analysis, Displaying the Data, Automatic Calibration and Longevity Testing

The real-life setups are not as repeatable as the previous experimental setups, since the setup is no longer in laboratory conditions, there is possibly noise from external light and general handling that affects the results. A more robust unit is currently being constructed for user testing, shown in the main thesis.

As stated in the last chapter, when measuring hydration clinically, SG, frequency, EC, volume or colour are rarely taken individually. The colour and inferred SG can be coupled with frequency of visits from recording inter-arrival times and volume from timing contact switch. On top of this, EC can be measured across the contact switch. This gives all except the osmolality needed for a comprehensive view of someone's hydration, according to European Hydration Institute (2016). This is all achieved from just an LED and a photoresistor.

Integration with Toilet: To test whether the data for hydration will increase people's perception of the toilet, it is quite essential to keep the user interface of the urinal the same as one would normally visit it. Changes in urinal colour or geometry may affect the way people perceive the toilet and it may skew the results. For instance, any sight of the technology or wires etc. may unnerve the user and reduce their willingness to use the urinal despite how beneficial the data may be for them. For this reason, the urinal system will be comprised of a front-end with the urinal and means of displaying the data and a back-end where the WBM is kept.

The ways of displaying the data may too affect the user's perception of the device. For this reason, I will keep the data displayed in the simplest form; a traffic light red, amber, green for dehydrated, intermediate and hydrated. I will then explore further options in the next Chapter.

The first prototype was built to attach to the back of a urinal with a solenoid valve to allow flushing of the urinal. As discussed previously, the solenoid valve proved to be too technical complex and instead analysis is triggered by contact probes.

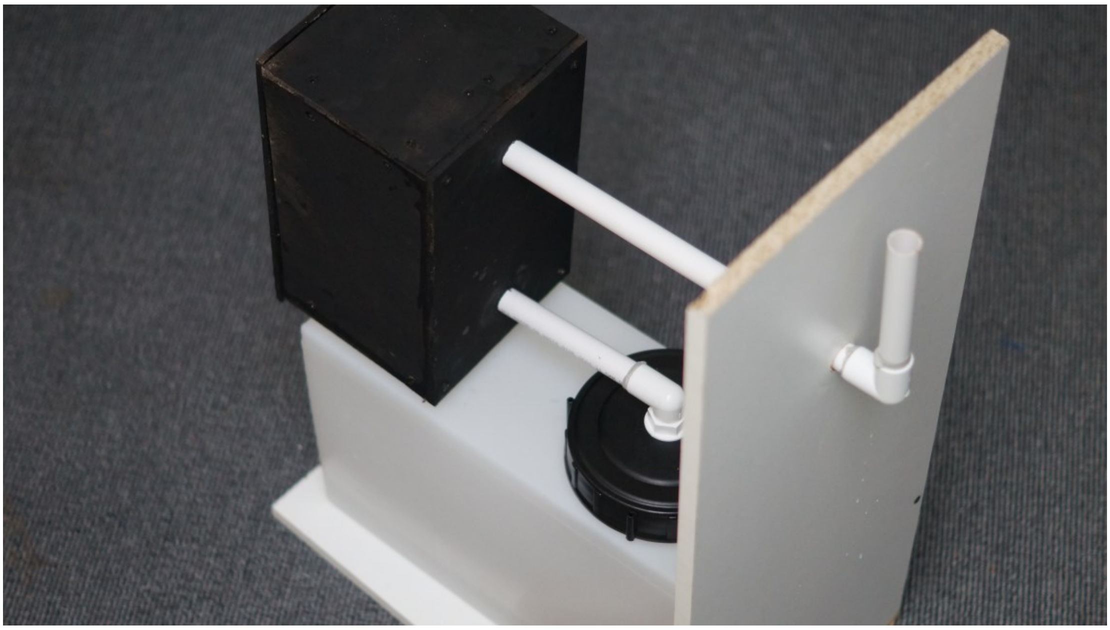


Figure C-12: Prototype to test on real users.

Prototype constructed to test on real users to gauge reception of the innovation. Source: J Larsson.

The space available is an existing toilet cubicle. The only requirements for the space is where to deposit the urine. Steps have been taken to minimise the WBM footprint so urine may be diverted into a holding tank shown in Figure C-12. The hydration status of the user will be displayed on the top of the urinal box and will be discussed in more detail in the following section. There are no other spatial requirements that need prioritisation.

Triggering Analysis: Any detected drop change from the contact probes will indicate something has entered the chamber and analysis of the colour and EC of the liquid - *function called RGB_EC()* - can be undertaken until the reading returns to the initial point.

After this function, then we have values for the start time of liquid entering the chamber *Time[0]*, RGB, EC and end time values *Time[1]*. From this we may extrapolate the volume of liquid by dividing by the time taken for 1L of water to pass through.

If in the eventuality that contact probes are not used, the unit is also able to use the same photoresistor and RGB LED continually on to record the change in light intensity as urine fills the chamber, as seen in Figure C-7. The coding for this concept is not as straightforward as expected because the response of the photoresistor is unpredictable as the liquid enters the chamber and the turbulence of air bubbles popping interfered with the results. This again, overly complicates the prototype and instead, triggering the analysis using contact probes is far less complicated.

A prototype was made to attach straight to a normal toilet. Made from a plastic bidet with the WBM attached to the base, shown in Figure C-13. This then allows much easier and quicker development and installation of the technology for testing.

Figure C-13: Portable Wellbeing Monitor.

Portable Wellbeing Monitor to retrofit onto an existing toilet. Source: J Larsson.

The downsides to the design was with pooling from previous tests. Pooling in the bottom of the bidet, at the mouth of the WBM affects the readings of the next test that can be seen in Figure C-14. Below are the results from four tests with tap water and simulant urine with yellow tinted saline water with sodium chloride and food colouring. It can be seen that the EC of the simulant affected the fourth test on the same sample of water as the first two tests.

Table C-2: The effects of pooling on four tests on water and simulant urine.

Trial	Liquid	R	G	B	EC (mS)	Volume (ml)
1	Water	255	255	255	38.16	207
2	Water	255	255	255	36.88	191
3	Simulant	255	255	189	7.27	198
4	Water	255	255	255	22.24	233

In the redesign of the mouth of the WBM, a more compact unit was arrived at that may sit in a urinal or toilet bowl.

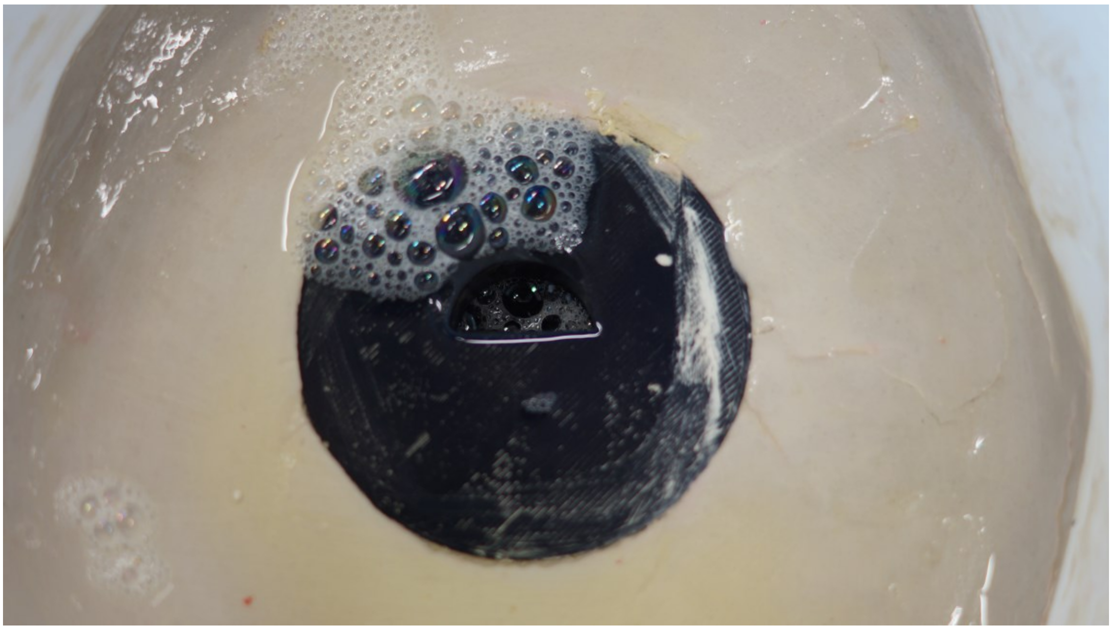


Figure C-14: Issues with pooling.

Picture showing how pooling - particularly bubbly liquid – does not break connection between contact probes and affects the conductivity values of the next test. Source J Larsson.

After this the concept shown in Figure C-13 was developed that was again smaller and had far less practical issues that have been discussed throughout this Chapter. The final concept was compact enough to enclose in a wireless concept shown in Figure C-15.

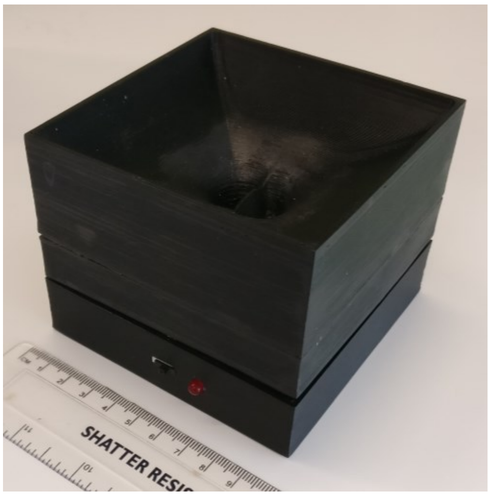


Figure C-15: Compact Bluetooth urine colour sensor.

Compact Bluetooth urine colour sensor. Source J Larsson.

Displaying the Data: The traffic light system uses red, amber and green to illuminated acrylic signs that display dehydrated, intermediate and hydrated respectfully. The text has been laser etched onto acrylic and LEDs have been positioned to shine internally into the acrylic, illuminating the edge of the text in the chosen colour.

```
#define Dehydration  8                        //Define traffic light LED pins
#define Intermediate 7
#define Hydration  6

if ( RGB_Array[2] < 51 ) {               //If the blue light absorbed is less than 51
    DISPLAY_LED = Dehydration;
   }
   if ( RGB_Array[2] > 51 ) {
    DISPLAY_LED = Hydration;
   }
                              //Flash the particular traffic light on/off for 150ms
   if (timer1 - timer0 > 150) {
    digitalWrite( DISPLAY_LED, STATE );
    STATE = abs(STATE - 1);
    timer0 = timer1;
   }
```

The LCD screen shows dehydrated, intermediate and hydrated as the traffic light system does above, but also includes a percentage value calculated from the colour of blue light absorbed by the urine.

A phone application that computes and displays the data over a prolonged time-period provides far more insightful data for the user and was simply prototyped because the data from the Arduino was transferred by Bluetooth during calibration – *because of the noise from USB connection.* However, the development of a fully functional app for testing is too complicated and outside of the researcher’s abilities. Additionally, it may influence the user’s view of how aspirational the technology is since they interact with the data through a lens of an already aspirational product. A mock preview of how the data may be displayed is shown in Figure D-7 and will be presented to the users in the final test as an example of what may be achieved from the technology. For the reason of influence the respondents as little as possible, the traffic light system has been chosen since red, amber, green is universally known and understood for dehydrated, intermediate and hydrated.

Automatic Calibration: Since the previous Chapter, the design has had to change numerous times and the need to redo the tests to validate the concept have presented problems for the progression of the concept. Slight changes in the physical design or hardware of the unit then changes the values that maybe received. The decision was made to automatically calibrate the unit as part on start-up. The values received by the Arduino were from zero to 1024 which is far removed from RGB values and EC; below are the steps taken to auto-calibrate the WBM.

The RGB colours can be calibrated by recording light intensities with no obstruction in the unit for all three values of RGB and another for no light at all and mapping all values thereafter onto this curve between zero and 255.

The values of RGB calculated in analysis, can then be mapped from zero to 255 regardless of the values the Arduino records.

Upon start-up of the unit, the EC can be calibrated for by pouring three know conductivities of sample fluid down the unit and storing these values and mapping all other recorded values onto this curve similar to that shown above. By the same method and eluded to above, the volume can be automatically calibrated for by pouring a known volume of liquid down the unit and timing how long it takes.

Longevity Testing: To ensure the WBM will remain accurate for the duration of the user testing, the factors that will be tested are; Battery life and Repeat testing.

Once again using a voltage divider from the power rail of the Arduino, one can have a battery monitor.

```
int sensorValuea3 = analogRead( A3 );
int sensorValueA3 = sensorValuea3/10 + sensorValueA3;

int BatteryLevel = map( sensorValueA3, 0, 1023, 0, 100 );

while( sensorValue < 5 ){                    //If the battery is less than 5%
        digitalWrite( Dehydration, HIGH );
        digitalWrite( Intermediate, HIGH );
        digitalWrite( Hydration, HIGH );
        delay(100);
        digitalWrite( Dehydration, LOW );
        digitalWrite( Intermediate, LOW );
        digitalWrite( Hydration, LOW );
        delay( 100 );
}
```

Ensuring the unit performs for the duration of the user testing, repeat testing has been undertaken. 117 donated samples of urine were collected and tested over a three-day period without cleaning of the unit between each test. Hydration was inferred by measuring the sample's EC and SG using a conductivity probe and refractometer for each metric respectfully.

Over the 117 samples, 18 *(15%)* were identified as dehydrated by EC and 51 *(35%)* by SG, however only 18 *(15%)* were considered dehydrated for both of the parameters. The WBM identified 15 *(13%)* samples that were dehydrated, identified by the urine's EC and SG. Three *(3%)* hydrated samples were detected as dehydrated and six *(5%)* were incorrectly detected as hydrated. This means that over the three-day intensive testing, the WBM was accurate 92% of the time. Moreover, the WBM was not as accurate as the conductivity probe, but was more effective than the refractometer by itself; they were effective 100% and 72% of the time respectfully.

Over the 117 tests, the unit reliably calculated hydration, however the unit needed regular recalibration. After investigating the cause of the fluctuating results, the cause seems to be in how the hardware was assembled. After prototyping the WBM numerous times, the decision was taken to proceed to user testing since correctly reading 92% of the samples.

Summary

The results are good enough to indicate hydration. Using the equations of the regression curves to calculate hydration. The regression of these curves are not as strong as the previous experimental setups, since the setup is no longer in laboratory conditions there is possibly noise from external light and general handling that affects the results.

Hardware: The findings show that as the distance of the chamber between the RGB LED and the photoresistor increases, the resistance range of the photoresistor decreases, but the amount of colour is absorbed by the liquid. The optimum distance between the two is approximately 50mm for blue light, but less for red and green light. An appropriate distance between the source and sensor appears to be between 30mm and 50mm. The wall thickness of the chosen transparent material to construct the chamber from, is not significant; simply provided it is transparent.

The chamber that holds the urine during analysis needs to have as little interference as possible. The identified sources of noise come from external light, residual liquid from previous samples and from interference in the chamber from air bubbles or solid particles.

Triggering the analysis is achieved by reducing the aperture after the analysis chamber as to allow the urine to back up, then connection is made between two contact probes acting as a switch using the urine to make the connection. This not only saves complexity having to use a mechanised flush to hold the sample in the unit, but also presents another option of reading the EC of the urine to make the hydration calculation more accurate. Bernoulli's equation gives an indication of an appropriate size of the chamber and outlet aperture that is consistent with prototyping tests where $1.5\ mm < r_{out} < 5.2\ mm$. If a user has a particularly fast urine flow, then an overflow diversion will have to be incorporated into the design to stop overflow.

The results from the contact probes show that there is a gradual drop in the sample's resistance as it drains from the chamber as seen in the main thesis. This may be from sedimenting particles in the sample that gradually increase the conductivity of the sample, taking a true reading that is accurate is difficult. Taking the mean of the conductivity while contact is made between the probes may give repeatable results, but it may not be precise.

While prototyping, many strategies were taken to minimise noise to achieve as accurate results as possible. This is achieved through several techniques in smoothing via firmware, but the majority comes from ensuring the source of power for the voltage dividers is stable. Power over USB from a laptop and even power from a power-bank were noisier than the unit being powered by a 9v battery. Unfortunately, a USB connection to the laptop provided power and also allowed the interrogation of the data received from the unit. The elimination of power over USB also meant that a Bluetooth transmitted had to be added to the unit to allow the laptop to see the data over serial connection, however this affords the use of an external database and more in-depth interrogation of the data.

Firmware: The findings show that the device is accurate with repeatability. A great deal of effort was taken to reduce noise from the system by using smoothing functions in the firmware. The *delay* function in the Arduino IDE presents an issue with taking readings from sensors. To not overload the serial port, data is read every 10ms however there are nine readings that may have been missed that may be more accurate. Instead the firmware takes all the readings over the 10ms and sends the average value; the author recommends never to never use the *delay* function and read all values like this, however long the time period.

There is also a ramp-up to the average value when the sensors start reading, this may be grounding issues with the electronics, but a smoothing function that takes into consideration the last value, reduces these interruptions further. From the graphs in Figure C-11, the smoothing function only needs $20ms$ for calculation to arrive at a stable value.

One may notice that red and green values have not entered into the calculation for hydration. The red and green LEDs may indeed by removed from firmware, but instead have been kept in to detect other components in urine for future calibration. Indeed, as it stands, purely for hydration, the blue light, EC, volume and frequency are all that is needed to infer hydration.

An external database that records RGB values, EC values, volumes and arrival times allows more interrogation of the data and deeper insights. For instance, inter-arrival times can be calculated from the arrival times *Time[0]* recorded for the day and compared to volumes contributed can indicate to volume of liquids consumed. It will not be used for the follow tests on users however, because it does not add to the experiment, but will be considered moving forward.

Preparation for User Testing: A free-standing urinal concept has been designed for the human user testing that fits in the environment of testing and the WBM has been attached to the back of it. It is the data that the user receives from the WBM that is of interest in user feedback and as such the aesthetics of the toilet has not been changed as this may affect their experience.

The development of the prototype shows that the technology will work for the duration of the test and so too will the battery life; in the eventuality that the battery does not sustain, a battery level indicator has been added at no extra cost. To instigate calculation, the unit now detects incoming urine by the contact probes, that also read EC of urine to refine the reading further. Since received intensities of light changes as the vessels fills with liquid, the RGB LED may constantly be on and used to trigger analysis without contact probes, however this was rejected from the additional benefit the EC probes provide.

The repeat tests on 29 samples shows that the calculations of hydration were correct to 90% and is accurate enough to proceed onto user testing, provided that users are aware of the WBM's accuracy. Below is a standard operating procedure for the WBM prototype where the technical components in the back-end will be hidden from view of the user:

> *Arrival*
>
> Before using this urinal please be aware it is being used for research and has test equipment attached to the plumbing of this system. If you have not signed a consent form before using this, please contact Jake Larsson (j.larsson@cranfield.ac.uk) before using it.
>
> *Use*
>
> You may use this urinal as you would normally. Your hydration status will be displayed on the traffic light system where red represents dehydration, amber represents intermediate and green represents hydrated.
>
> *Leaving*
>
> The calculations are calibrated based on recognised methods of measuring hydration and preliminary tests have shown this urinal to be accurate 90% of the time. Use the information as you wish, the urinal will automatically be ready for the next visitor, do not forget to wash your hands!

For replication of the test, the unique bill of materials, schematics and firmware are shown below.

Bill of Materials

Table C-3: Bill of Materials.

IDs	#	Component	Footprint	Properties
Bat1	1	9v Battery Connector		
Bat2	1	9v Battery		
C1	1	Capacitor	C1310	10uF
C2	1	Capacitor	C1310	4.7uF
D1	1	RGB LED	5mm-RGB-LED	
R1	2	Resistor	0309/10	10kohm
R2	3	Resistor	0309/10	150ohm
R4	1	Photoresistor		
U2	1	5V Regulator	T0220	

Schematics

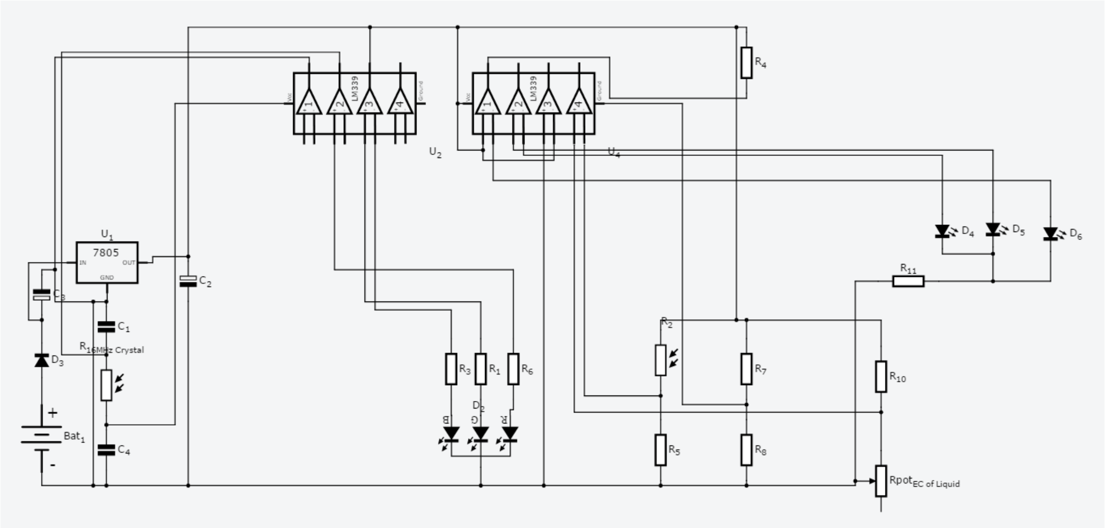


Figure C-16: Schematic of WBM unit.

Schematic of WBM unit. Source J Larsson.

Code of WBM for Hydration Inference

```
#include <SoftwareSerial.h>

#define BT_SERIAL_TX 9
#define BT_SERIAL_RX 10

SoftwareSerial
BluetoothSerial(BT_SERIAL_TX,
BT_SERIAL_RX);

#define RED 4 //R Pin
#define GREEN 2 //G Pin
#define BLUE 3 //B Pin
#define BTpin 10 //Bluetooth State
Pin
#define Dehydration 8 //Trafficlight
Red Pin
#define Intermediate 7 //Trafficlight
Amber Pin
#define Hydration 6 //Trafficlight
Green Pin
#define ON 9 //Power LED Pin

#define sweep 75

#define Vin 5 //Voltage in
#define R1 560 //Resistor 1
#define Ra 25 //Wire & Pin
Resistance
#define TemperatureCoef 0.019
#define K 2.88 //Cell Constant
#define Temperature 36 //Urine
Temperature

int calibrate_state = -2;
unsigned long one_L;
unsigned long Time[2];
unsigned int sensorValueA[2];
unsigned int sensorValueB[2];
unsigned int sensorValueC[2];
unsigned int TOT_Array[10];
unsigned int EC_average;
unsigned int EC[10];
unsigned int RGB_Array[3];
unsigned int TOTRGB;
unsigned int TOTSG;
unsigned int TOTEC;
unsigned int RESULTA;
unsigned int RESULTB;
unsigned int RESULTC;
unsigned int Lookup_ZERO;
unsigned int Lookup_SG0;
unsigned int Lookup_EC0;
unsigned int Lookup_RED;
unsigned int Lookup_SG_RED;
unsigned int Lookup_EC_RED;
unsigned int Lookup_GREEN;
unsigned int Lookup_SG_GREEN;
unsigned int Lookup_EC_GREEN;
unsigned int Lookup_BLUE;
unsigned int Lookup_SG_BLUE;
unsigned int Lookup_EC_BLUE;
```

```
int threshold = 2800;
int STATE;
int timer0;
int DISPLAY_LED;

void setup() {
  Serial.begin( 9600 );
  pinMode( GREEN, OUTPUT );
  pinMode( BLUE, OUTPUT );
  pinMode( RED, OUTPUT );
  pinMode( ON, OUTPUT );
  pinMode( Dehydration, OUTPUT );
  pinMode( Intermediate, OUTPUT );
  pinMode( Hydration, OUTPUT );
  pinMode( BTpin, INPUT );

  BluetoothSerial.begin( 9600 );
}

void loop() {
  unsigned int vol;
  int sensorValuea3 = analogRead( A3 );
  int BatteryLevel = map( sensorValuea3, 0, 1023, 0, 100 );
  int timer1 = millis();

  if ( BatteryLevel < 5 ) {     //If the battery is less than 5%
    digitalWrite( Dehydration, STATE );
    digitalWrite( Intermediate, STATE );
    digitalWrite( Hydration, STATE );
    digitalWrite( ON, STATE );

    if ( timer1 - timer0 > 100 ) {
      STATE = abs(STATE - 1);
    }
  }
  else { //If battery more than 5% then always on
    digitalWrite( ON, HIGH );
  }

  while ( calibrate_state < 3 ) {
    if ( calibrate_state == -2 ) {
      Serial.println( "Awake" );

      for (int i = 0 ; i < 5 ; i += 1) {
        digitalWrite( Dehydration, LOW );
        digitalWrite( Intermediate, LOW );
        digitalWrite( Hydration, LOW );
        digitalWrite( ON, LOW );
        delay(50);
        digitalWrite( Dehydration, HIGH );
        digitalWrite( Intermediate, HIGH );
        digitalWrite( Hydration, HIGH );
        digitalWrite( ON, HIGH );
        delay(50);
      }

```

```
      calibrate_state = calibrate_state +
1; //0;
    }

    for ( int i = 0 ; i < 5 ; i += 1 ) {
      digitalWrite( Dehydration, LOW );
      digitalWrite(  Intermediate,  LOW
);
      digitalWrite( Hydration, LOW );
      digitalWrite( ON, LOW );
      delay(50);
      digitalWrite(  Dehydration,  HIGH
);
      digitalWrite(  Intermediate,  HIGH
);
      digitalWrite( Hydration, HIGH );
      digitalWrite( ON, HIGH );
      delay(50);
    }
    calibrate_state  =  calibrate_state  +
1; //0;

    if ( calibrate_state == 0 ) {
      Serial.println(  "Calibrating  Step
1/2..." );
      sensorValue( RED, GREEN, BLUE,
0, 10, "Calibrate," );
      Lookup_ZERO = RESULTA;
      Lookup_SG0 = RESULTB;
      Lookup_EC0 = RESULTC;
      sensorValue( RED, GREEN, BLUE,
255, 10, "Calibrate," );
      Lookup_RED = RESULTA;
      Lookup_SG_RED = RESULTB;
      Lookup_EC_RED = RESULTC;
      sensorValue( GREEN, BLUE, RED,
255, 10, "Calibrate," );
      Lookup_GREEN = RESULTA;
      Lookup_SG_GREEN = RESULTB;
      Lookup_EC_GREEN = RESULTC;
      sensorValue( BLUE, RED, GREEN,
255, 10, "Calibrate," );
      Lookup_BLUE = RESULTA;
      Lookup_SG_BLUE = RESULTB;
      Lookup_EC_BLUE = RESULTC;
      threshold = RESULTC - 100;

      Serial.print( "RAW_0," );
      Serial.print( Lookup_ZERO );
      Serial.print( "," );
      Serial.print( Lookup_SG0 );
      Serial.print( "," );
      Serial.print( Lookup_EC0 );
      Serial.println( "" );

      Serial.print( "RAW," );
      Serial.print( Lookup_RED );
      Serial.print( "," );
      Serial.print( Lookup_GREEN );
      Serial.print( "," );
      Serial.print( Lookup_BLUE );
      Serial.print( "," );
      Serial.print( Lookup_SG_RED );
      Serial.print( "," );
      Serial.print( Lookup_SG_GREEN );
      Serial.print( "," );
```

```
  Serial.print( Lookup_SG_BLUE );
  Serial.print( "," );
  Serial.print( Lookup_EC_RED );
  Serial.print( "," );
  Serial.print( Lookup_EC_GREEN );
  Serial.print( "," );
  Serial.print( Lookup_EC_BLUE );
  Serial.println( "" );

  for ( int i = 0 ; i < 5 ; i += 1 ) {
    digitalWrite( Dehydration, LOW );
    digitalWrite( Intermediate, LOW );
    digitalWrite( Hydration, LOW );
    digitalWrite( ON, LOW );
    delay(50);
    digitalWrite( Dehydration, HIGH );
    digitalWrite( Intermediate, HIGH );
    digitalWrite( Hydration, HIGH );
    digitalWrite( ON, HIGH );
    delay(50);
  }

  //     Serial.println( "Pour Calibration Fluid A in Container" );
  //     delay(2000);
  //     Serial.println( "Pour Calibration Fluid A in Container For... 3" );
  //     delay(1000);
  //     Serial.println( "Pour Calibration Fluid A in Container For... 2" );
  //     conductivity();
  //     Lookup_EC[0] = EC_average;
  //     threshold = EC_average;
  //     delay(990);
  //     Serial.println( "Pour Calibration Fluid A in Container For... 1" );
  //     delay(1000);
  //     Serial.println( "Finished, Stop Pouring" );
  //     delay(1000);

  //     for ( int i = 0 ; i < 5 ; i += 1 ) {
  //       digitalWrite( Dehydration, LOW );
  //       digitalWrite( Intermediate, LOW );
  //       digitalWrite( Hydration, LOW );
  //       digitalWrite( ON, LOW );
  //       delay(50);
  //       digitalWrite( Dehydration, HIGH );
  //       digitalWrite( Intermediate, HIGH );
  //       digitalWrite( Hydration, HIGH );
  //       digitalWrite( ON, HIGH );
  //       delay(50);
  //     }
```

```

     //      Serial.println( "Pour 500ml
of Calibration Fluid B in Container" );
     calibrate_state = calibrate_state +
2; //1
   }
   //
   //   conductivity();
   //
   //   while ( EC_average < threshold
) {
   //     if ( calibrate_state == 1 ) {
   //      Serial.print( "Calibrating Step
2/2..." );
   //       Time[0] = millis();
   //                    calibrate_state   =
calibrate_state + 1; //2
   //     }
   //
   //     conductivity();
   //
   //     Lookup_EC[1] = EC_average;
   //     Time[1] = millis();
   //    one_L = 2 * ( Time[1] - Time[0]
);
   //   }

   if ( calibrate_state == 2 ) {
     Serial.println(          "Calibration
Finished" );

     for (int i = 0 ; i < 10 ;  i += 1) {
       conductivity();
     }

     Serial.println( "Ready for Use" );
     calibrate_state = calibrate_state +
1; //3

     for (int i = 0 ; i < 3 ; i += 1) {
       digitalWrite( Dehydration, HIGH
);
       digitalWrite( Intermediate, HIGH
);
       digitalWrite( Hydration, HIGH );
       digitalWrite( ON, HIGH );
       delay(150);
       digitalWrite(  Dehydration,  LOW
);
       digitalWrite( Intermediate, LOW
);
       digitalWrite( Hydration, LOW );
       digitalWrite( ON, LOW );
       delay(150);
     }
   }
 }

 if ( calibrate_state >= 3 ) {
   analogWrite( RED, 0 );
   analogWrite( GREEN, 0 );
   analogWrite( BLUE, 0 );

   conductivity();

```

```
  while ( EC_average < threshold ) { //If contact made between poles, analyse
    if ( calibrate_state == 3 ) {
      Serial.print( "EC_average: " );
      Serial.println( EC_average );
      Serial.println( "Calculating..." );
      Time[0] = millis();

      sensorValue( RED, GREEN, BLUE, 255, 10, "Calculating," );
      TOT_Array[0] = RESULTA;
      TOT_Array[3] = RESULTB;
      TOT_Array[6] = RESULTC;
      sensorValue( GREEN, BLUE, RED, 255, 10,  "Calculating," );
      TOT_Array[1] = RESULTA;
      TOT_Array[4] = RESULTB;
      TOT_Array[7] = RESULTC;
      sensorValue( BLUE, RED, GREEN, 255, 10, "Calculating," );
      TOT_Array[2] = RESULTA;
      TOT_Array[5] = RESULTB;
      TOT_Array[8] = RESULTC;

      RGB_EC();

      calibrate_state = calibrate_state + 1; //4
    }

    if ( RGB_Array[2] < 51 ) {
      DISPLAY_LED = Dehydration;
    }
    if ( RGB_Array[2] > 51 ) {
      DISPLAY_LED = Hydration;
    }

    if (timer1 - timer0 > 150) {
      digitalWrite( DISPLAY_LED, STATE );
      STATE = abs(STATE - 1);
      timer0 = timer1;
    }

    timer1 = millis();
    conductivity();

    Time[1] = millis();
    TOT_Array[9] = Time[1] - Time[0];
    vol = 1000 * ( Time[1] - Time[0] ) / one_L;
  }

  if (calibrate_state == 4) {
    Serial.print( "Vol, " );
    Serial.print( vol );
    Serial.println( ",ml" );

    for ( int i = 0 ; i < 10 ; i += 1 ) { //Flashing LED Function
      for ( int j = 0 ; j < 255 ; j += 1 ) {
        analogWrite( DISPLAY_LED , j );
        delay(1);
      }
```

```
    for ( int j = 0; j < 255 ; j += 1 ) {
     analogWrite(   DISPLAY_LED   ,
255 - j );
     delay(1);
    }
    delay(100);
   }
   delay(10000);
   calibrate_state = -2; //recalibrate
  }
 }
 timer0 = timer1;
}

void RGB_EC() {
 RGB_Array[0] = map( TOT_Array[0],
Lookup_ZERO, Lookup_RED, 0, 255 );
 RGB_Array[1] = map( TOT_Array[1],
Lookup_ZERO,   Lookup_GREEN,   0,
255 );
 RGB_Array[2] = map( TOT_Array[2],
Lookup_ZERO, Lookup_BLUE, 0, 255
);

 if ( TOT_Array[0] < Lookup_ZERO ) {
  RGB_Array[0] = 0;
 }
 if ( TOT_Array[0] > Lookup_RED ) {
  RGB_Array[0] = 255;
 }
 if ( TOT_Array[1] < Lookup_ZERO ) {
  RGB_Array[1] = 0;
 }
 if ( TOT_Array[1] > Lookup_GREEN )
{
  RGB_Array[1] = 255;
 }
 if ( TOT_Array[2] < Lookup_ZERO ) {
  RGB_Array[2] = 0;
 }
 if ( TOT_Array[2] > Lookup_BLUE ) {
//If values not in lookup
  RGB_Array[2] = 255;
 }

 Serial.print( "RAW, " );
 for ( int i ; i < 10 ; i += 1 ) {
  Serial.print( TOT_Array[i] );
  Serial.print( "," );
 }
 Serial.println("");

 Serial.print( "RGB, " );
 for ( int i ; i < 3 ; i += 1 ) {
  Serial.print( RGB_Array[i] );
  Serial.print( "," );
 }
 Serial.println("");

 float   SG0   =   TOT_Array[3]   /
TOT_Array[0];
 float   SG1   =   TOT_Array[4]   /
TOT_Array[1];
 float   SG2   =   TOT_Array[5]   /
TOT_Array[2];

```

```
  Serial.print( "SG, " );
  Serial.print( SG0 );
  Serial.print( "," );
  Serial.print( SG1 );
  Serial.print( "," );
  Serial.print( SG2 );
  Serial.println( "," );

  float Av = ( TOT_Array[3] +
TOT_Array[4] + TOT_Array[5] ) / 3;
// Average Voltage
  float Volts = Vin * Av / 1024; // Volts
  float mSiemens = 1000 / ( Volts * (
R1 + Ra ) / ( Vin * 10 - Volts ) - Ra );
//1/Resistance from voltage divider
  float D = mSiemens / ( 1 +
TemperatureCoef * ( Temperature -
25.0 ) ); //Temperature
Compensation

  Serial.print( "EC, " );
  Serial.print( D, 4 );
  Serial.println( ",mS" );
}

void conductivity() {
  EC_average = 0;
  for (int i = 0 ; i < 9 ; i += 1) {
    EC[9 - i] = EC[8 - i];
  }

  for ( int i = 0 ; i < 10 ; i += 1 ) {
    sensorValueC[0] = analogRead( A2
);
    sensorValueC[0] = analogRead( A2
);
    sensorValueC[1] =
sensorValueC[0] + sensorValueC[1];
    delay(1);
  }

  EC[0] = sensorValueC[1];

  for (int i = 0 ; i < 10 ; i += 1) {
//   Serial.println( EC[i] );
    EC_average = EC[i] / 10 +
EC_average;
  }
  sensorValueC[1] = 0;
}

void sensorValue( int LED1, int LED2,
int LED3, int x, int delayTime, String
TEXT ) {
  for ( int i = 0 ; i < sweep ; i += 1 ) {
    analogWrite( LED1, x );
    analogWrite( LED2, 0 );
    analogWrite( LED3, 0 );

    for ( int j = 0 ; j < delayTime ; j += 1
) {
      sensorValueA[0] = analogRead(
A0 );
      sensorValueA[0] = analogRead(
A0 );
```

```
    sensorValueA[1] =
sensorValueA[0] + sensorValueA[1];
    sensorValueB[0] = analogRead(
A1 );
    sensorValueB[0] = analogRead(
A1 );
    sensorValueB[1] =
sensorValueB[0] + sensorValueB[1];
    sensorValueC[0] = analogRead(
A2 );
    sensorValueC[0] = analogRead(
A2 );
    sensorValueC[1] =
sensorValueC[0] + sensorValueC[1];
    delay(1);
  }

  sensorValueA[1] =
sensorValueA[1] / ( delayTime / 10 );
  sensorValueB[1] =
sensorValueB[1] / ( delayTime / 10 );
  sensorValueC[1] =
sensorValueC[1] / ( delayTime / 10 );

  TOTRGB = 0.2 * sensorValueA[1] +
0.8 * TOTRGB;
  TOTSG = 0.2 * sensorValueB[1] +
0.8 * TOTSG;
  TOTEC = 0.2 * sensorValueC[1] +
0.8 * TOTEC;

  Serial.print( TEXT );
  Serial.print( TOTRGB );
  Serial.print( "," );
  Serial.print( TOTSG );
  Serial.print( "," );
  Serial.print( TOTEC );
  Serial.println( "," );

  sensorValueA[1] = 0;
  sensorValueB[1] = 0;
  sensorValueC[1] = 0;
  delay(1);
  RESULTA = TOTRGB;
  RESULTB = TOTSG;
a
 }

 TOTRGB = 0;
 TOTSG = 0;
 TOTEC = 0;

 analogWrite( LED1, 0 );
 analogWrite( LED2, 0 );
 analogWrite( LED3, 0 );
}
```

Appendix D. Review of Displaying Data

Taking the data, information, knowledge, wisdom pyramid or hierarchy of knowledge as a starting point, the data received from the WBM could be communicated in a number of ways (Rowley, 2010). Firstly, the raw data could be shown, i.e. the volts read by the Arduino or the calculated colour of the urine could be shown on a screen, this however, is not very useful to the user. Secondly, the data could be used to inform the user and provide them information about their hydration, i.e. a red light for dehydrated, amber light for intermediate or green light for hydrated. The third tier could be to inform the user of their hydration status as before, and guide them by providing further information, i.e. a screen that says, *"Salt content is high, you are advised to drink some water*". The final level, would be a communication which is much the same as the knowledge level before, but accumulates information over time and feeds this forward; i.e. a screen may say, "*You are urinating significantly more than usual and specific gravity is higher than normal, this maybe a sign of something else. Please seek advice from a health professional*".

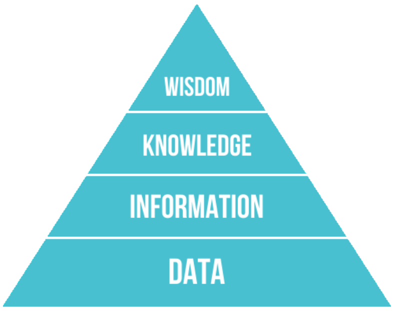


Figure D-1: The hierarchy of data.

The hierarchy of data. Source (Rowley, 2010).

The higher tiers are clearly more beneficial implications, but have difficulties in development; time, resources, skills needed and ethical impact of such a system. Additionally, this Chapter sets out to is to see if the data is of value to the users, but also how it may affect their behaviour.

As discussed, hydration is a complicated measure that can be inferred by six indicators according to European Hydration Institute (2016). The calculation of hydration based on colour, EC, volume, frequency and inferred SG and the communication of this data may take many forms. Within bathrooms themselves there are only a few examples of displaying data, weight scales or pregnancy tests.

Collection of data displays used in bathrooms, including weight scales, pregnancy test, water temperature, blood sugar test kit, ear thermometer.

Figure D-2: Collection of data displays.

Collection of data displays. Source https://www.google.co.uk.

There are other activities that require data display that are usually undertaken in bathrooms for privacy reasons, such as blood sugar monitoring. On the other hand, connected devices allow access to data on a smartphone or computer, such as smart scales. In short, there are limited examples of digital displays in bathrooms, perhaps because of the presence of water, that usually only display one metric, but the possibility of displaying more complex data can be achieved through connected devices.

Survey Low Cost Data Displays

Keeping the solution low cost a traffic light system that uses red, amber and green LEDs is the simplest form of displaying data. It is used in many areas and is universally known to mean bad, ok and good respectfully. Food standards use a traffic light system for recommended daily allowances of different parameters, white goods products are labelled indicating energy consumption and even performance is coded by a traffic light system (FSA, 2007). Other wearable technologies often use a traffic light system to indicate healthy heartrate levels or activity.

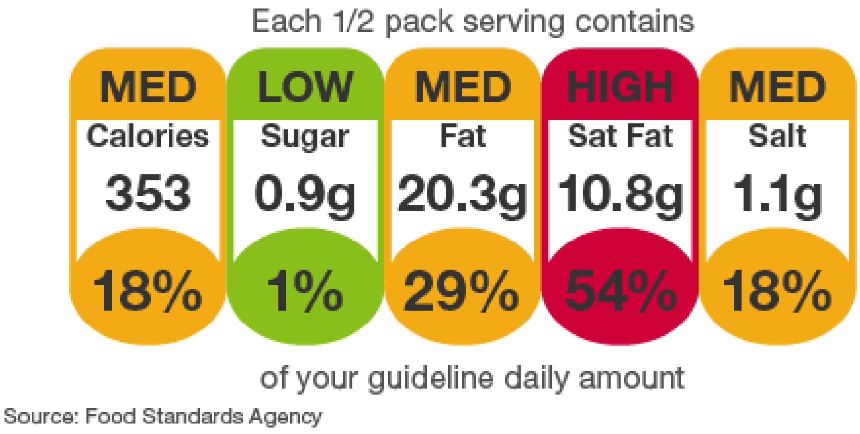


Figure D-3: Typical traffic light display of information.

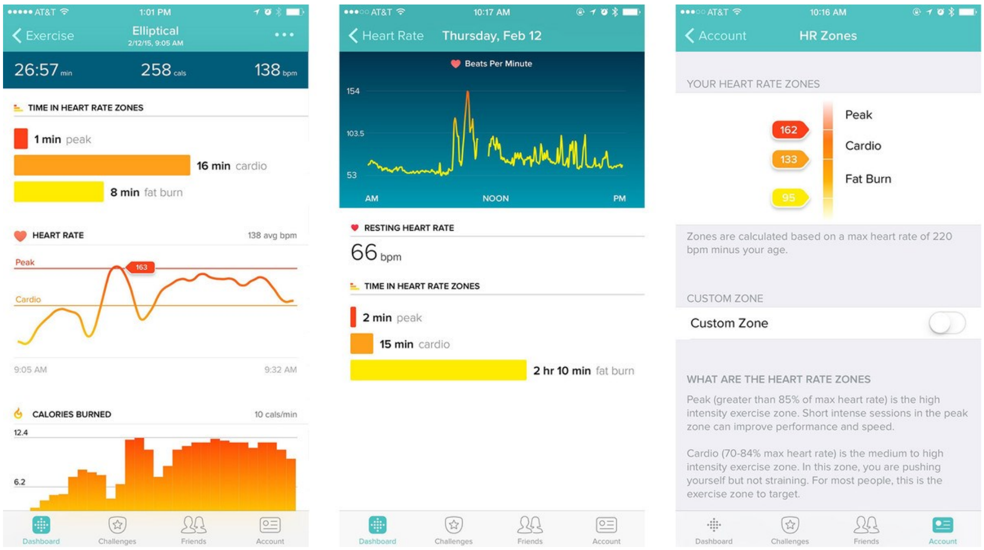
Typical traffic light display of information on food package. Source (FSA, 2007).

A digital screen presents options to display more data, such as the exact values of specific gravity or electrical conductivity. Within bathrooms, LCD screens have been used for gaming or advertising (Shaw, 2011). Hobbyists online have made low cost mirrors that display data such as weather forecasts. This may be used in the bathroom in which the toilet sits, however the raspberry pi was already rejected as a technology to use as it is too high cost.

Figure D-4: Bathroom displays.

(Left) LCD displays above urinals. Source (Shaw, 2011). (Right) Using a mirror as a data display screen. Source https://www.raspberrypi.org.

A current trend in wearable technologies is the ability to monitor and track fitness and wellbeing. There exist many wearable technologies for sports use or everyday tracking of general metrics. For instance, Garmin is a well-established technology for measuring runners heart rates and step rates. FitBits are for more general use that measure one's heart rate and movement by accelerometer. These sensors can measure steps taken for monitoring calories burned and quality of sleep – *based on movement during the night*.



26:57 min 258 cals 138 bpm

1 min peak

16 min cardio

8 min fat burn

138 avg bpm

10 cals/min

66 bpm

2 min peak

15 min cardio

2 hr 10 min fat burn

Zones are calculated based on a max heart rate of 220 bpm minus your age.

Peak (greater than 85% of max heart rate) is the high intensity exercise zone. Short intense sessions in the peak zone can improve performance and speed.

Cardio (70-84% max heart rate) is the medium to high intensity exercise zone. In this zone, you are pushing yourself but not straining. For most people, this is the exercise zone to target.

Figure D-5: Data displayed on Fitbit app.

Data displayed on Fitbit app. Source: https://www.google.co.uk.

How People Respond to Data: The survey of display technologies suggests that it is not simply the cleanest and simplest way to communicate all the data, instead it is how the user can interpret the data. For instance, the WBM measure five parameters; colour, volume, frequency, electrical conductivity and specific gravity, although more information may be available like time since previous visit. It depends on what information the user is after.

This presents the issue, should the raw data be shown for the user to make of it what they wish or should the data be computed to provide the user with adequate information to remain hydrated? The hierarchy presented by Rowley (2010) suggests that the higher tiers of the hierarchy provide more value since knowledge or wisdom provides more meaning than data.

Since the driver behind the WBM concept is to change the stigma of toilets by providing more meaning, value and appeal, it is best that the data be used to provide the user with knowledge and guidance about their hydration.

A traffic light system can be adopted by the hydration monitor to mean red is dehydrated, amber is intermediate and green is hydrated with supplementary information about what to do if the light turns red or green. Semantic constraints rely upon our knowledge of the situation and of the world, but nearly worldwide people appreciate that red means negative and green means positive in this context (Norman, 2013).

A screen that notifies the user can show more information such as the value of conductivity of urine or the specific gravity. This does not add any additional value to the user however since most people do not know what a certain reading of specific gravity means over another. Additional information could also be given for example *"Dehydrated: It is advised you rehydrate and have a glass of water"*. A prototype was made and is shown in Figure D-6, but was not pursued as it uses too many of the Arduino's pins than is available for the rest of the sensors.

Considering the WBM uses a Bluetooth HC05 unit to send the data to a laptop for calibration, it can also be sent to a smartphone and the data may be logged on an application. This allows far greater interrogation of the data and the ability to show the user their hydration over days or weeks.

Proposed Solutions: The survey of display methods has provided three clear avenues to display the hydration data. Of course, one could use audio feedback as well as or instead of visual, the choice comes down to what is most natural. The point of view or the choice of feedback signifier comes down to the culture of the user (Norman, 2013). The three display methods were prototyped and are discussed in more detail below.

The traffic light system uses red, amber and green to illuminated acrylic signs that display dehydrated, intermediate and hydrated respectfully. The text has been laser etched onto acrylic and LEDs have been positioned to shine internally into the acrylic, illuminating the edge of the text in the chosen colour.

The LCD screen shows dehydrated, intermediate and hydrated as the traffic light system does above, but also includes a percentage value calculated from the colour of blue light absorbed by the urine.

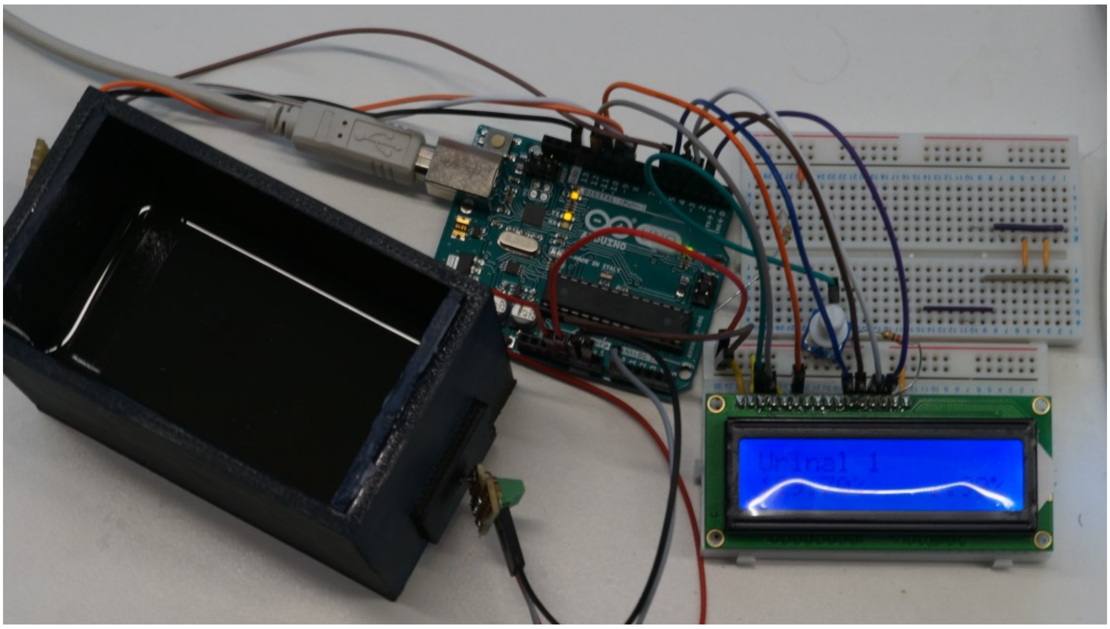
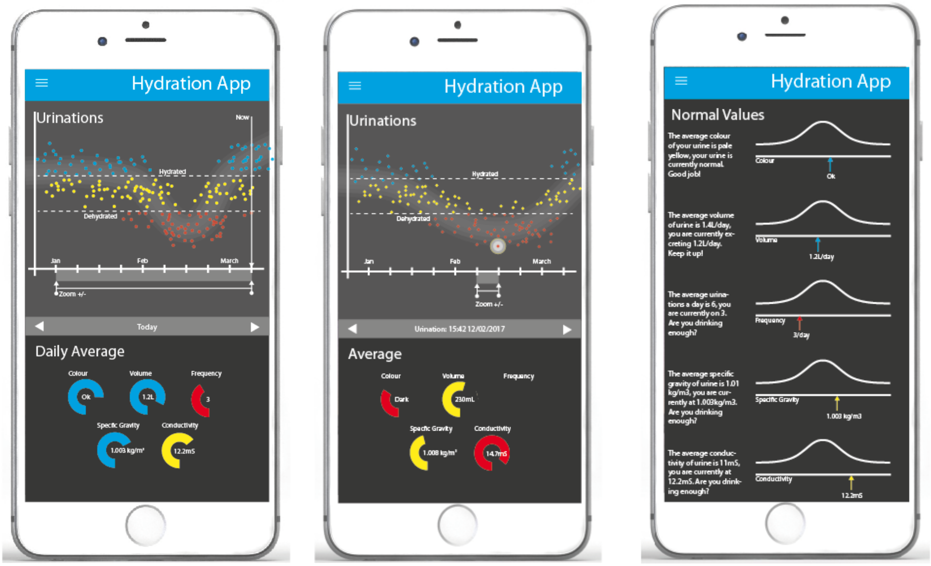


Figure D-6: LCD screen showing user hydration levels.

LCD screen showing user hydration levels and percentages based on absorption of blue light. Source J Larsson.

The implication and development of an application that computes and displays the data over a prolonged time-period is too complicated. A mock preview of how the data may be displayed is shown in Figure D-7. For this reason, the traffic light system has been chosen since it is universally known and the proposed app solution has been added to a questionnaire for user feedback.



The average colour of your urine is pale yellow, your urine is currently normal. Good job!

The average volume of urine is 1.4L/day, you are currently excreting 1.2L/day. Keep it up!

The average urinations a day is 6, you are currently on 3. Are you drinking enough?

The average specific gravity of urine is 1.01 kg/m3, you are currently at 1.003kg/m3. Are you drinking enough?

The average conductivity of urine is 11mS, you are currently at 12.2mS. Are you drinking enough?

Figure D-7: Mock smartphone application.

Mock smartphone application made to display hydration data. Source J Larsson.

Appendix E. Sitting Postures

In the late 1940s, the United States Air Force had a critic problem that their pilots could not keep control of their planes. It was hypothesised that it may have been the technology or human error, but after many inquiries officials identified the design of the cockpit may be the source of the problem. The design had been made for the average pilot from data gathered in the 1920s and perhaps now the cockpit was just too small and the average man had grown since then. In 1952, Daniels measured 140 dimensions of size of 4,063 Air Force personnel at Wright Air Force Base in Ohio, including thumb length, crotch height, and the distance of a pilot's eye to his ear. The intention was to calculate an updated average for these dimensions. What Daniels found was not a single person fit within the average range on all ten dimensions. One pilot may have a big chest, but small hips or another average eye to ear measurement, but significantly longer arms. When selecting just three of the ten dimensions, less than 3.5% of pilots would be average on all three. In short, an *'average'* pilot did not exist. If a cockpit was designed to fit the averages of all dimensions, the design would fit no-one.

The purpose for this anecdote is to say we see a similar situation with the design of the toilet – *the cockpit of the bathroom*. It appears that the toilet has been designed for an average height; from the height of the floor to bend in the knee, the distance from bend in knee to the anus, and the width of the hips. Instead the toilet, according to Daniels' findings in 1952, only fits 3.5% of the population and such these dimensions are non-optimal – *in terms of comfort* – for all.

The studies conducted by Rane and Iyer (2014), Sakakibara et al. (2010) and Sikirov (2003) all propose that squatting is the more beneficial posture to defecate with regards to straining and general health. Only Sakakibara et al, (2010) critically look at the ergonomics of the squatting posture, whereas the other studies imply that the benefits of squatting is achieved by lowering the height of the toilet.

Figure E-1: Displacement sensors.

The final displacement sensors (a) and their location on a toilet (b). Source J Larsson.

Measuring Lean While on the Toilet: A mobile distance measurer has been constructed from an ultrasonic range finder and an Arduino to record the distances of toilet users from the cistern of the toilet and can be seen in Figure E-1. The test was undertaken in a male toilet on a male population for three days where the results are shown in Figure E-3.

These sensors do not allow us to identify when users are sat or when they are standing, but standing visitors may be inferred from distances over 60 *cm* away. The example given in Figure E-2 shows four different seating postures for different distances away from the sensor.

Figure E-2: Postures on toilet of approximately. Source: J Larsson.

Postures on toilet of approximately (a) 20cm, (b) 30cm, (c) 40cm and (d) 50cm away from sensor.

Looking at the collective results for distance away from the sensor we see the distance people sit from the sensor appears to be normally distributed with a mode of the distribution at 57 *cm* away from the cistern. Implying people are sat on the edge or lean forward as shown by the following figures. If we then superimpose this distribution on top of a regular toilet silhouette, we see how far forward the majority of people are sitting.

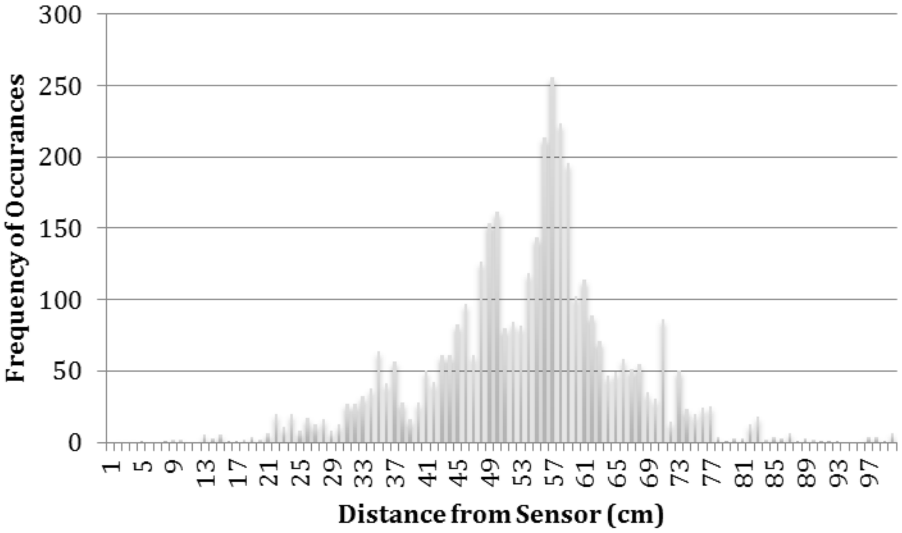


Figure E-3: Distribution of user distance away from toilet.

Graph to show distribution of user distance away from toilet cistern.

Clearly, we cannot see how people are actually sitting, but assuming people are sat, if we then taking a measurement from the middle of the toilet seat we see that the angle of 'lean'[2] between three standard deviations above and below the mean is approximately from 38° and 72° with an average of 51°. Again, observing how these distances correspond to my own postures – *average height for a male from the UK* (Peebles et al., 1998) - we see that 20cm – *over five standard deviations away from the mean* - is practically sat upright and 50 *cm* is fully leaning forward. The sensors and the test do not discriminate or distinguish between sitting or standing – *or even squatting on the toilet seat*. There is a local peak before the mean of 50cm; which for me personally is fully leaning forward. The assumption made is that the majority of visitors are in postures (c) and (d) shown in Figure E-2.

---

[2] 'Lean' is considered the inverse of the angle between the torso and the thighs.

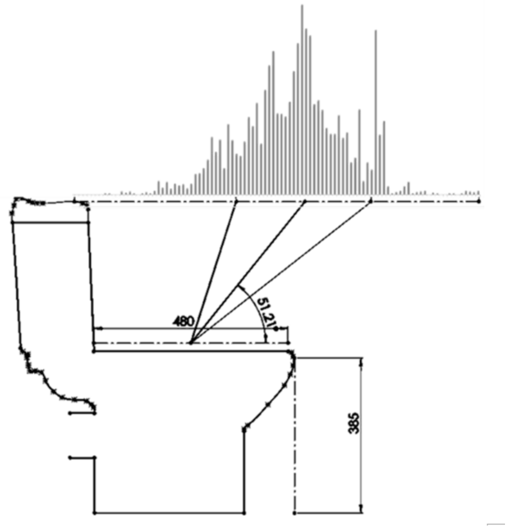


Figure E-4: Distances away from sensor on average toilet cross-section.

Distribution of distances away from sensor superimposed onto average toilet cross-section.

The findings of this short test imply that in fact the shape of the toilet is not correct for defecating. These findings reflect those behaviours identified, though not explicitly voiced, in the ethnographic research undertaken in Chapter 2. It is suspected from these results as well as the observation of resting the elbows on the legs seen in Figure E-2, that a seated posture is not comfortable for defecating and users are leaning forward to decrease the angle between the body and the thighs. These observations imply a 90˚ seat-like toilet is by no means the most comfortable design for defecation, furthermore the 22.5˚ angle of squatting – *and there most comfortable* - recorded by Sakakibara et al, (2010) does not appear achievable on a sitting toilet.

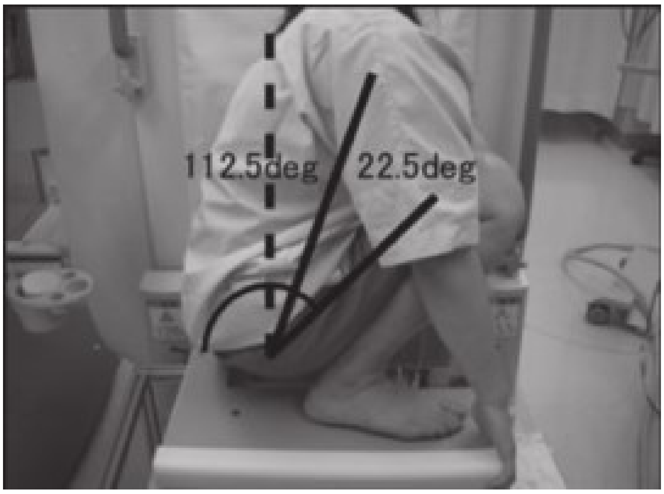


Figure E-5: Least strain while defecating posture.

Study conducted by Sakakibara et al, (2010) showing the most comfortable and least strain in defecating when the torso and thighs are 22.5° from one another.

Proposed Solutions: This realisation is by no means a new contribution. Kira (1976) undertook a thorough investigation in different designs that promote the squatting posture. Figure E-6 below shows how the squatting posture maybe achieved through different orientations and Figure E-7 shows several toilet seat forms and how the posture may, theoretically, differ on each of them.

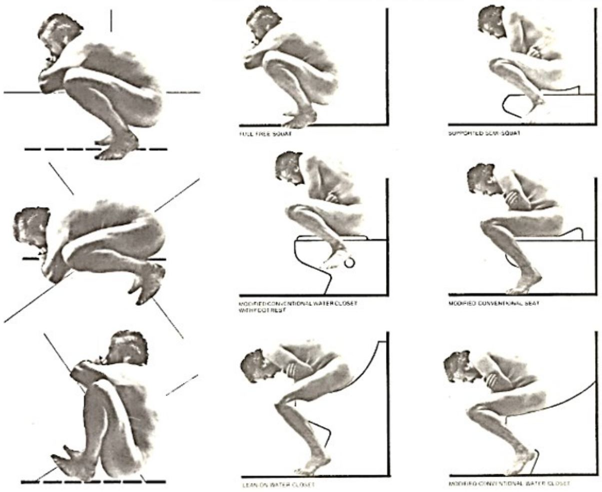


Figure E-6: Orientations of squatting postures.

Different orientations of squatting postures for toilet seat design. Source: (Kira, 1976).

The health benefits from squatting, as aforementioned, are clearly the most import factor of this research (Rane and Iyer, 2014; Sakakibara et al., 2010; Sikirov, 2003). Designs in the past seem to see this as an immovable paradox. Kira (1976) claims there is a contradiction between amount of support and general comfort when promoting a squatting position. As the amount of support on the buttocks decreases, that seemingly encourages squatting, the amount of pressure increases. There must exist better ways to promote a smaller angle between torso and thighs while supporting the buttocks and maintaining the comfort of a sitting posture.

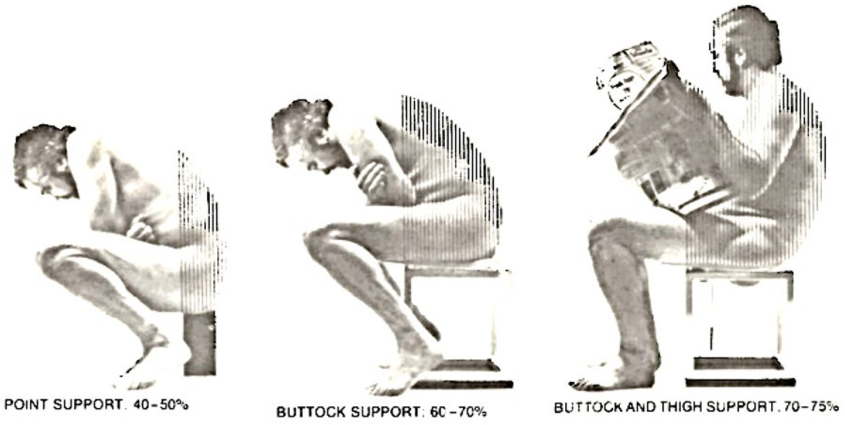


Figure E-7: Buttock support for different seating postures.

The variety of buttock support for different seating postures. Source: (Kira, 1976).

Figure E-8 shows how one may achieve the angle of thighs-to-torso necessary for a squatting posture for defecation while supporting the body creating the comfort of sitting. This is a promising idea that falls outside of scope for the rest of the research, but maybe revisited later.

Figure E-8: Cinema seats.

Inspiration from cinema seats to achieve a squatting posture. Source: J Larsson.

Appendix F. Arrival Times to Indicate Illness

Normal toilet behaviours from literature 6 *urinations/cap/day*, 1.1 *defecations/cap/day*, contributes, 1.4 *L* of urine and 250 *g* of faeces on average a day (Rose et al., 2015). This along with previous usage can generate a profile of normal usage and any deviation from this profile will indicate abnormal usage – *e.g. contraction of diarrhoea*. From the research conducted by Rose et al. (2015) shows that the number of urinations and defecations are Normally distributed implying that the amount of time between visits varies from person to person. For a sufficiently large group of individuals visiting the toilets, we expect to see the time between visits to fall under a probability density function.

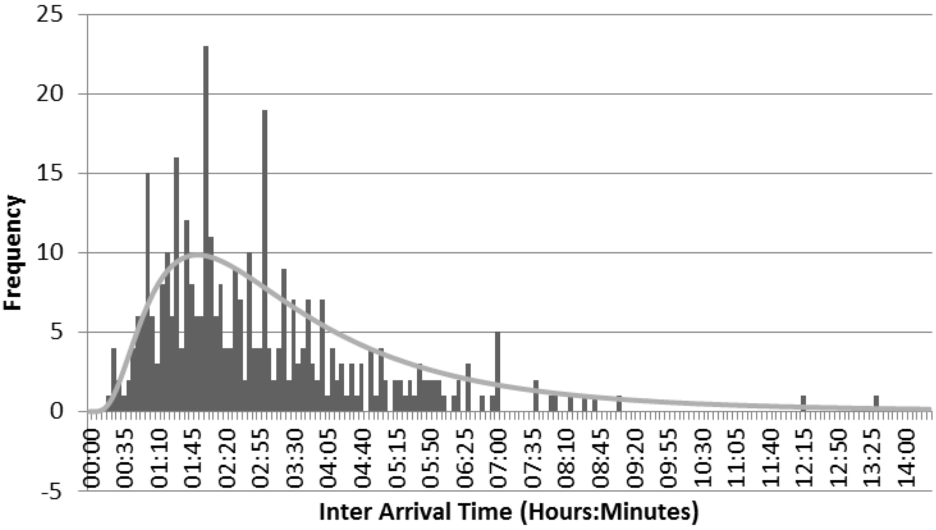


Figure F-1: Inter-arrival time to the toilet.

Graph to show lognormal distribution representing the inter-arrival time – the time in-between visits -to the toilet from 90 visits by five respondents.

The arrival times of five participants over 12 days were collected by use of phone app, where they would record the time they visited the toilet and whether it was a urination of defecation. Over the 12 days, 498 urinations visits and 75 defecations were recorded. Figure F-1 shows inter-arrival times for an individual have mean of three hours, eight minutes *(03:08)* and standard deviation of two hours, six minutes *(02:06)*, if we ignore the times greater than 10 hours between arrivals – *ignoring when people are sleeping.* The spread of inter-arrival times fits a lognormal distribution[3].

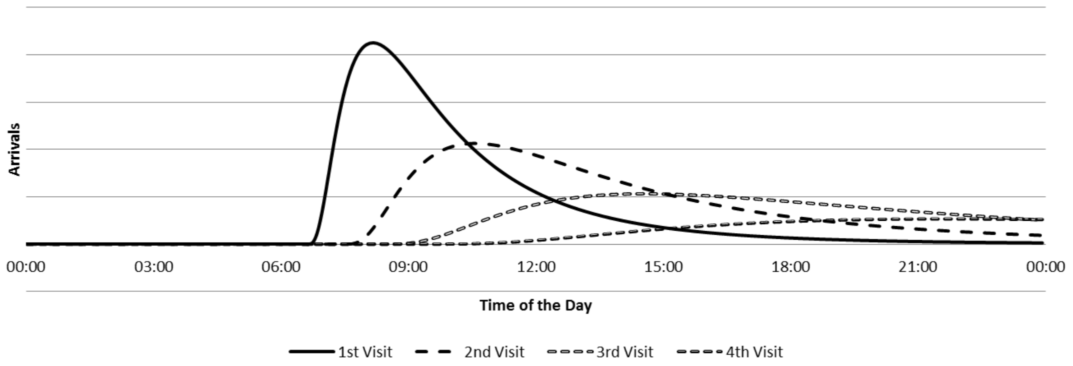


Figure F-2: Distribution of arrivals to the toilet.

Graph to show first lognormal distribution arrivals to the toilet after waking up followed by second third and fourth visits obtained by translations of the original distribution.

Of course, the distribution of second visits will range over two hours because there will be those that visit for the second time 40 minutes after wakeup and those that visit two hours and 40 minutes after wakeup – *the average of course being two hours from wakeup*. For the subsequent visits throughout the day the smoothing of the first lognormal distribution continues. The mean and standard deviations from Poop Log have been used to generate the predicted arrival sets as demonstrated in Figure F-3. The sum of all the distribution of visits throughout the day is what we would expect a general visit distribution to the toilet to look like. There will be some peak visits and anomalies throughout the day such as people breaking for lunch or going to visit the toilet just before sleeping.

---

[3] The inter-arrival times of individuals have a close relationship to a lognormal distribution with a KS statistic of 0.04

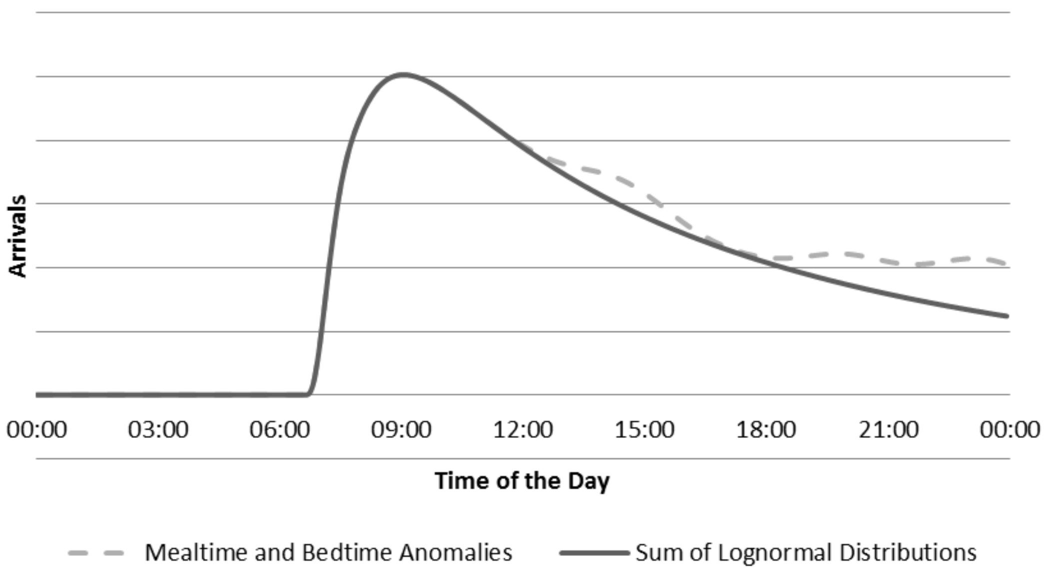


Figure F-3: Predicted distribution of toilet visits.

Graph to show predicted distribution of toilet visits throughout the day, based on a sum of multiple lognormal distributions.

The visits appear to follow the distribution as predicted seen in Figure F-4. Although there are spikes around 7:30 and 8:00am, among others, that indicate that the indirect data collection method is not as reliable and accurate as it could be. The method that follows will be a direct measurement technique to obtain robust data that indicates arrival times.

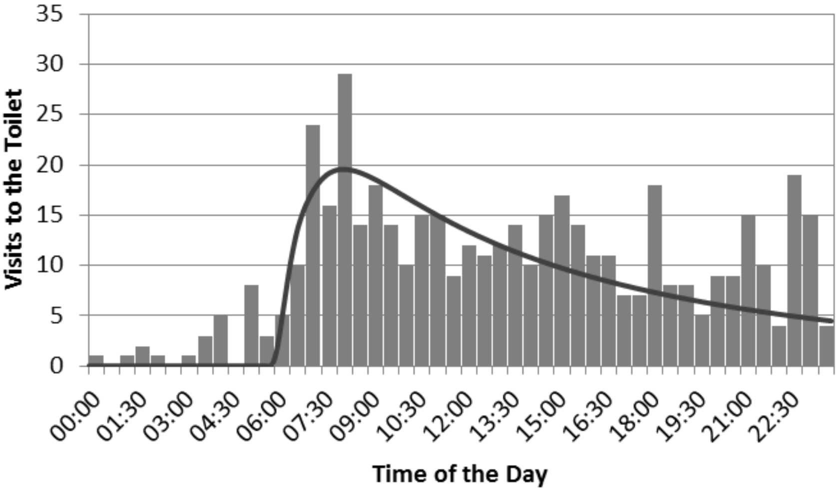


Figure F-4: Toilet arrivals times of respondents.

Graph to show the times of arrival for five respondents over 12 days superimposed with the predicted sum of lognormal inter-arrival distributions. Source: J Larsson.

The original purpose of this research for applications that are wider than this thesis; the stochastic modelling of arrivals and the loading rates of faeces and urine on a household toilet of ten persons. An example of stochastic arrivals is shown in Figure F-5. The transferable learnings of this research is the deviations from expected distributions of arrival can indicate abnormal behaviours and even more serious health concerns. Below the average frequency of arrivals can be another indicator of dehydration, but increased or erratic frequency may indicate other factors coupled with the other parameters being measured.

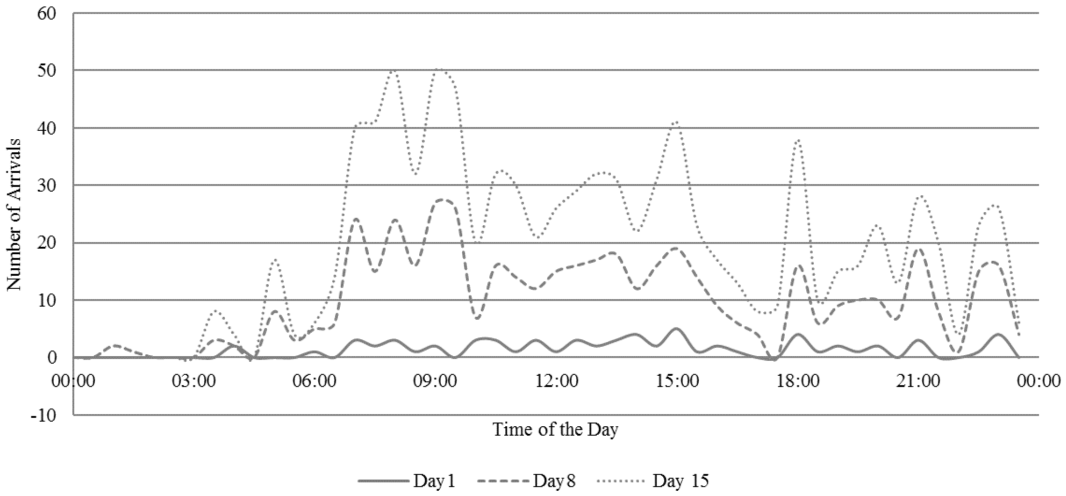


Figure F-5: Stochastic modelling of arrivals.

Graph to show stochastic modelling of arrivals in a ten-person household. Source: J Larsson.

Appendix G. Questionnaire

Date: ____ **Respondent:** ____________________

Urinal Feedback Pre-Questionnaire

How much do you agree with the following statements?

Q1) Toilets or urinals are **valuable** to me.

1: Strongly disagree
2: Disagree
3: Neither agree nor disagree
4: Agree
5: Strongly agree

Q2) Why?

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Q3) Toilet or urinals are **aspirational** to own.

1: Strongly disagree
2: Disagree
3: Neither agree nor disagree
4: Agree
5: Strongly agree

Q4) Why?

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Q5) Which of the following **needs** are met by toilets or urinals? (Circle one or more)

1: Physiological
2: Social
3: Psychological
4: Self-fulfilment/Esteem
5: None of the above

Q6) What **statements** do toilets or urinals express? (Circle one or more)

1: Qualities of the self
2: Signs of status
3: Symbols of social integration
4: Reminders for self-improvement
5: None of the above

Q7) Please **describe** a toilet by listing it’s features and attributes:

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Q8) The above features and attributes bring me **contentment**.

1: Strongly disagree
2: Disagree
3: Neither agree nor disagree
4: Agree
5: Strongly agree

Q9) I am concerned with my **health and wellbeing** with respect to the poor hygiene of a toilet.

1: Strongly disagree
2: Disagree
3: Neither agree nor disagree
4: Agree
5: Strongly agree

Q10) Toilets and urinals **belong** in bathrooms or outhouses.

1: Strongly disagree
2: Disagree
3: Neither agree nor disagree
4: Agree
5: Strongly agree

Date: ____ Respondent: _____________________

Urinal Post-Questionnaire

Over a day/week/month of use of the technology, that ca be part of a urinal, toilet or a separate device, the data shown on page 10 may be available to you on your smartphone or other device.

Q11) Do you regard the wellbeing monitor to be more or less **valuable** than a normal urinal specifically to you?

1: Less 2: More

Q12) The wellbeing monitor is **valuable** to me.

1: Strongly disagree
2: Disagree
3: Neither agree nor disagree
4: Agree
5: Strongly agree

Q13) Why?

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Q14) Do you regard the wellbeing monitor to be more or less **aspirational** than a normal urinal specifically to you?

1: Less 2: More

Q15) The wellbeing monitor is **aspirational** to own.

1: Strongly disagree
2: Disagree
3: Neither agree nor disagree

4: Agree

5: Strongly agree

Q16) Why?

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Q17) Which of the following **needs** are met by the wellbeing monitor? (Circle one or more)

1: Physiological

2: Social

3: Psychological

4: Self-fulfilment/Esteem

5: None of the above

Q18) What **statements** does the wellbeing monitor express? (Circle one or more)

1: Qualities of the self

2: Signs of status

3: Symbols of social integration

4: Reminders for self-improvement

5: None of the above

Q19) The data from the wellbeing monitor brings me **contentment**.

1: Strongly disagree

2: Disagree

3: Neither agree nor disagree

4: Agree

5: Strongly agree

Q20) The wellbeing monitor **reassures** me about my health and wellbeing.

1: Strongly disagree
2: Disagree
3: Neither agree nor disagree
4: Agree
5: Strongly agree

Q21) The data from the wellbeing monitor would be beneficial everywhere.

1: Strongly disagree
2: Disagree
3: Neither agree nor disagree
4: Agree
5: Strongly agree

Observing the categories of products on page 9:

Q22) Please indicate the category toilet or urinal would belong to: (Circle one)

1: a 2: b 3: c 4: d 5: e

Q23) Please indicate the category the wellbeing monitor would belong to: (Circle one)

1: a 2: b 3: c 4: d 5: e

Q24) Please indicate the categories of aspirational products: (Circle one or more)

1: a 2: b 3: c 4: d 5: e

Q25) Please indicate the categories of products that satisfy health and wellbeing concerns: (Circle one or more)

1: a 2: b 3: c 4: d 5: e

Q26) Please indicate the categories of products that belong in bathrooms or outhouses: (Circle one or more)

1: a 2: b 3: c 4: d 5: e

Q27) What is your age?

Q28) What is your nationality?


a


b


c


d


e
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Appendix H. Ethical Approval

Below are the confirmation of ethical approvals from the CURES team at Cranfield University for the ethnographic research on Ghanaians, urine testing on the WBM unit for accuracy and repeatability, user testing and questionnaire and the arrival times and sitting postures tests on users.

Ethnographic Research

SEREC
Tue 27/01/2015 15:58

Inbox

To: Tierney Ross; Larsson, Jake;

Dear Jake

Your proposed research activity SEREC 164-2014 has been reviewed by SEREC and confirmed as posing a low risk in terms of research ethics.

Please remember that SEREC occasionally conducts audits of low risk projects and we may therefore contact you during or following execution of your fieldwork to verify that you are following good practice.

Guidance on good practice in research ethics is available at https://intranet.cranfield.ac.uk/researchethics/Pages/SEREC.aspx

With best regards,

Michelle Everitt

Project Co-ordinator, Research and Innovation Office, Building 31

E: M.Everitt@cranfield.ac.uk

T: +44 (0)1234 758029

Urine Testing

donotreply@infonetica.net

Mon 27/03/2017 15:54

To: Larsson, Jake; **Cc:** Williams, Leon;

Dear Jake

Reference: CURES/2457/2017

Title: Reinvent the Toilet Challenge: Testing of urine hydration sensor with samples collected by method 1

Thank you for your application to the Cranfield University Research Ethics System (CURES).

Your proposed research activity has been confirmed as Level 1 risk in terms of research ethics. You may now proceed with the research activities you have sought approval for.

Please remember that CURES occasionally conducts audits of projects. We may therefore contact you during or following execution of your fieldwork. Guidance on good practice is available on the research ethics intranet pages.

If you have any queries, please contact cures-support@cranfield.ac.uk

We wish you every success with your project.

Regards

CURES Team

User testing

donotreply@infonetica.net

Tue 11/04/2017 10:34

To: Larsson, Jake; **Cc:** Williams, Leon;

Dear Jake

Reference: CURES/2499/2017

Title: Testing the receptiveness of a new urinal prototype that provides feedback to users on their current hydration.

Your proposed research activity has been reviewed by CURES and you can now proceed with the research activities you have sought approval for.

Please remember that CURES occasionally conducts audits of projects. We may therefore contact you during or following execution of your fieldwork. Guidance on good practice is available on the research ethics intranet pages.

If you have any queries, please contact cures-support@cranfield.ac.uk

We wish you every success with your project.
Regards

CURES Team

Arrival times and Sitting Postures

donotreply@infonetica.net
Mon 23/01/2017 10:33
To:
Larsson, Jake;
Cc:
Williams, Leon;

Dear Jake
Reference: CURES/2235/2017

Title: Toilet Arrival Times

Your proposed research activity has been reviewed by CURES and you can now proceed with the research activities you have sought approval for.

Please remember that CURES occasionally conducts audits of projects. We may therefore contact you during or following execution of your fieldwork. Guidance on good practice is available on the research ethics intranet pages.

If you have any queries, please contact cures-support@cranfield.ac.uk

We wish you every success with your project.
Regards

CURES Team

Appendix I. Hypothesised Model

The hypothesised model in Figure I-1 incorporates the adaptation of the dimensions of innovation model by Verganti (2003), where the needs that are met by the product user experience - *user needs* - section of the model is replaced with Maslow's Hierarchy of Needs. This is discussed by Norman (2004) where the form of the product - *product language* – is connected to the image of the ideal self – *self actualisation* – as discussed by Park, Macinnis, & Priester (2006) and again by Norman (2004).

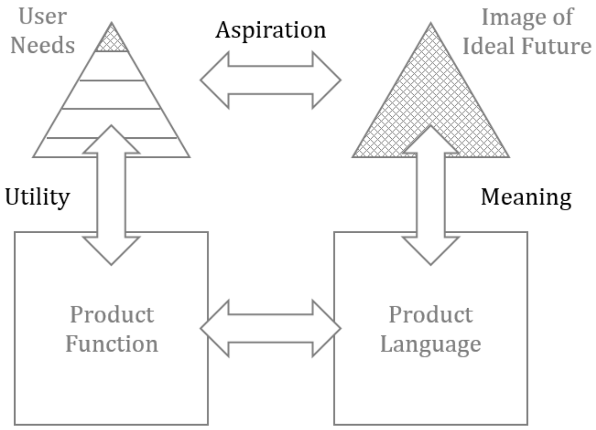

Figure I-1: Hypothesised model of aspirational products.

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