CRANFIELD UNIVERSITY

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The Development of the User Interface of an Innovative Sanitation Solution Targeted at Developing Countries

School of Applied Sciences

MSc by Research
Academic Year: 2013 - 2014

Supervisor: Dr. Leon Williams
Secondary Supervisor: Dr. Richard Franceys
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This thesis is submitted in partial fulfilment of the requirements for the degree of MSc by Research
(NB. This section can be removed if the award of the degree is based solely on examination of the thesis)

Case Study Impact Statement

Around the World, 2.6 billion people do not have access to a toilet, leading to the deaths of 1.5 million children per year through associated diseases (Kone, 2012). Novel approaches to this problem are needed that utilise the latest research and technology to safely deal with human waste in developing countries. These new sanitation methods have to be carefully developed to meet the needs and aspirations of their target audience.

The Bill and Melinda Gates Foundation are seeking to address this with an international competition called the ‘Reinvent the Toilet Challenge’. The winning entries from different universities will employ the latest technology and research to safely deal with the waste and to utilise the potential of the waste.

Executive Summary

This thesis will provide academics and new product development (NPD) practitioners with a strategic methodology for a design-thinking based approach to design products for developing countries. This transfer of knowledge will be possible by discussing potential methods before selecting the most appropriate to utilise with the use of a Case Study to give context.

The research will commence with a scoping phase to show methods of gaining understanding of the wider problem followed by approaches to down select and synthesise this information into appropriate project requirements. When clear direction has been established, the implementation and development can take place to produce an outcome to meet the project requirements. Suitable validation techniques will be used to ensure the success of the research.

The Case Study that will be used is focused on the development of a user interface for a new sanitation system for developing countries. The system is being developed by Cranfield University, as part of the Reinvent the Toilet Challenge funded by the Bill and Melinda Gates Foundation.

Keywords: *New Product Development (NPD), Developing countries, Sanitation, Reinvent the Toilet, Product innovation, User interface*

Figure 0

(C4D, Cranfield University. Ross Tierney © 2014)

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I would like to take this opportunity to thank Dr. Leon Williams for his guidance and drive to get me to this point, incredible dedication.

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LIST OF ABBREVIATIONS

The Following list will explain the meanings of the abbreviations used in the research:

NMT	Nano Membrane Toilet
CAD	Computer Aided Design
BoP	Bottom of the Pyramid
TRL	Technology Readiness Level
NPD	New Product Development
UN	United Nations
KNUST	Kwame Nkrumah University of Science and Technology
SWOT	Strengths/Weaknesses/opportunities/Threats
WSUP	Water and Sanitation for the Urban Poor
ABS	Acrylonitrile Butadiene Styrene
CEO	Chief Executive Officer
CNC	Computer Numerical Control
CAM	Computer Aided Manufacture
CFT	Cross Functional Team

1 Introduction

The focus of this study is to show the steps taken for effective development of a user interface of a new sanitation system targeted at developing countries. Simple products for developing countries have huge potential as they can massively improve the lives of 2.2 billion people worldwide live in poverty (U.N, 2014).

Six billion people have access to a mobile phone; four-and-a-half billion have access to a toilet. This figure from the UN (2013) shows the growth of mobile phones has been phenomenal, in 30 years of computational progress it has reached a larger number of people than centuries of sanitation.

The Case Study that will be used within this research will be the development of the user interface of a radical toilet system developed by Cranfield University for the ‘Reinvent the toilet challenge’, funded by the Bill and Melinda Gates Foundation. The Cranfield system is being designed for single household, with around 10 people using it per day.

The waste enters the toilet in a mixed stream and whilst in a **holding tank**, hollow **membranes** extract pure water as a vapour. The vapour condenses on **hydrophilic beads** and is stored in a **water reservoir** for use in agriculture or cleaning. The solid, dewatered waste is extracted using an **Archimedes screw** and drops into **briquette container** at the back before being coated with a fine layer of **polymer mist** to prevent pathogen transfer and odour.

Chapter 1 - the Introduction.

Chapter 2 - A state of the Art to review current technology

Chapter 3 - Review of the Literature

Chapter 4 - Declaration of Aim and Objectives

Chapter 5 - Methodology explanation

2 State of the Art

This Chapter will examine the current State of the Art with the focus of improving understanding of a range of technology that may be of use in the design and development stages.

2.1 Broad scoping

The stages of the State of the Art are outlined in the following diagram to give a clear systematic overview of the process to any future researcher or practitioner. A more detailed explanation of the stage and justification for logic behind it follows the diagram.

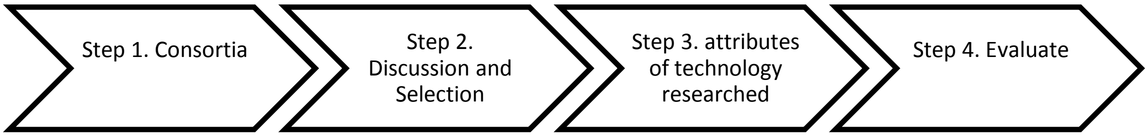


Figure 1 – Diagram detailing the State of the Art Stages

- Step 1: The Consortium of specialists are assembled. These specialists are to be selected for having a good knowledge of the area of interest and would be able to recommend potentially valuable technology.
- Step 2. From a discussion of 30 minutes the top 10 technologies are identified in a simplified Mind Map tool.
- Step 3. The selected technologies are researched further to take the holistic results to a deeper level understanding.
- Step 4. Evaluation to find the best individual attributes of the systems as opposed to just the best complete systems.

The Design Team from the Case Study noted that when selecting the Consortium of Experts it’s worth considering that a large group is beneficial for gaining a high number of responses but can be difficult to manage in the discussion phase. Depending on the nature of the project, it can also be of benefit to have a variety of interdisciplinary specialisms to ensure a variety amongst the team, provided that all involved are knowledgeable on the subject.

The Design Team decided the starting topic for the discussion should be the opening research question or a slight adaption of the statement to provide a good number of quality areas of interest.

For example from the Case Study topic of ‘Unconventional toilet set-ups’ was used as a focus for discussion. This topic was chosen amongst the Consortium as the best way of finding systems with potentially similar constraints.

Once the subject is established, the technology was discussed and recorded concisely, the method used to do this was a simplified mind map that was a clear and effective method of noting and displaying the technology selected. It has been referred to as a ‘Simplified Mind Map’ rather than just a ‘Mind Map‘ because a typical version branches off further to show deeper levels of thought. The Mind Map was popularized by Tony Buzan in his book ‘Use your head’ (Buzan, T. 1982) but even this refers to the fact it had been used previously for centuries.

The results will act as drivers of scoping to be researched further. The number of drivers required will vary between projects as it will be dependant on the resources available to the team, the amount of previous work in the area of interest and the depth required for further research. The template of the mind map (Appendix 1.) is a very simple way to record the discussion and ensure the project’s subject stays at the core of the drivers that are identified.

For the Case Study, 10 ‘Unconventional toilet set-ups’ were identified, which provided a variety of technology, but also allowed for a good level of detailed research to take place by the relatively small team of three. The term ‘Driver’ comes from ‘innovation driver’. (Appendix 2.) The outcome was as follows:

Drivers (D) identified

- D 1. Flap toilet
- D 2. Western flush
- D 3. Aeroplane
- D 4. Large ship small boats
- D 5. Space travel
- D 6. Clean team
- D 7. Loowatt
- D 8. Caravan
- D 9. Dry flush
- D 10. Pit latrine/porta (no barrier)

Please note, this list of ten systems and the type of experts used were specific to the Case Study. The recommendation to future researchers would be to select their respective area of interests and specialists accordingly.

After relevant technology was identified, the State of the Art was reviewed and assessed. For the Case Study this involved researching the different toilets and exploring the key attributes and features that may help the development of the toilet in that project.

The toilet that is ubiquitous in the developed world is the flushing pedestal toilet, also commonly referred to as the Western Toilet (Appendix 3). The technology has changed little since the late 18th century when Alexander Cummings took out a series of patents on the first toilet bowl with swirling flush (Appendix 4) (Callow, 2012). The major engineering development was the siphon that drew the water and waste from the pipe into the bowl. From the User's perspective the S-trap that formed a seal preventing smell from escaping into the toilet room was where the benefit lay, as the associated smell of defecation is the most undesirable aspect (George, 2011).

In the developing world pit latrines are by far the most commonly used sanitation setup. Improvements to these types of toilets have been slow over the years with most being notorious for bad odour (Grimason, 2000).

A simple flap-barrier, such as the American Standard pit-latrine toilet is a low cost and reliable method at preventing a continuous odour escaping into the toilet room. An improvement on this design is a stronger seal to the toilet, controlled by a handle on the side of a pedestal set-up, being pushed after use causes the waste to fall below. The flap is counterweighted so it is forced against the opening of the bowl until the handle is pushed. This gives a very good seal when not in use but as soon as the waste is 'flushed' by pressing the handle, the holding tank below has a clear airflow and odour will escape. The simplicity of the mechanism and the obvious method of use are very positive aspects of the system (Appendix 5).

A new system aimed at developing countries is from an organisation called Loowatt based in London UK, with a pilot project in Antananarivo, Madagascar, for small household toilets. The system uses a long roll of starch-based film to seal each persons waste individually after each use, before the regular collection of the sealed bags for processing at a centralized biogas plant (Mattens, 2012). The system uses no power or water and as all the waste is sealed right after use there is no smell. The only draw back is the consumable film that has to be added regularly. This system would not be particularly useful to the Case Study, as sealing the waste straight away would prevent the membranes from being able to extract the water (Appendix 6). Continuing with the progression of technology with something of a leap is the vacuum flush toilets seen in particular on aeroplanes and trains. Aeroplanes are unable to use the water seal to prevent smell, as movement during the flight from turbulence or a rough landing would cause the water to spill. To flush the waste away they also cannot use large amounts of water like on a western toilet, as the plane should not carry any unnecessary weight. To meet these requirements, aeroplane toilets use a powerful vacuum and a small amount of water to expel all of the waste to a holding tank. The same system is now used on most modern trains but a simple drop can still be found on trains in less developed countries. The system was first patented in 1975 by James Kemper and first put into effect on a Boeing aircraft in 1982 (Kemper, 1975). A section of the connecting pipe between the waste and the holding tank is a made from a flexible polymer that is depressed in its resting state constricting the pipe shut. The pressure within the waste-holding tank is lower than the ambient pressure surrounding the toilet bowl and when the flush is pressed, the flexible section opens and the waste is sucked into the holding tank (Kemper, J 1975). Although the section is open when the flush is taking place creating a through-flow to the outside from the holding tank, no smell escapes as air is being sucked into the tank. The complex system gives an effective smell barrier but requires a considerable amount of power (Appendix 7).

Not having access to sewers or a mains water supply is a ‘temporary’ issue for aeroplanes and trains as they are likely to only be away from these for several hours. On a prolonged space mission however, astronauts can spend months in orbit. The toilet designed for NASA’s shuttles cost $23.4million (George, 2008) and is understandably very complicated in both, process and use (Appendix 8). Defecating and urinating whilst in space requires the user to strap themselves into the toilet and use tightly fitting special apparatus that diverts the solids and liquids for easier collection and also storage (Wichman, 2005). The solid waste is pulled into partially permeable bags to further dry the waste before holding in a tank and being exposed to the vacuum of space, effectively freeze drying the waste before being ejected when the tank is full. Since 2010 on the International Space Station: urine, sweat and other grey water can be recycled back into clean drinking water (Hadfield, 2007). After all, by closing the loop and not wasting water, less water needs to be launched in the first place.

The State of the Art is examining and gaining a better understanding of the different technology currently in use that may be relevant to the research question. This information should now be presented in a simple style that allows the researcher to see the differences between the technologies reviewed.

2.2 Recording System Features

A table that clearly displays the differences between the State of the Art drivers is a good method of collating the findings from the research. During the discussion within the Consortium of experts, key features should be noted as common themes between the drivers. The Consortium should decide on the most important of these to use as criteria for the research table.

There were four features chosen in the Case Study that are at three important points of the system chain, as well as the method of power. The method of powering the system was deemed to be an important factor in the value of a technology to the Case Study.

Table 1 - Research table of the State of the Art from the Case Study

Criteria ➔ System 🡣	Flush mechanism	Sealing method	Storage of waste	Type of power used
Aeroplanes	Vacuum	Metal/plastic cover	Tank	Electric
Porta-loo	Gravity and hand pump	Plastic flap but often no seal	Tank with chemical	Gravity and user
Porta (no barrier)	None	None	Holding tank	None
Caravan	Two-step system: Pre-flush to coat bowl then full flush	Handel opens hole before use and closes after use	Cassette or tank	Gravity
Space	Air pulled through bag	Hydro-philic bag	Dehydrated then storage tank	Battery electric
Small boats	Electric pump and macerator	Trap door	Tank or cassette	Battery electric
Dry flush	Continuous bag sealed in segments	Action twist seals in segments	Sealed bags stored with in toilet in large bag for easy removal	Battery electric

Clean team	No flush	Toilet lid	Small tank with chemical	No power required
Loowatt	Continuous bag sealed in segments	Manual action seals in segments	Sealed bags stored within toilet in large bag for easy removal	No power

With the research table populated with the relevant data it was a lot clearer to see where differences between systems lie. These systems were then analysed further, to not only establish what the features of these systems were, but also to quantify their effectiveness.

2.3 Identifying attributes

A more rigorous and accurate approach was then needed to further break down each system into individual attributes and strengths. To do this the selected systems highlighted in the broad scoping were then evaluated further through team discussion to focus on the flush mechanism and effectiveness of smell prevention. There isn't a perfect system out there to meet the requirements of the Case Study, however a range of individual methods exist, each with their own attributes. A fusion of these different systems were adapted to aid the design team develop the appropriate system. A scoring criterion was developed that highlighted systems that met some of the requirements of the Case Study. In the most basic way so as to understand this approach: the higher the score, the better the system but it also allows evaluation on the individual criteria. It would be very difficult and time consuming to complete this table with full readings and accurate figures such as specific power consumptions and smell prevention, therefore it's purely the teams estimations to work as an approximate indication. If more time and resources were available the full table would have been completed but it was deemed unnecessary to obtain that level of rigour. It would be recommended to future researchers to set up designated levels and quantitative data to divide the performance. This ranking method is based on the Likert scale (Likert, 1932) that allowed for incremental performance differences to be decided by the Consortium of Experts. Questionnaires to rate a larger number of people's opinion on the rating could also improve accuracy if a future researcher deemed it appropriate.

Table 2 - Evaluation Table Ratings

Performance Indicator scale				
Poor	Below Average	Average	Above Average	Excellent
1	2	3	4	5

By using the Performance Indicator table it became clear which systems reviewed in the State of the Art were the most valuable to the future of the research. By using the tool it also highlighted the areas where some of the systems had very poor performance judging against what was required by the Case Study. An additional system that was found during the brainstorm session was the Evolute flush system that was used instead of a traditional western toilet to reduce water required. The consortium of experts did not believe this to fit into the brainstorm title of 'unconventional toilets' as a system but the technology that was used to reduce the amount of water could be of interest and worth evaluating further. Evaluating the Evolute system against the other unconventional set-ups would not be true to the initial purpose of the task so it was evaluated with the Western toilet to the same criteria.

A future researcher may find it possible to combine the information table and the performance indicator table into one large table that has all of the data. This table however, may only work with smaller projects with less systems to evaluate and fewer criteria as the team on the Case Study decided for clarity it would be better to use separate tables for clarity.

Table 3 - Evaluation table of the State of the Art form the Case study

	Performance Indicator							
System	Power consumption	Amount of Water required	Prevention of Smell	Ease of Use	Cost per unit	Running cost	Reliability	Total
Aeroplane	1	4	5	5	1	4	4	24
Flap	5	5	1	5	5	5	5	31
Porta (no barrier)	5	5	1	5	5	5	5	31
Caravan	5	4	2	1	4	4	4	24
Space	1	5	5	1	1	4	5	22
Dry-Flush	3	5	5	4	3	2	2	24
Clean team	5	5	1	5	5	5	5	31
Loowatt	5	5	5	5	3	4	4	31
Additional drivers								
Western	5	1	5	5	1	4	4	25
Evolute	5	4	5	5	2	4	4	29

2.3.1 Findings of State-of-Art

The ratings displayed performance of the systems and highlighted some of the shortcomings in specific areas. This approach and the findings will be likely to improve the quality of the Idea Generation phase after increasing the design team's knowledge of the topic and also their critical thinking on the subject.

The State of the Art from the Case Study gave some surprisingly high results, in particular, the 'Flap' and the 'Porta' that both received perfect scores for all but one of the criteria, smell prevention, happened to be the most important. Simplicity worked in the favour of another system the 'Clean Team' that received slightly higher results for smell as it used a chemical agent and a regular service. The Evolute system with a novel rotating system that maintains a constant smell barrier was scored highly and its mechanism was noted as being potentially very interesting for the next stage.

The high-scoring simple systems may prove to not be valuable for the Design Team in the idea generation phase mainly due to them scoring poorly on smell. Where those systems scored well was on such areas as cost and reliability and they will likely be of great interest in the later development stages of the design work as an idea is refined. It is important to have a broad approach to the scoping phase and then narrow in and down select on key pieces to conduct thorough research. It should be advised however, not to discard what has been found during the whole process of discovery as the value may be found in a later stage.

3 Literature Review

This chapter will explore philosophies, research, projects and literature that have influenced behavioural change for innovative thinkers and researchers today and that strive to improve the quality of life for people in developing countries. This literature review will conclude with some of the key literature that has influenced creative thinking for inventors over the past few decades. The knowledge obtained from this chapter will then be used to contextualise the research problem and the gap and opportunity spaces.

The section is also conducted in order to gain a broader understanding of existing academic research into the overall field and also bring more clarity and focus to the research problem.

Figure 2 - Literature Review Stages

Step 1. Identify important words to be used in database searches and rank in order of importance.

Step 2. Resource Database search using ranked Key Words.

Step 3. Read and dissect the literature identifying key themes to use as topics within the literature to highlight the differences between how other people have discussed the relevant topics.

Step 4. Evaluate and establish where new research is needed within the field.

A keyword table was developed that evolved during this initial process. This was a simple ranking system of important words that would be included in the searches on article search databases.

Words of primary importance will be the key words from the Aim and the research topic as well as some profound related words. Secondary and tertiary tier words would be words of interest that could give valuable information to support the project.

In the Case Study the primary words centred on toilet design and New Product Development and secondary and tertiary words were used to give a broad but supportive round of results.

Table 4 - Case Study. Key Word Ranking

Primary	Secondary	Tertiary
Product design	*Semantics*	*Management*
Toilet interaction	*Engineering*	*Modular*
Development	*Kansei*	*Technical specifics*
Prototype system	*Radical innovation*	*Product architecture*
Innovation	*Optimisation*	
NPD	*Gates Foundation*	
Methodology	*Flush mechanism*	
Developing countries	*Case Study*	
Ergonomics	*Research methods*	
Behaviour influence	*Odour*	
User-centred design		
Interface		
User testing		

The primary words were the most relevant to the project and would be expected to give the most relevant and beneficial journal articles so at least one would feature in every search. It was important to read widely around the subject (Kumar, 1999) so the secondary and tertiary words were to ensure broad and varied selection of results is returned.

After reading and annotating each of the articles, they were compared and evaluated against each other through clustering and down selecting in order to make the focussed comparisons on themes easier. The three points used to down-select and cluster were relevance, key themes and level of detail.

The publication date was also considered but deemed to be not important, as large sections of the research would not be affected by time. Core human behaviour and attitudes are not likely to have changed too significantly. The star rating of journals could also have been picked but as various articles refer to, (Warner, 1998) (Nawab, 2006) (George, 2011) this is something of a taboo subject and not many people like to talk about, let alone research it.

The outcome of this structured Key Word search was over 40 Journal articles and three books that were read and evaluated. The key themes identified within the literature review are arranged into individual sections for clarity and distinction.

Theme 1. System Design
Theme 2. User behaviour
Theme 3. Ergonomics

Three key themes were chosen in the Case Study that would be broad enough to allow a good length of discussion but were also vitally important aspects that would likely be important to any NPD project. These themes were ranked according to importance.

3.1.1 Theme: System Design

Designing a toilet for public use in an area such as a train station is very different to designing one for a private household. User attitude and behaviour takes a much greater importance to ensure successful adoption. It’s clear that when the target user is part of a closed group the opinions of that group are valued much more than just their body shape and comfort (Nawab, 2006). Public toilets are known as public conveniences for the reason people can use them if they have to when they are out of the house (Cai, 1998). It's very plausible that the average user of a public toilet in such a location will never have to use that particular toilet again.

When designing a public toilet for community use in a developing country that people will use the on a daily basis the user's behaviour and attitudes towards going to the toilet have to be carefully studied to ensure a successful adoption. Open defecation is an all too common occurrence in these communities and is the most common cause of disease. Changing user behaviour will always be a challenge in design and none more so than in this case when the action is so natural and common. Careful consideration, research and planning must be utilised as stated in the report by Warner (1998) "The understanding of social issues is paramount if one intends to introduce an alternative sanitation system" (Warner, 1998). Although the Case Study is being designed for an exhibition rather than straight into a house in a developing country, deep consideration of the target user has shown to be considered.

3.1.2 Theme: User Behaviour

The innovation consultancy, Quicksand, conducted in-depth research over ten months into the behaviours, attitudes and beliefs surrounding sanitation in low income India called The Potty Project (Quicksand, 2011). The focus of the study was to create and disseminate user centred insights and covers all aspects of toilet use in communities in developing countries. Similar to the You & Cai (1998) target market, the focus is on public toilets but without the experimentation into ergonomics.

The relevance to the Cranfield toilet of the two reports mentioned above is that You & Cai (1998) briefly discusses user attitudes to define a direction with the majority of the paper studying ergonomics of toilet use to develop a comfortable public toilet. The Quicksand report purely focuses on what people would want from a public toilet in a developing community but barely mentioning design, they do however highlight the importance of aspiration. "Build an aspirational image around sanitation" (Quicksand, 2011) is one of the headings and a statement very relevant to the Case Study. This is elaborated upon by explaining that it's not only the health and safety issues associated with Sanitation but a desirable brand could also increase conscious uptake.

The study is purely a resource and doesn't move into the development of a system. It works as a rich source of information for designers working on tackling the problem of sanitation in India but has relevant research that applies to all of the people in the world without access to adequate sanitation.

There are similarities between the work of Quicksand and the 2006 work by Nawab et al. (2006) that focussed on the cultural preferences and ecological sanitation systems in a province in Pakistan. This research also worked as just a resource for others rather than actively seeking a solution through development from their findings. The conclusion echoes the quote by Warner (1998) that it's only through spending time to gain deep understanding of the target market and using these people in the development process that a successful system will be produced.

The subject of the Case Study is a system to be targeted for use in the family home in a developing country, specifically Ghana and it is also more than likely the user would have never had a toilet in their home before. A study into toilet practices of people In Kintampo, Northwest Ghana (Okechukwu, 2012) found that only 15.6% of people have toilets in their homes. The people of the region without their own toilet would mainly use a public toilet (61.3% of the remaining), with 38.4% practicing open defecation (<1% uses another person's toilet). A survey of 536 Ghanaians found that 61.7% of households had never considered installing a household toilet (Jenkins M. , 2007). To convince them to spend money on their own toilet when they already have a method they are accustomed to would be a very difficult task. It has to be an aspirational object for the homeowner that they want to use and want to have in their house.

Jenkins also noted the importance of odour in negative perceptions of current public toilet use. In a survey, smell was the most disliked attribute of current defecation places (27.1%) followed by cleanliness (26.6%) (Jenkins M. , 2007) this can be attributed to the sight or smell of fresh faeces being believed to transmit sickness (Rheinländer, 2013). Chris Peot, the head of Washington D.C's Biosolid treatment facility, attributes this to a pre-programmed human response to be afraid of our own waste. He continues to say that "women are the most vocal because they are more protective". This interview was in the book the 'The Big Necessity' by Rose George (2008) and discusses the issue of sanitation around the World with many sections relevant to the 'Reinvent the toilet project'. From testing prototypes to user attitudes in different countries, George (2008) explores the topic as an outsider questioning a subject that is often ignored and almost taboo. The study comments that marketers in developed countries refer to the purchase of a toilet as a "Distress purchase" because it is only replaced when necessary.

One country that treats the toilet differently however is Japan. 'Here the toilet is modified, improved upon, innovated. It's a design object, a must have, a desirable product.' (George, 2011) Designing a toilet to be desired is big business in Japan. The most famous toilet brand in Japan is Toto who are famous for their hi-tech toilets famously including a bidet function. Toto's approach is to make people want to upgrade their current toilet to a more expensive model with more functions even though their current toilet (most likely) works fine. A report looking into the change of domestic culture in Japan describes the transition in Japan from pit toilets to the most advanced in the World in the space of 60 years (Chun, 2002).

When working on the Clean Team's toilet, the design firm IDEO.org had to take a broad approach and design a whole brand strategy to complete the story of the project ethos. The system they developed used a simple toilet design with a high touch service, to collect the waste and replace the bucket.

The Design Team from the Case Study will to have a similar holistic approach to make people want their toilet by conveying the benefits of a new system, are far better than their current methods. The target group have very little disposable income and already use alternate methods on a daily basis, so convincing them they should upgrade their current method for a more costly solution is particularly difficult.

When Toto tried to break into the American market the promotional posters simply stated; “When a shower is a masseuse, and a bathtub is a whirlpool, a toilet should do more than just flush” (Toto, 1995) this can be seen in the Appendix (App. 9). They compare it to other everyday items that have been improved and make the user think that the toilet is also due an upgrade. Little change has occurred to the basic principles of the toilet in the past 200 years, unlike many other industries that have seen quantum leaps in technological improvement.

Nawab (2006) noted that people will buy cell phones and weapons instead of Latrines and concluded that ‘safety needs’ and ‘status needs’ are preferred to the ‘physiological needs’. If the Cranfield toilet can itself improve safety by the users not having to leave the house at night, and also improve the status of a potential user by being an aspirational product perhaps this will become higher on the priorities of the people. People aspire to owning what we consider the ‘classic’ toilet the IDEO.org team noted that the design should look and feel like a robust fixture within the home (IDEO.org, 2011). Giving the impression of a plumbed in permanent toilet will have to be considered and is another indication of the importance of the design to build confidence in the product and also become an aspirational object. Supporting this information from the target area is the well-documented associations with attractive design and positive user perception and an attractive product will likely create a strong sense of pride amongst its owners (Ulrich, 2012). The target market’s aspiration to own the product will hopefully transfer to buying into the system and finally having pride in having the system in their house.

Nawab (2006), Rose (2008) and many others have commented on the difficulties experienced when asking people about their attitudes towards going to the toilet. Sjaak Van Der Geest, an anthropologist who has written some very insightful work on attitudes towards defecation, even accuses other anthropologists of avoiding one of the most basic human needs because writing about such an issue would be dirty and childish (van der Geest, 2007).

3.1.3 Theme: Ergonomics

Designing any product will have to take into account the person using it, Ergonomics is the process of improving the interaction through careful consideration to the person and how the object is used.

For the Case Study the research must take into account how people use a toilet, something of a taboo subject amongst some but vital to develop the user interface of one such system.

The most commonly referenced anthropometric data for toilet use is the study by I. McClelland & J. Ward (1976). Ten separate measurements were taken from the 140 subjects in three different body positions to give a broad range of measurements for men and women. It is stated in the article that a larger group was hoped for but lack of volunteers restricted this, the team also hoped for some disabled participants but instead had to just document able bodied individuals within two age groups, 18-30 and 60 and over. The lack of volunteers was attributed to the type of study and due to the user needing to be naked from below the waist. The measurements recorded act as a base for dimensions, but gives little in the way of qualitative feedback from the subjects with regards comfort and their behaviour.

The report by You & Cai (1998) builds upon the results of McClelland & Ward (1976) by producing its own relevant anthropometric data to apply to the re-design of the squatting type toilet for use in China. Tests were also conducted into improving comfort by adjusting the angle of the user’s feet whilst in the squatting position and results taken in the form of heartbeat monitoring to test relaxation and subject’s personal opinion for qualitative data.

Both sets of results showed that an angle of 15° to be the most comfortable and this was implemented into three prototypes for testing. The prototypes were tested and compared by 30 subjects before the results and opinions were taken into consideration before a final design was developed. The results of this final design was tested by a further 40 subjects with more favourable responses than the previous three.

You & Cai (1998) were developing a system for public convenience in China, a train station for example, and the early survey questions were asked in similar locations to 100 random people. These were closed questions to produce data as a basic direction for the project by obtaining a simple indication of what are their preferences on public toilets.

3.1.4 Gaps and opportunity from literature

To identify where opportunities for new valuable research lie in this area, the literature had to be reviewed further.

The broad but significant themes used in the literature review were selected to loosely group the literature for evaluation. To gain a rough visual understanding of how the literature is related the topics are used to create a new tool that combines a Research Matrix with a Venn Diagram to plot the sources of information in relation to each other and relevance to the Research problem, with sources closest to the centre, being the most relevant to the new research.

The Venn diagram is a widely used method of showing relations between a finite collections of sets (Venn, J. 1880). Within this literature it was of benefit to show where common areas lie within the different material and also how close it is to the research topic.

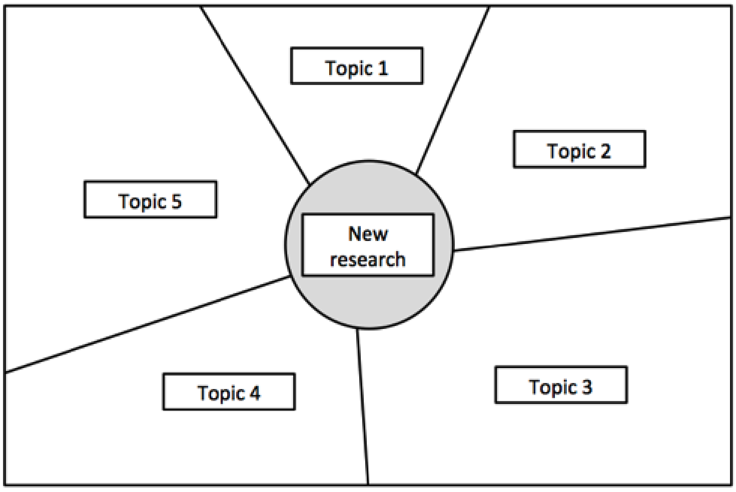


Figure 3 - Example of Literature Review gap tool

It is clear from the example in the Case Study that some areas have more sources than others. One issue with this tool was with the links between the topics that were not next to each other, to get around this, post-it notes were used to mark the connection. For example, ‘Toilet Design’ was across from ‘Toilet Behaviour’ and the IDEO.org report (2011) was equally fitting for both topics.

Figure 4 - Case Study. Literature Review gap tool
(C4D, Cranfield University. Ross Tierney © 2014)

The purpose of this clustering was to see how the most relevant articles to the Case Study relate to each other and what are the unique areas of research to be explored by this research. To isolate these opportunities a research matrix was used to classify how the different articles relate to the new research and where the opportunity for new research lay. The Research Matrix below highlights seven articles that were the closest and most relevant to this research and also how they have large opportunities to be to be exploited.

Table 5 - Example of Literature Review opportunity table

Focus	Articles	Key focus	Opportunity

The Literature Opportunity table should only be populated with the best articles related to the research to make sure that the information displayed was of the highest quality and concise. In the Case Study, these were chosen by selecting the articles closest to the centre of Literature Review Gap Tool and how they conveyed key themes within the articles. The Balanced Score Card influenced this tool, a system developed in 1987 by Art Schneiderman and further developed by Kaplan & Norton (Lawrie, G. Cobbold, I. 2002).

Table 6 - Case Study. Opportunity within Literature Review

Focus	**Articles**	**Key focus in Literature**	**Opportunity**
Toilet form	Bichard, J 2005 Nawab, B 2006	Public setting	Private setting

	IDEO.org, 2012	Simple toilet, radical service	Radical toilet, simple system
Target setting	Cai, D., & You, M 1998 Chun, A 2002	Developed country	Developing country
Observing and recording rather than implementing	Jenkins, M. & Scott, B 2007	Observing user attitude and behaviour	Implement user behaviour and attitude
	McClelland, I., & Ward, J	Recording ergonomics	Implementing ergonomics

3.1.5 Literature Review Key Findings

Identifying the key findings in existing literature builds a strong foundation for the next phase as well as helping to identify opportunities for new research. Quotes that have high relevance or a profound impact on the direction of the research can be highlighted and evaluated further to effectively direct the implementation phase. To do this, the impact on the project must first be discussed and then how this impact will be utilised by the project in the form of requirements for the implementation phase will be addressed. A simple table that has three columns allows this to be displayed clearly.

Table 7 - Example of Literature Review Impact Quotes

Quote	Impact	Project Requirements
Quote 1		
Quote 2		
Quote 3		

It was recommended that only a low number of quotes were chosen as the more chosen the more diluted their impact would be, between three and five would be advisable. In the Case Study three quotes were selected as these were determined to be highly significant and were well supported by other research, as they cannot just be stand out pieces of information which was also imperative. It is important that the quotes selected must really emphasise a specific point and to give profound insight into that aspect of the project.

Table 8 - Case Study. Example of Literature Review Impact Quotes

Quote	Impact	Project Requirements
"Build an aspirational image around sanitation" Quicksand (2011)	For a system to be adopted by target user it has to be aspirational	The design will have to make the user not only want to use it but also want it in their homes
"Flush toilets are considered prestigious and desirable" Nawab, B (2006)	People want what a flush toilet brings to the house; dignity, safety, convenience without the smell associated with non-flush toilets	The final toilet will have to have the benefits of the western flush toilet to fit the requirements of a house in a developing country
"Complexity of water-flush causes confusion and discourages use." IDEO.org (2012)	Flush mechanisms are the only way to meet the requirements of the project but have to take the user into consideration	Develop a flush mechanism that will require no change in user behaviour

The first quote states that to increase the chance of success of this toilet it has to be aspirational. For the Case Study, this would mean that the outcome has to be desirable- people have to want to own it and want to have it in their house.

The second states that flush toilets are prestigious. The greatest benefit from the users perspective of what a flush toilet is comes from the prevention of smell. This was also refers to the findings from literature (Rheinländer, 2013) and the Primary Observations in Ghana.

The final quote refers to the user's requirements with the flush mechanism; even if flushes are desirable, if they are not as simple as possible and intuitive for the user, they won't be used.

The Key findings of the literature review should help to concentrate the vast information discovered during the phase and help the researcher with key pieces to move forward. It is advised to keep the full literature in an organised system for easy reference in the future as the project progresses. In the Case Study, the Topic titles used during the Gap and Opportunity identifying section were used as chapters for the articles to be grouped together (Appendix 3).

The key findings of the Literature review will be used as one of the main ingredients during the Investigation Phase when the requirements are being defined. It may be beneficial to the researcher to have the raw data and original articles easily available throughout the project. The value of a Literature Review to the Scoping Phase is not only learning from others but also identifying where there is gap in the Literature. The original work can be referred back to as the new research evolves and develops to ensure it is relevant and valuable.

4 Aim and Objectives

The Aim of this project is to develop an ambiguous user interface of a new private toilet aimed at people in developing countries.

The Objectives state the logical, structured approach to the research that is essential for any design project. Systematic objectives should be in place to best fit the research question comprising of appropriate individual methods that fit within the remit of the project. The approach to this research challenge will be a four stage methodology that intends to be simple yet effective:

Figure 5 - Project Objectives

To Scope:

- State of the Art
- Literature review
- Observations
- Down selection workshop
- Interviews

To Investigate:

- Consortia of experts
- Design brief
- Progress monitoring tool
- Concept tools

To Implement:

- Consortia of experts
- Concept generation and development
- Workshops
- CAD
- Soft models
- Prototypes

To Validate:

- Expert analysis
- Evaluation matrix

- Design brief reassessment
- Engineer drawings

4.1 Identifying Project Deliverables

It is important to have complete understanding of where influences lie within a project and how these influences affect the overall Aim of the project. Clarity on what is required to be delivered is also key for any effective project plan. In the Case Study, the outcome does not have to be a fully working version to go into the houses of people in developing countries. Instead, the final solution will be used at an exhibition to provide attendees with an understanding of the research and system currently being developed and the direction the team are taking. After in-depth discussions amongst the whole team it was decided that there would be a prototype showing how the system works and also an aesthetic prototype to give people an understanding of the intended appearance of the system.

To define the level of completion required in a project, the Technology Readiness Level (TRL) monitors is the method often used for its simplicity and universal nature. TRL is a type of measurement system created by NASA to assess the maturity of new technology being developed (Mankins, 1995)

Table 9 - Summary of TRL developed by NASA (Mankins, 1995)

TRL 1	Basic principles observed and recorded
TRL 2	Technology concept and/or function formulated
TRL 3	***Analytical and experimental critical function and/or characteristic proof-of-concept***
TRL 4	***Component and/or and or breadboard validation in laboratory environment***
TRL 5	Component and/or and or breadboard validation in relevant environment
TRL 6	System model or prototype demonstration in relevant environment

TRL 7	System demonstration in a space environment
TRL 8	Actual system completed and “flight qualified” through test and demonstration
TRL 9	Actual system “flight proven” through successful mission operations

The Case Study is only required to reach a TRL3 and if TRL4 could be reached that would exceed expectations. This is because the initial brief set out very difficult requirements to the competitors and it’s understood that this will take time to reach. In the meantime, TRL3 gives a good indication on whether the system is worth funding to the next level of development based on the likely hood of success and also the strength of the team.

5 Methodology

This research was intended to be very clear for other practitioners or designers to be able to gain insight into the Methodology implemented for a project of this nature. To ensure this, the 'practical chapters' such as Scoping or Implementation, open with arrow-boxes containing the steps taken when commencing that section. The chapters such as Discussion and Conclusion do not have these boxes as they do not require a multi-stage process. To also help with clarity, alternative options for methods are offered when possible.

A linear Four-Stage Methodology was chosen for the Case Study because its simple well defined phases that ensured development even with such a complex and multifaceted project. The four stages comprised of the Objectives and the Objectives were themselves made up of individual methods. This methodology was chosen because the project in the Case Study was determined from the beginning to be very complex and requiring a lot of collaboration with other teams. It was decided that using a simple linear method that would accommodate a potentially unpredictable project would be the safest option.

This Methodology can be criticised as being vague but the ambiguity worked well for the Case Study as it gave the required flexibility that was predicted at the start. It also worked well with the two lines of research being developed simultaneously as the phases allowed progress to be made individually before combining to one outcome. Another Methodology that could have been used is Stage Gate. It was decided that the Stage Gate approach may be too results-driven and being that this was a very innovative project the results might not be as frequently achieved as other projects. It was also noted as leading to a low level of understanding being held up to each point (Trott, 2008).

The Four-Stage Methodology is detailed below, explaining the methods used, the justification for why those methods were chosen and also other possible methods that could have been used instead.

5.1 To scope

To scope existing relevant technology and existing systems in use in target area to improve understanding.

The following methods were used for the Scoping phase:

- State of the Art
- Literature review
- Observations
- Interviews
- Expert consortium

Justification: New Product Development must be fundamentally and comprehensively customer orientated and driven (Baxter, 1995). To gain an understanding of not only this target market but also the problem as a whole, a series of methods were used to their individual strengths to gain the best understanding possible. Followed by a State of the Art was conducted to evaluate what technologies are currently in use that could be of interest to the project. To evaluate these on a deeper level, the Design Team gave ratings against criteria that could be of value to the project. The next method used was a Literature Review of mainly journal articles and books broadened the knowledge base and brought clarity and focus to the research problem. This discussed philosophies and approaches of other research in relevant areas to identify where gaps are found and where opportunities for new research exist.

Primary research was conducted in the target area after identifying a series of areas that would be of particular interest to the team that could not be accurately researched through secondary sources. Informal interviews with the target user gave real detailed feedback.

A consortium of experts was utilised to give deeper understanding throughout this stage, from mind mapping technology in the State of the Art to discussions on user preference in Primary Observations.

Alternative methods and approaches not chosen:

Questionnaires to the end target users was determined to be too rigid and relaxed discussion would be more beneficial to keep discussion free and flowing.

Conducting ergonomic testing was determined to be unnecessary as the final outcome would be for a display at an exhibition. If the project is successful at reaching the next phase where it would be used in the environment, then more thorough testing would be conducted into ergonomics and user preference. The research by McClelland, I & Ward, J (1976) provides very detailed dimensions for the ergonomics associated with toilets and should provide all the relevant dimensions that are needed currently. If more specific dimensions are required, the approach of Cai, D & You, M. (1998) would be a very good method to follow.

5.2 To investigate

By synthesizing what was identified during the scoping phase, the constraints for the Implementation phase can be established to meet the project brief.

The following methods were used for the Investigation phase

- Concept tools
- Workshops
- Expert consortium
- Defining gaps and opportunities
- Design Brief
- Progress monitoring tool

Justification:

A concept tool was developed to efficiently convey different concepts to a wider team.

Workshops were used to collect the opinions of the whole team in the Case Study to help give direction for the development of the external appearance of the toilet.

The expert consortium is external to the design team and enriched the quality of the research with the individual's knowledge and experience. This was of particular benefit when generating ideas for preventing the odour.

A Design Brief was created to declare the outcomes of the Investigation phase and give clear direction for the Design Team.

When working with numerous components that are being developed by different teams from scratch, a monitoring tool was created. This was used to ensure the Design Team can track the status and capture key information of the components that will effect the design of the external appearance.

Alternative methods and approaches not chosen:

The Quality Function Deployment (QFD) method could also be utilised if there is more time available and more detail is required. The QFD method developed by Dr. Yoji Akao, translates customers qualitative needs and desires into Quantitative technical requirements for use in product development (Akao, 1992). This could be of great value when taking the opinions of the target market on sizes and comfort and turning this into improved designs of prototypes for real testing.

5.3 To Implement

The implementation phase employs the requirements established in the investigation phase to direct the development of the outcomes of the project. In the case study, this implementation is divided into two directions that both lead to the completion of the user interface.

a) To develop a flush mechanism that maintains a seal between the holding tank and outside at all times, requires no additional water or power

b) To design the overall aesthetic of the prototype ensuring a design that would fit with the aspirations of the target user

The following methods were used for the Implementation phase

- Concept generation and development
- Prototyping/engineer drawing/CAD
- Soft models
- Workshops
- Expert consortium

Justification:

Concept generation and development ranging from initial ideas and early sketches, into full CAD models are steps in synthesising what was learned in the scoping and investigation phase into what is required for the project. Using these methods to convey the idea during development workshops and during meetings with external consortium allows everyone to understand and respond to an idea and continuously improve it.

The final outcomes from the implementation phase of the Case Study are required to reach a TRL level of three or four as it's for a display at an exhibition.

Alternative methods and approaches not chosen:

It was not considered necessary by the team to develop a full working prototype but rather just what would be able to convey to the exhibition what is the end target for the Cranfield team. At this stage of the process it was also not required to go into too much depth about material selection, this would happen if the following round of funding were reached.

5.4 To Validate

Appropriate validation methods will be selected and implemented to confirm the effectiveness of the research.

The following methods were used for the Validation phase:

- Expert analysis
- Design Brief reassessment
- Evaluation matrix
- Engineer drawings

Justification:

Expert analysis will be provided by the senior manager from Clean Team who was an advisor to the project and gave invaluable insight to the target area. This person's opinion is incredibly valuable as they have the technical sanitation expertise as well as having a really deep understanding of the target area and the people with in it. The validation from the flush mechanism will be provided by an external team of design experts who are also involved with a sanitation project and will understand a project of this nature.

Alternative methods and approaches not chosen:

Full testing would not be required as this is still the first round. Surveys at the Reinvent the Toilet fair would have been very useful for gathering feedback but this might detract from the overall purpose of the Cranfield exhibition stand. Surveys of target markets were also not deemed appropriate due to timing, budget and logistical constraints.

5.5 Approach to anonymity within the research

Anonymity within this research has been discussed and deemed that all people referred to or who have contributed will be acknowledged by a descriptive title rather than by name. For example, "a senior professor of engineering" rather than the person's real name. This was decided due to the large number of people involved with the project. It was also important during the research phase, as the questions were on a sensitive topic, it was decided it would be best if no names were used.

6 Primary Observation

Primary research and observation of daily life in the target area is a vital method for gaining an understanding of the problem that is being addressed and meeting with people who are the target user.

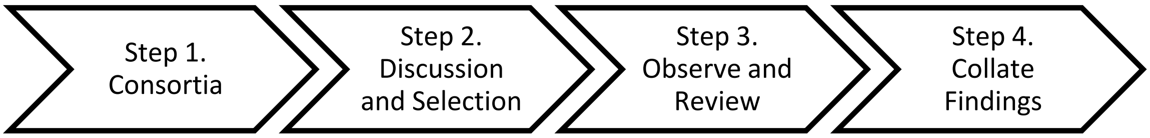


Figure 6 - Stages of Primary Observation

Step 1. Assemble a Research Team with a varied experience and roles within the project.

Step 2. Before visit, outline key areas of interest to be researched

Step 3. Observe and interview people to gain insight on the predetermined topics. Recording with appropriate methods.

Step 4. Amongst the Research Team, discuss key findings of the observations highlighting significant images and quotes.

For the Case Study, a research trip to Ghana was arranged for the assembled Research Team to get first hand insight into the core of the problem and the target user. A selected core group was chosen with a variety of expertise to ensure a mixed outlook. Ghana was chosen due to members of the team having many years experience in sanitation in the area and existing contacts. This was decided as a way to reduce the risk of potential problems with Observations, as primary research is subject to both variances and bias by the observer (Kumar, 1999). To ensure a productive research trip key areas of interest should be discussed and identified and some questions noted that would give insight to the key areas. The number of areas of interest will depend massively on the type of project being conducted and the Aim of that project. For the Case Study four key areas of research interest were selected that were quite broad but vital to the project as they were areas that could not be easily explored without being in the specific target area.

For the four key areas are defined below and explained why they are of interest:

- **Existing options/solutions** – What is currently being used and how could it be improved?
- **Housing configurations** – Can the building affect the design of the toilet?
- **User preferences** – What are the desires of the target user when it comes to sanitation and how can this be used to guide the development of the toilet?
- **User behaviour** – How will the person interact with the toilet?

A selection of the questions to explore these areas were:

Q1. What social brackets exist in the target area and which one would the Cranfield system fit into?

Q2. What are people's preferences towards toilets in their homes?

Q3. What are typical housing/living arrangements in the target area?

Q4. What are seen as aspirational products in the target area?

Q5. What is the current method for many people of defecation in these areas?

Q6. How are current sanitation schemes conducted in the area?

Why these questions – what is your logic here?

If it's possible, having local knowledge is incredibly effective way improving the quality of a research trip, not only will it help with arranging meetings to fulfil the target questions but it can also act as an icebreaker if the setting is somewhat unusual to either the researcher or the subjects. In the Case Study, these 'Fixers' as they're known, helped plan visits to local housing of a variety of social and economic classes as well as visits to current approaches to dealing with sanitation in the area of Kumasi, Ghana. The group comprised of four team members of different backgrounds and expertise, to give a varied outlook from the observation. The research trip lasted 8 days and was split between Accra, the capital and Kumasi, the country's second largest city.

6.1 Existing options

Existing options currently in use by the target market will clearly be a key aspect of the Scoping Phase and identifying the strengths and weaknesses with the objects and where potential improvement could be found will also be highly valuable. For the Case Study, understanding what the current sanitation options for the people of Kumasi are and what people's opinions are towards them is a vital first step.

As 57% of the population of Ghana use public toilets (Van der Geest, S. 2007) it was important for the team to visit a number of these in and around the target area. A user fee was introduced to the toilets in Kumasi by the military government in 1981 and in the late 90's the toilets were privatised. There was great potential for earning large sums of money from the privatisation (Davis, 2007) however, the profit was clearly not transferred back into improving the facilities for the local people. The team noted that the conditions in some of the public toilets, especially the very inexpensive ones in the Ashtown region of Kumasi were very bad. Public toilets in Kumasi cost between $0.03USD and $0.15USD depending on quality. The average daily wage in Ghana is $2.30 (United States Department of State, 2013).

Figure 7 - Public Toilet. Kumasi, Ghana costing $0.03USD (C4D, Cranfield University. Ross Tierney © 2014)

Figure 8 - Public Toilet. Kumasi, Ghana. Costing $0.15USD (C4D, Cranfield University. Ross Tierney © 2014)

6.2 New solutions

Studying existing solutions and approaches will allow a design team to understand not only what can improved methods are currently being utilised in a target area.

The team from the Case Study visited a local initiative through information from the fixer that sought to give an alternative to the public toilets of the area. Instead of paying to use the public toilets that were not only inconvenient but also potentially dangerous as women using it at night were often vulnerable to attack.

In Kumasi, the research team visited an existing sanitation project initiated by Unilever called the Clean Team. This was a simple toilet with a sealable bucket inside that stored the waste in a chemical until the clean team came to the user’s house, sealed the bucket and took it for safe disposal, replacing the bucket with a new clean one.

Figure 9 – Research Team evaluating existing systems (C4D, Cranfield University. Ross Tierney © 2014)

The simple system is well developed and has given a great deal of thought to the target user.

Figure 10 - Research team visiting existing sanitation systems being installed

Figure 11 - Clean Team toilet being installed in a resident's house (C4D, Cranfield University. Ross Tierney © 2014)

A senior manger provided some key insight into decision-making amongst the family when asked a question “who initiates installing the Clean Team system in the home?” The answer was “Women are the most respondent customers to the Clean Team scheme even though men are usually the breadwinners. The women are concerned with the well being of the family and are usually he ones seen taking the children to the public toilets.” Appealing to the aspirations of the women of the households could be an astute strategy for the Design Team.

6.3 New Product Development in target market

It’s important to give a lot of consideration to how a new product will be adopted by a target area. When designing for developing countries scepticism and mistrust can prevent adoption and adhering to tradition, culture and habit can also have a huge impact on success. Therefore observing and discussing attitudes towards products and how people interact with them can have a vital impact on the design of a new product.

The Clean Team toilet was designed by IDEO.org; the humanitarian branch of IDEO, the internationally renowned design consultancy. They took a broad approach to this project seeing the task as not just designing the toilet but building the complete brand and the strategy that accompanies it. They developed posters, business cards, uniforms and radio spots as this system is unlike any other previously tried in the area and would only work if it was trusted. The IDEO.org approach is very heavily based on user centred design and deep immersion into the target environment and consumers. For the toilet in the Case Study, this approach would not be possible due to cost but it would also not be entirely necessary for the end goal. As previously discussed an exhibition is the primary focus so it made sense to use the research conducted by IDEO.org and learn from their experiences. The preliminary findings report from 2011 proved an invaluable source for getting an understanding of life in the region and attitudes to sanitation. areas for additional consideration, such as newspaper being the standard method for anal cleansing followed by placing in a waste bin next to the toilet and how Odour is one of the most significant issues with existing sanitation solutions (IDEO.org, 2011).

6.4 Standard of living

Current living conditions are a key factor in understanding where a product can fit within a target user's lives. One house that the Clean Team were delivering a new toilet to, lived an elderly man with severe mobility issues, his wife cared for him and carried out most of the daily chores. The house had two rooms, a bedroom and a living room (Figure 15)

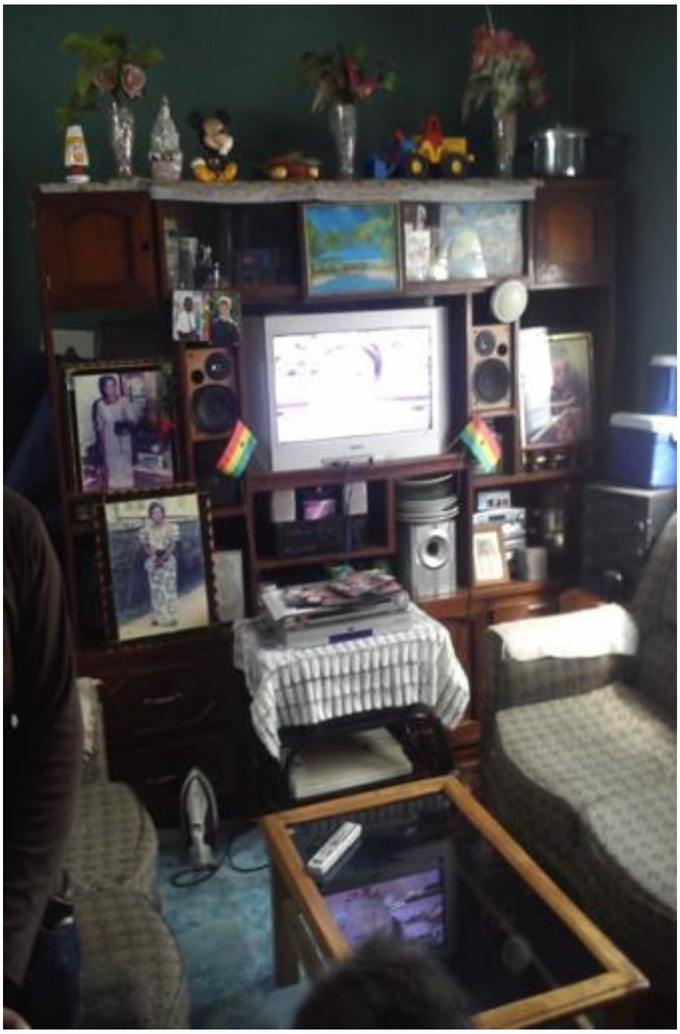


Figure 12 – Living room in house of target user
(C4D, Cranfield University. Ross Tierney © 2014)

This house would fall into the social status bracket of ‘lower middle income’. They own a lot of modern conveniences- Television, iron, fridge, hi-fi stereo, DVD player, Personal Computer not connected) even a ceiling fan. However, they didn’t have a toilet in the house. So although they have a pretty high standard of living judging by their commodities and the quality of their dwelling, their toilet options are the public toilets away from the house. This is a considerable inconvenience for most people but for an elderly man who is virtually housebound this is a massive hindrance.

The Clean Team toilet was delivered to the house and was placed in their living room, a concept that at first seems bizarre to most people from a developed country. However there is a high chance that this would be the location of the Cranfield Toilet within the house. It is pretty common for houses in developing countries to consist of only one room and in that room people eat sleep and cook in that room. Now if they do not use a public toilet and instead use a chamber pot or the ‘flying-toilet’ method (defecate into a plastic bag and throw it out of the house) they would already be accustomed defecating in that one room.

During a later interview with a former manager from the clean team about how common would this scenario be, the response was as follows:

“This is a common situation in Ghana. From experience with WSUP (Water and Sanitation for the Urban Poor) communities and also with most of the Clean Team customers, the situation is largely the same. It is so because most of these areas are typically high demand areas. Lots of people want to live there even though rent is not cheap. They prefer them because they are closer to town, transportation is easy and cheap and usually very conducive for their small businesses or trade. Even though rent in newer areas (usually fitted with toilets) cost much less than these areas, because they are further away from town, people do not prefer them.” (Clean Team manager, Interview, 2014)

This house has persisted to be a defining image of the approach of the Case Study. The system being developed in the Case Study is the smallest system out of all on the Reinvent the Toilet Challenge grantees and could feasibly fit into the house of the user. Observing the spectrum of living standards is an important part of understanding the context of the project aim.

Another house that was visited had a small outer room area where they kept their Clean Team toilet. This was a narrow space about 1m wide and 3 meters long. The odour in this area was very strong even though the room was relatively well ventilated.

Figure 13 - Target user's current solution

(C4D, Cranfield University. Ross Tierney © 2014)

It is also worth noting the concrete step in front of the toilet; this was because the size of the toilet was considerably bigger than the standard 435mm height of the average toilet bowl, it was in fact 532mm. This proved too high for the older woman of the house so they had to make a small addition to the toilet set-up.

6.5 Target market observations

Gaining an understanding of the literal target market, meaning what are other products on sale in the community gives insight into the aspirations of the community and where market potential may lie. Whilst on the main shopping streets of the local area around Ashtown, the Case Study team noted the common sight of electronic items and home appliances on offer. It was discussed that it is these items that could be associated with the Cranfield toilet: Aspirational home appliances to improve quality of living. The Cranfield toilet also has added benefits to the local environment and health of population, Below is a range of goods from kettles to washing machines- those two items are examples of conveniences rather than essential goods. The household would likely have an existing method for completing either of these functions, even just if it’s in it’s most basic method like boiling water in a pan on open fire, or washing clothes by hand in a pale of water.

Figure 14 – Home appliances on sale in Kumasi of a similar level that the Cranfield toilet.

(C4D, Cranfield University. Ross Tierney © 2014)

Figure 15 - Aspirational products on sale in the area show a society with very modern product aspirations
(C4D, Cranfield University. Ross Tierney © 2014)

Here is a shop in the same region selling computers and televisions certainly not items that people would associate with small towns in Ghana but as electronic goods are becoming cheaper and more accessible to the world's poorest. Even the notion of what is the world's poorest is shifting, the average annual wage of Sub-Saharan Africa has climbed by two thirds since 1998, from just over $1,300 to $2,200 (Gates, 2014).

Figure 16 - Market in rural region selling fridge freezers (C4D, Cranfield University. Ross Tierney © 2014)

This is a photo from a village between Accra and Kumasi in a relatively rural lower income area that even had fridges on sale, giving a strong indication that wealth and aspirational goods is not only necessarily confined to the city.

6.6 User perceptions

When the local people were asked if they like the pedestal set-up or a squatting set-up the response was very strongly in favour of the pedestal toilet. This was seen as the more desirable and aspirational of the two set-ups and what people would want in their homes. Public convenience toilets such as at bus stations were observed to be virtually always squat toilets. This is most likely down to the cost but there is also the added benefit to the user that as they are more hygienic as they avoid the inevitable body contact that occurs from sitting toilets (Cai, 1998). These public squatting toilets were often poorly maintained and had a terrible odour, which may also be in the mind of people when comparing the two toilet styles. In an informal interview/discussion with a Ghanaian national who works in Sanitation in Ghana, this public vs. private link to the sit vs. squat discussion was also raised. She said that she prefers to squat for public toilets and sit if she's at home for hygiene reasons.

The Case Study Research Team discussed the idea of sitting versus squatting and it was agreed that the pedestal toilet is the correct configuration for the Cranfield toilet. It is aspirational and comfortable and as it's in the house of the user and only used by the family or a select few, the hygiene concerns are not so much of an issue. It will also give the technical teams more space to fit the system in.

6.7 Key findings

Observations from the target area are vital for completing the gaps in knowledge that cannot be filled with a Literature Review or State of the Art. A research trip should be well planned and structured to give insight into key areas that will help the development of a product. For the Case Study, the range of knowledge and experience in the team proved to be a positive mix that fostered productive discussion and early idea generation.

As 2.6 billion people do not have access to a toilet around the world (Kone, 2012) there is bound to be a spectrum of wealth and living conditions. Whilst in Ghana the team noted a very high standard of living that has to be considered when designing for this market. They have virtually every convenience of a developed country yet no toilet. The surrounding area also had a wide range of electrical domestic appliances for sale that suggested the toilet being developed by the team on the Case Study could appeal to the target market and not be too radical as first thought.

7 Investigation

The investigation phase is the crucial synthesis of the scoping phase and the project brief to determine the direction of the practical implementation of the research. In the Case Study, designing the user interface also requires developing an odour barrier as well as the overall appearance of the unit.

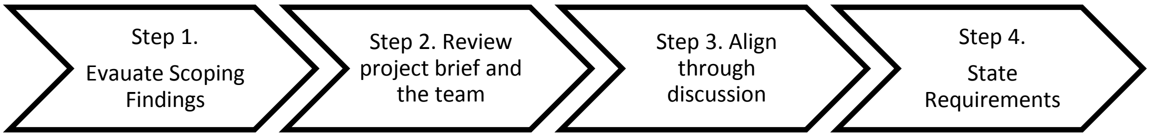


Figure 17 - Stages of Investigation

Step 1. All findings and areas of interest highlighted during the scoping phase are to be extracted and discussed

Step 2. Reassess the Project Brief and the resources and capabilities of the team

Step 3. Align steps 1 & 2 to establish what needs to be produced at the end of the project

Step 4. Clearly state the requirements of the project or the task and ensure all parties are agreed. It would be advised to take this opportunity to also agree on other imperative specifics such as budget, date, personnel etc. Documenting all of this into a Design Brief will help with clarity.

7.1 Deconstruct and decompose the research problem

It is important to ensure the research problem is understood to the deepest level possible and that nothing is taken for granted. The initial team discussion began by asking the question, “what does the User Interface actually consist of?” The initial belief of what this brief would involve was simply to design the outside of the toilet to be accepted by the target user.

The team defined the user interface as the 'interaction between the user and the system.' This interaction is made up of the complete user experience that forms their perception of the system. The experiences come from the human senses, so it's likely their first impression will be based on the appearance of the toilet. Further feedback comes from touch and how it feels to even sound. For example, closing the toilet lid could make a noise that gives the impression of cheap workmanship or materials. Smell would obviously be a big part of this as well. One of the Key Findings from the Scoping section was the significance of bad odour and the importance of preventing it. No matter how nice the toilet looks and feels if the toilet cannot contain the bad odour people will have a negative perception of it and will not want it in their homes.

In the book 'Product Design and Development' (Ulrich, 2012) there is a recommendation to decompose a complex problem into individual sub problems and then tackle each problem. The user interface decomposed to form two sub problems. The importance of preventing odour was identified as being a separate task that would be developed at the same time as the External Appearance to eventually combine and form the complete User Interface.

7.2 Requirements of the Case Study- Odour Barrier

To identify core requirements that will define the development of the new odour barrier component; the scoping sections have to be down-selected for key areas of interest and cross examined against each other. The Design Team on the Case Study determined these requirements during structured discussion to evaluate all of the areas of interest raised during the scoping phases.

7.2.1 No additional water can be added to the system

One of the overall project constraints of the toilet in the Case Study is that toilet cannot be connected to a water supply infrastructure. (Kone, 2012) Additional confirmation of having to be a water-free action came from another department on the project that are in charge of the dewatering membranes. The more water added to the Cranfield system during the ‘flush’ would increase the volume of material to be treated, which would have a negative impact on the operational cycle of the membranes (they would need to be removed and cleaned more frequently), and on the overall energy demand of the system.

A possible solution would be to recirculate condensed water from the reservoir to the bowl but this water may still have odour and also represents an undesirable energy demand. It would also be reliant on there being water in the reservoir to clear the waste, which might not always be the case.

7.2.2 No additional power can be used

In a similar set of circumstances to the issue of water, the overall project remit also required the system to not rely on being connected to mains electricity and was echoed by the team in charge of powering the system. The Engineering team stated that the Cranfield system is already going to require a lot of energy to work the basic functions and as their role is to provide the system with power they do not want to have any more power required than absolutely necessary.

When water is not being used to remove the waste, using power would seem the obvious next step. An aeroplane for example, cannot use a large amount of water so instead uses a large amount of power to remove the waste using a high-pressure vacuum. The system currently has three main areas needing power; the vacuum pump for the membranes, the Archimedes screw and the Nano-mister.

7.2.3 Preventing odour

The case studies’ sponsor, The Bill and Melinda Gates Foundation placed a lot of emphasis on the importance of preventing smell. Smell was even mentioned by Bill Gates himself as one of his personal areas for concern: "It should be possible to have a toilet that does not require running water, whose cost is very low and whose smell characteristics are as good or better than a flush toilet. But, it doesn't exist yet," (Economic Times, 2012) (The Indian Express, 2012).

The importance of smell was also witnessed first-hand by the Research Team's field trip to Ghana when visiting the poor conditions of the public toilets in the lower income areas of Ashtown, Kumasi. It was also discussed in an interview with the founder of a bio-digesting toilet firm who said, "It was the main reason for people to not use public toilets and openly defecate instead. Even the university students at KNUST who are the more educated in our society will openly defecate if the toilets are bad". It was also noted that it is not uncommon for users of public latrines to remove their outer clothing before entering the latrine. Smell is also perceived to be a major impediment to household latrine adoption in Ghana, (Van der Geest, 2007)

The waste will stay in the holding tank directly below the bowl and produce very bad smells as anaerobic digestion takes place. To prevent this in a normal toilet water provides an air trap but this would not be possible with the Cranfield system due to water constraints. A physical barrier to prevent bad odour escaping has to be used that will allow faeces and urine to travel in the opposite direction.

7.2.4 No change to user behaviour

It was highlighted during the literature review that complex water flushes that didn't fit into the normal or obvious routine caused confusion and often-discouraged use (IDEO.org, 2011). If a system is over complicated misuse is very common, even if an additional step to the normal sequence is required it is likely that confusion will arise. This is not the fault of the user but an indication of bad design. The pinnacle of design comes when a system is entirely intuitive and cannot be misused. If we look to the 'Ten principles of good design' by Dieter Rams, one of the principles states 'good design makes a product understandable' it goes onto to say 'At best, it's self explanatory' (Swan, 2011).

This toilet system will be a radical product for the users; they will likely never have had one in their home before. Therefore, everything should be as self-explanatory as possible, to ease the acceptance.

7.3 Requirements of the Case Study- Toilet Appearance

The design of the overall appearance of a new product is a vital part for how the user feels about it and is generally what their first impression is based upon. The object in the Case Study has to be desirable to the user and meet the technical requirements of the system.

When the project doesn't allow for access to the target user, this has to be improvised with people who have the best understanding to the needs of that target user. To ensure the Design Team delivered the best outcome to try to meet these expectations, the other members of the Case Study team are used to guide the development and to ensure a crowd-sourced mutual view during weekly working meetings. Many of the team had spent considerable time in the region with other projects and had some had also attended the previous fair so they will have a good idea of what is expected.

The prototype to be produced is to give people a good understanding of the user experience of project and what will be delivered in the final full model and will only have value in its production if it is as realistic and truthful as possible. In the Case Study, its purpose is to give the exhibition attendee's an impression of what overall appearance, size and user experience is being developed and aimed for by the Cranfield team.

To design the appearance with some realistic properties such as approximate form and size, some data would have to be completed by the other departments even if it was just estimates when possible. The components and features that would define the shape were:

- Holding tank
- Membranes

- Beads
- Motive force/compactor
- Misting chamber and unit
- Briquette holder
- Water reservoir

Unable to work with a definitive form as a starting point the design team sought to gain a better understanding of what the rest of the team were wanting and expecting from the appearance and benefits of the final toilet prototype. To do this a tool would need to be developed that would allow for different concepts to be assessed with the same criteria with the goal of down-selecting the ideas presented.

To do this, business model tools and idea description methods were assessed to find the best approach. The SWOT (Strengths / Weaknesses/ Opportunities /Threats) analysis was one of those considered but it was decided this is too early in the phase for ideas to be discussed in such a definitive manner (Baxter, 1995). Instead just the core of the concept should be discussed with key data for the Consortium to make their own decisions on. One tool that was discussed and deemed to be a good starting point was the Business Canvas developed by Alexander Osterwalder and Yves Pigneur (Appendix). The benefits of a new business model are shown in a simple layout explaining benefits broken into nine building blocks that convey the logic of how a company intends to make money (Osterwalder, 2010).

In the Case Study the Design Team tailored the canvas to be of more benefit to what was required from the task as well as the stage of the project, which would be advisable to any designer looking to implement such tool.

The purpose of Business Canvas is to explain how a company will make profit in a series of sections (Osterwalder, 2010). The tailored version has to use different sections to convey the core of an idea to a range of experts from different fields that also work on the project. To do this the Design Team wanted to keep the new tool very concise to maintain interest and also give over just key pieces of information to not overwhelm the others. It is essential to consider not only the desired outcome of the exercise but also the audience. It was also important to keep the exercise very visual but also including some key pieces of specific data so a balance of information would allow the audience to form their own decisions on aesthetic and technical preference.

The first canvas used by the Case Study consisted of the name of the concept and four sections that were a mix of visual and technical information:

- USP of system
- CAD render
- Sketches of development
- Technical data

To ensure the tailored Canvas would achieve the results required a test run was conducted with a few random people that were available. This is advisable before the real audience are introduced to optimise the test.

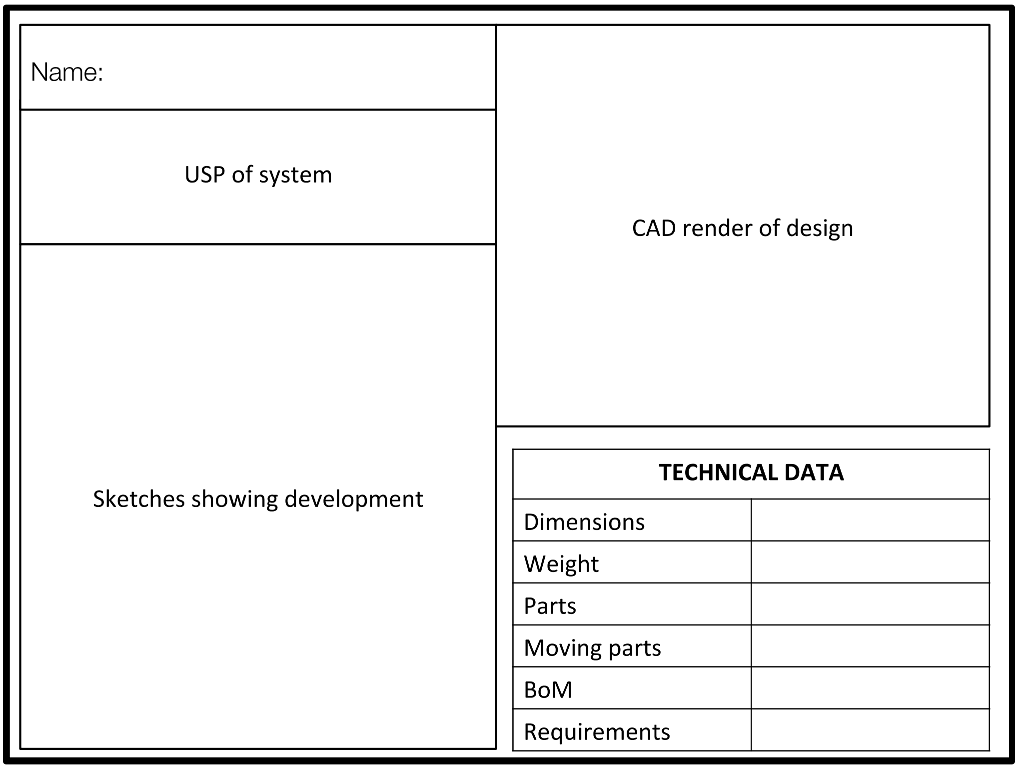


Figure 18 - Example of Tailored Business Canvas (C4D, Cranfield University. Ross Tierney © 2014)

Feedback from the test group stated that the images were quite hard to see having one A4 sheet of paper proved difficult for the small group to all evaluate at the same time.

In the Case Study, the Design Team decided instead of having the discussion around a table, they would use the same technique for discussion as they used during their own earliest idea generation phase and have the images large on a wall. For the discussion this would be one full size image to judge accompanied by the Canvas as well for each idea. To also give more clarity and space the Canvas would now be split onto two pieces of paper (Appendix 8 & 9).

When tailoring the Business Canvas to convey concepts to a wider team, the Design Team found that certain considerations need to be addressed. The team developed these set of questions to be asked:

1. What will the desired findings/results be?
2. Who are the target audience/subjects?
3. How developed are the ideas?
4. How large will the group be?
5. Will the findings be qualitative or quantitative?
6. How will the workshop be conducted?
7. How many ideas are to be presented?

All of these points will have an effect on how the tool will be designed and need to function. In the Case Study, answers to these questions were as follows:

1. *What will the desired findings/results be?*
   The desired results will be the design Team gaining a better understanding of the attitudes of the wider team with regards to the aesthetics and core principle of the concept.
2. *Who are the target audience/subjects?*

The target audience/subjects will be the wider team from varied backgrounds who will require the information concisely

3. *How developed are the ideas?*

   The ideas to be presented will be in the very early stages and will be there to represent possible key design drivers.

4. *How large will he group be?*

   The group will consist of around 10 people from the different teams on the project.

5. *Will the findings be qualitative or quantitative?*

   The findings will mainly be focussed on the quantitative data as key information, but qualitative feedback will be valued as additional vital opinions to help with development.

6. *How will the workshop be conducted?*

   The workshop will be an informal group discussion firstly with each concept being given a brief introduction with the rational and key data explained.

7. *How many ideas are to be presented?*

   A small number of ideas are to be presented due to the audience/subject time constraints and wanting to also be able to receive valuable qualitative feedback on each concept as well.

Figure 19 – Example of completed Case Study Canvas
(C4D, Cranfield University. Ross Tierney © 2014)

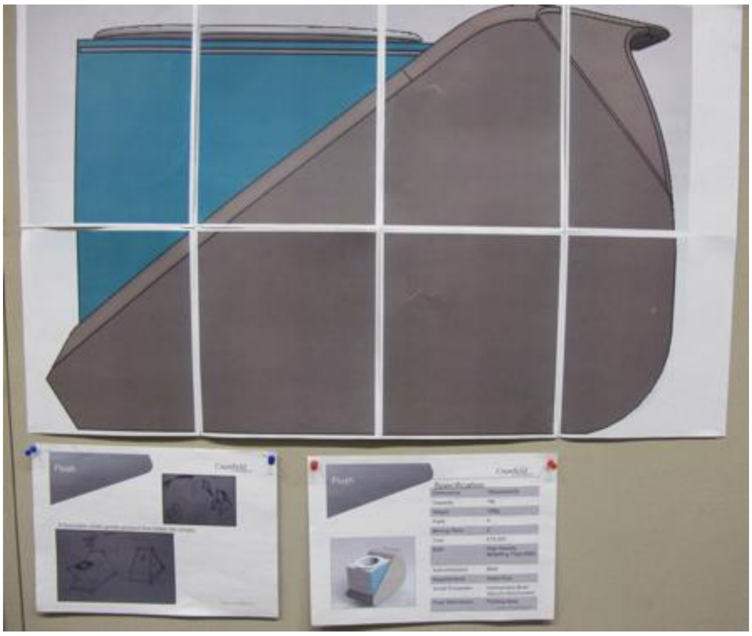


Figure 20 - Example of each concept displayed for Consortium down-selection workshop in the Case Study
(C4D, Cranfield University. Ross Tierney © 2014)

Figure 21 - Down-selection workshop Case Study
(C4D, Cranfield University. Ross Tierney © 2014)

The Measure of Merit was decided to be a simple survey of preference to gain quantitative and definitive feedback. To gain more insight on a deeper level the subjects were asked to make a note of any comments they had on a post-it note. As previously mentioned the purpose of this task was not to gain a definite solution, but more as an insight for the Design Team on the thoughts of the rest of the team to get better direction to go forward.

Possible other methods of gauging attitudes were the Thurstone method and the Likert Scale, but this was decided to be too detailed and unnecessary (Blaikie, 2009).

In the Case Study, the results selected a design that had a very distinctive shape but it was the inclusion of discussion and feedback on post-it notes that proved the most valuable. In total 24 comments were collected from the designs and these comments were then down-selected to the most valuable that the whole team agreed upon. There wasn't a desired number to reduce the pack down to and it would be advised that other teams do not place such restrictions either. The down-selection should be focussed on ensuring those to be taken forward that the whole team are important to the initial brief. The down selected comments from the Case Study were as follows:

- Aspirational aesthetic design
- Easy to clean
- High gloss white
- Look like it’s built into the home
- Easy access for maintenance staff and user
- Small footprint to fit within a typical small dwelling
- Minimum material as possible
- Simple manufacture
- Space for all components with hydrophilic beads being able to detached

Many of these points had arisen throughout the research phase, for example number four is very similar to a quote highlighted by the Literature Review from the IDEO.org report (2011) that stated, “The final design should look and feel like a robust fixture in the home”. Numbers seven and eight are just good common practice for ensuring low-cost manufacture.

7.3.1 Component progress monitoring

The user interface of the product refers to every aspect of interaction between the person and the object. Sight and touch being obviously very important but it’s the whole user experience that goes into forming the user interface.

The outside of most products are developed after the size and configuration of the internal components are determined or at least towards the end of development. In the Case Study these internal components are also entirely new and going through their own development by the different teams.

The prominent engineer James Dyson has stated that “a product shouldn’t be that the engineer does the engineering and the product designer is coming along and doing the shell, I didn’t think it worked. I think a product should express its engineering, function and performance” (Dyson, 2013) this approach of a more integrated development can be seen in the ethos of many other successful brands currently. To express the engineering a more complete approach has to be taken where the development of the components happens along with the design of the outside. The hugely influential designer Victor Papanek stated that the role of ‘team synthesist’ can be thrust upon the designer. There is an element of truth to this in the Case Study and this shall therefore be dealt with accordingly.

A method had to be developed for monitoring and comparing the progress of the components that were being developed. By printing a large flow chart of the system and having each team explain the current state of their component and other recent developments the productivity of the team meetings was increased and the structure of these meetings was improved. This tool could be customised for most NPD projects and even be utilised on a higher Project Management level if needed, as it’s a simple template that can help with organisation.

Listing the components in their correct sequence across the top and measuring options down the side axis allows a clear display of the progress of the complete system. The addition of the TRL scale would be an advisable inclusion for any future project that aims to take a product to market.

Table 10 - Example of Progress monitoring tool used in the Case Study

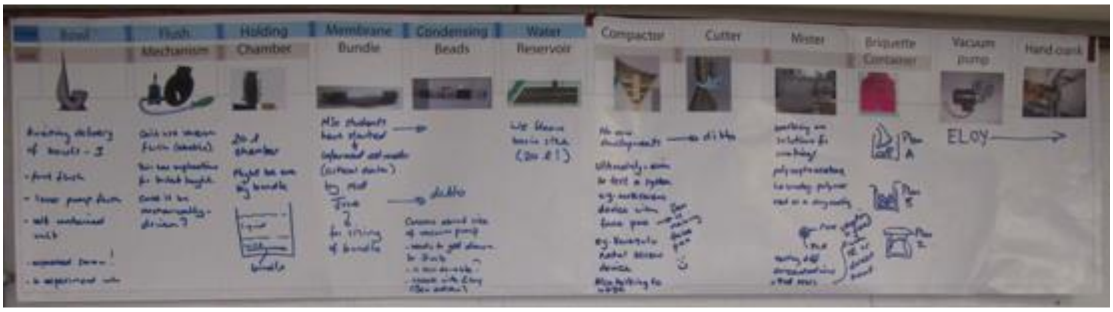
Object	Holding tank	Membranes	Condensing beads
Latest image			
Comments	Material selected	Current testing low success rate	Test successful
Maturity	Concept	Testing	Testing

Connectivity	N/A	Tested in sequence	Tested in sequence

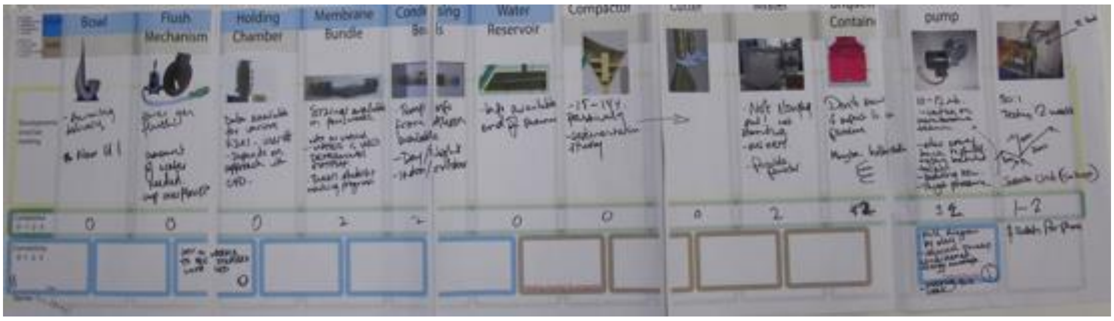
Images from: (Cranfield University. Ross Tierney © 2014)

This tool can now be populated in the correct sequence during the team meetings for the progress to be monitored and connectivity discussed as can be seen below from the Case Study.

A.



B.



C.

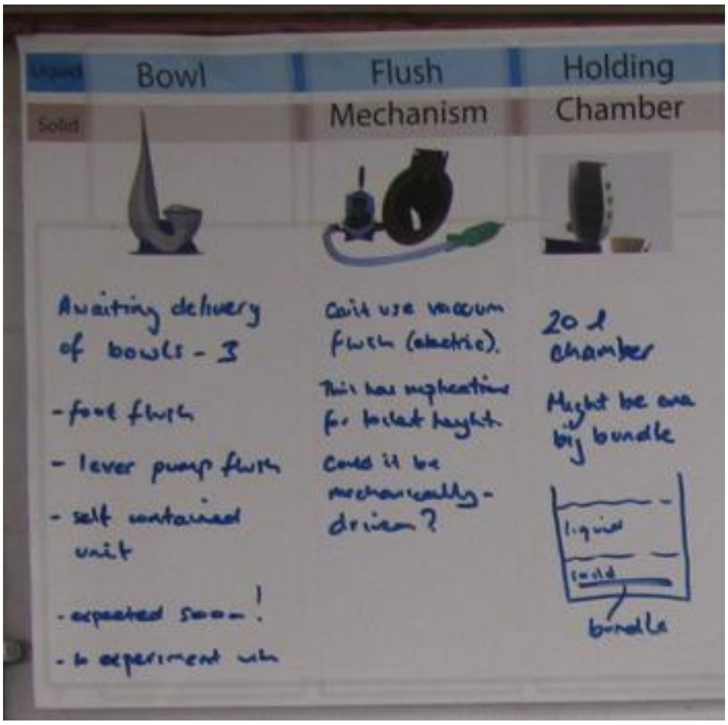


Figure 22 - Case Study. A-D shows the progress monitoring tools from three separate meetings
(C4D, Cranfield University. Ross Tierney © 2014)

The purpose of the tool was primarily to monitor progress but it also highlighted blind spots within the system. As discussion moved from one component to the other it made the team discuss the system in a holistic sequential manner.

"There will be a non-return Flap between membrane and beads -Who's designing that?" Meeting minutes, 7th may

Due to the progress of each component being monitored on a regular basis and with an approach to view it in place of a wider system, it became apparent that the progress was not at the stage hoped for by July 2013. It was determined that it would be highly unlikely that the components would be finished and ready for linking to leave enough time for the Design team to develop the external casing in time for shipping to India.

After reviewing what were the expected deliverables and project guide lines set forth by The Bill and Melinda Gates Foundation, it was determined that the Case Study would divide the full prototype and work on two separate prototypes.

The first prototype would be referred to as the Works-Like rig (appendix 10) and would be developed primarily by the Water Sciences department but with involvement from the Nano department. It would be a scientific model that would allow for testing and adjustments to be made and would be built by a local manufacturer experienced in making scientific testing rigs.

The other prototype would be an aesthetic model designed by the Design Team and constructed by a fabricator who was selected after their extensive portfolio had some pieces similar to the intended appearance of the Looks-Like model. This model would be purely to give people an insight into what the Cranfield team are trying to reach the next stage of the challenge. This approach is widely used in NPD as it can improve the efficiency of the development by testing and improving one specific aspect at a time (Hallgrimsson, 2012). If the Cranfield toilet were successful in securing funding for the next stage, then a full working prototype would be developed. After proving the full system works in laboratory this would then be shipped to the target area for real user testing.

7.4 Design Brief

It is advisable to future practitioners to construct a project Design Brief once the Aims and Objectives are stated. This will act as a good record of what is agreed will be achieved with other key pieces of information such as dates and budgets also being potentially important to be added, so all parties have the same understanding of the project. The Example from the Case Study : fig 29 & 30.

Introduction

Design the user interface for an innovative sanitation system targeted at people in developing countries. The project is part of the Reinvent the Toilet Challenge funded by the Bill and Melinda Gates Foundation who will host an exhibition in Delhi to evaluate the different systems. The User Interface is comprised of two tasks, developing a flush mechanism and designing the overall appearance of the system.

Flush Mechanism

Requirements

1. No additional water
2. No change to user behaviour
3. No additional power
4. A constant odour barrier

Additional Considerations

- As simple as possible to reduce final cost and risk of failure
- 1.25 litre holding volume for the waste
- As small as possible to reduce overall size required for the toilet
- Adaptability to other systems

Deliverables required

The user interface has to be conveyed to a wide audience at the Reinvent the Toilet Fair in Delhi, March 2014. A full-scale prototype of the toilet has to be produced that gives attendees a complete understanding of the ambitions and direction of the Cranfield entry.

Figure 23 - Design Brief for Case Study. Flush Mechanism

The External Appearance

Requirements

1. Aspirational appearance
2. Fit all components in correct and practical sequence
3. Small footprint
4. Standard dimensions of normal pedestal toilet

Additional Considerations

- Easy Clean
- White high-gloss finish
- The design has to look good with or without the two external Membrane Columns each with the dimensions 750mm x 100mm x 100mm
- Look like a permanent appliance
- Simple manufacture for next level of development
- Easy access for maintenance staff and user
- Minimal material as possible

Deliverables required

A proof-of-principle prototype has to be developed to explain the flush mechanism and allow for further testing to the idea.

Personnel:

- 1 x Full time researcher (1 year)
- 1 x Thesis researcher (3 months)
- 1 x Supervisor (1 year)

Design team budget: *Confidential*

Date of completion: All prototypes have to be ready for crating on **December 20th 2013** ready for shipping on **January 7th 2014.**

Figure 24 - Design Brief for Case Study. External Appearance

The Design Brief is a synthesis of the initial Project Brief/Research topic, the Scoping Stage and discussions with the team. To ensure all parties are happy with the agreement the brief should be formed with the key people present to discuss the writing of the content.

The Requirements are the main rules of the brief and have to be adhered to for they are the real essence of the task. The Additional Considerations are there to give better direction as the project develops to ensure an outcome that best reflects the previous work.

In the Case Study, it was determined through discussion that the User Interface that is to be designed is not just the external shell as one might first think. It is also to develop a method of preventing the user from coming in contact with the sight or smell of the waste in the holding tank without using a conventional flush method. The importance of this was noted by the Research Team whilst in the target area, talking to local people and through findings in the Literature, in particular Rheinländer (Rheinländer, 2013). The User Interface of the toilet involves a combination of four out of five of the senses (excluding taste) to create an overall opinion of the product. By developing a method of blocking the user from the bad odour and the undesirable sight associated with toilets the user experience would be much better, which is the goal of any User Interface. The Design Team decided that the research would run two seemingly separate design projects simultaneously that would come together to form the complete user interface. These would be, firstly, to develop an odour barrier and secondly, to design the outside appearance of the toilet. The design brief reflects the two parallel lines of development as they are inextricably linked to one another and therefore must be run in unison to complete their total task.

If the Case Study is successful and a next round of funding is secured, then the level of detail for the brief will be greatly improved upon but at this time it's not deemed necessary. If a greater level of detail is required, a section assigning Specifications would also be included to give greater clarity on what is required. Specifications present the design team with an unambiguous agreement on what the team will attempt to achieve in order to satisfy needs of the customer (Ulrich, 2012).

8 Design, Build and Validate

By working on the requirements described during the investigation, the design and build phase will have a strong foundation and good direction towards meeting the project aim.

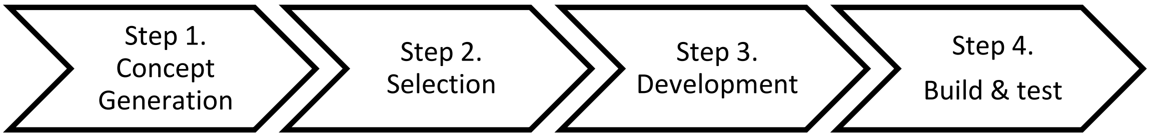


Figure 25 - Stages of Design and Build

Step 1. In a small group of design experts and valuable contributors, ideas are generated based on the key project requirements. These ideas are conveyed using sketches, maquettes or CAD models

Step 2. These ideas are discussed amongst the group and evaluated against the project constraints and the additional considerations.

Step 3. Now a final design has been developed which complies with requirements and approved by the full team the build can begin using appropriate methods to match project brief.

Step 4. Once the concept has been developed and validated with appropriate methods, the build can begin under regular progress monitoring before finally running appropriate tests

In the Case Study this implementation phase has two roles: developing the odour barrier and designing the outside of the toilet itself. The odour barrier will be the first task, as this will have an effect on the design of the outside due to its final size and overall design.

8.1 Case Study- Odour Barrier Development

The waste enters the toilet bowl as a mixed stream and then needs to be transferred to the holding tank to be dewatered by the hollow membrane bundle. The task is to allow solid and liquid to enter in one direction but no bad odour to move in the opposite direction whilst adhering to the four restraints produced during the investigation phase:

- No water to be added
- Constant odour barrier
- No additional power required
- No change to user behaviour

These four requirements are quite conflicting so this is a very difficult task, but the team decided it was best to aim for the hardest requirements to really push innovation.

8.1.1 Idea generation

A flush suggests water being used to move the waste but in this case it's just the process of moving the waste from the bowl to the holding tank and preventing odour in the opposite direction.

It's important to maintain a small group during the idea generation phase to allow for good communication and a good quality of ideas from a select few who fully understand the problem.

In the Case Study, the Design Team worked in a small group of around three or four occasionally with input from an external specialist. Regular discussion took place with sketched ideas on the walls of the design studio or on large pieces of paper. The team also attempted a different method of conceptual design where they each worked individually coming up with their own ideas before reconvening and discussing each other’s.

To convey ideas, the easiest method was quick sketches moving into CAD modelling using SolidWorks and soft modelling with simple maquettes.

The State of the Art proved an invaluable source to begin the discussion and the idea generation needed to develop an appropriate flush mechanism. The best attributes of each method would have to be combined to develop an entirely new design to meet the four primary constraints as well as al project concerns such as reliability and end cost. It was also from the state-of-art that the Evolute system was highlighted as a piece of technology of key interest due to the high score on the smell prevention criteria. This system then formed the inspiration and a base of the idea as it was decided to have good potential for development. The sealed rotating cup is a very good method for emptying the waste into the holding tank but preventing a direct flow of bad smelling air from escaping. The next stages came in trying to improve upon the other factors such as water usage and power.

The Evolute system uses a pre-spray of a small amount of water to lubricate the bowl before use. After use, a normal looking flush handle is pushed down and a cup at the bottom of the bowl rotates to empty the waste directly into the sewer and is then sprayed clean with a precise jet of water to clean any possible remaining faecal matter. Only using 10% of the water of a conventional toilet is an impressive reduction but still not good enough to meet the Project requirements of no water used at all.

Figure 26 – The Evolute System that was identified in the State of the Art
Image from: http://www.innoglobe.com.au/evolute.html

Instead of a motor and jet of water requiring power and additional water, the Case Study method would need to be more passive and simple.

The design team began rough sketches on the walls of the studio to allow for discussion and input from a small group of people at a time to ensure a diverse mix of ideas and expertise. This included a Professor of Nano Technology and materials with a background in engineering and a local fabricator with many years of engineering experience.

By using the same evaluation criteria utilised during the State of the Art and further investigation phase, more effective concept generation and design development could take place. Attributes of the designs within the State of the Art were assessed and used as core values when designing. These core values were: cost, reliability, odour prevention and ease of use.

The four requirements selected in the investigation phase of the Case Study almost appear to contradict each other to the point that a working solution would not be possible. For example: if water cannot be used like on a plane, a large amount of power is required to extract the waste with Vacuum pressure instead.

The design team first began looking at the main principle of the Evolute system, the rotating cup. The question was raised as to how could this action take place without power and also without requiring a large change in user behaviour?

After considering the user behaviour as a starting point the design team sought to integrate the action of flushing into the user's normal sequence of behaviour. To do various sequences of normal toilet use were noted with the one below being accepted as being normal:

Common sequence of events going to the toilet:

1. Open door to toilet
2. Close toilet door
3. Lift up toilet seat lid
4. Remove or lower clothing
5. Sit on toilet
6. Relieve oneself
7. Cleanse
8. Stand up
9. Wash hands
10. Open door
11. Leaves
12. Closes door

The team discussed each of these steps as a way to turn the behaviour into a simple method of power generation. The action needs to be able to transfer wasted energy from a simple action that could be used to generate the small amount of power needed to rotate the cup. The three selected as possible actions for energy harvesting were: Open/Close toilet door, Sit on toilet and Open/close toilet seat lid. The design team discussed the power generation possibilities of the toilet door; this action could be used to generate a relatively large amount of power, as it's a rotation with potentially a large lever action if the hinge is considered the pivot. As the team discussed this possibility a number of potential complications arose to the point more problems were generated than solved. For example: If the door breaks, how is power generated? How would the door connect to the toilet? In a one-room house, perhaps there is no door suitable?

The second action discussed was when the user sits on the toilet. The potential weight could generate a large amount of energy depending on the size of the person. This action also prompted the discussion on how gender affects this idea. Men tend to urinate standing up so this also has to be in included. An obvious way around was that the whole toilet sits on a platform that lowers and builds power in an accumulator before being released when the power is needed.

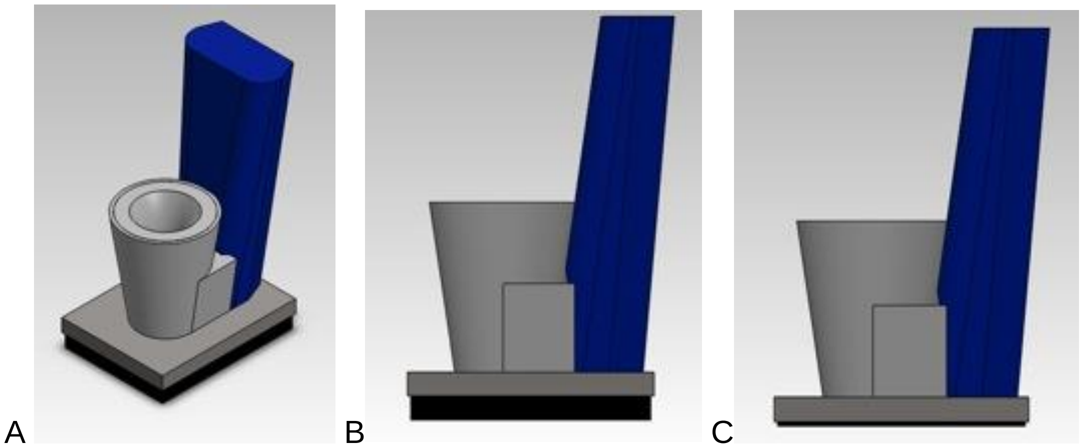


Figure 27 - Failed Concept from Case Study (A). The toilet is raised when no one is sat on it (B) when someone is using it; it is depressed where it transfers their weight into stored power (C)
(C4D, Cranfield University. Ross Tierney © 2014)

Fig. 33 is a simple CAD model of the idea, showing how the base could be formed of two parts, one that slots over the other to allow for the whole toilet to lower when the user stands on the toilet. The idea was dismissed pretty quickly as it failed to address one of the concerns about inclusiveness.

One obvious concern with this is the size of the person. It was raised at the Barcelona conference about designing a toilet that fits the needs of children/elderly/disabled, it would have to be quite difficult to ensure a system that would work with a very small child as well as a fully grown adult.

The Design Team reassessed the sequence of normal User behaviour and now experimented with utilising the action of opening and closing the toilet lid.

8.1.2 A snap-shot of the stages of flush mechanism development from Case Study

Simple sketches allow conveying an idea quickly and effectively and encourage collaboration and ideas to develop. This should be a regular activity to allow reflection on an idea and given time to discuss the positive and negatives. It would also be advised to document all stages of the development process as some early ideas may have use at a later stage.

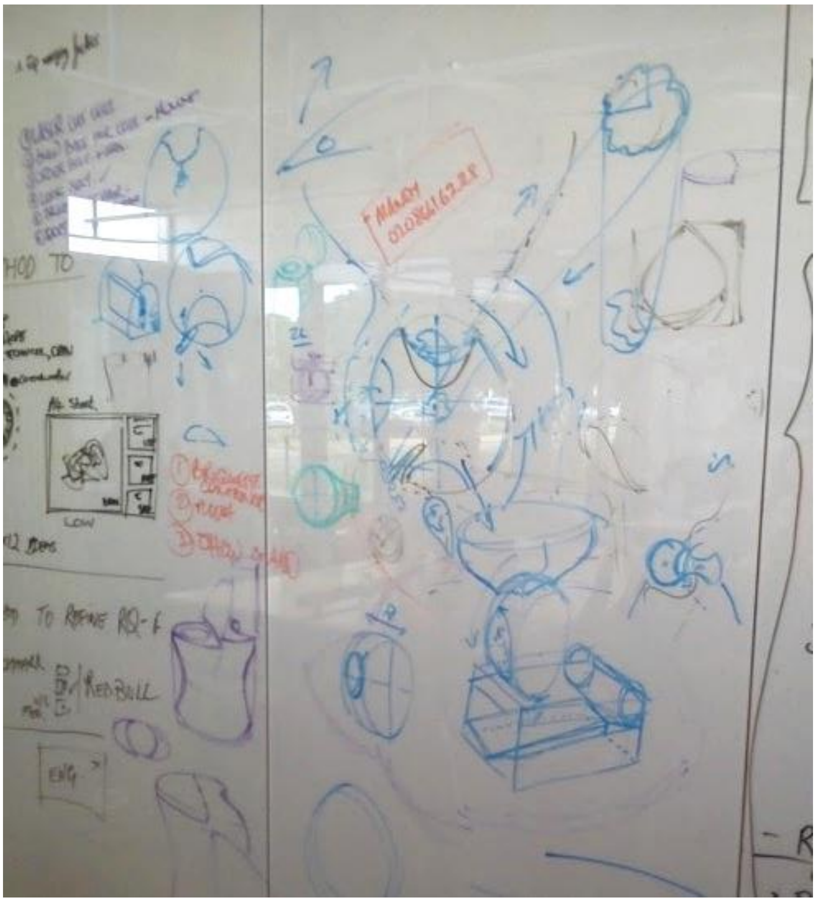


Figure 28 - Idea generation board used by the consortium of experts to discuss ideas quickly and easily on a large scale
(C4D, Cranfield University. Ross Tierney © 2014)

In the Case Study The Design Team sought to develop an innovative flush mechanism with the requirements established in the investigation phase. To do this, expert consortium were assembled of three people with design backgrounds and one with a background in engineering and fabrication. Working on large boards for idea generation helped with open discussion.

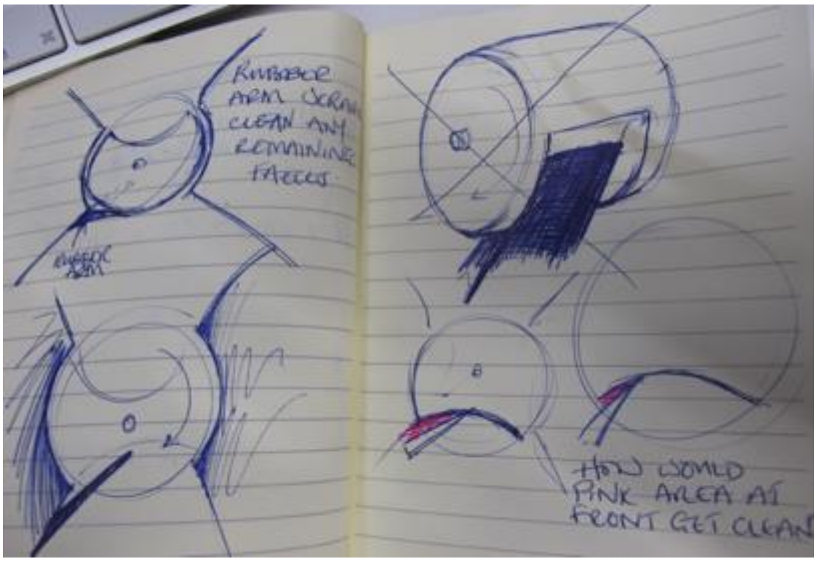


Figure 29 - Early sketches exploring simple concepts of scrapers
(C4D, Cranfield University. Ross Tierney © 2014)

Figure 30 - Early sketches exploring simple concepts of moving scrapers (C4D, Cranfield University. Ross Tierney © 2014)

The early ideas from the group discussion are to be researched and refined. In the Case Study, early popular concepts built around the rotating cup idea paired with an additional cleaning blade and were popular amongst the design team and the external consultants. The cleaning blade is made from a flexible-polymer that is constantly pushing into the rotating drum and presses into the cup as it rotates and removes anything that does not fall off due to gravity into the tank. It was determined that the flush mechanism with a fixed blade would require a very specific and irregular shaped bowl to work that it may be difficult to manufacture and ensure effective action. Simple CAD models also showed this wouldn’t work therefore a new idea that involved a separate moving blade was discussed.

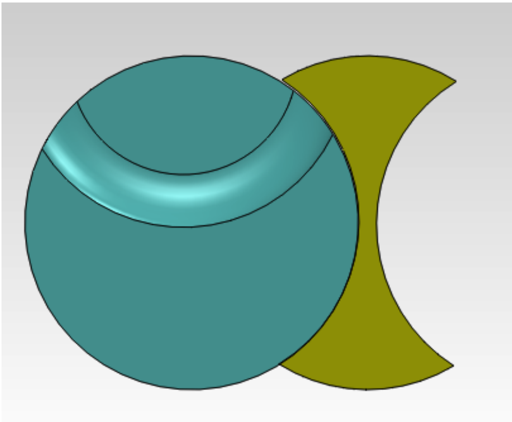


Figure 31 - CAD models to improve the idea
(C4D, Cranfield University. Ross Tierney © 2014)

CAD Modelling is a vital tool during Idea Generation and Development phases and running simple animations is a very effective method of conveying the idea to the expert Consortium for intermediate evaluation. In the CAD model above the idea of a second swipe is shown that would allow for the bowl to clean itself after each use.

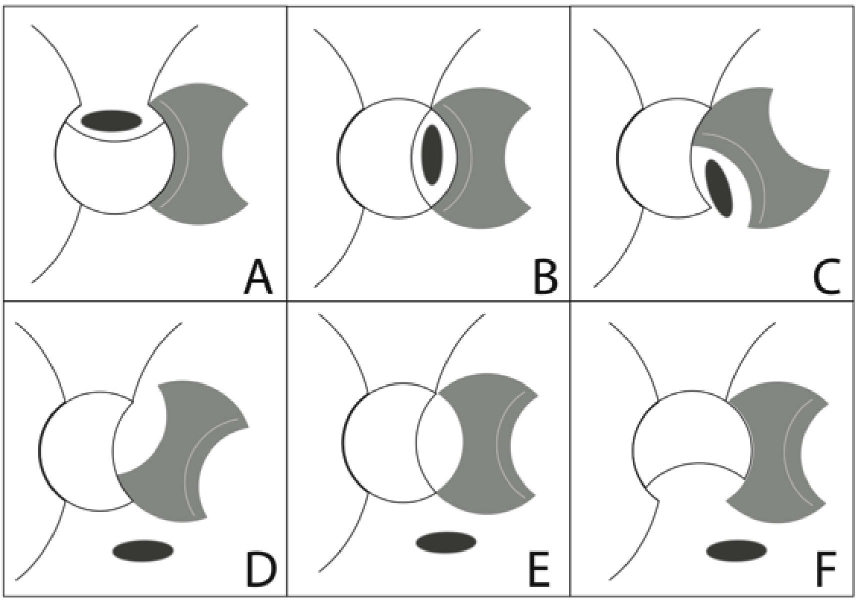


Figure 32 - Explaining Concept Process with CAD
(C4D, Cranfield University. Ross Tierney © 2014)

The actions that take place in basic step by step sequence for ease of understanding

A. Waste enters the cup
B. Cup rotates
C. Cleaner rotates scraping waste into holding tank
D. Cleaner continues rotation to 180’ from start
E. Cup continues rotation until it is 180’ from start and facing down.

Simple CAD models explaining the idea’s principles help to take the sketches further and discussion. This can be a valuable method of conveying ideas extremely clearly to a wider team who may not have design knowledge or experience.

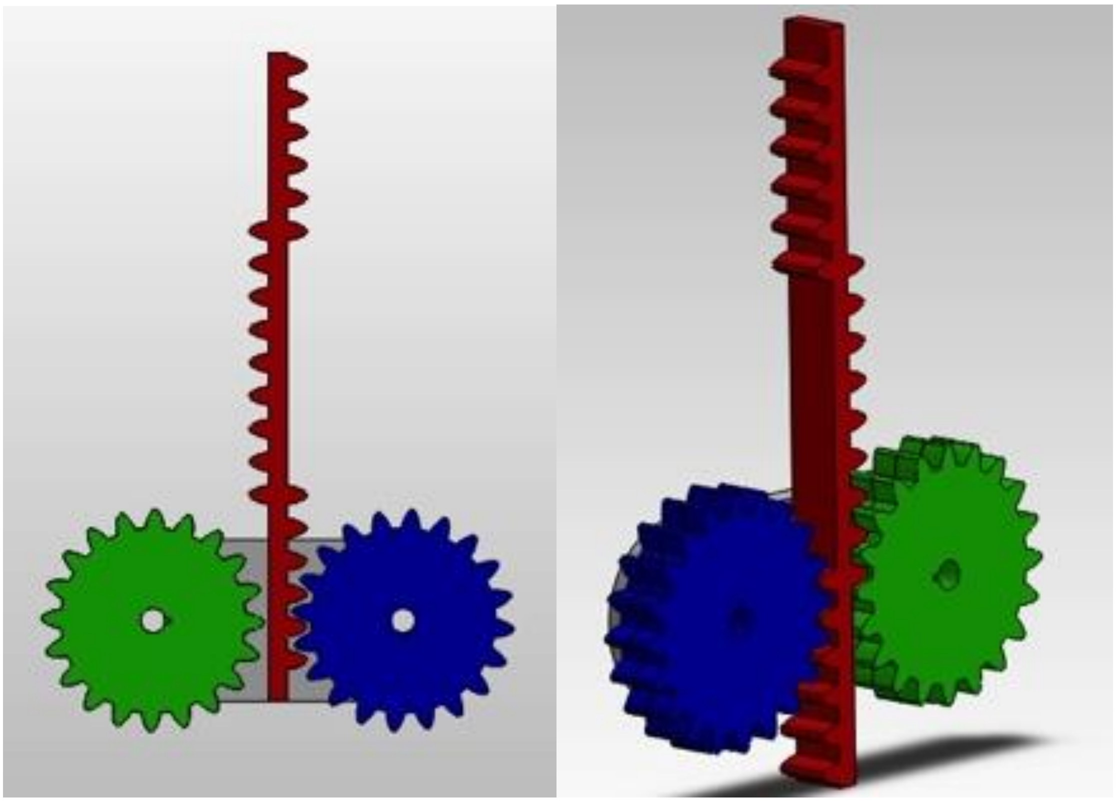


Figure 33 - Mechanism Exploration with CAD, starting to move into 3D models (C4D, Cranfield University. Ross Tierney © 2014)

CAD modelling allows for simple simulations to be conducted experimenting with the interaction between parts a lot quicker than if physical models were being used. During the idea generation and development stage it is important to utilise the strengths of virtual modelling with CAD and Physical models to the advantage. CAD has revolutionised the way products are conceived and developed allowing the designer to quickly visualise ideas, gain practical data such as dimensions and weights and carry out performance simulations. The benefit of physical models tends to come more from the qualitative human aspect such as comfort, texture and use (Hallgrimsson, 2012).

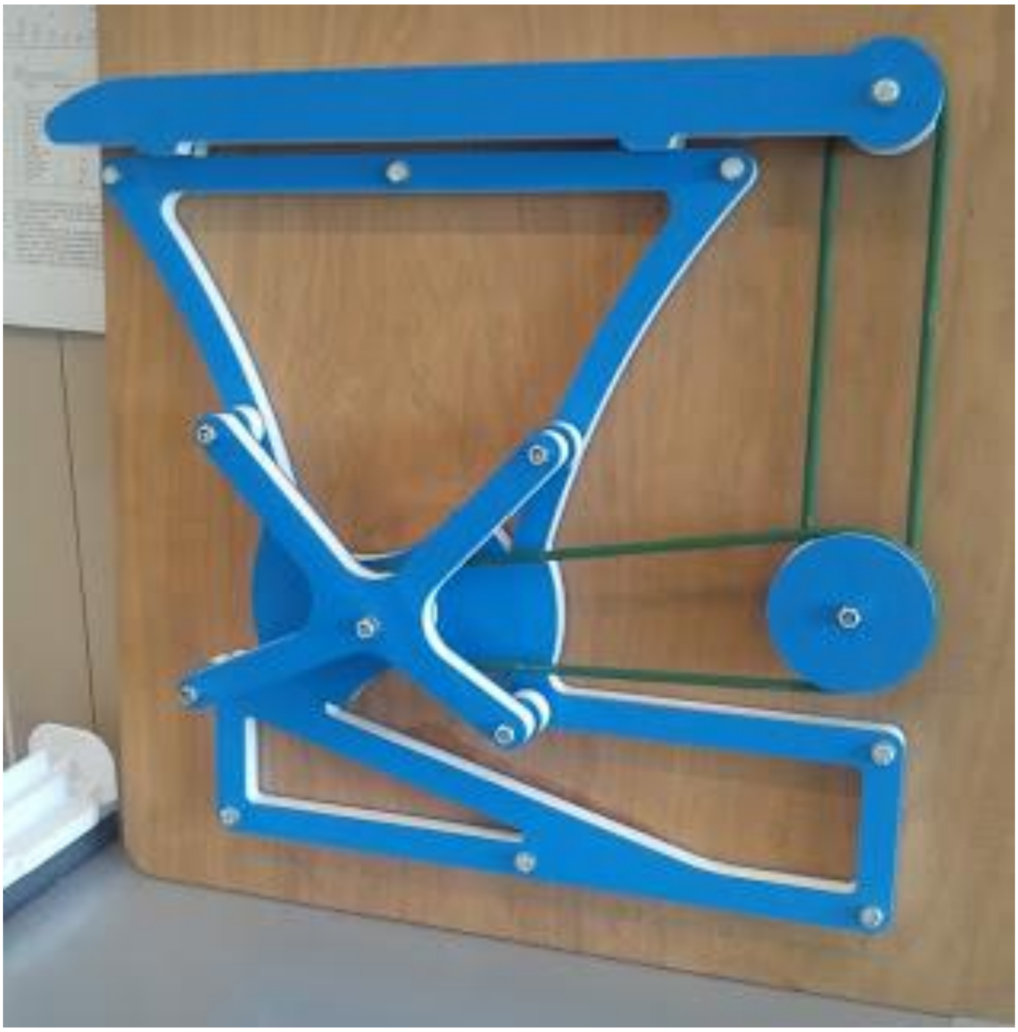


Figure 34 - Soft modelling testing and explaining principle
(C4D, Cranfield University. Ross Tierney © 2014)

This simple cross section model from the Case Study was used to convey to the rest of the team the action that is involved with powering the new flush mechanism. CAD modelling is a very quick method of explaining an idea but the Design Team in the Case Study found that a wider team of non-designers were more engaged with physical models. The final focus of the Case Study is an exhibition with the majority of attendees being non-designers from very diverse backgrounds so the team learned early on that it could be a good idea to display objects that encourage physical interaction.

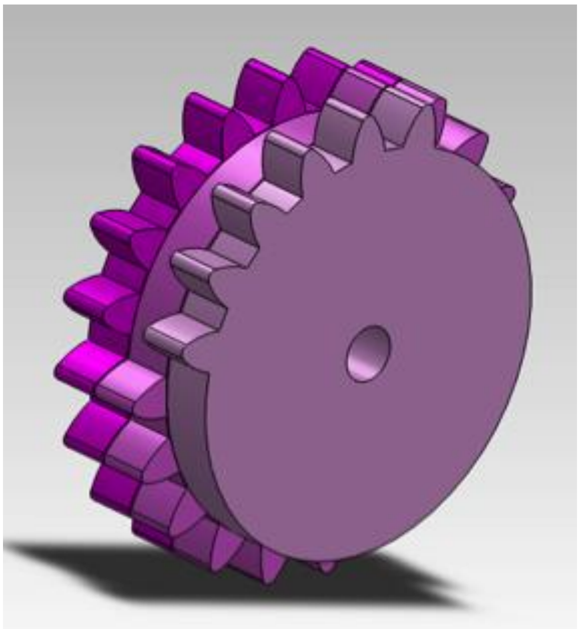


Figure 35 Split gear to allow different gears to be driven off of one wheel (C4D, Cranfield University. Ross Tierney © 2014)

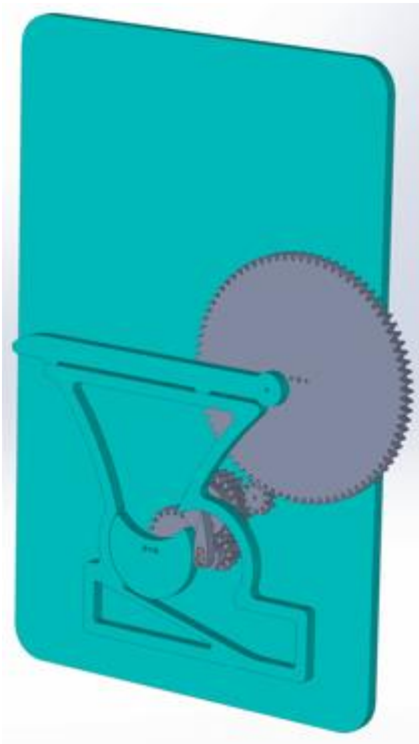


Figure 36 - Developed CAD models showing improved principles of idea (C4D, Cranfield University. Ross Tierney © 2014)

As the design improves and develops, a series of prototypes will be required to show the iterations and the latest improvements. In the Case Study the first prototype had been used to demonstrate how the power requirement could now come from integration into the user's normal behaviour. The following prototype has to show the next level of complexity that has been developed by the Design team and the consortium of experts for discussion with the wider team. This prototype had to show how the new mechanism could work using a second cleaning blade still powered from the user's action of closing the lid. The CAD modelling for this was considerably more complex as a series of gears working in sequence had to be arranged to utilise a small amount of power very effectively.

Figure 37 - Mechanism prototype rotating cup and secondary swipe all driven by the closing of the toilet lid
(C4D, Cranfield University. Ross Tierney © 2014)

The prototype in Figure 44 from the Case Study allowed for the idea and the more complex mechanism required to be explored and discussed further. The Design Team began by building the system on CAD before using a Laser cutting machine to cut the individual pieces of 20mm Acrylic for assembly. Once the assembly was complete, the prototype showed the wider team how the idea would work and the system could still be powered by the user closing the toilet lid but also with an additional swipe action included.

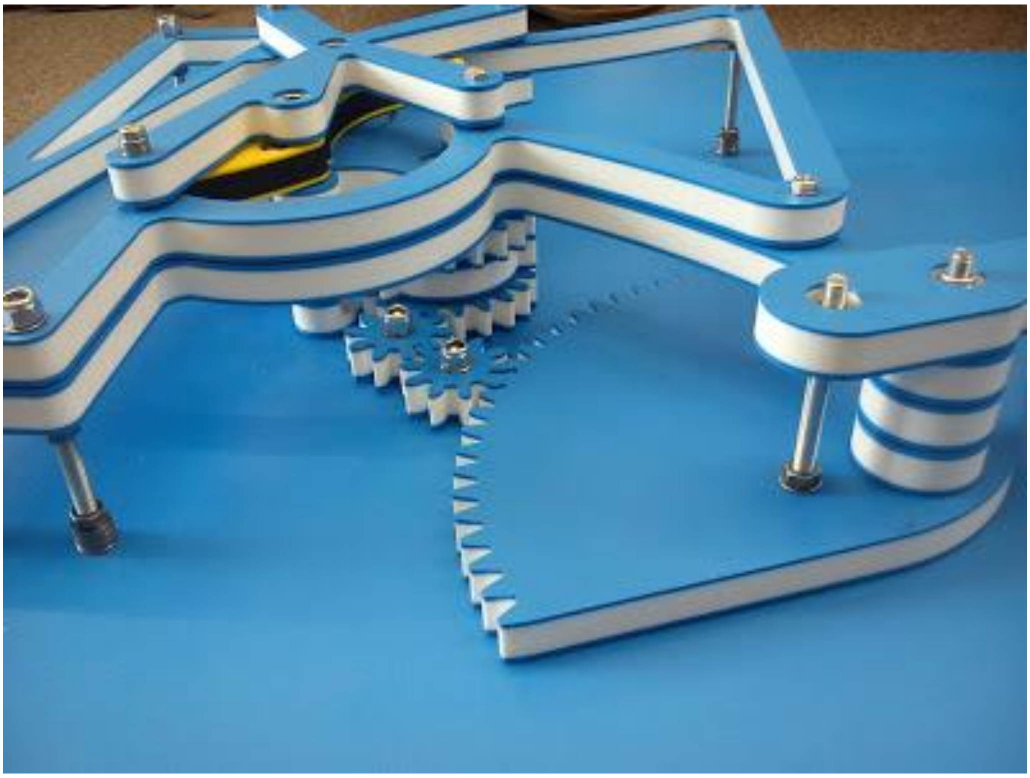


Figure 38 - Mechanism prototype gears
(C4D, Cranfield University. Ross Tierney © 2014)

Another interesting discovery the design team found in the transition from CAD model to physical model, was how sometimes CAD doesn't take into account real world forces. For example, the rotating drum on the concept would become disengaged easily. The design team used the small consortium of experts to discuss this and eventually theorised it was due to the CAD model not being affected by gravity in the same way the physical model was. This was only an issue as the gears had to disengage for the action to work but once disengaged they were likely to move and then become difficult to realign to the right point.

8.1.3 Testing the prototype

To test this and also try to counter the problem, a simple series of tests were conducted to run the action of opening and closing the lid multiple times applying pressure to different moving components. It was found that the easiest place to stop the misalignment from occurring was by preventing the main rotating drum from freely rotating. With each test the lid was opened 20 times, if it got to the end without jarring the result was entered as 'finished'. The scraper was then moved back to the marked position and the test starts again from the lid closed. If jarring occurs the number at which the jarring occurred is noted and the test begins again.

Table 11 – Misalignment Testing

Test number	Not holding	Pressure on drum	Pressure on scraper
1	13	Finished	6
2	2	Finished	Finished
3	8	Finished	13
4	5	15	4
5	2	Finished	6

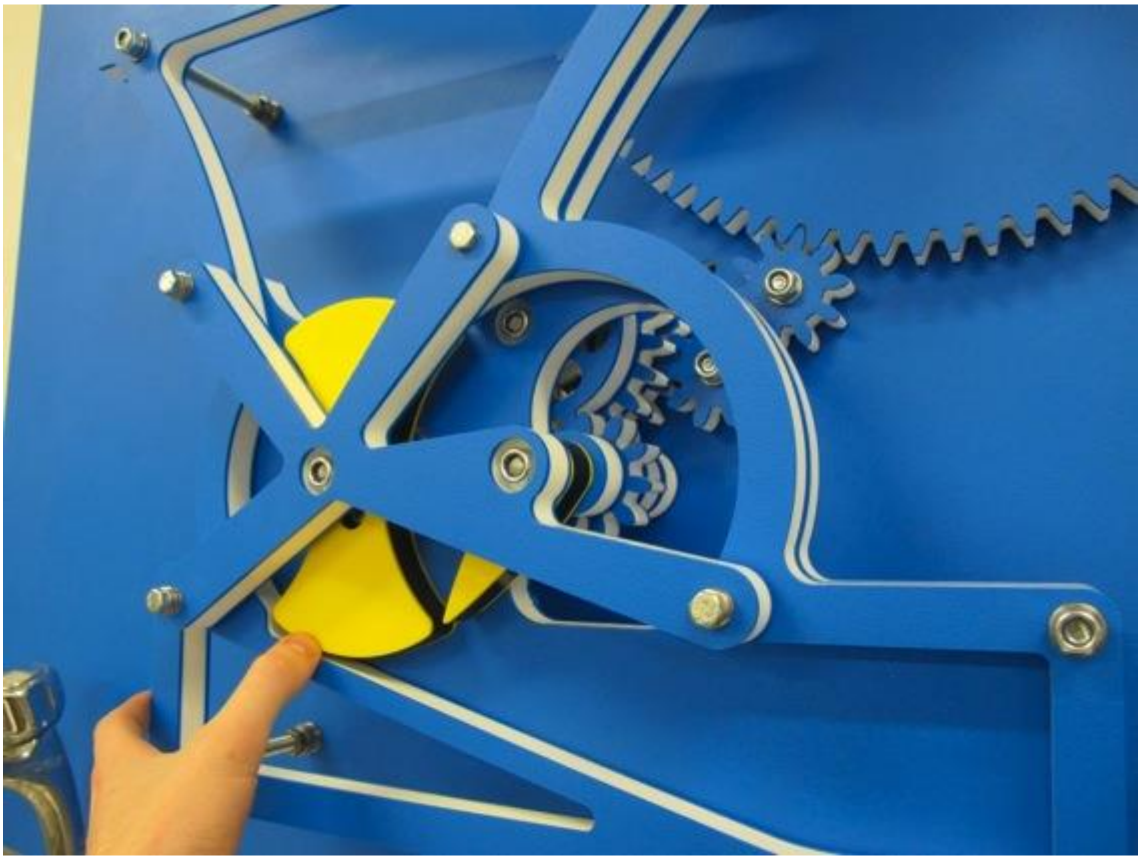


Figure 39 – experimenting with pressure to separate areas to prevent misalignment- this shows ‘Pressure on drum’
(C4D, Cranfield University. Ross Tierney © 2014)

There was a clear indication that holding the drum whilst rotating prevented misalignment. If holding the scraper were also as successful after 5 tests, a second round of more rigorous testing would be used to establish which is the better place to apply pressure. This was not necessary and the next prototype will include a method of restricting the drum from freely rotating.

Although this may appear crude, it is a very simple and effective way that gave the team instant results. It was also through this testing that the Design Team saw the benefit to having a really open and accessible prototype that showed clearly how the components interacted and would need to work in the final model.

With the third major prototype, the Design Team on the Case Study wanted to now produce a three dimensional model that would also allow for simple testing to take place. The previous models were more for demonstration and were therefore mounted on a large board for ease; a 3-D model has to be a stand-alone piece and could ideally be to scale to receive feedback from people on their opinions on the idea.

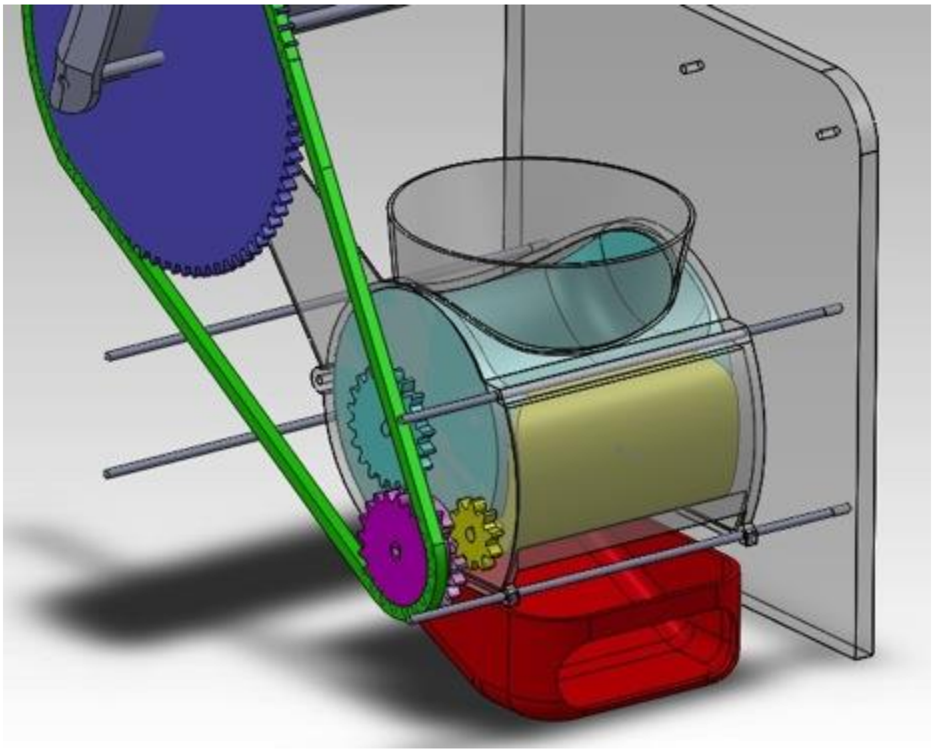


Figure 40 - CAD development of prototype with external structure (C4D, Cranfield University. Ross Tierney © 2014)

Early CAD work began with a few core pieces before slowly building up the working mechanism and also the supporting structure. Consideration had to be given to the surrounding structure that would take into account what happened when the prototype was being physically opened and closed. This was learned from the previous prototype that didn't take into account gravity. For the new prototype the Design Team discussed every possible way the prototype would be used to make sure it would work as desired in physical form every time.

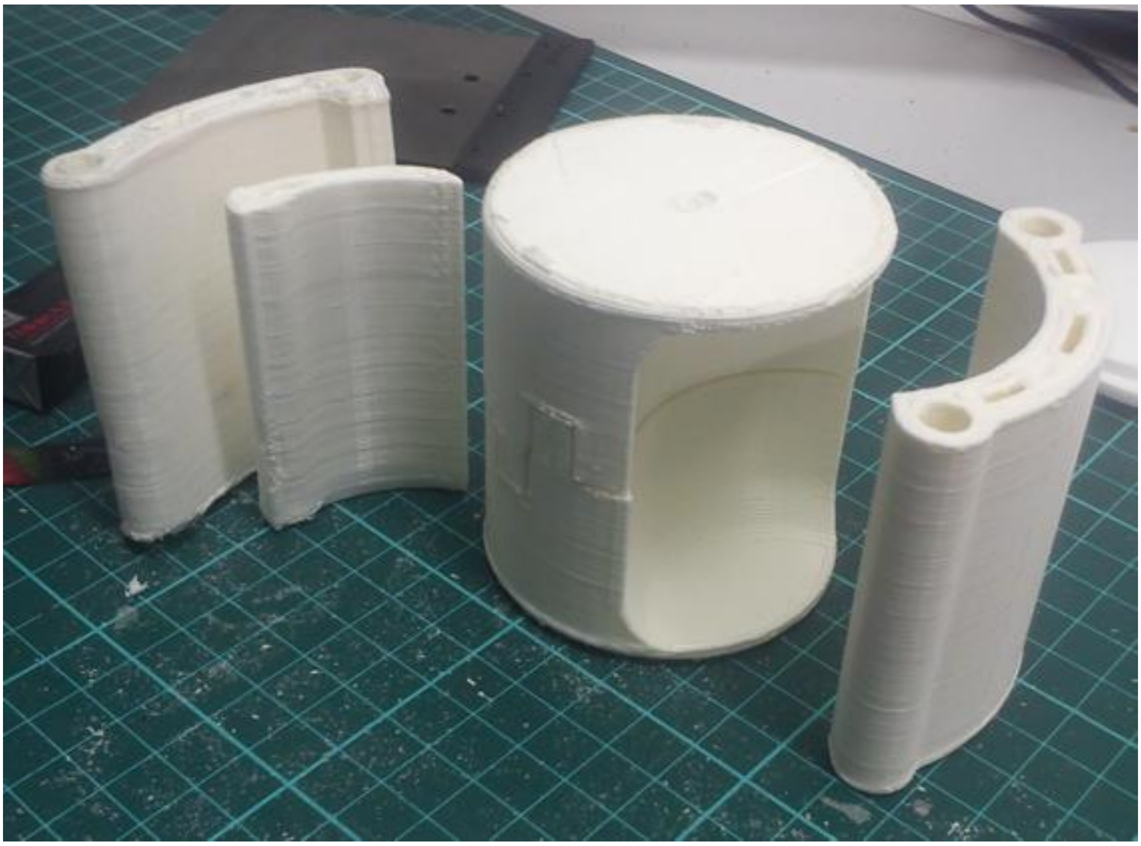


Figure 41 – Flush mechanism test pieces, 3D printed in PLA, scale 1:3 (C4D, Cranfield University. Ross Tierney © 2014)

The Design Team wanted to utilise the benefits of Rapid Prototyping and 3D print some of the components to conduct some very simple experiments looking at dimensions of the moving parts. Before the 1:3 scale model was assembled it was clear that the model in its current form would be quite difficult to understand as the swipe moves inside the cupped section of the drum. With that in mind the team redesigned the model also taking into consideration the easy access of the 2 dimensional rigs and instead designed it with completely open sides so the swipe is clearly visible.

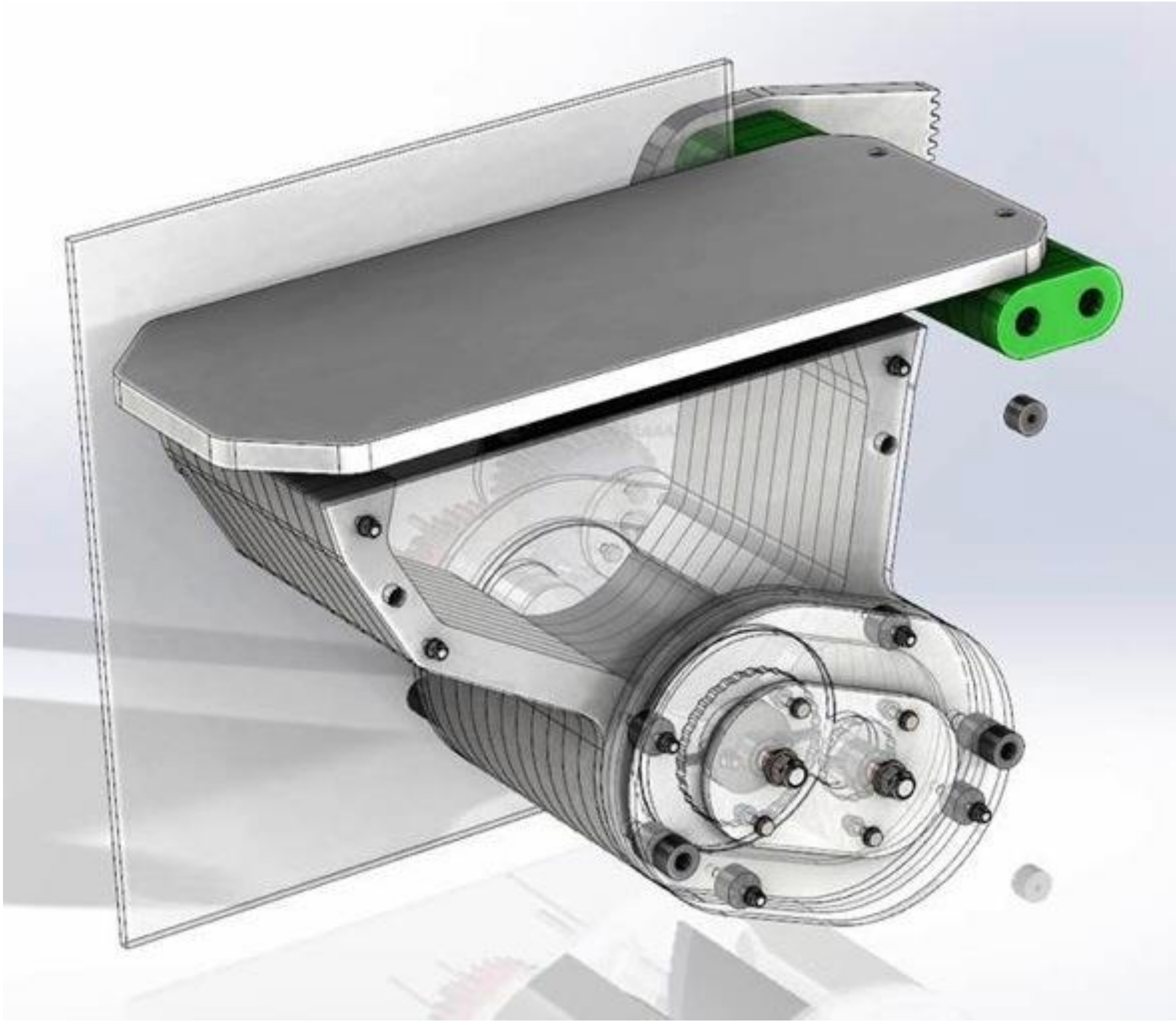


Figure 42 - CAD development of flush mechanism prototype with easy to see action
(C4D, Cranfield University. Ross Tierney © 2014)

The Prototype CAD model was almost completed and was sent to a local engineering firm who had previously been involved during the expert consortium discussions and idea generation phase. Outsourcing fabrication can very useful for freeing up time and ensuring a high quality model is produced, this will depend on resources available. The model was sent to the fabricators who adjusted parts to make them easier for their manufacturing and inserted the proper screw and bolt sizes.

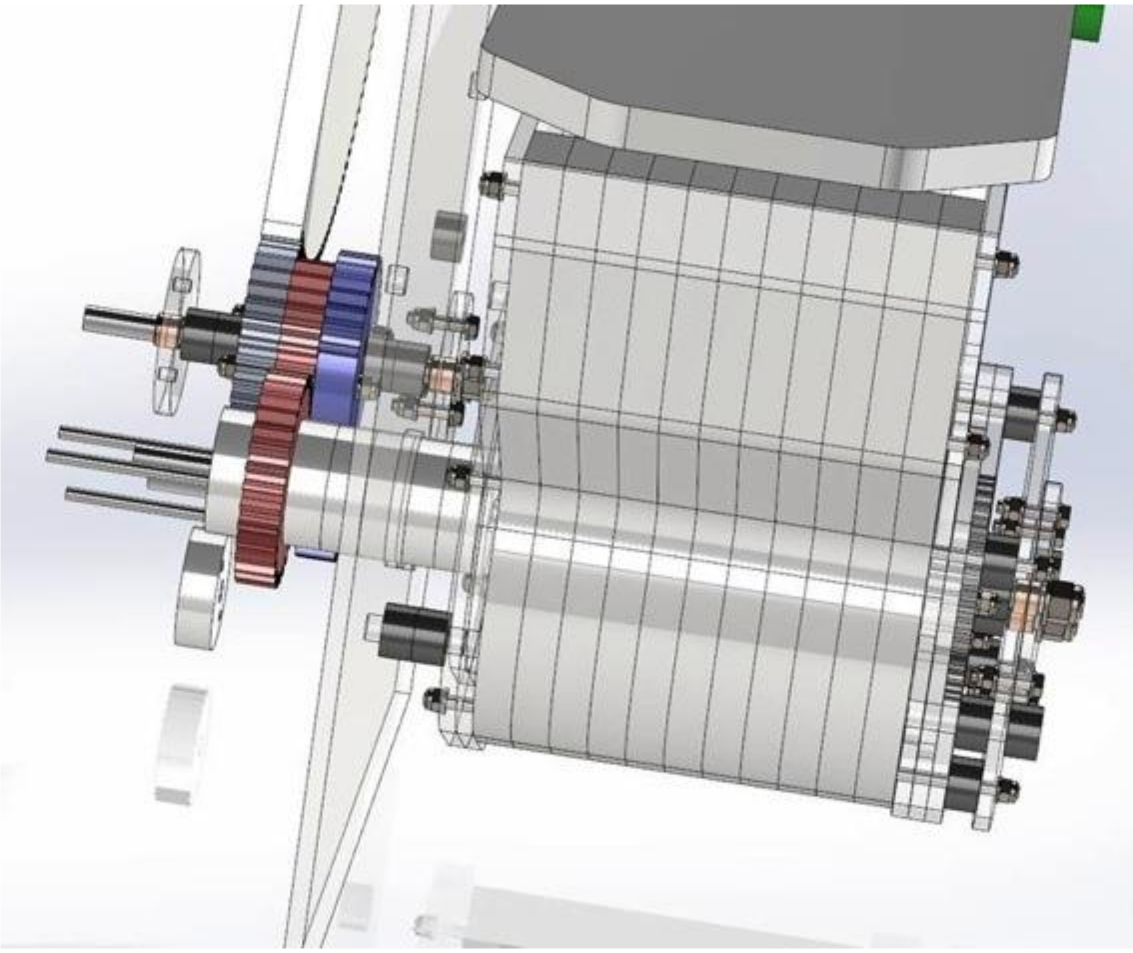


Figure 43 - CAD Development of prototype including fastenings
(C4D, Cranfield University. Ross Tierney © 2014)

The parallel lines along the white body show how this was going to be fabricated. Each line is a split between the different individual pieces Laser cut from flat acrylic and held together using long rods with threaded end sections and bolts.

The local engineering firm were incredibly valuable throughout the project, from the early discussions through to fabrication and packaging. It would be obvious to say use a well-trusted engineering firm but if possible, involve them as early as possible because external knowledge especially in important areas such as engineering will always be of value. On the following page is the engineered drawing of the prototype as the cutting parts began.

Figure 44 - Engineers drawing of prototype 3

The difficulty in building a CAD model of a working mechanism will obviously vary massively. The third major prototype being developed in the Case Study is very difficult and would take an experienced CAD modeller around 75 hours to complete. It is also advisable to produce small test sections if needed, or even very small quick physical models as the full model develops to ensure the outcome will be working and of a high standard.

After the CAD model has been agreed upon as being complete the pieces can start to be produced. In the Case Study, this was a number of laser cut pieces of plastic, mainly ABS and Perspex.

Figure 45 - Pieces of component after Laser-cutting
(C4D, Cranfield University. Ross Tierney © 2014)

Assembling these parts should be relatively straightforward as the full CAD model can be used as instructions and it’s a matter of patience and ensuring every part is in the correct place.

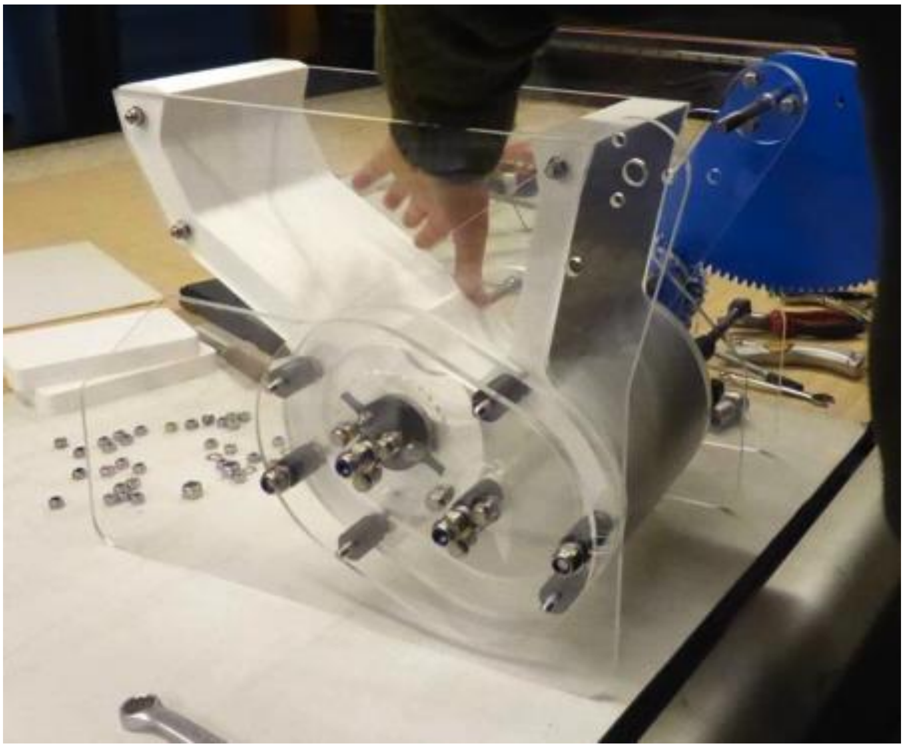


Figure 46 - Assembly of flush mechanism prototype from acrylic and Perspex (C4D, Cranfield University. Ross Tierney © 2014)

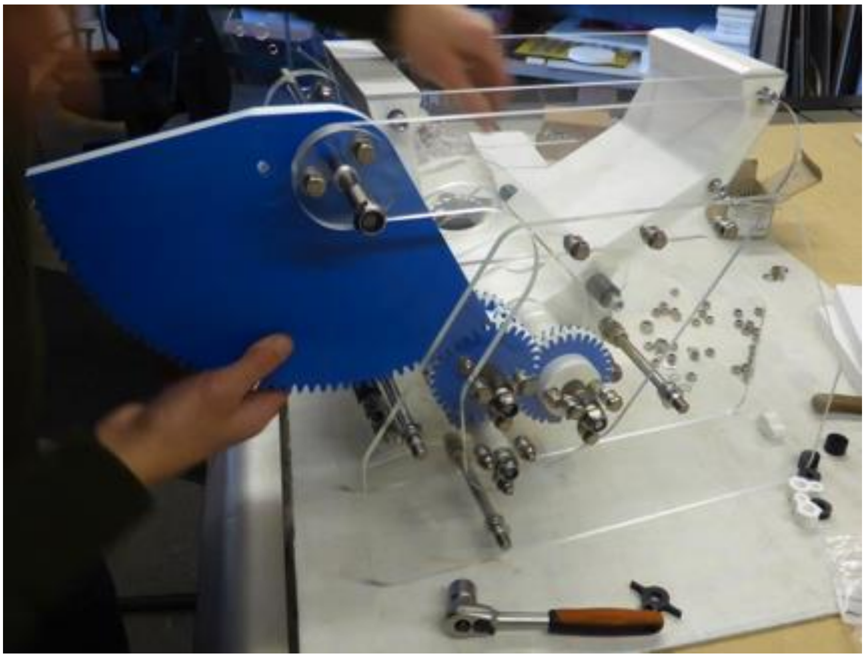


Figure 47 - Assembly of flush mechanism prototype pieces- driving gear (C4D, Cranfield University. Ross Tierney © 2014)

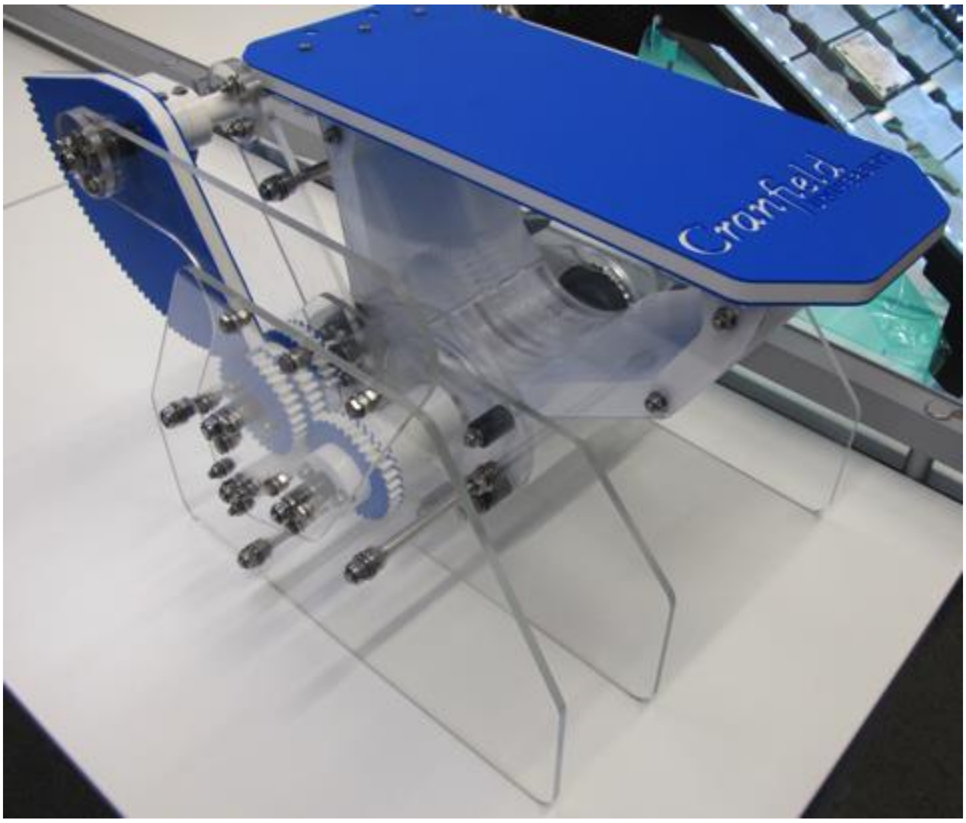


Figure 48 - Completed flush mechanism prototype (C4D, Cranfield University. Ross Tierney © 2014)

The completed flush mechanism prototype of the Case Study has been designed to maintain the openness and easy understanding of the earlier prototypes and also allows for quick adjustments to be made as well. The mix of transparent Perspex pieces with opaque ABS makes for a complex mechanism to be understood simply by a wide audience for use during team meetings developing the product or at an exhibition like the "Reinvent the Toilet Fair" which is the focus of the Case Study. Using open sections for the gears not only allows people to see very easily but also the Design Team to experiment with alternative components such as different sizes or materials.

CAD models tend to progress is continuously and produce a final outcome without always showing the stages that preceded it. The best physical prototypes have to show a clear development to the previous to not waste valuable time and resources. The progression should be in logical increments with each new version encouraging original discussion and innovation. To monitor and ensure this progress is continuous a simple table can be used to ensure each major prototype is a valuable use of time.

The Benefit to the project is the important section and the team should all agree the prototype would be important and would progress the project further. Here is an example from the Case Study with the benefits from each of the prototypes all of which show clear value and worth for the progression of the project. Additional columns could also be added to make note of other details or requirements, such as target completion date, estimated cost or even simple technical data.

Table 12 - Prototype benefit table from Case Study

Prototype number	Feature	Benefit to the research
1	2D cross section showing method of powering the system	Clearly displaying the idea to the wider team
2	2D Cross section showing mechanism for how the idea could work	Allowing simple tests and discussions about the feasibility and quality of the idea
3	3D display and test rig showing full concept	Experimenting with different components and testing the full concept

This incremental approach is referred to as Evolutionary Prototyping as this is a useful approach when the design specifications are uncertain or changing (Lidwell, 2010) and therefore monitoring each stage in the evolution is beneficial for ensuring efficient progression.

8.2 Case Study- Design of the external form of the toilet

The Design Team from the Case Study began working on simple quick sketches that could display the ideas coming from the discussions. The discussions were based on the key requirements set fourth during the Investigation Stage and using the design chosen by the wider team as the base for further development.

8.2.1 Early concept generation

The Design Team primarily used pens and paper but it would sometimes be hard to picture how large a toilet would be. As they knew the seat would be the standard height of 435mm sometimes it was best to draw it full scale onto a glass wall in the studio with dry-wipe pens to see how the form would be in real size. Checking a design to full scale is highly advisable to ensure what is being worked on is practical and still has the desired aesthetic appearance and characteristics.

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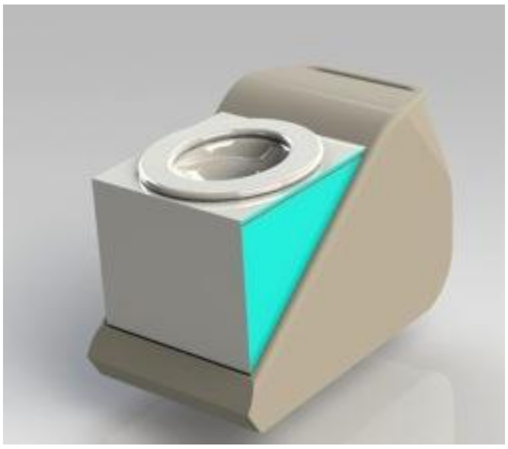
B. 

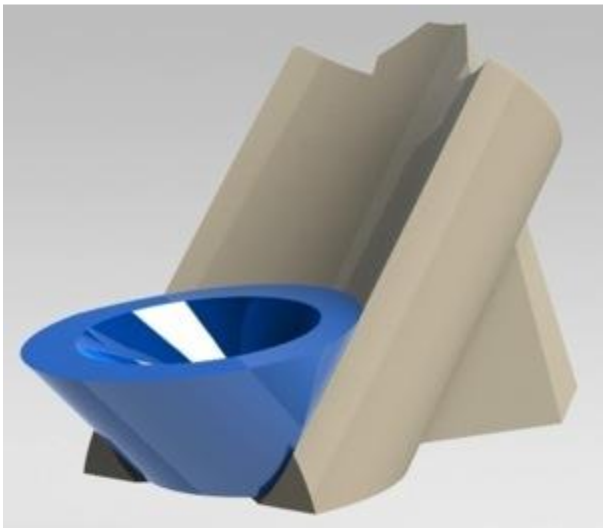
C. 
D. 

Figure 49 – Image Sequence A - D are the four losing design directions offered to the whole team from the Case Study during the down-selection and feedback workshop

(C4D, Cranfield University. Ross Tierney © 2014)

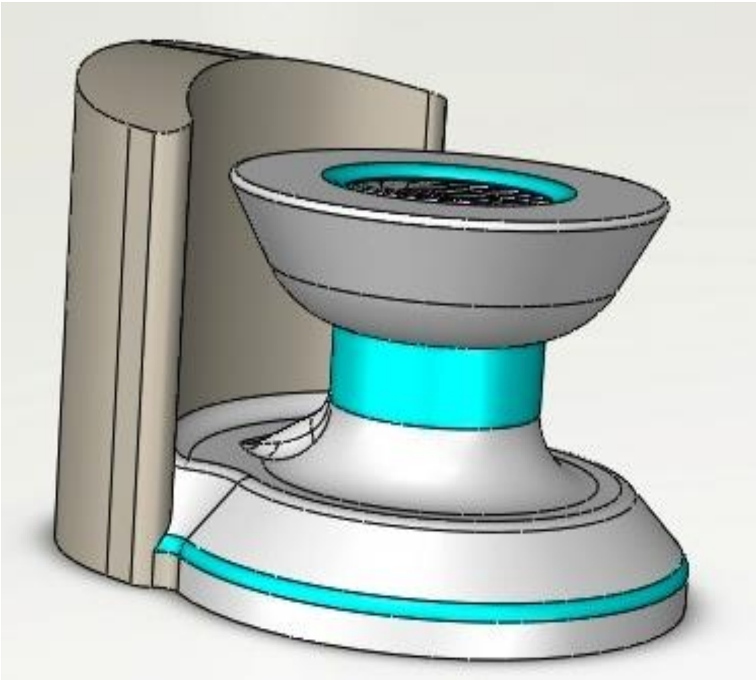


Figure 50 - The toilet chosen from the Case Study down-selection workshop

(C4D, Cranfield University. Ross Tierney © 2014)

This was the design chosen by the wider team during the selection meeting. It was agreed a unique shape was important for building a strong brand identity around a distinctive prototype.

8.2.2 Component configuration

As the other departments in the team progressed, component sizes began to be produced and the Component Progress Monitoring tool was very useful in documenting and consolidating data. As the quote from James Dyson (Dyson, 2013) mentioned earlier in this document, external design and internal component engineering have to be developed in unison for a product to work. With that in mind the Design Team worked simultaneously on the style of the object and the linking of the internal components, continuously striving to bring the two lines of development together into a complete unit. Basic CAD models of the rough components were built up and brought together to help with the weekly group discussions and also for the Design Team to have a good understanding of the system as it evolved.

Figure 51 - The components in simplified form being positioned in correct sequence using CAD
(C4D, Cranfield University. Ross Tierney © 2014)

This configuration is in the simplest set-up, which would not be practical, as the toilet would have to go on top. To be more realistic a support structure that could potentially be used constructed by 45mm modular framing was considered. The original brief stated that the outcome had to be a household system and fitting with standard toilet size, this current configuration would be around 1.5m off the ground conflicting massively with the project requirements.

It is always advisable to ensure the project brief and task requirements are always considered and available during all stages of development to ensure the direction is appropriate, having them on the wall of the design studio is also recommended.

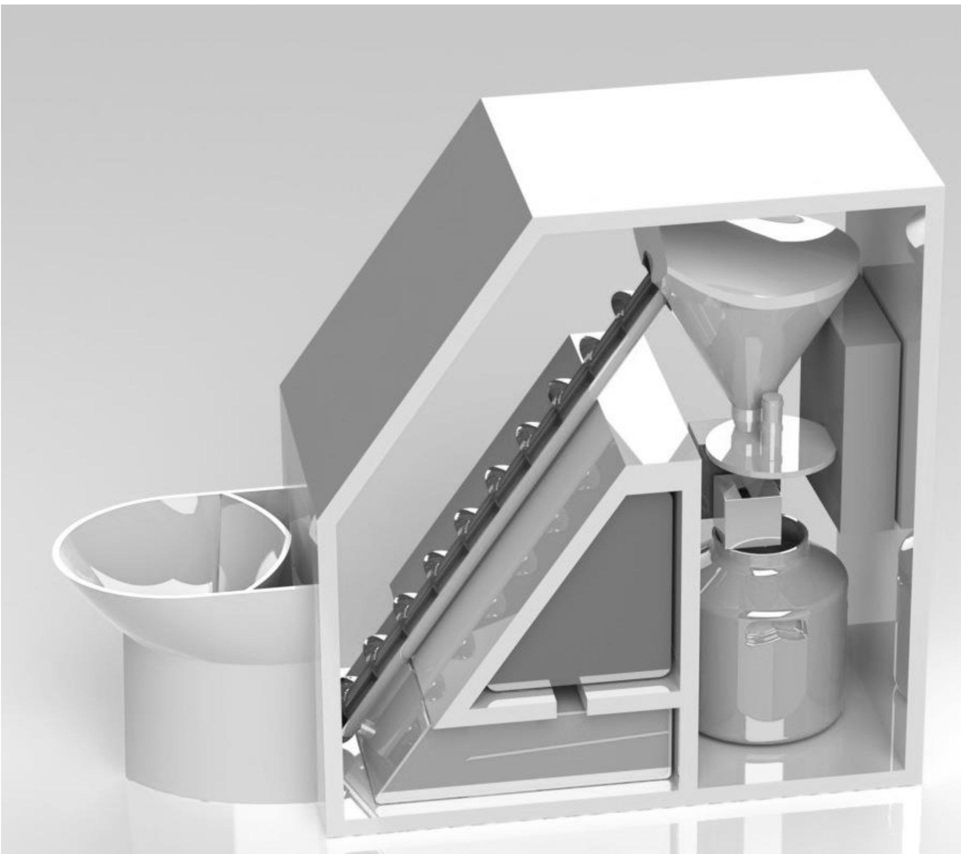


Figure 52 - Components in correct sequence and practical configuration
(C4D, Cranfield University. Ross Tierney © 2014)

In the Case Study, the components were now brought together in a more practical configuration that allowed for the toilet bowl to be at the correct level by using an Archimedes screw to raise the waste to an appropriate height. This set-up was not well received by the other departments, as it would not be the optimum placement for some of the components. It was then decided that there has to be a lot more collaboration amongst the teams to reduce the amount of time being taken to bring the components together. This model was not to scale but gave a good indication of layout and component requirements.

8.2.3 Team and component influenced development

When working with a large multidisciplinary team, overall simply too many individuals in one place can stifle progress in meetings at one time. Although these opinions will likely be valid and of use, it can be difficult to make definite strides forward and make efficient use of the time. In the Case Study a new weekly meeting was proposed that was based on the Cross Functional Teams (CFT) approach consisting of a smaller group of one person from each of the teams who was deemed to have the greatest understanding of their section (Trott, 2008). This new consortium of experts consisted all of the relevant departments and expertise but in a very manageable number of around five people. This would be highly recommended when working on the outside design of a system as the configuration will often require compromise and understanding of the different teams and respective components to establish the best internal structure. It was during the small working meetings that the water sciences team stated they needed their tank to be at a steeper angle and would therefore need more height. As one of the most important requirements stated that the dimensions should be of a standard toilet to ensure comfort for users, raising the toilet seat 80mm would not be acceptable. After much discussion of the importance to the function, the Design Team raised the toilet 120mm and gave it a comfortable step which was decided should also double as the water storage. This addition at first seemed a big problem but resulted in an improved design and easier access for the user, which was another requirement.

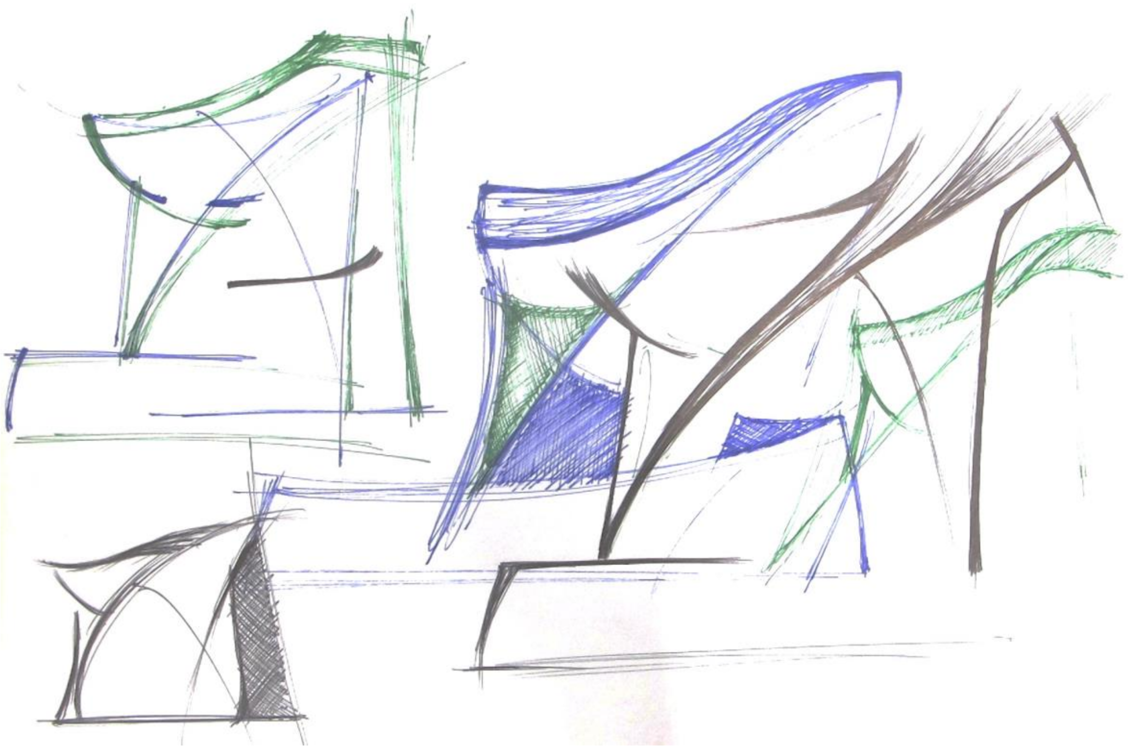


Figure 53 – Quick sketches experimenting with form taking into consideration the step and the larger volume required from the design selected by the team (C4D, Cranfield University. Ross Tierney © 2014)

Figure 54 – CAD render showing the simple design of the outside

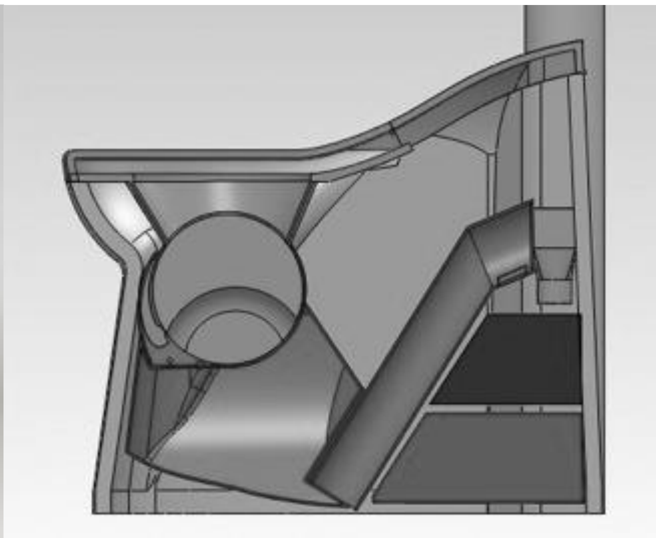


Figure 55 - Evolution of design and integration of internal components

The quick sketches were from the team trying to work to the Design Brief and meet the Requirements whilst also incorporating the bowl shape identified during the design down-selection meeting.

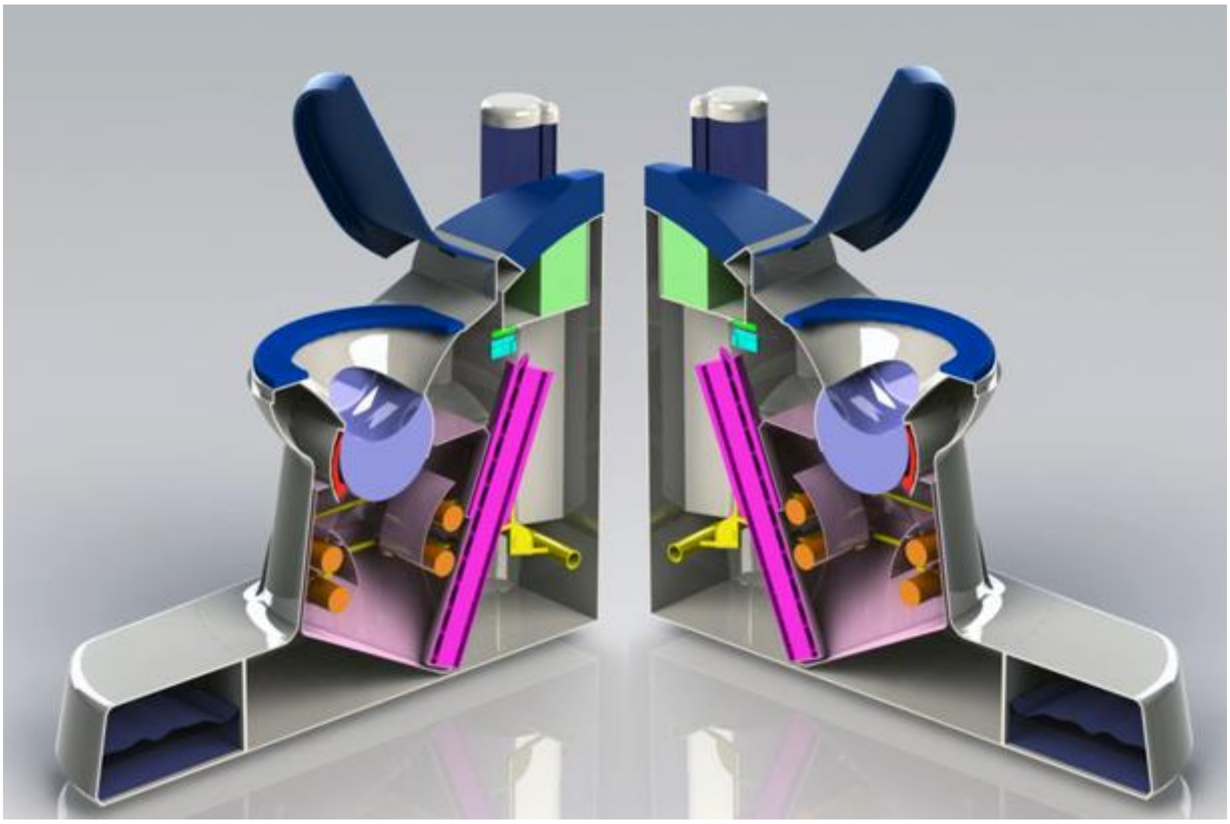


Figure 56 - Cross section of whole system
(C4D, Cranfield University. Ross Tierney © 2014)

As the styling and component configuration begin to come together it's important to ensure that the initial brief, the task requirements and the wider team's needs are being met by the external design of the product. A good approach to ensuring these needs are being covered, is making every aspect of the design as clear as possible to explain the reasoning behind the form which has been produced. This split image is visually quite striking and looks exciting but it is also is very informative and has all of the components to scale in the correct sequence.

In the image above, the flush mechanism can be seen in the correct position above the holding tank which will allow for waste to drop into it but without a direct airflow for the bad odour to pass out.

Figure 57 - 3D Print of Full Toilet to scale of 1:10 created during the latter development stage of Case Study
(C4D, Cranfield University. Ross Tierney © 2014)

3D printing is a very useful tool to have a much better appreciation of the form of the object. In the same way that was previously mentioned about physical prototypes having their benefits over CAD work, it's a lot easier for the mind to truly appreciate the form when it's real and physically able to be held and seen. This was intended as a quick model to be able to see how the form looked for real, to do this the printer was set to the largest layer size of 0.5mm, which although printed the model in around four hours the quality is relatively poor. The model has quite a large "Staircase effect". That is the term given to the finish on curved section of a print where the layers become visible. The lower the layer thickness the smoother the curve and the less evident the staircase effect is (Hallgrimsson, 2012). The purpose of this model was just for the team from the Case Study to view during a meeting so the quality doesn't have to be perfect. If it was being shown to a client or had to be the best quality possible it would be recommended to print as low a level as possible, in the case of this machine 0.1mm gave a very good finish but will take five times as long.

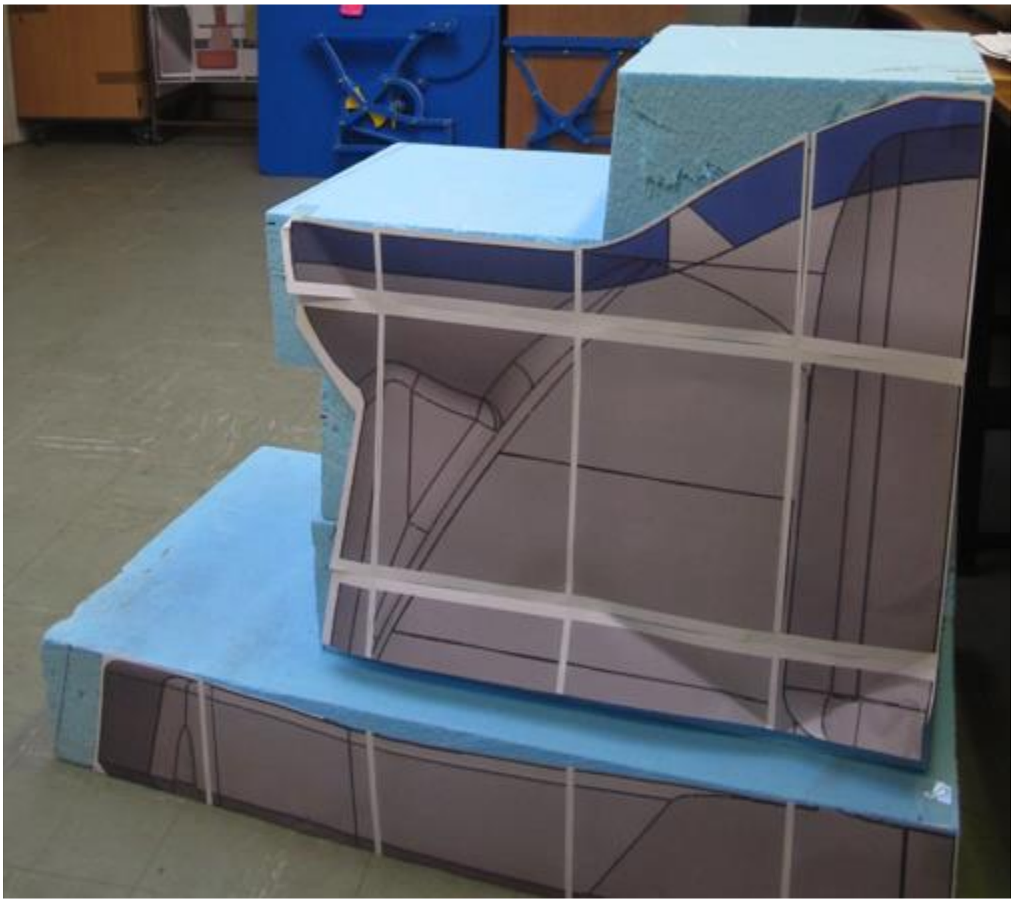


Figure 58 - Full size model for user experience testing
(C4D, Cranfield University. Ross Tierney © 2014)

Receiving feedback on a full-scale model is very important especially on the vital details such as size and comfort. Soft models such as the one from the Case Study above are extremely valuable in understanding user perceptions and opinions. One example of this feedback is the footstep at the base; this was measured to be larger than the average foot from the front of the toilet and the team thought this would be more than enough room. However, when the testers sat on the toilet they moved their feet much further in front than anticipated. As this is only a display unit for an exhibition this user testing it was not deemed necessary to conduct this type of experiment too rigorously and the time wasn't available either, instead three women of different heights (between the 25th and 75th percentile for average height), and four men of different heights (between the 25th and 95th percentile for average height) were used to give qualitative feedback. The other reason for this relaxed testing for sizes, is that the majority of dimensions on a toilet are relatively identical, so the majority of parts were just following standard toilet sizes. If this system was to go into further development the rigorous methods of ergonomic and user preference testing employed in the article 'An ergonomic approach to public squatting-type toilet design' (Cai, 1998) would be applied to ensure a comfortable use for all people. Another possible approach could be the Quality Function Deployment as used by Gonzalez (2003) in an article developing better school furniture.

Figure 59 - Computer render of final design

(C4D, Cranfield University. Ross Tierney © 2014)

At the same time as the final sizes were being confirmed, so too was the styling. The final design took influence from the latest range of high-end toilets with sleek and distinctive lines as requested by the wider team and also maintains elements of the identifiable bowl design that was similar to the one selected by the team in the down-selecting design meeting. Many changes had to be made to the original one chosen by the team so it would meet the requirements of the Design Brief. These included a larger volume needed to fit the components and a less pronounced bowl for easy cleaning.

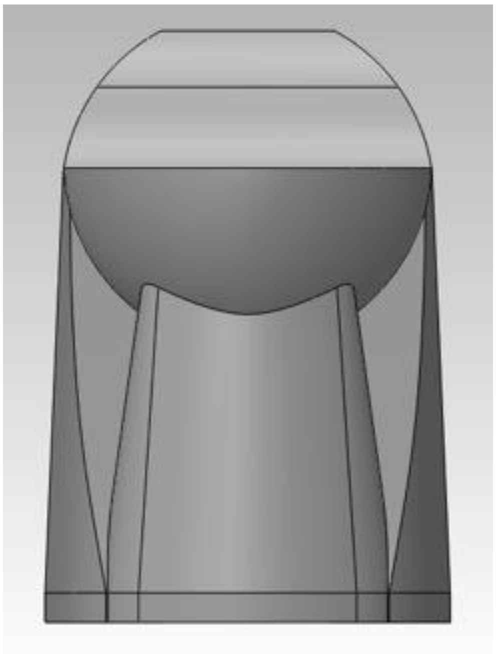
During the Literature Review a passage was selected as a key quote as it was a theme that arose on more than one occasion this was “Build an aspirational image around sanitation” (Quicksand, 2011), It was with this in mind that the Design Team took inspiration from the World’s leading toilet brand Roca.

Figure 60 - The Roca Khroma Toilet was the styling aspiration behind the toilet in the Case Study.

Image from: http://www.architonic.com/pmsht/khroma-roca/1083016

The design team also took influence from the Ashanti Stool that was observed during the Research trip to Ghana to be of great cultural significance to the target market. The team asked a sanitation expert in Kumasi who acted as a guide during their time there, if she thought people would be offended by a toilet influenced by the Ashanti stool, to which she replied “not at all, they would like it or even find it funny”.

Figure 61 - The Ashanti Stool that the inspiration for the front of the toilet. Image from: http://www.hamillgallery.com



The design of the front of the toilet

(C4D, Cranfield University. Ross Tierney © 2014)

The Design Team from the Case Study noted that drawing influence from a range of sources can end up diluting or confusing the overall unique identity of an object and would advise designers to be cautious of this. To develop a unique appearance, the Design Team worked around three main drivers for the external design of the object whilst also keeping in mind the aesthetic requirements that came from the team. The first being encasing the internal configuration of components as this is the principal structure but doing so in as small shape as possible. Second is striving for an aspirational aesthetic by taking influence from the World’s leading toilet company and finally a reference to the culture of the target market. The third being a gesture towards Ghana where the target market is. It was discussed whether this could ailienate other markets but it was decided that a subtle hint would be pretty discreet from the outside but could show that consideration was shown to the target audience.

Figure 62 – Front view of toilet **Figure 63 - perspective view of toilet**

(C4D, Cranfield University. Ross Tierney © 2014)

Figure 64 - The final aesthetic prototype
(C4D, Cranfield University. Ross Tierney © 2014)

The final prototype was fabricated by a specialist model making company that had been identified for having produced work similar to what was desired by the team. The prototype gives people an understanding of what the user interface for this system would be like. This includes having the flush mechanism rotate when the toilet seat is opened or closed, side panels which open showing how a service person would be able to access their internal areas and the overall look and feel of the piece. It is important to give as close to the user experience as possible baring in mind, as previously mentioned, the user interface comprises of a range of minute aspects which go into building up a person’s impression of an object, be that, the sight, touch and even the sound of how a person interacts with the object.

Figure 65 - The final prototype showing how by closing the lid the drum of the flush mechanism rotates exactly how it would on the finished toilet (C4D, Cranfield University. Ross Tierney © 2014)

8.3 Exhibition to World experts

The Design Team developed the exhibition stand to further emphasise their work concentrating on the needs of the user and bridging the gap between the target market and the technology. It would be advisable to future designers working towards an exhibition to consider how their work is being displayed and presented and ensure the stand is used to their benefit.

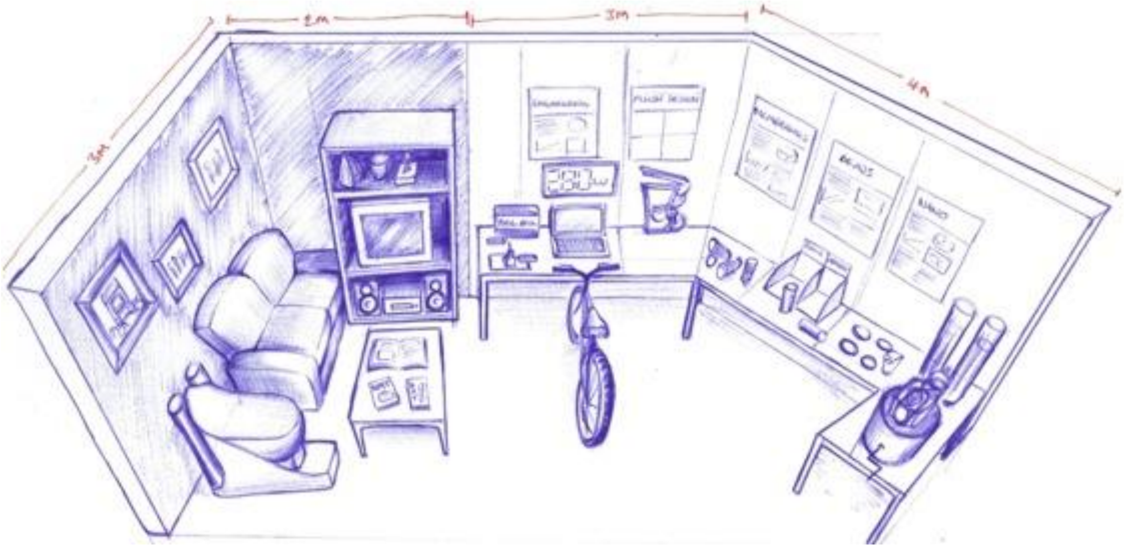


Figure 66 - Plan of the stand complete with mock-Ghanaian living room (C4D, Cranfield University. Ross Tierney © 2014)

Figure 67 - The Exhibition stand at the Reinvent the Toilet Fair - Delhi 2014 (C4D, Cranfield University. Ross Tierney © 2014)

The position of the bike and the ’works-like’ prototype swapped because it was decided it would give a better flow when explaining the full system to visitors. This is another example of ensuring the display at the exhibition is made to work to the benefit.

The Bill and Melinda Gates Foundation hosted the exhibition in partnership with the Department of Biotechnology for the Indian Government and invited some of the World’s leading organisations to see the team’s entries. Some of those in attendance are listed below:

African Minister's Council on Water	Ford Foundation
IDEO.org	Eawag
UNICEF	American Standard
Water For People	Global Interfaith WASH Alliance
Save the Children	Centre for Urban and Regional Excellence (CURE)
EOOS	UN-Habitat
California Institute of Technology	World Toilet Organization
Synapse Product Development	USAID
Quicksand	Practical Action
Unielver	Indian Institute of Technology Delhi
Water and Sanitation Program, World Bank	University of KwaZulu-Natal
WaterAid	Delft University of Technology

It is advisable that if a project is to be validated by qualitative feedback, it should be ensured the people giving the feedback are as experienced in the topic as possible. In the Case Study the Reinvent the Toilet Fair was a perfect place for this feedback as a large number of the World’s leading experts in the relevant fields were present. The interactive nature of much of the Case Study’s display was of great benefit for ensuring the visitors were engaged with the system and getting a better understanding of what the team are aiming to accomplish.

Figure 68 - The toilet being inspected by the Indian Minister of Science and Technology

(C4D, Cranfield University. Ross Tierney © 2014)

Figure 69 - Ambassador of Burkina Faso to India trying the toilet for size

(C4D, Cranfield University. Ross Tierney © 2014)

The attendees of the fair were very diverse all united by the issues in sanitation. From government officials who were there to see the potential future of sanitation, to a schoolteacher asking if the toilet from the Case Stud would be appropriate for her school in rural South Africa. To create a poster suitable for such a diverse audience the Design Team used the very clear but interesting cross-section used during the team meetings to show the internal workings. To make the poster a bit more striking the image was mirrored to give the illusion a toilet had been sliced straight down the middle and butterflied out. Some of the key components with a brief description were also included to the poster along with the explanation of how the flush mechanism works and what were the requirements of the development. As the team would be present to answer any questions it was not appropriate to go into great detail on the poster, the purpose was to give people an understanding and if they needed more information an expert was on hand to answer any questions.

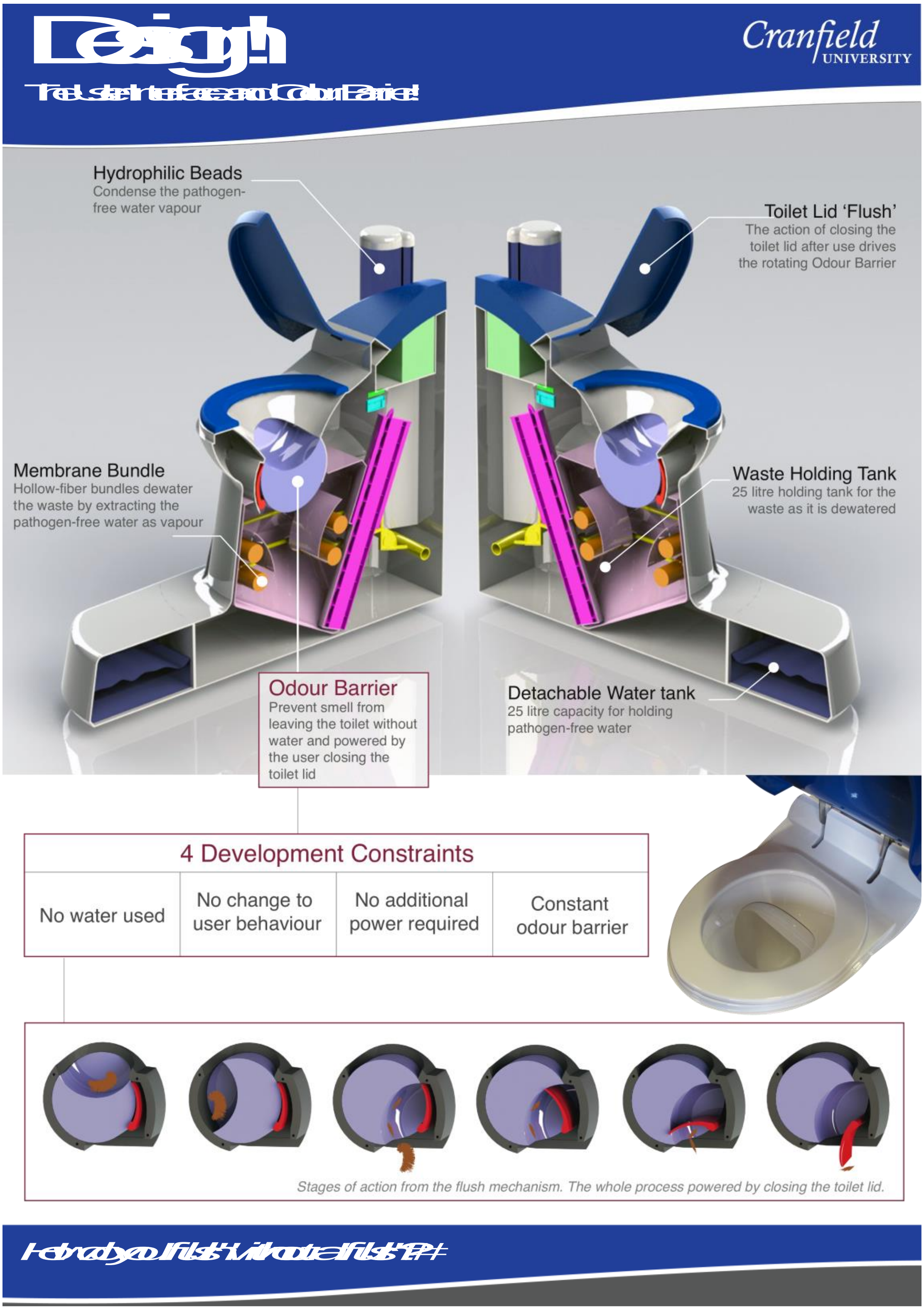


Figure 70 – The poster from the Reinvent the Toilet Fair explaining the Flush mechanism rationale and showing how the components fit within the toilets as well as a few select key features (C4D, Cranfield University. Ross Tierney © 2014)

The team deemed the Reinvent the Toilet fair a success and the prototypes that were on display were a fitting reflection of the work that preceded it. The Implementation phase for the Design team produced two individual prototypes with different purposes to combine and give the best explanation of the complete User Interface. The implementation phase began with in depth discussions on what are the requirements of the project are and how will these be considered throughout. For the flush mechanism external experts were brought in for idea generation that focussed on the requirements and used the knowledge from the scoping phase, the State of the Art in particular, to formulate concepts. The ideas began with simple sketches before using CAD models and then physical prototypes when necessary. Weekly discussions using a wider team of experts would focus the development and ensure the concept is progressing as well as possible. The final prototype is a 3D flush mechanism that shows the concept clearly and will allow for the Design Team to run simple tests in the next phase to develop the concept further.

The implementation of the design of the outside of the toilet also began with discussing the requirements and simple sketches but also relied on information from the other members of the wider team to understand the internal components. Two research approaches were developed to improve this section; one was to monitor the progress of other components and one was to gauge opinion of the whole team as to their opinions on the designs of the outside of the toilet.

9 Results of the Research

This multifaceted project does not lend itself easily to a traditional research project. The initial brief did not require rigorous testing but instead wanted to see what could be possible. The final outcomes are to be produced to a level that gives people at the Reinvent the Toilet fair an idea of what the team would aim to do if they reached the next round of funding.

9.1 Qualitative feedback on the Cranfield entry to the Reinvent the Toilet Challenge

"I was really impressed with your work—it was great to see so much consideration of design in your project"

Senior Design/Project Leader - IDEO.org

"The Cranfield entry was the only team to really truly understand the user"

Account Director - Synapse (Design firm)

"I'm really impressed with the flush mechanism and think you could be on to something really great and I want to help in any way I can"

Professor at University Kwazulu Natal and senior advisor to the Reinvent the Toilet Challenge

"The flush mechanism is the best thing I've seen at the fair, did you have a watch maker on your team to do the gears?"

Engineer researcher from Toronto University.

"It's really impressive and it's clear a great deal of thought has gone into the user on this project."

The CEO of Santec. RTTC grantee

The feedback that was received reflected the Design Team's aim with three of the top five quotes acknowledging the importance target user. The flush mechanism was also well received and interested a lot of people and it was also more formally recognized as being one of the best innovations of the fair and was presented to a select group of leading experts of sanitation. This feedback shows people really value the contribution to knowledge.

9.2 External appearance of toilet system

To evaluate the final design of the outside of the toilet, images were sent to a Clean Team senior manager who was also born in the target area and whose expertise was used in the scoping phase. *"I think the toilets look great. It can fit well into people¹s spaces and since lots of people are into the western style design, I can see many people wanting to use it. It looks very glossy (easy to clean) and nice, many people would be proud to own one."* The final line of people would be proud to own one is the real essence of what wanted to be achieved through the external design. The whole team discussed this feedback and the importance of whom it came from. To have such positive feedback from someone who knows not only the sanitation industry but also the people of the target market extremely well is a huge success. This success is a reflection of the great deal of time and consideration that went into the Scoping, Investigation and Implementation phases.

9.3 Flush mechanism

The requirements of the flush mechanism were no water, no additional power, no change to user behaviour and a constant smell barrier. At this stage of the project it is difficult to say for definite if there is a constant odour barrier as it has not been possible to fully test due to budget and time constraints. The mechanism however, is based on an existing system that has a constant odour barrier so the new system, should work in theory as well. In the next phase this will be developed and tested further,

To establish the effectiveness of the development of the new flush mechanism in the Case Study, the Design Team returned back to the grading system used in the State of the Art. This was deemed an appropriate method of rating the new system as it had already been used to evaluate the technology currently in use. The Consortium of Experts involved in the rating in the State of the Art were reassembled to rate the newly developed flush mechanism. It was accepted this would not be entirely accurate as the new flush mechanism is still in a very early stage so on a question such as 'cost per unit' an informal estimate had to be made based on what is comparable to the other systems within the table.

Table 13 – Rating the new Flush Mechanism

	Performance Indicator							
System	Power consumption	Amount of Water required	Prevention of Smell	Ease of Use	Cost per unit	Running cost	Reliability	Total
Aeroplane	1	4	5	5	1	4	4	24
Flap	5	5	1	5	5	5	5	31
Porta (no barrier)	5	5	1	5	5	5	5	31
Caravan	5	4	2	1	4	4	4	24
Space	1	5	5	1	1	4	5	22
Dry-Flush	3	5	5	4	3	2	2	24
Clean team	5	5	1	5	5	5	5	31
Loowatt	5	5	5	5	3	4	4	31
Western	5	1	5	5	1	4	4	25
Evolute	5	4	5	5	2	4	4	29
New Flush Mechanism	5	5	5	5	3	5	4	32

The estimated results of the grading gave the new flush mechanism the highest result out of all those surveyed. The reliability of this was discussed further as an issue of bias arose. Although the team sought to be honest it was still determined further external opinion would be needed.

The team from ‘Case Study 2’ was identified as being the ideal group to rate all of the systems with neutrality. To do this the group was shown each system, with a brief description and key facts for each, they were then asked to rank the systems using the same method as previously discussed.

Table 14 - Independently rated new Flush Mechanism

System	Total	Mean
Aeroplane	130	21.6
Flap	158	26.3
Porta (no barrier)	145	24.16
Caravan	129	21.5
Space	116	19.3
Dry-Flush	141	23.5
Clean team	160	26.6
Loowatt	164	27.3
Western	134	22.3
Evolute	143	23.8
New Flush Mechanism	169	28.16

These results were only intended as a validation technique to ensure that the system that has been produced would be worth developing further if the further funding allows. As previously stated the purpose of this stage of the project brief was to give people an understanding of what the team intend to do.

It is important to match the validation techniques to the level of development required. A recommendation for the Case Study to take the concept further would be conducting rigorous testing into materials, component shapes and forces to determine what makes the best flush mechanism. This would have to be carried out with a very strict systematic approach to ensure the best outcome that would eventually lead to a fully self-cleaning system.

The odour barrier of the toilet developed in the Case Study has great potential for development and has already received recognition from a number to of different sources. Although still in the early stages, the design being developed has potential to become a hugely important and disruptive technology not only for the developing world but also for the developed world considering Standard flushing toilets use around eight litres of water per flush (George 2011). The strength of this technology lies in the strict Requirements that were set out in the Investigation phase to really force the Design Team to work towards the hardest constraints possible.

The Flush Mechanism was selected at the Reinvent the Toilet Fair as one of the best individual innovations and meant that the Design Team had to present this to a select committee of sanitation experts from leading international charities.

9.4 Concept explanation tool – Tailored Canvas

A relatively simple but effective tool that was developed to explain concepts to a multidisciplinary team resulted in incredibly valuable feedback and would be recommended for use by other designer’s or practitioners working on a similar project. The tool has to be carefully considered and constructed to maximise benefit by working through a number of questions. The questions will allow a team to tailor the Canvas for their own project needs to ensure the meeting they will be using it in will be as efficient as possible.

Questions

Q1. How effective was the tool at conveying the ideas?

A1. The tool was very effective and made the workshops with the client much easier. We used a series of categories and these were particularly effective for quickly explaining the main features.

Q2. How did the questions help with the development of the tool you used?

A2. They helped massively they really made us think about what the task was and what the goal of the workshop is.

Q3. Did you feel the tool was easy to understand if the target audience is not from a design background?

A3. Yes, that was really what we wanted to do so the tool did a good job of that and that came from the questions we went through at the beginning

Q4. How else did the tool help with the project?

A4. When we began to categorize the concepts to fit on the different cards it became clear that some of the categories had far less concepts than others and we needed to go back to the drawing board and work on a few new ideas to balance them out

Q5. Did the trial workshop help shape the tool

A5. The test we did was with other designers in the studio who might be familiar with concept explanation so the feedback we got was good. In hindsight, after having used it for real I think we should have made it simpler, it was a bit busy and perhaps didn't need to be.

Q6. Do you have any other comments on the tool?

A6. Only that we should have simplified it apart from that it was great.

The preparation for this tool is extremely important as shown by the feedback from one of the team members on the new Case Study. What they have highlighted is something that hadn't been previously thoroughly considered; the test group need to be as similar to the primary target group as possible to make sure the new Tailored Business Canvas will work as well as possible.

9.5 Validation of Implementation

The purpose of this research was to develop a User Interface for a new sanitation system. The Case Study that was used throughout this research can now be reviewed by referring back to the Design Brief that was set earlier in the recommended to be set earlier in the project as a way of stating definitive requirements within the project. The requirements were seen as the definite

Design Brief – Case Study

Flush Mechanism Requirements

- No additional water *-Yes*
- No change to user behaviour *-Yes, utilise behaviour rather than change*
- No additional power *-Yes*
- A constant odour barrier *-Yes, based on results of a similar system*

Additional Considerations

- As simple as possible to reduce final cost and risk of failure *Yes*
- 1.25 litre holding volume for the waste *Yes*
- As small as possible to reduce overall size required for the toilet *Yes*
- Adaptability to other systems *Yes*

Deliverables required

A proof-of-principle prototype has to be developed to explain the flush mechanism and allow for further testing to the idea.

-Yes, a 3D test prototype was developed in time

The External Appearance

Requirements

- Aspirational appearance -*Yes, confirmed by expert*
- Fit all components in correct and practical sequence -*Yes*
- Small footprint -*Yes*
- Standard dimensions of normal pedestal toilet -*Yes*

Additional Considerations

- Easy Clean -*Yes*
- White high-gloss finish -*Yes*
- The design has to look good with or without the two external Membrane Columns each with the dimensions 750mm x 100mm x 100mm -*Yes*
- Look like a permanent appliance -*Yes*
- Simple manufacture for next level of development -*Yes, rotomoulded shell*
- Easy access for maintenance staff and user -*Yes*
- Minimal material as possible -*Yes*

Deliverables required

The user interface has to be conveyed to a wide audience at the Reinvent the Toilet Fair in Delhi, March 2014. A full-scale prototype of the toilet has to be produced that gives attendees a complete understanding of the ambitions and direction of the Cranfield entry.

-Yes, a full sized prototype was produced in time that function the same way the interface of the real toilet would.

The Design Brief in the Case Study has been successfully completed

It is always good to refer back to the earlier stages of the research to ensure the project is on track. The brief was referred to continuously throughout the development so evaluating the implementation from the Brief was a valuable and successful task.

10 Discussion

Five key areas of improved understanding will be identified and discussed using ‘Triangulation’ as it is a very valuable technique for increasing the validity within Qualitative research. This method does not automatically mean the sources arrive at the same result as many researchers know this is unrealistic (Mathison, 1988) these inconsistencies are not to be considered negative but rather an opportunity for a deeper meaning to be uncovered (Guion, 2011) as patterns emerge.

10.1 Importance of odour

When the team discussed “what is the user interface” it was concluded it was a combination of the users senses reacting to the object forming an experience. A bad odour would create a bad experience for the user. During the research trip to Ghana, the team were taken to the low cost public toilet by a sanitation expert who mentioned that people often remove their shirts before entering the toilet as the smell can cling to clothing. It was also noted in the Literature Review that the perception of odour is a major stumbling block when it comes to nbuilda. According to the head of solid waste management for Washington D.C, women in general are more affected by the smell than men (George, R. 2011) and considering the manager from the Clean Team interviewed during the research trip said that it tends to be the women who see the value in having their own toilet, removing the bad odour from the situation may be of huge benefit when it comes to implementing the system. The findings indicating the importance of preventing odour, lead to a large amount of time being spent by the Design Team trying to prevent this.

10.2 Understanding the target market aspirations

The stand that exhibited the new toilet system was constructed to look like a Ghanaian living room. The team weren’t implying the toilet would go into everyone’s living room, but has to go somewhere in a house that has most likely never had a toilet before. It is also easier to convey the high standard of living with the living room than any other room.

Highlighted during the Literature Review, the research by IDEO.org (2011) explained how every aspect of the sanitation system had to be considered in order to deliver a brand that people can trust. The Design Team from the Case Study followed the same thought process in order to convey the whole story of what their system involved and show a deep understanding of the target market. This started with understanding the technology the project is based on. As the system is relatively small, it would make sense to target a household system rather than a public toilet set-up like some other teams working on the global challenge. If this is going into someone’s house it will likely cost more than a public system simply due to economies of scale and processing volumes. Therefore it was very early in the project that the system being developed would not be aimed at people in absolute poverty but the middle to upper lowest class. By 2015, 2.7 billion people will lack access to a toilet (U.N.U, 2010) and within that huge number there will be a spectrum of wealth that is still facing the same basic problem. This was also confirmed at the Reinvent the Toilet Fair, where a designer from another team mentioned that whilst researching in peri-urban in India, the house they were in had no toilet but a TV showing the Disney Channel.

A key quote identified in the Literature Review was from the Quicksand report (2011) on user attitudes towards sanitation that declared, “An aspirational image had to be built” around sanitation to improve the likelihood of success (Quicksand, 2011). During the primary research in the target area on this project, the team noted the high standard of living by people in a region called Ashtown and this now became a very specific target market to work towards. The challenge arises in conveying the target market and the high standard of living to other people, in the Case Study’s instance, an exhibition. To do this the team sought to ‘complete the story’ and give people an understanding of how the right technology can meet the needs of the target market.

- The design of the toilet had to be aspirational so it was a desired product that people would not only accept into their homes, they had to *want* it in their home as it was something to be proud of.
- The benefit that the toilet gives clean water for use is an improvement from a simple bucket-collection system.
- The system could not smell, as nothing aspirational has a negative odour association, hence the development of the flush mechanism
- The stand showed a standard housing setup with a photo on the wall of the real living room it was copied from.

Figure 71 - The mock-Ghanaian living room with toilet prototype and flush mechanism prototype
(C4D, Cranfield University. Ross Tierney © 2014)

The feedback received at the fair was very positive however a statement from the Clean Team manager had particular significance for the team, after stating her belief that "many people would be proud to own one". This gives great confidence for the team moving forward that the findings from the research were accurate and the needs and aspirations of the target market have been met.

10.3 Problems with existing solutions to this sanitation issue

There are a number of toilet systems that if implemented correctly could radically alleviate the problem facing people who do not have access to a toilet. Out of all of the systems evaluated during the State of the Art and seen during the research trip to Ghana, the best overall system is Loowatt's sealing bag system that is simple and effective and has great potential. The benefits of the system are that it used no power or water, prevented odour and made the collection very easy.

There will be advantages and limitations to every system. There will be benefits to the Case Study system that cannot be matched by Loowatt, such as clean water production and reduced volume for collection so in theory this can coexist and give the target user more choice.

The problems with existing options that are common in the developing communities are well documented and discussed (Nawab, 2006; Jenkins M. 2007; Quicksand, 2011) and also seen first hand by the research team that visited the target area. Pit latrines are notoriously in poor condition and often are very dirty. Improved systems such as the sealing bucket project currently running in Kumasi, are definitely an improvement by giving dignity, improved safety and ownership to people. At first this appeared to be a perfect system, however when the research team visited the houses, it was apparent that although a chemical is used, the smell is not entirely masked and the odour could be quite strong in some of the houses.

The Clean Team have since approached the team from the Case Study with interest into retrofitting the new flush mechanism to their toilets so that a chemical would not have to be used, showing the recognised value of this mechanism.

The initial purpose of this whole project however, was just to see what was possible. The brief that was set was incredibly complex but many of the teams involved have been able to meet the requirements. With the Design Team in the Case Study, they too set very difficult constraints for the development of the flush mechanism trying to work to the overall ethos of 'seeing what is possible' and although the mechanism was not complete it has been well received and looks set to be developed further. There is also a great deal of potential for the mechanism to be integrated into other systems on the challenge or even pit latrine

10.4 Multidisciplinary team

Working within a diverse team will have challenges as methods and working styles will often vary between specialisms but there will be opportunities for great learning from the different approaches as well. In the Case Study, the role of Design within the project was almost considered an afterthought by some of the team at first. As referred to previously within this research, the quote from James Dyson explained (Dyson, 2013), the external design of the object has to be considered from the beginning of the project.

Designing a user interface for an innovative sanitation solution required a great variety of multidisciplinary approaches to complete the final Aim.

10.5 Communicating a concept quickly

The tool developed by the Design Team to convey different concepts to the wider team proved to be a very effective method of communication. By taking the essence of the well-established Business Canvas and tailoring it to be an effective method for a more informal discussion, the result proved to be very beneficial when working with a multidisciplinary team. It was used during a concept down-selection workshop with the whole team from the Case Study to gain feedback on what did they have in mind for the overall appearance of the toilet that they were working on. By using five very different concepts each with distinctive characteristics the team made comments on post-it notes of what qualities they liked didn't like form the designs and additional qualities they believe are valuable for the overall.

The series of questions that are used to determine what needs to be considered when a researcher is attempting to tailor their own Canvas is very important to the method.

The findings from this stage were implemented on a new project design project. A common criticism about Case Study research such as this is that basing all of the success and failure on one case does not lead to a very fair test (Yin, 2009). After the Design team from the Case Study finished with the project, their knowledge and experience was then utilised for a new project that had many similar themes. The new project was designing a new emergency sanitation solution for a relief situation.

Table 15 - The differences between the two Case studies

Design brief	Case Study	Case Study 2
Setting	In home-permanent	Emergency setting
Technology	High-technology	Low-technology
Main purpose	Processing waste	Storing waste
Service	Rapid deployment	Service based business
Workshop audience	Academic team	Multi-national NGO

The Business Canvas was then tailored for a further purpose. The new case study, or Case Study 2 as it will be referred to, is a group project of seven researchers whose backgrounds includes, product design, material and manufacture and branding. Their client is a multinational NGO with many years experience in this area but very little in the development of products.

The new design team needed to convey their concepts to group of non-designers who are experts in the field of sanitation. Using the Tailored Business

Canvas as a base they created a new template for a Business Canvas tool that would clearly convey the group’s concepts and highlight the key attributes.

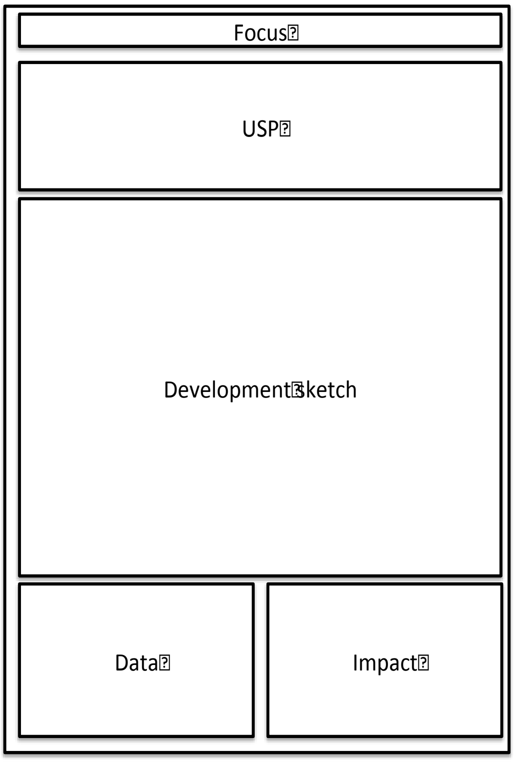


Figure 72 - Example of the Tailored Business Canvas from the new Case Study

(C4D, Cranfield University. Ross Tierney © 2014)

Figure 73 - Completed Tailored Business Canvas for the new Case Study

(C4D, Cranfield University. Ross Tierney © 2014)

The New Case Study used the new Business Canvas to convey 50 concepts quickly and effectively to a varied team. The team effectively tailored the canvas for their own unique needs, the criteria was more detailed and the Canvas utilised colour and categories to differentiate between the large number of ideas quickly and easily showing. These alterations were made after discussing the accompanying questions and deciding what is important to their team to convey to their target audience.

10.6 The future of the project

The next stage for the design team is thorough testing and further development of the flush mechanism as this has great potential for implanting into many different systems. This will involve utilising experts of materials and CAD Simulations to optimise the design and ensure all requirements are adhered to. From testing and development of the mechanism the next stage will then involve optimising the design for manufacture in a target area taking into account materials, processes and costing's to ensure a viable system that meets the Bill and Melinda Gates Foundations initial brief. This will involve people in the target area to with a better understanding of distribution networks and manufacturing facilities for the building and deployment of the toilets and then the servicing and management of toilet whilst they are in use. Some of these people have been identified already; they include members of the Clean Team that is already based in the target area with extensive knowledge on the subject. New academics have also been considered that would strengthen and add diversity to the team. Finally the end of life of the individual components will have to be carefully considered to ensure a truly effective system that is sustainable and responsible. This would be considered throughout the design process to create a system that is easy to maintain through modular and upgradable components with simple connections. The collection of the dewatered solid waste would be conducted once a week and would follow a lot of similarities with the Clean Team model and the maintenance would be typically conducted every six months where certain components that are susceptible to soiling would be safely removed and reconditioned after being swapped for new parts. Having someone local in the area who can perform the simple maintenance would greatly improve the system and the service the user receives.

11 Conclusion

The research has been successful because a final outcome has been produced by the Case Study that met the research question of the project. This user interface was developed that comprised of an aspirational aesthetic design that housed all of the components in correct working sequence as well as a constant odour barrier mechanism that didn't require water, power or a change to the user's behaviour. The outcome of the Case Study was successfully produced due to a rigorous methodology that began with a scoping phase to form detailed findings through examining appropriate literature, technology and insights into user behaviour relating to the appropriate field of study. Methods of examining the findings further to select the key pieces of information were also implemented that produced detailed project restraints that ensured a well guided development. The four objectives, to Scope, to Investigate, to Implement and to Validate were all accomplished.

The variation between stages and methods undertaken throughout this research could appear too disparate to some but when trying to develop a radical system that has to bridge the gap between complex technology and a target market that will likely have never owned such an object, the number of issues to resolve will be wide reaching and potentially never addressed before.

11.1 Stakeholders of the project

Design Team: The main team mentioned in this research, tasked with designing the User Interface of the Cranfield University entry to the Reinvent the Toilet Fair. The Team consists of one full time Designer (one year), one part time designer (three months) and one supervisor (one year).

Wider team: The other team members from the different departments also working for the Cranfield entry. The departments include Engineering, Nano-materials, Water Sciences and the senior advisors.

Research team: The team who conducted primary research in the target area.

11.2 Transfer of Knowledge

This research would be valuable for future practitioners or designers as it has a rigorous and multidimensional approach that succeeds in meeting a difficult brief. Some key areas that may prove of value are:

- ‘Key Word Ranking’ for Literature searching
- Strategic approach for gathering valuable primary research in a target area
- Rating system used in identifying technologies of interest in State of the Art
- Synthesis of research findings into project requirements
- Component progress monitoring tool
- Utilising the strengths of CAD modelling and physical prototype
- Literature Review opportunities table
- Literature review gap tool
- Tailored Business Canvas for conveying concepts

The Tailored Business Canvas could prove to be the most valuable as it has already been successfully trialled and received positive feedback in a project that had similar issues of conveying ideas succinctly to non-designers.

11.3 Recommendations

11.3.1 Humility, Flexibility and Confidence within a Design Team

The role of the Design Team on such a project is to bridge the gap between the technology and the target user. With that in mind, it is important to act as a facilitator for both and have to approach the project with a very open and accepting attitude.

Preconceptions of what the user requires can hamper progress or deliver an outcome that is not true to the needs and desires of the target user. It is advisable to approach the project with an open-mind and try to understand the problem from the user's perspective, as they will have real experiences that will be invaluable qualitative information that can't be learned from secondary sources.

From the other side of the project, when working with a large, multidisciplinary team the designer has to be flexible to the technical requirements of the system they are working with. However, this does not mean the role of the designer is to be subservient to the wider team. It's possible the wider team has not had contact or needs to understand the target user in the same way that the designer does and it's therefore very important to deliver this point to the wider team. No matter how good a system is, if the user doesn't want to use it, the system will fail.

The role of the designer is to understand the target market primarily their needs and desires and work with their own team to synthesise the research and the technology into an object that fits with the target user.

11.3.2 Target area visits

Due to the resources availability only one research trip to the target area was possible in the Case Study. It is noted by many NPD researchers that involving the target market at the earliest opportunity is highly advisable (Trott, 2008) for capturing ideas and having this so early on in the project gives a great foundation to the research. To improve authenticity of the project it would be highly recommended to either be based in the target area or have a subsequent research trip later in the project as the concepts develop. Having access to the target market is a very useful way of producing and then down selecting ideas as well as having more accurate feedback to guide development. This would be especially useful as the prototypes are being produced and tested, as the real feedback would be extremely valuable.

11.3.3 CAD Simulations

With the benefits and high performance of CAD programmes currently in use today running simulations is a very quick process. In the Case Study, the Design Team had expert CAD designers and builders but who had very little experience with the simulation features available. It would be recommended that if a future team did not have in-house capabilities to do these tests that they outsource to specialists in this area they are able too. In the Case Study this was not an option due to budget constraints and although it would have produced a better outcome, what was produced met the requirements set forth in the project brief.

11.4 Limitations to the research

Having only one full time member of the Design Team for the whole year certainly limited the amount that was accomplished. For three months of the year long project, a second full time researcher was involved which saw productivity and quality drastically improved. If the resources were available for two researchers to have worked on the project for the whole year the benefit would be substantial in many areas of the project.

A secondary research trip in the development stage would have also improved the quality of the work by giving real-time feedback on the ideas as a way of validating the accuracy of the research and synthesis stage.

11.5 Reflections on Research Methodology

This research documented a rigorous methodology for the development of the user interface of a new product that would be targeted at developing countries. The stages of the research were discussed throughout to demonstrate to future researchers or practitioners how a similar project should be approached. By examining the benefits of alternative methods that could have been utilised, the reader can select the appropriate methods for a new project related to NPD, developing countries or innovative sanitation systems. The Methodology was based on four Objectives that shall now be reviewed individually.

To scope- the objective was accomplished because a well-planned approach to the phase saw the Case Study find valuable material through three main methods. The strategic approach to the Research Trip produced valuable primary research through observations and informal interviews in key, pre-determined areas of interest. The rigorous approach to the Literature Review was an efficient method to find and concentrate the best information and extract key pieces that will have the greatest value to the project. Finally the State of the Art discussed and rated the technology to evaluate individual strengths within the different systems that could be of value in the development and implementation phases.

To investigate- the synthesis of the scoping findings into strict requirements to meet the project brief for the Case Study is discussed thoroughly to ensure the research remains true to the Aim. A tool was also developed for the investigation phase that allows for a very quick and efficient explanation of concepts. A second tool is also developed for monitoring progress to aid the Design Team tracking

To implement- The Implementation phase was successful because of a combination of well-considered requirements and good design practice forced directed creativity to tackle a problem and produce a final complete outcome. This phase started with simple sketches and progressed to effective use of evolutionary prototyping to convey ideas, inspire discussion and encourage innovation.

To validate- Appropriate methods were chosen to confirm the success of the outcomes of the Case Study. For the technical equipment, grading the new technology against the existing technology. In the Case Study, the method chosen for validation of the Flush Mechanism was the same method used to grade the different systems in the State of the Art to ensure consistency and fair test. The newly developed system was adjudged to be the best out of all of those trialled, by the opinion of an assembled group of design experts with knowledge of sanitation design. This was the level of validation required to meet the project brief.

The Validation for the overall aesthetic design came from both the technical requirements and expert analysis for the user acceptance. In the Case Study the technical requirements are: all components are in correct sequence in the smallest space. And for the aesthetic validation, expert feedback from a sanitation specialist who lives in the target area and believes it would be well accepted.

The user interface of such a complex system required a great deal of work and a wide range of methods that have to be carefully selected to obtain the best results.

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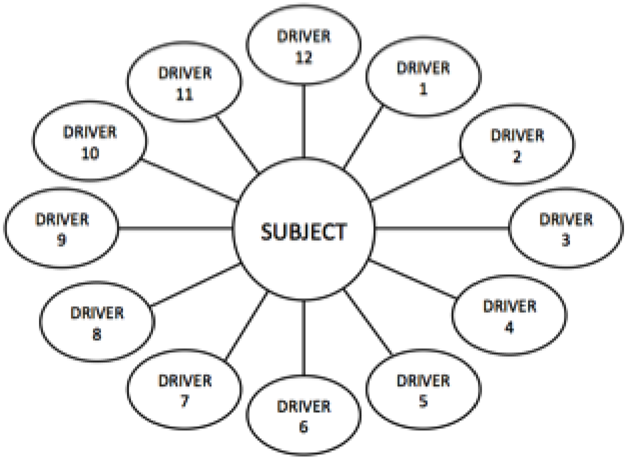
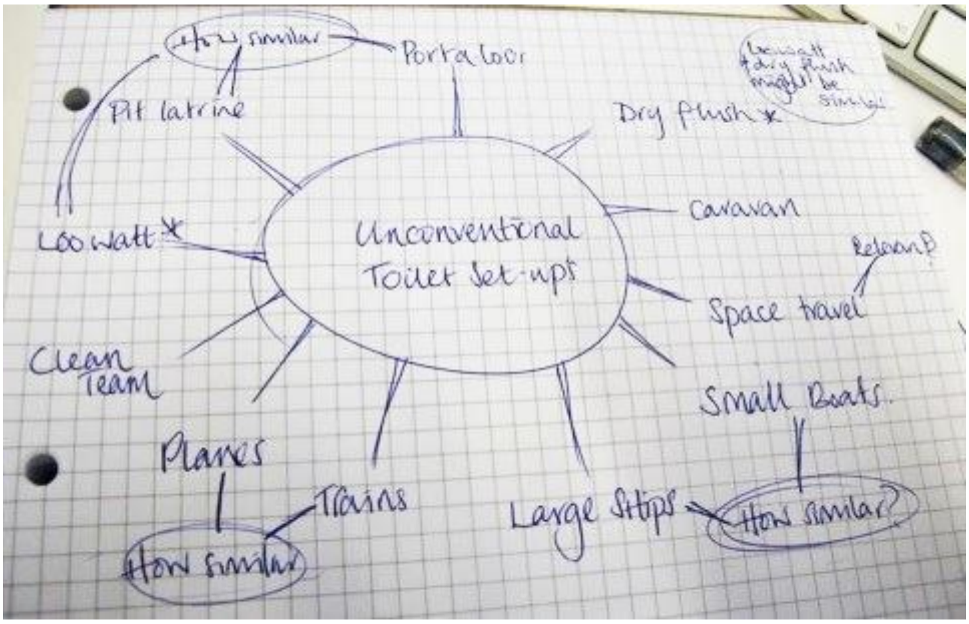
APPENDICES



appendix 1 – Diagram of template to be used for Mind Map

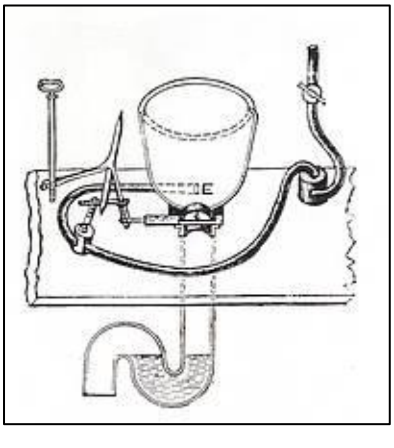


Appendix 2 – Mind map of drivers identified for the State of the Art in the Case Study (C4D, Cranfield University. Ross Tierney © 2014)

Appendix 3- Western Toilet

Image found:

http://maplesplumb.com/plumbing/water-saving-toilets-faucets-tubs-showers-sinks



Appendix 4- Cumming's flushing toilet

Image found:

http://www.villeroyboch-group.com/en/about-villeroy-boch/stories/the-history-of-the-toilet-sanitations-ups-and-downs.html

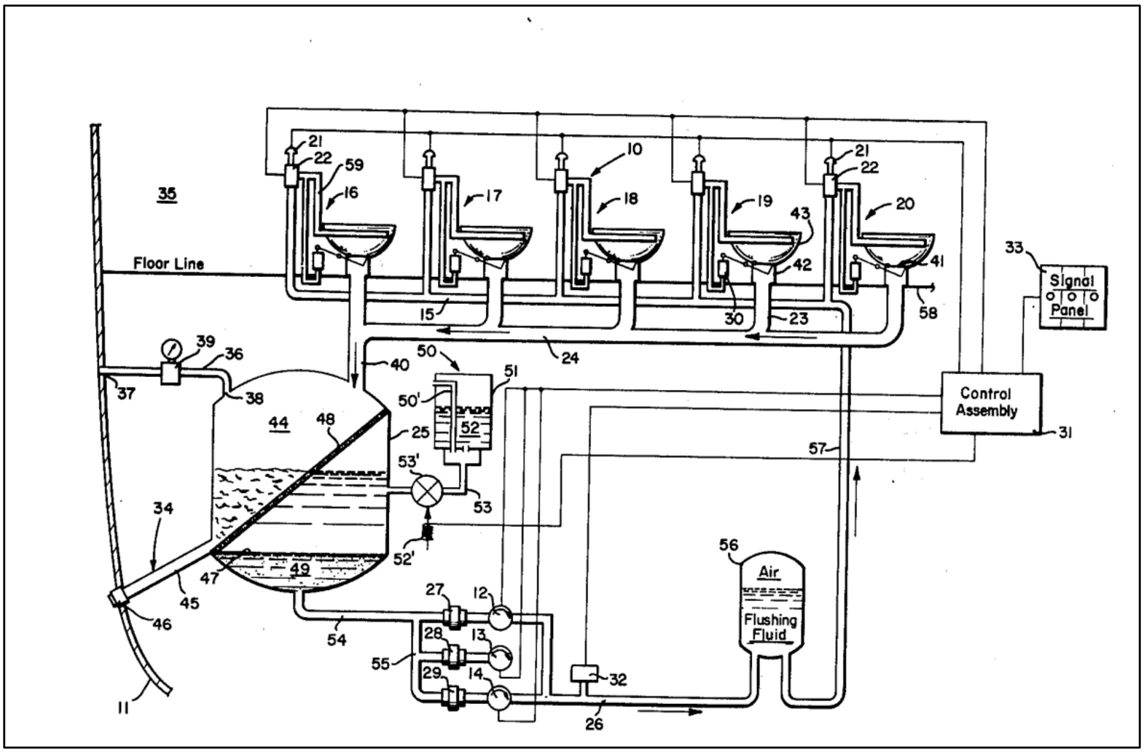
Appendix Error! Use the Home tab to apply 0 to the text that you want to appear here.**5- Improved flap toilet**

Image from: (C4D, Cranfield University. Ross Tierney © 2014)

Appendix 6- The Loowatt toilet

Image from:

http://inhabitat.com/toilet-made-from-poo-transforms-excrement-into-energy/

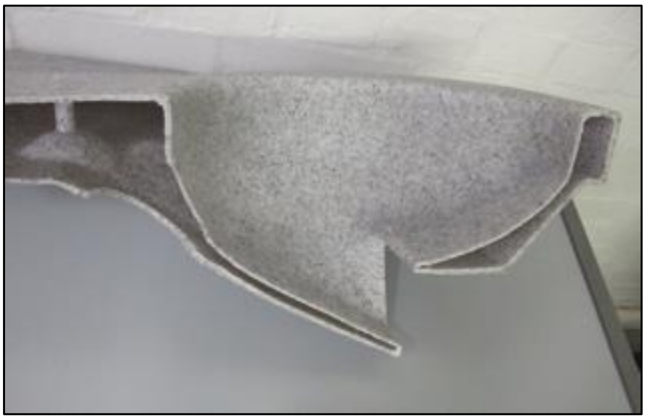


Appendix 7- Aeroplane toilet patant (Kemper, 1975)

Appendix 8- Space toilet

Image from:

http://www.cleveland.com/nation/index.ssf/2009/07/spacewalk_no_202_unfolds_on_40.html

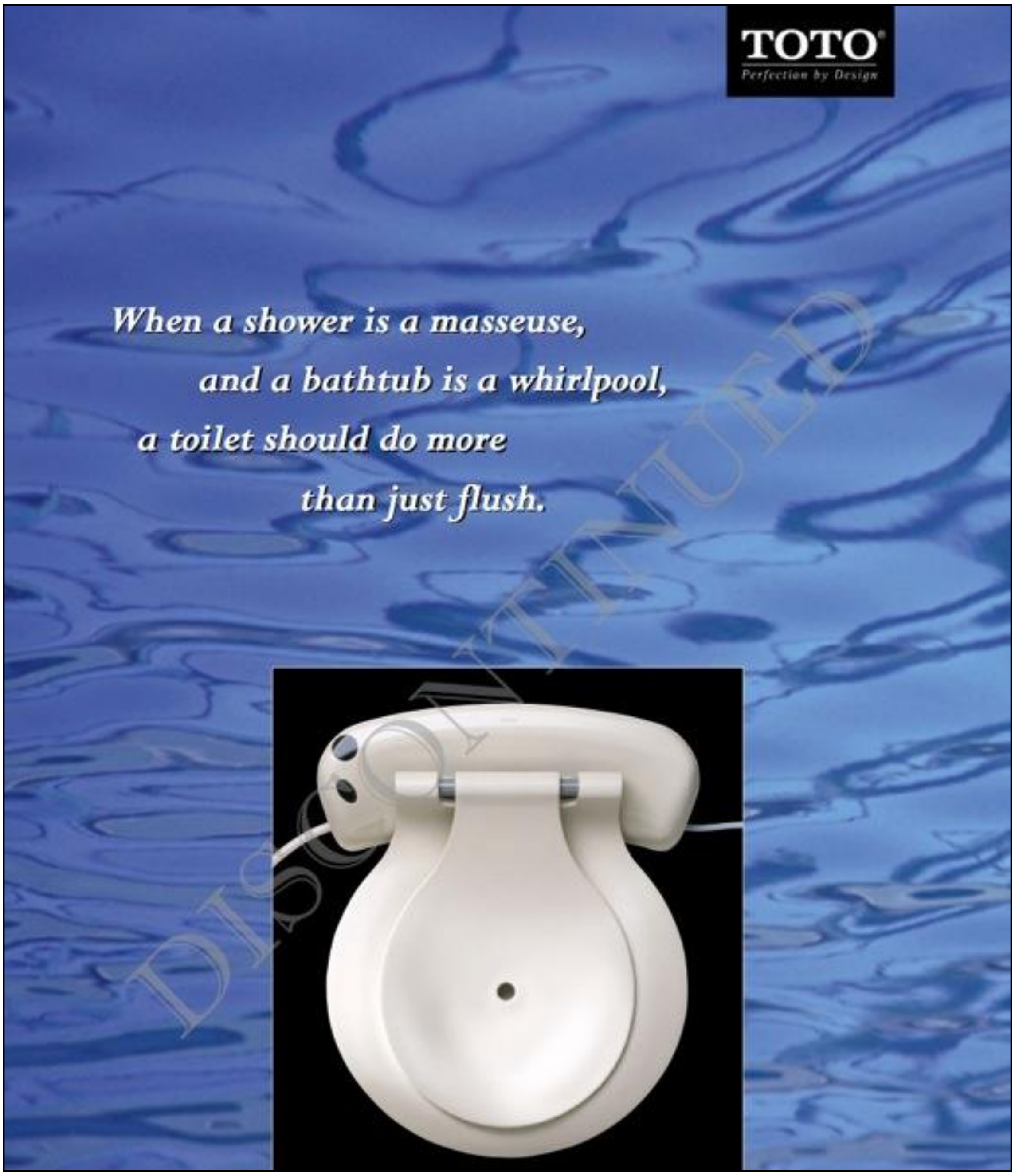


Appendix 9- Porta toilet

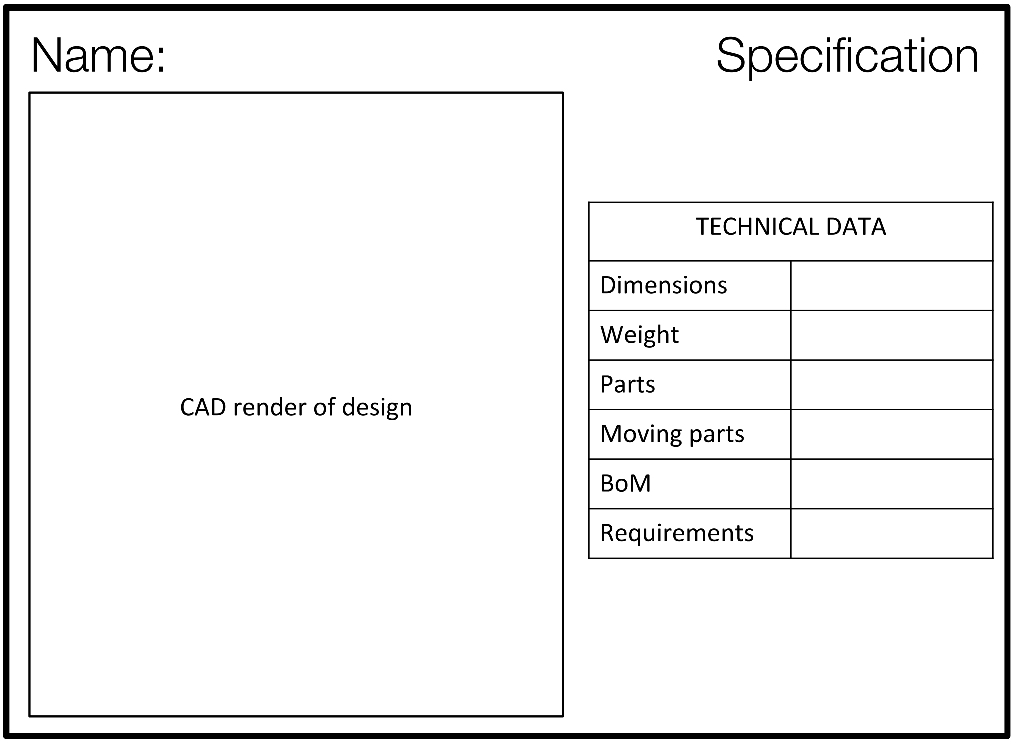
Image from: (C4D, Cranfield University. Ross Tierney © 2014)

Appendix 10- Caravan toilet

Image from: (C4D, Cranfield University. Ross Tierney © 2014)



Appendix 9- Toto toilet advert
Image from:
http://admin.totousa.com/Product%20Downloads/SS-00519,%20SW803,%20V.03,%20DISC.pdf



appendix 8 - Updated example of Canvas part 1

(C4D, Cranfield University. Ross Tierney © 2014)

appendix 9 - Example of Canvas part 2

(C4D, Cranfield University. Ross Tierney © 2014)

appendix 10. works-like prortype

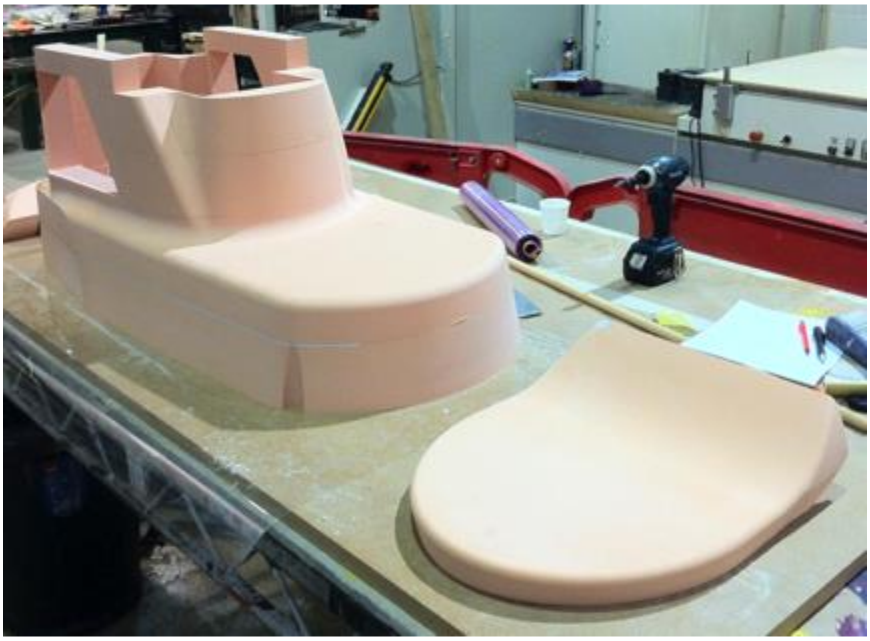


Figure 74 - Dense modelling foam having been machined now being assembled (C4D, Cranfield University. Ross Tierney © 2014)

Figure 75 - Main body made using a CNC machine and dense modelling foam then smoothed off to prevent any joins from showing
(C4D, Cranfield University. Ross Tierney © 2014)

Figure 76 - Toilet lid being cast in blue resin
(C4D, Cranfield University. Ross Tierney © 2014)

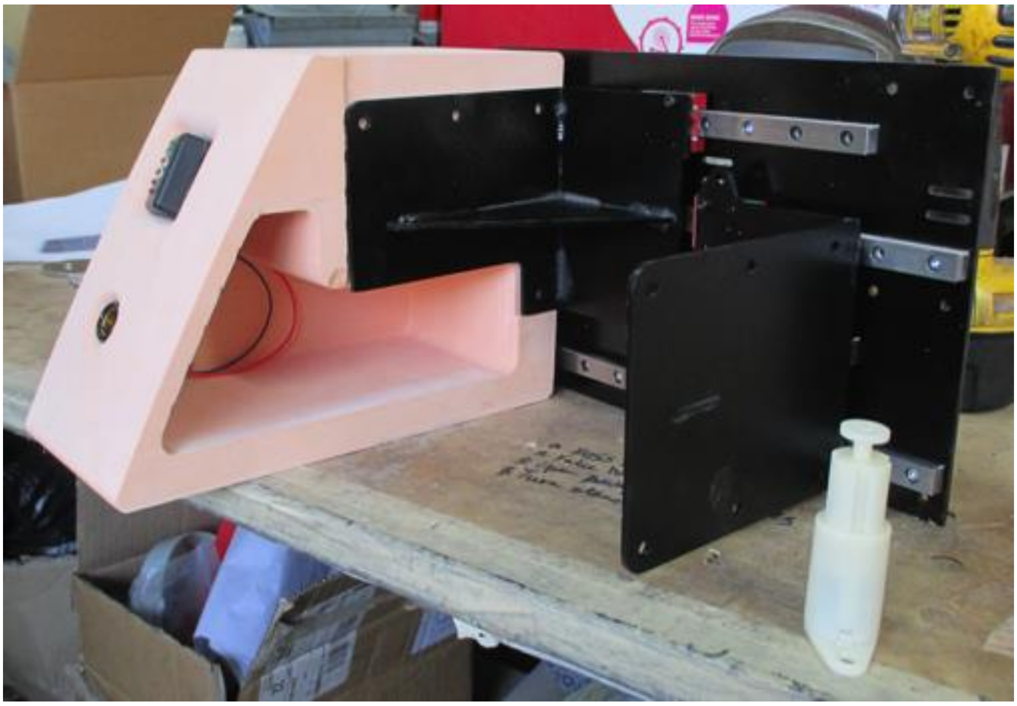


Figure 77 - side compartment and opening mechanism
(C4D, Cranfield University. Ross Tierney © 2014)

Following photos courtesy of Dr. Richard Franceys © Cranfield university

meeting with Biofilcom in Ghana

Research in Agbogbloshie Ghana

Research in Agbogbloshie Ghana

Primary research discussion and Idea generating

Idea generation session