O-glo

by Arun Joshi

The following pages are highlights from the produced Research, Ideation and Development reports for O-Glo. If you wish to see the full reports please ask Arun Joshi or take a business card. Thank You.

INTRODUCTION

We are living in a modern society concerned about health, fitness and well-being. In the UK alone there has been an increase of 4.9% in organic produce sales coinciding with a fall of 1% in the market of non-organic food and drink (Soil Association Organic, 2016). Likewise in 2015 the gym & fitness industry saw an increased total market value of 5.4% (The Leisure Database Company, 2016).

Undoubtedly this conscious health push is a positive move within society. Although despite these health kicks and forward thinking there may have been a significant aspect overlooked by the vast majority of people...the air we breathe.

As a society we are becoming more aware of what we put into our bodies. Be it the type of food we eat or ensuring we have the correct volume of fluids per day. But the quality of the air we breathe rarely ever gets a second thought, and when the average human body consumes close to 11,000 litres of air per day (Health Discovery, 2016) surely it is time to educate ourselves on how the air we breathe really can affect our bodies.

In 2016, a report by the Royal College of Physicians stated that:

“every year in the UK, outdoor pollution is linked to around 40,000 deaths”
(NHS.uk, 2016)

The World Health Organisation (WHO) also call it “a public health crisis” (The Huffington Post, 2016).

“Today, 54 per cent of the world’s population lives in urban areas, a proportion that is expected to increase to 66 per cent by 2050. Projections show that urbanization combined with the overall growth of the world’s population could add another 2.5 billion people to urban populations by 2050...”
(Un.org, 2016).

As the quote above illustrates over half of the world’s population lives in urban areas including, but not restricted to, cities and mega cities*.

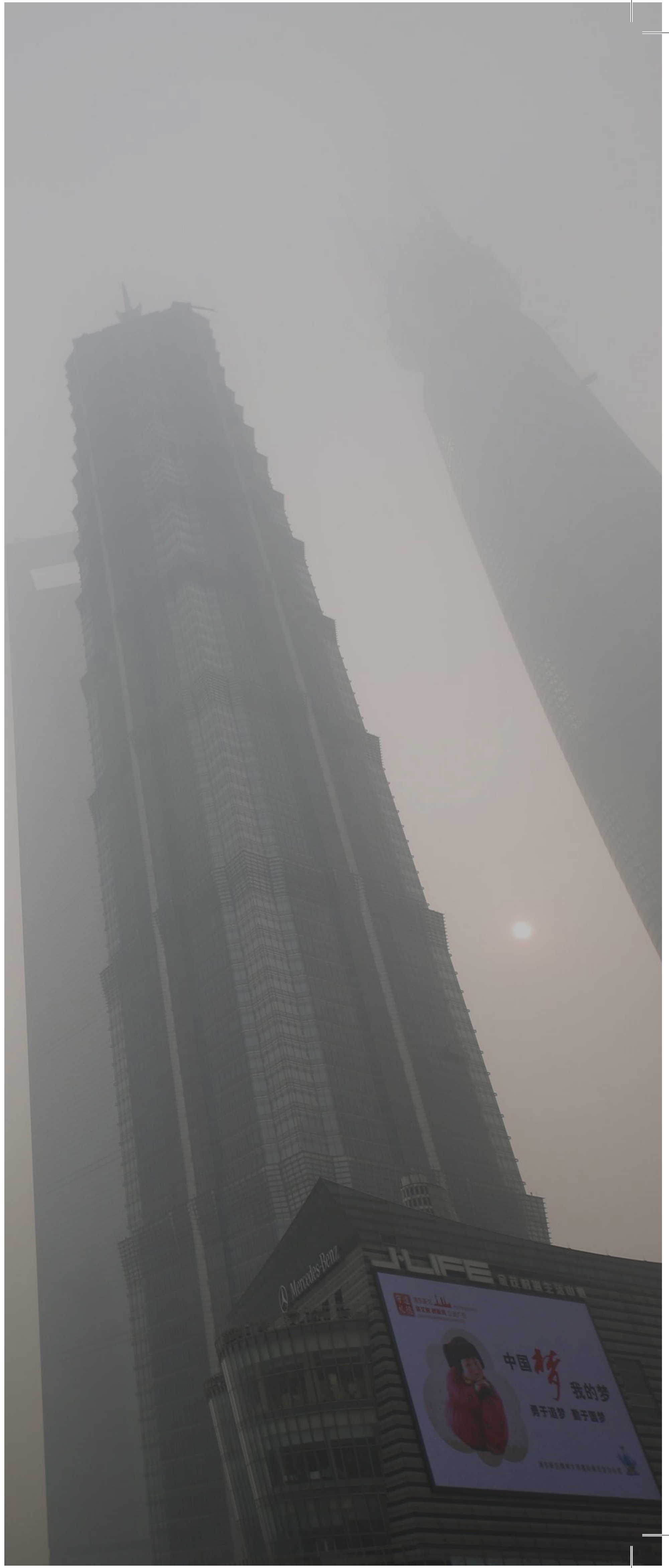
Combine this with the fact that 80% of people living in urban areas are exposed to air quality levels that exceed WHO limits (WHO, 2016) then there is no doubt that there is a need for greater understanding into the health implications that air pollution causes to the people living in these areas.

Most recently,

by the 5th of January 2017 London had already breached it’s annual air pollution limit for the year
(theguardian.com, 2017)

To date the actions taken to reduce the dangers of air pollution in cities has been minimal. The need for a product to promote this change has been desperately needed by many urbanites.

** Mega City - “a metropolitan area with a total population of more than 10 million people”*
(Webs.schule.at, 2016)



RESEARCH

SUMMARY

RESEARCH SUMMARY

The aim of the research report was to: To understand the health effects that air pollution has on urban populations. The research report was a chance not only to gain great understand into the topic of air pollution, but also to establish a user group. Identifying this group then allowed for key insights to be produced.

SECONDARY RESEARCH
A literature review suggested that inhaling small particles named PM2.5 could contribute to adverse health effects such as strokes and lung cancer. This proved to be critical due to the fact that PM2.5 particles are so small that they bind with red blood cells and prevent them from carrying oxygen to vital organs. Secondary research also showed that commuters in urban environments were a substantial population group exposed to poor health due to PM2.5 pollutants. Primary contributors in cities were the modes of transport these commuters used. The research also highlighted the need for greater variety in products available on the market but also that the market is sizeable.

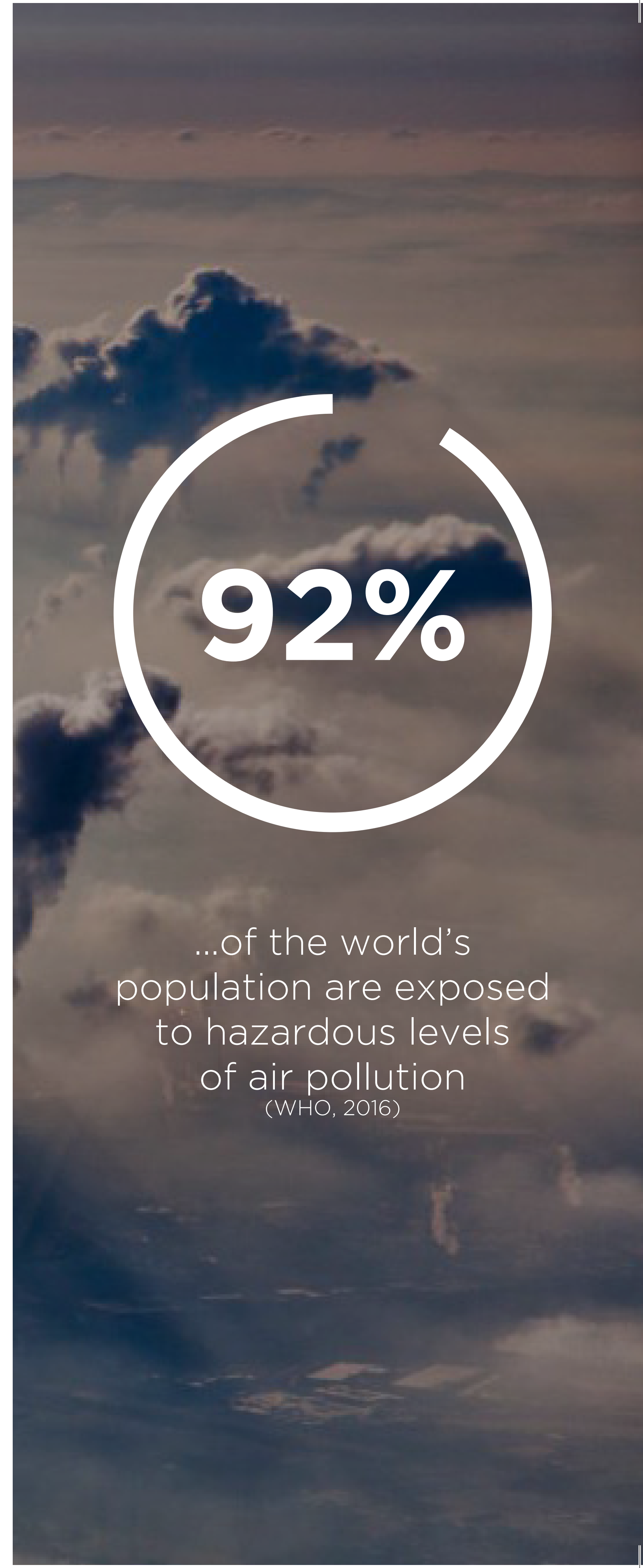
PRIMARY RESEARCH
Primary research focused on gathering a range of qualitative and quantitative data from the identified population group; looking specifically at their experiences, knowledge of air pollution and also how possible product solutions would fit their lifestyle choices. Interviews were also conducted with air quality experts to obtain thoughts and opinions more grounded in scientific study.

Data showed that many commuters were partially aware to the issue of air pollution but not its risks. Many used the fact that they could not see it, so therefore could not to anything to combat it, as an excuse to not take action. Many participants said they would be willing to change their daily routines, but that they would only do so if there was no stigma attached to those actions. A multi-functional solution was also a key factor when determining their decisions to use a product. Users and experts both believed that prevention/reduction to inhalation could be more beneficial than monitoring, though each method did have positives.

TRANSLATED FINDINGS
Through a combination of the secondary and primary research data, a set of key insights were generated. The insights were used to produce a Persona and URS. These two sets of data presentation could be used throughout the rest of the design process to ensure that the product produced would effectively meet user wants and needs.

DESIGN AIM/TASK
The research report highlighted two main areas of the larger issue that needed tackling. Firstly that people need a visual stimulus for when air pollution is high in their environment and secondly that they want to reduce the amount of PM2.5 they directly inhale. Using the insights generated the following brief was constructed for the Ideation stage:

To produce a product for people living in cities, with a focus on commuters, that looks to improve the quality of air inhaled, and to educate/raise awareness of the health risks of poor air quality.



ONLINE SURVEY FINDINGS

33% commute on trains. If taking bus or trains, walking to one further stop is common

UNDERGROUND

Unwilling to spend money on product they have no knowledge on

74% believe their commuting method was not detrimental to health

107
PARTICIPANTS

Only 18% believe trains exposed them to the most air pollutants

Many do not take steps to reduce the quantity of pollutants inhaled whilst commuting

82% commute along a busy road at least once a day

91% never use air quality products, but 94% would use one if air pollutants were visible

81% said there was not enough public awareness about pollutants

KEY COMMENTS

"It's a new silent killer."

"Wearing a breathing mask is not a good look."

"Its a matter that needs to be sorted out, the only way to do this is to make people more aware of the health consequences. "

"Doesn't really seem like there's anything I can do other than wearing a mask and looking like a weirdo."

"I believe that I labour under a false impression that walking and cycling do not expose me to much air pollutants."

PERSONA

Emily moved to London just over 2 years ago after leaving her parents' home in Cornwall. She is a young, ambitious professional trying to make her career in an exciting new environment. As an event planner her job takes her all over London and as such Emily spends a lot of time using public transport. She takes the tube from Islington to New Cross and, weather permitting, walks the last 15 minutes to her work in Greenwich. On Fridays she walks from the office to Canary Wharf where she attends her spin class. Although Emily prefers to walk through parks or along the river she often finds herself walking down roads as they cut the most amount of time off her journeys.

When Emily uses the tube and walks along the road she always finds the air around her is thicker and smells odd. She often sees black spots on her tissue when she coughs or blows her nose from these trips. Although finding this disgusting she feels this is just the way of life in a city and doesn't even know what she could do to avoid this. She considers checking how bad the air quality is where she lives but either ends up forgetting when she gets home or gives up after trying to figure out all the scientific terms on the websites.

When in the city, Emily occasionally sees cyclists wearing face masks or pedestrians covering their nose with scarves. She often wonders if she should be doing the same but quickly dismisses the thought thinking how stupid she would look walking around like that. Emily justifies her relationship with city air as something firstly she can't control and secondly doesn't know enough about to bother changing her life. Emily sometimes wonders if she could see what the quality of air looked like she might take her exposure more seriously.

KEY	0 = Low/no interest 10 = High/ strong interest

FRUSTRATIONS

- Constantly having to adjust her daily routine depending on weather, transport delays and other factors
- Wants to be healthier in all aspects of life, but doesn't have a great enough understanding of air quality
- Avoids using a product and gadgets that makes her stand out in a crowd
- Wishes she could interact more with people she regularly sees on the tube
- Not knowing what to do when the air around her is stifling and unpleasant
- Feels alienated and frustrated when she does not understand scientific terms

GOALS & MOTIVATIONS

- To increase the number of times she walks in city parks and along the river
- Have a balance between sensible, healthy living and a fun relaxed life
- To feel she is in control of the air she is breathing in the environment surrounding her
- Wants to enjoy her time spent whilst travelling on the tube to work
- To start a family whilst living in the city and raise happy and healthy children
- Improve her level of fitness in her spare time

EMILY SPENCER

AGE: 26
RESIDENCE: Islington, London
WORK: Greenwich, London
OCCUPATION: Event Planner
INCOME: £32,000
PHYSICAL CONDITION: Healthy
TRANSPORT MODE: Train & Walking
TRIPS PER WEEK: 8+

"Maybe if I knew more about air pollution I would take action, but I'm just not sure what to do."

"I think we all realise it is there, even if we don't know where it is"

URS

A1: Must provide users with a visual means to measure the level of pm2.5 (per 10ug/m3) in their immediate environment.

A2: Must provide detailed information to improver users knowledge of the dangers of pm2.5.

A3: Must insensitive users to take less frequented travel routes and modes that will expose them to lower levels of pm2.5.

A4: The product must make the user feel at ease (alleviate self-conscious thoughts) in social and public environments.

A5: The product must have measurable health goals to encourage continued use.

A6: The product must reduce direct pm2.5 inhalation by 10 ug/m3 per journey.

B1: Should inform users on the specific negative health impacts of the pollutants they are exposed to more than 8 times a week.

B2: The product should be able to be stored in a backpack or on-person, with ease, within 15 seconds.

B3: The product should not reduce the user ability to communicate. This includes but is not limited to speech and non-verbal communication.

B4: The product should be compatible with users' smart devices. Including but not limited to phones and music devices.

B5: Should filter the level of pm2.5 in the immediate environment.

C1: Could alert the user to high levels of pm2.5 in their immediate environment through a senses/physical based stimulus, or a combination.

C2: Could allow users to tangibly see the quantity of pm2.5 in the air in their immediate environment.

C3: The product could encourage awareness among other users and age groups through the use of interactive visual information.

IDEATION

SUMMARY

IDEA GENERATION

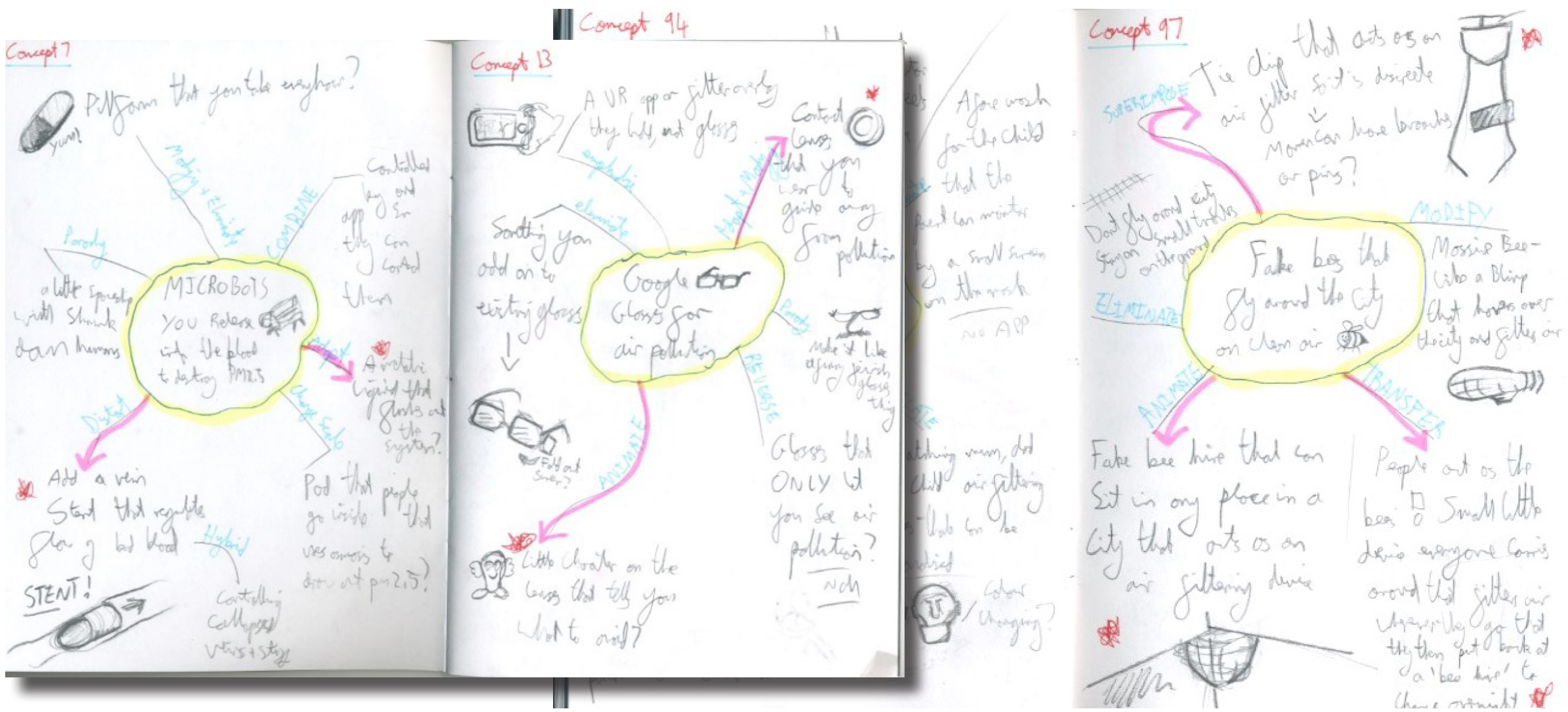
COMBINING SCAMPER & SYNECTICS

After completing individual ideation sessions and group ideation sessions I had collated a large number of ideas. However I still felt that I had not found enough ‘brilliant’ ideas yet and so decided to use a combination of SCAMPER and SYNECTICS in order to try and squeeze out every idea possible.

Initially I had started by using SCAMPER only but found that often I was coming up with variations or new ideas that didn’t fit the SCAMPER guides. I had picked SCAMPER simply because it was a method I was used to. I decided because of these reasons I would look at other techniques to change/adapt ideas.

I started by looking at WIZ and though it was very interesting decided that I lacked enough time to use this method to its full potential and as such did not use it. When I looked into SYNECTICS I found that it prompted me to think of variations that had not occurred to me when using SCAMPER. For example I had never thought to ‘Change the scale of the problem’. Initially I was looking at personal products but using this method allowed me to come up with solutions that looked at involving communities more.

I decided to combine SCAMPER and SYNECTICS as I thought that they complimented each other well and that it meant there was a great scope for ideas to be generated.



When doing SCAMPER and SYNECTICS I was comfortable accepting the fact that I would not be able to come up with a new/varied solution for every letter of each method. I instead decided to write down any interesting or new solutions and not get bogged down trying to create ideas for every letter not matter the time it took.

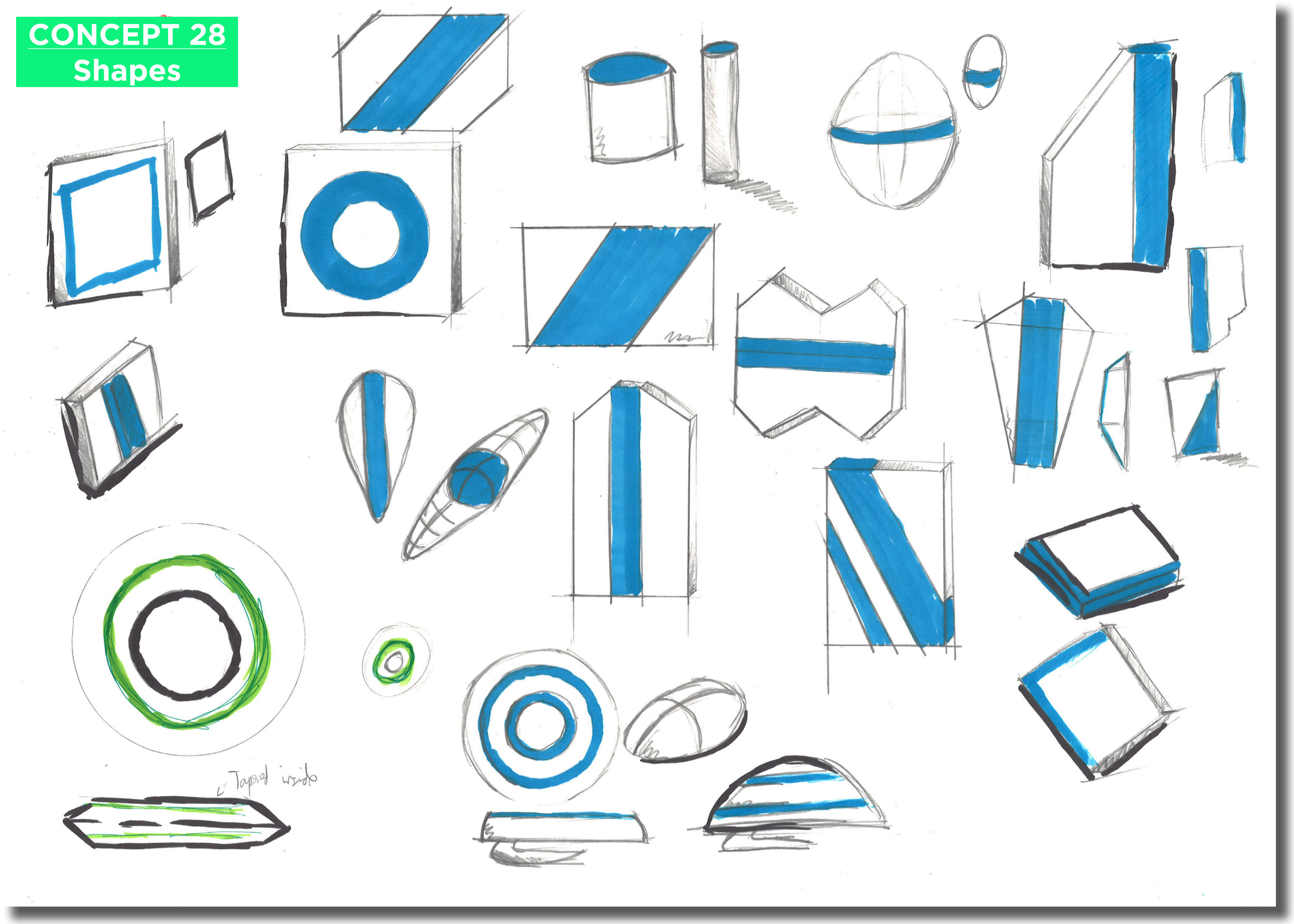
I found combining these two methods was very useful and helped to squeeze out a handful of great ideas. I also found that mind maps were actually useful for me when using this method. I also gave me a change to make use of investigative doodles alongside ideas.

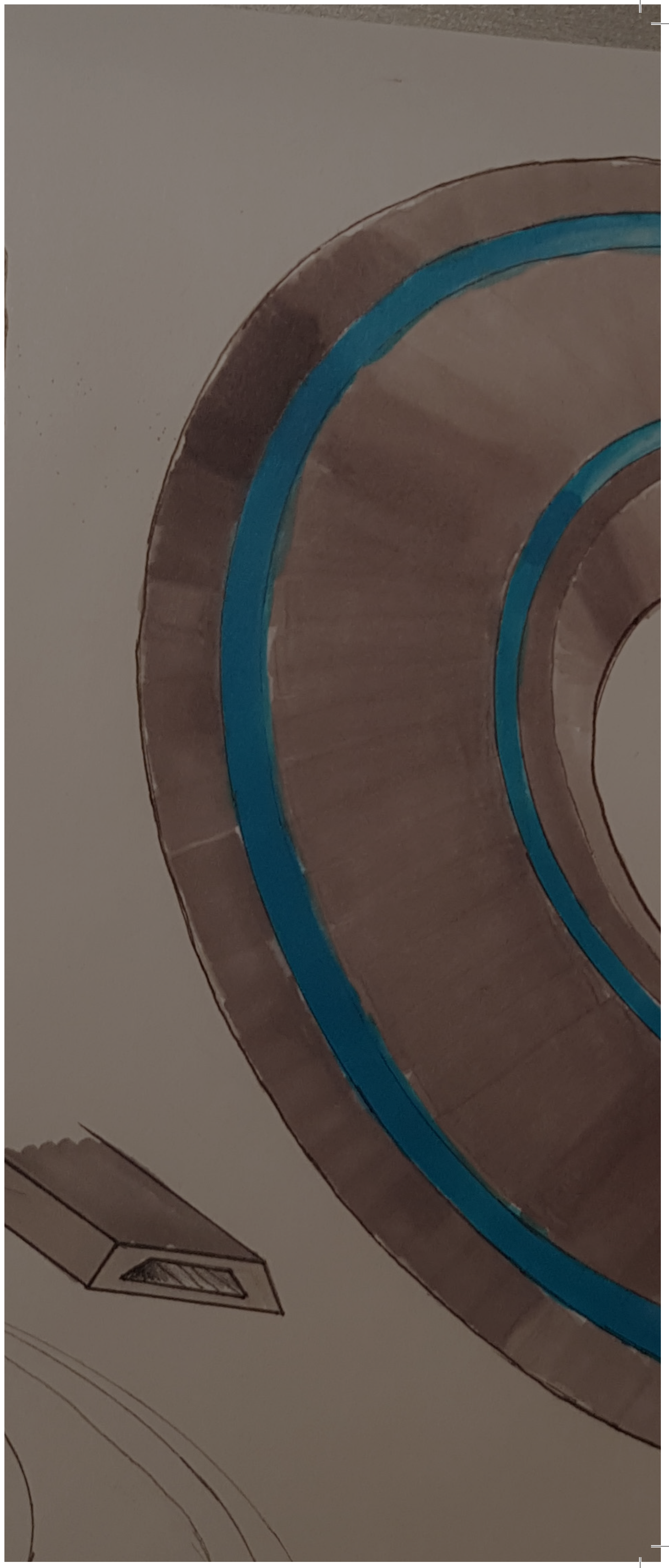
CONCEPT DEVELOPMENT

This concept is perhaps a safer avenue to explore and is still new to the market place. The basic idea is a wearable product that can clip on to the user's scarf, belt, tshirt, bag or even bike. As the user moves through their everyday life the product will begin to analyse the air quality in each environment they are in. If the user is in an area of poor air quality the lighting aspect of the product will begin to turn red. If the user moves into an area of medium air quality then the colour will change to yellow and similarly it will turn to blue if the area has good clean air.

Another aspect to this product is the use of an App. As the user moves through cities their air tracking product will wirelessly connect with an app and begin to build a visual representation of air quality in different areas around the city. This app will then be available to not only the product user but also the general public. This means that easy access to information is available to the public and ultimately awareness of air pollution in cities can be raised. In this way commuters can then choose 'cleaner' air routes to their chosen destination.

The styling of this product is a key focus as there are hundreds of wearable device these days and I did not want this product to get lost in a sea of FitBits and Pedometer style products. Before starting model making I looked at exploring forms and shapes to ensure that I had a truly striking design people would not only be proud to wear, but also would start raising the profile of the dangers of air pollution.

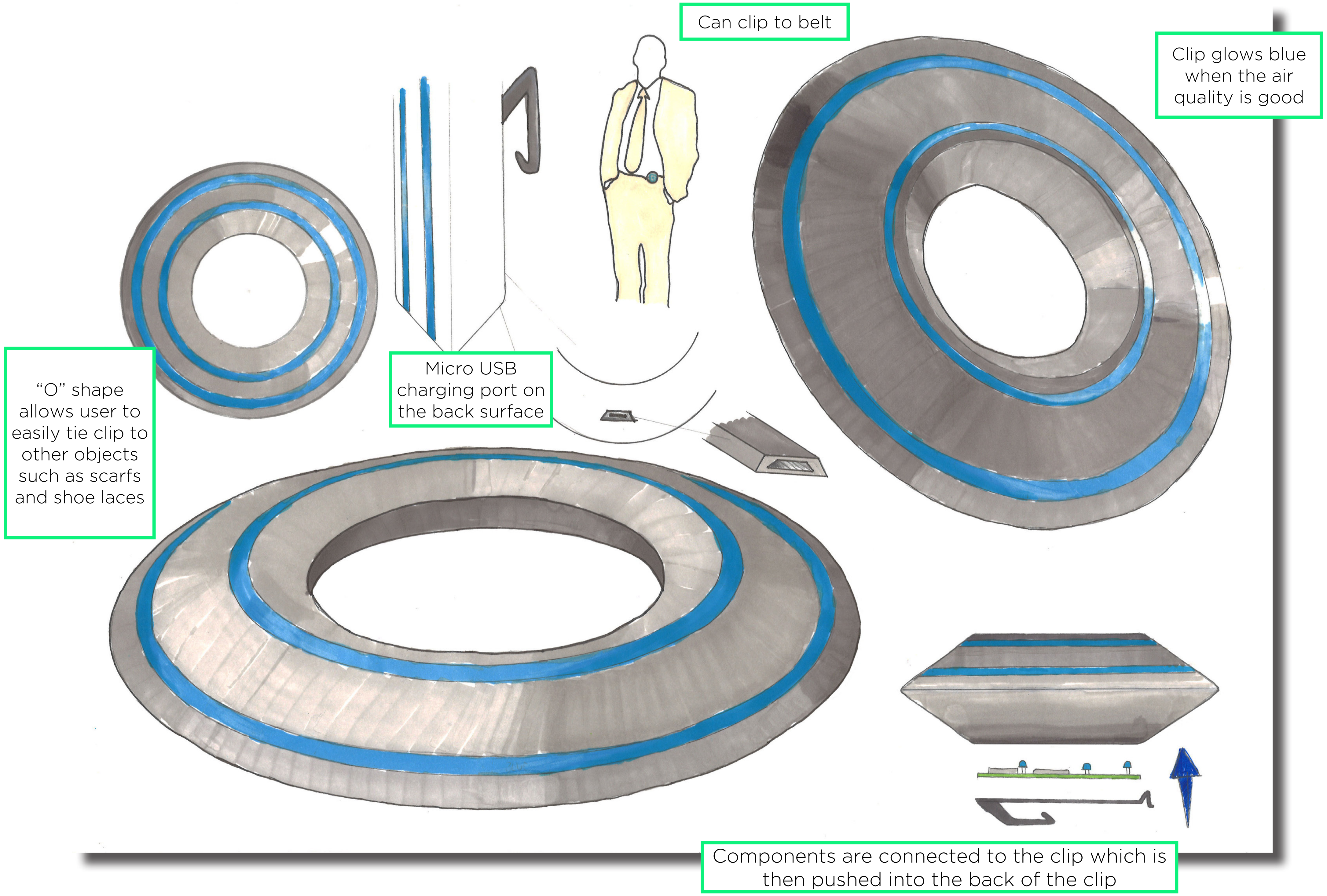




INITIAL CONCEPT DETAILS

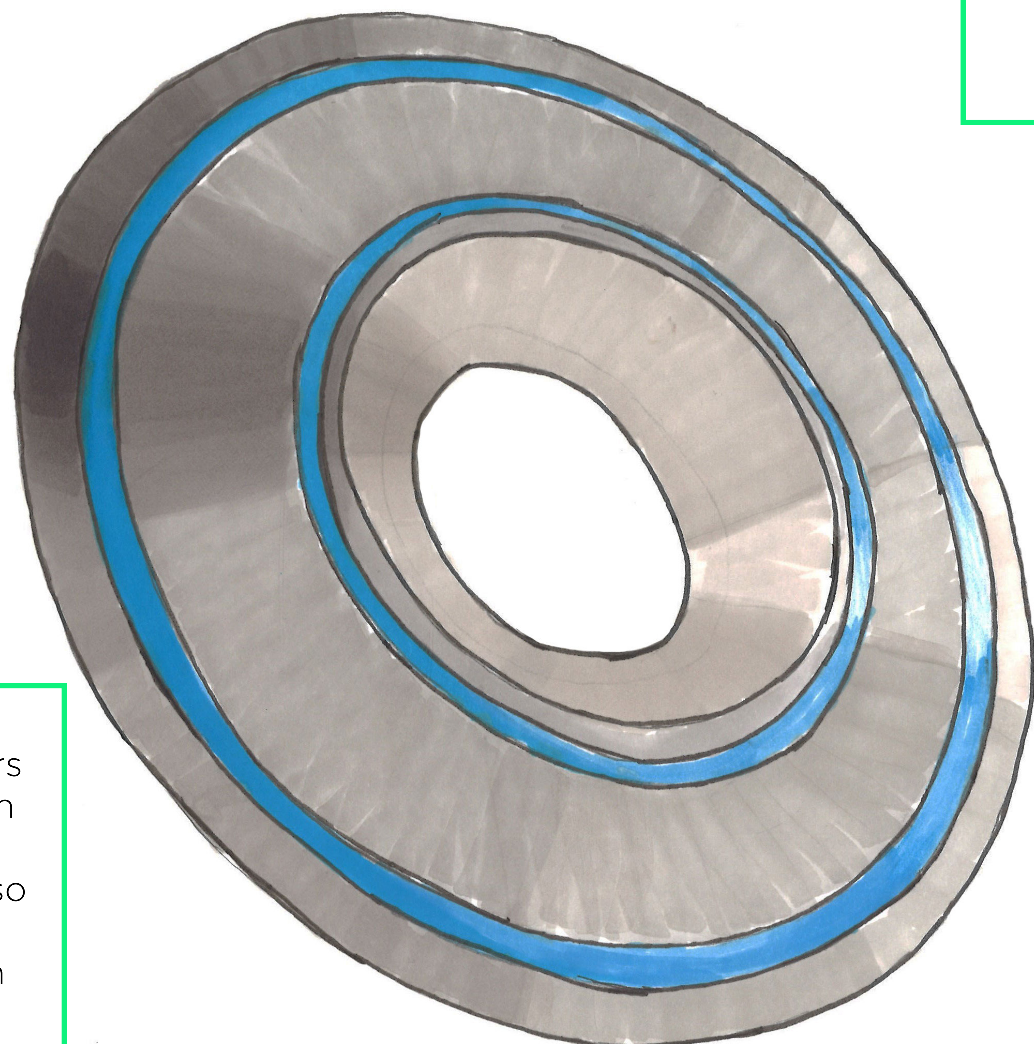
The product developed in solution to the brief is a personal and wearable device that tracks user movement through the city whilst capturing live data as to the concentration of PM2.5 (hazardous air pollution particles) in their environments visited. The product also comes with an accompanying app. The product also makes use of an ring of LED lights that change in response to different levels of air pollution. When users pass through levels of low air pollution the LED lighting will glow blue symbolise health and fresh air. As users move through into areas with lower air quality the ring will start to turn orange to warn the user of poorer air quality; the LEDs will in turn change to red when the user is in an area of high PM2.5 concentration.

The products GPS data along with the air quality data is then synced to the accompanying app on the users phone. The app then takes this data and builds a map of air pollution hotspots across the users city. Through the app users can then adjust their journey routes dependent on the concentration of air pollution they may encounter. They can also stream a live map of air pollution in their immediate environment and also receive detailed breakdown as to how they can travel in a healthier way. Users also have the option to allow their data to be made public. This in turn will sync there data to other users apps to allow for a more extensive map of air pollution across their city and enhance the sense of community in a city.

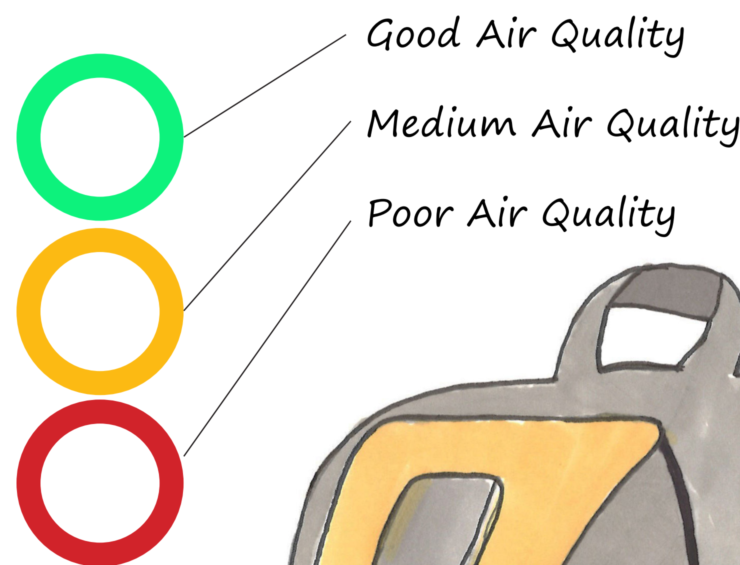


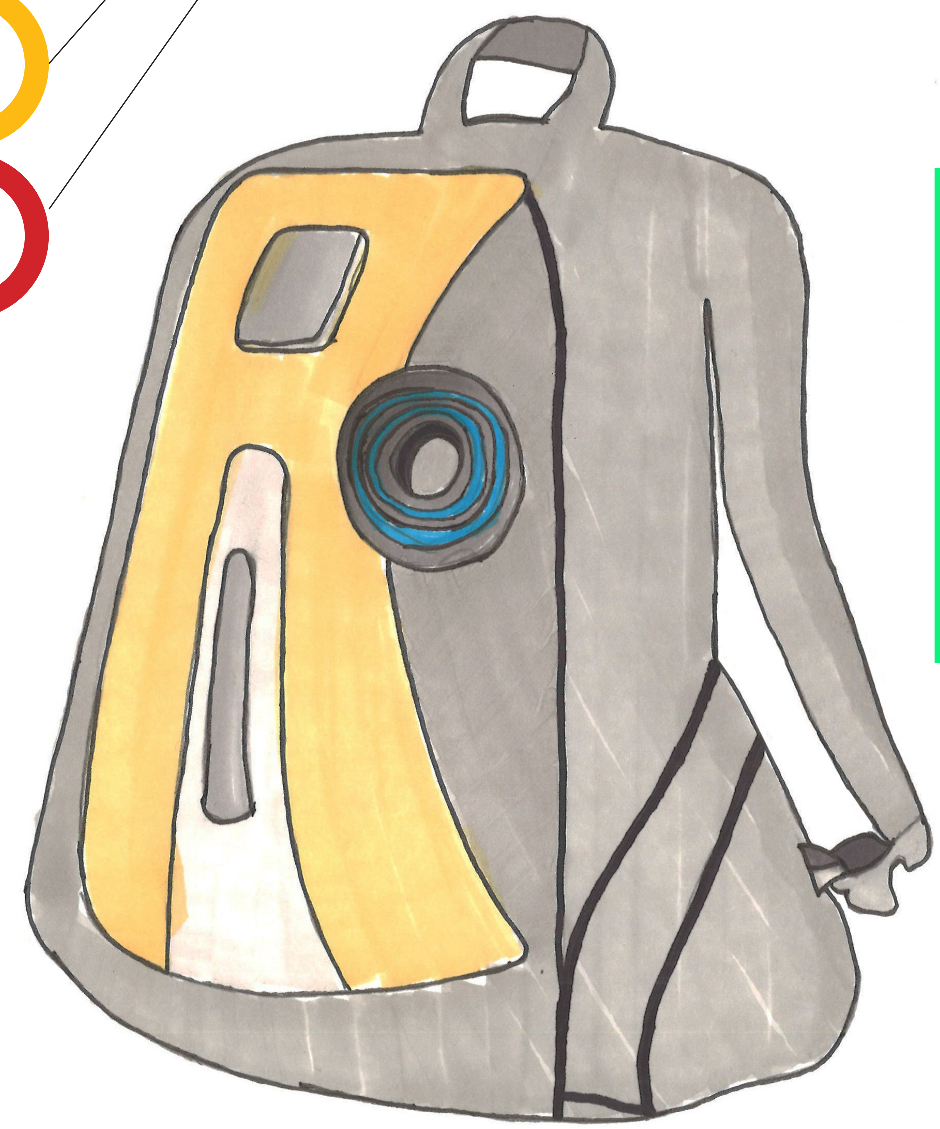
INITIAL CONCEPT DETAILS CONT.

Reduced hole through this bag clip increase the area available for components to be embedded



Clip can be easily attached to backpacks, purses, trousers, belts and has potential to be attached to items such a runners reflective arm bands, bikes and laptop cases

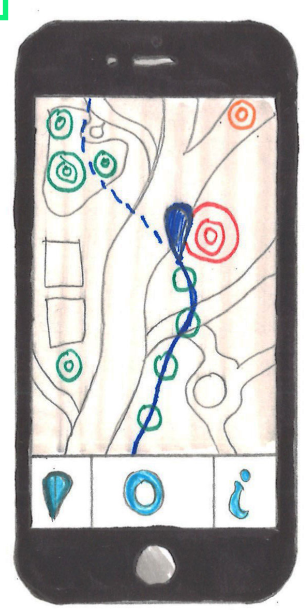




Clip is large enough to ensure when it glows not only the user is aware, but also members of public can see the quality of air they are in as well.

“O” Shape offers versatility when attaching the items and is also a unique and striking design

APP



The clip is linked to an app that tracks the users progress as they move through the city whilst wearing the clip.

This creates a virtual map that locates ‘hot spots’ of poor air quality to avoid. The user can use this map to plan a route to a destination that is exposed to the least air pollution.

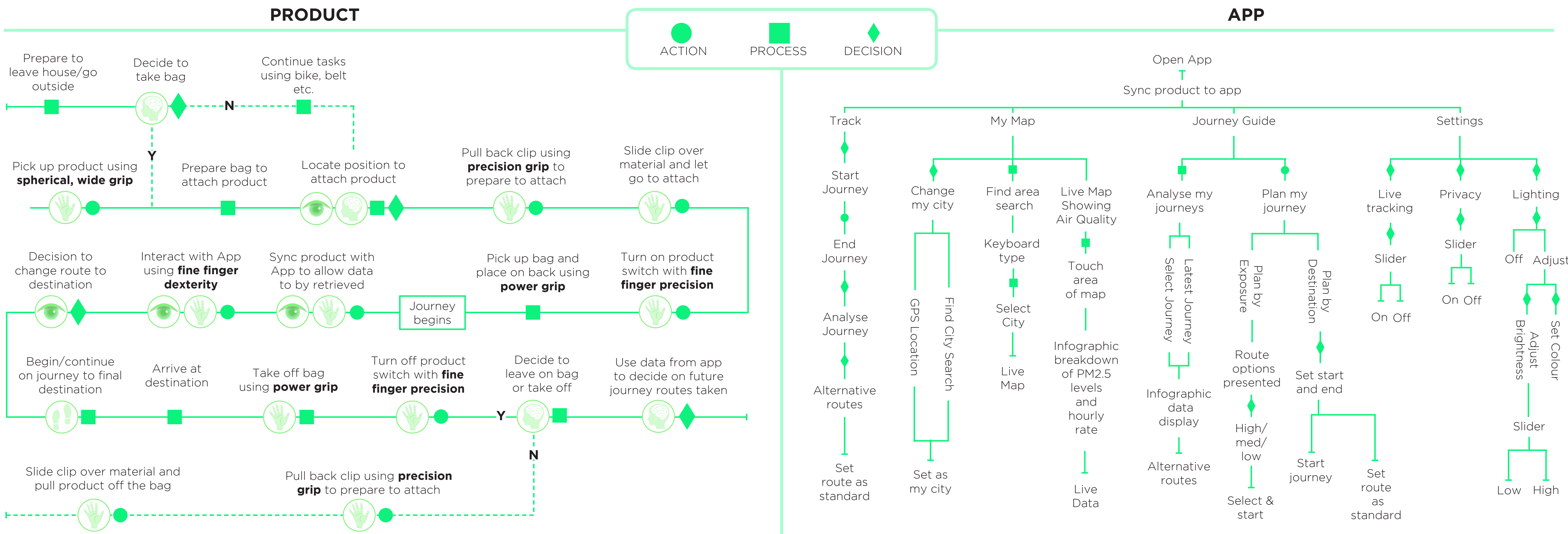
DEVELOPMENT

HUMAN FACTORS

SUMMARY

USER JOURNEY & TOPIC SELECTION

The user journey highlights the stages of using the product to identify aspects that could be redesigned to reduce user discomfort and provide an overall more pleasurable product experience. Each product step corresponds with a sense (**vision, dexterity, locomotion** or **cognitive**). Though not a sense; cognition was identified as recurring theme. The app does not identify with locomotion. The user journey of the product and app were then analysed to identify areas to be developed in order to reduce user discomfort through usability, functionality and desirability.



FUNCTIONALITY

Allowing the product to easily attach to a bag will ensure that the user does not have to try and find alternative placement for it

-

Ensuring information displayed on the product is relevant and useful to the products user and secondary users

-

Selecting the correct form for the product to display the most amount of useful data whilst not alienating users

USABILITY

Dimensioning the product using anthropometrics will allow users to hold and attach the product to their bag without causing discomfort

-

Correct lighting intensity will ensure the user can clearly see when the product is reacting to air quality without causing disability glare or harming users eyes

-

Correct dimensioning of the clip will help users attach the product to a range of items

DESIRABILITY

Ensuring the visual display of information on the product not only is correlated to the product function, but also supports the emotional ideologies of the user

-

Aesthetics of the product and the information display should make the user feel proud and empowered to wear the product in a public environment. Making sure it does not look out of place attached to a bag is vital

FUNCTIONALITY

Visual delivery of statistics about their journeys and making the data relatable and non-alienating

-

Correct use of layout and haptic feedback will help the user to navigate the app quickly and with little stress. This in turn will allow users to easily transition from app to product to benefit the health and well being of the user

USABILITY

Correct button sizing using anthropometric data to reduce the chance of human error

Making the app as visual as possible through the use of affordance to reduce the cognitive demand whilst using the app

-

Reducing the amount of information a user has to interpret, and ensuring information is presented in a concise way to reduce the cognitive demand and promote efficient use of the app

DESIRABILITY

Selecting colours that allow clear contrast that also stick to the branding/aesthetics of the physical product.

-

Use of layout to reduce the amount of information that is displayed per page and to give the app a clean and simple styling

-

Flexibility to allow users to keep data private or public to support their ideological values

DEXTERITY & HUMAN ERROR

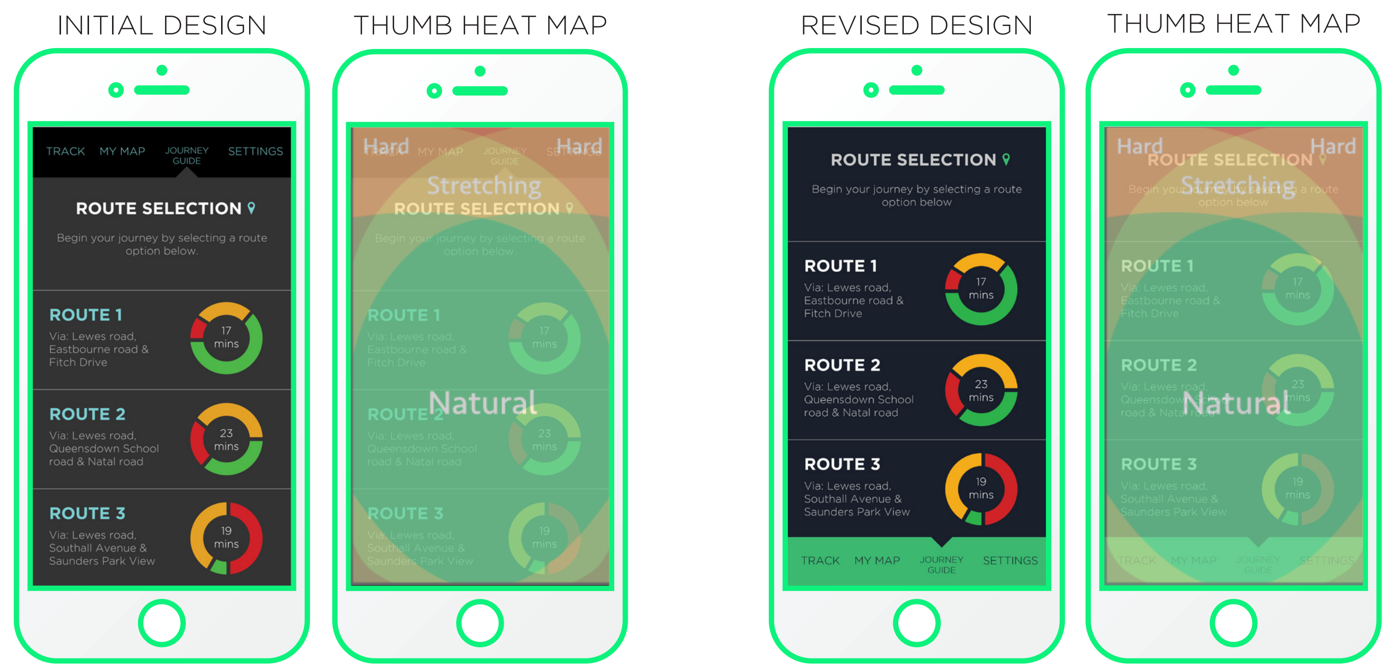
FINE FINGER DEXTERITY

Mobile phone apps make use of precision finger movements, and incorrect layout will cause severe discomfort and frustration whilst also reducing how well the product is able to function. Ensuring that all users are able to use the app whilst not physically stretching will create a more desirable bond between the user and product.

The primary interaction with a mobile uses fine finger dexterity, with 75% of these interactions using the thumb (smashingmagazine.com, 2012) As such the range of motion available at the thumb whilst holding a mobile needed to dictate the layout of the interface.

The diagrams to the right show a heat map displaying the area of a screen that a user can reach. Green areas on the screen highlight where 100% of users can reach, and 80% of those whilst in comfort (Otten et al. 2013). Areas in orange represent where users are pushed slightly out of their comfort zone, and red areas highlight areas of the screen where users were not only out of their comfort zone, but also out of stretch of their thumb. The green area is know as the 'thumb-zone' and provides a framework ensuring user-friendly designs (smashingmagazine.com, 2016).

Using this data coupled with user testing the layout of the app needed to be restructured to ensure user comfort and ease of navigation through each screen. The original menu bar was located along the top edge of the screen, but with the knowledge that this area is less accessible, this vital navigation tool was relocated to the bottom of the screen. This left screen 'titles' at the top of the users phone which need no interaction and the main navigation method near to the users thumb increasing usability.



HUMAN ERROR

'Error of commission involves performing an act incorrectly' (Sanders & McCormick, 1993) and is a primary cause of human error for interfaces. This specifically refers to incorrect sizing of tasks/button that users interact with. Incorrect sizing of buttons can lead to users selecting incorrect options, ultimately reducing functionality of the product whilst increasing user frustrations.

For mobile phone interfaces the result is that 'when small touch targets are grouped near each other, users can accidentally hit neighbouring targets and initiate unintended actions' (smashingmagazine.com, 2012). This human error can lead to user frustration, reduced app usability (and functionality), increased task duration and ultimately a lower psychological pleasure to the product.

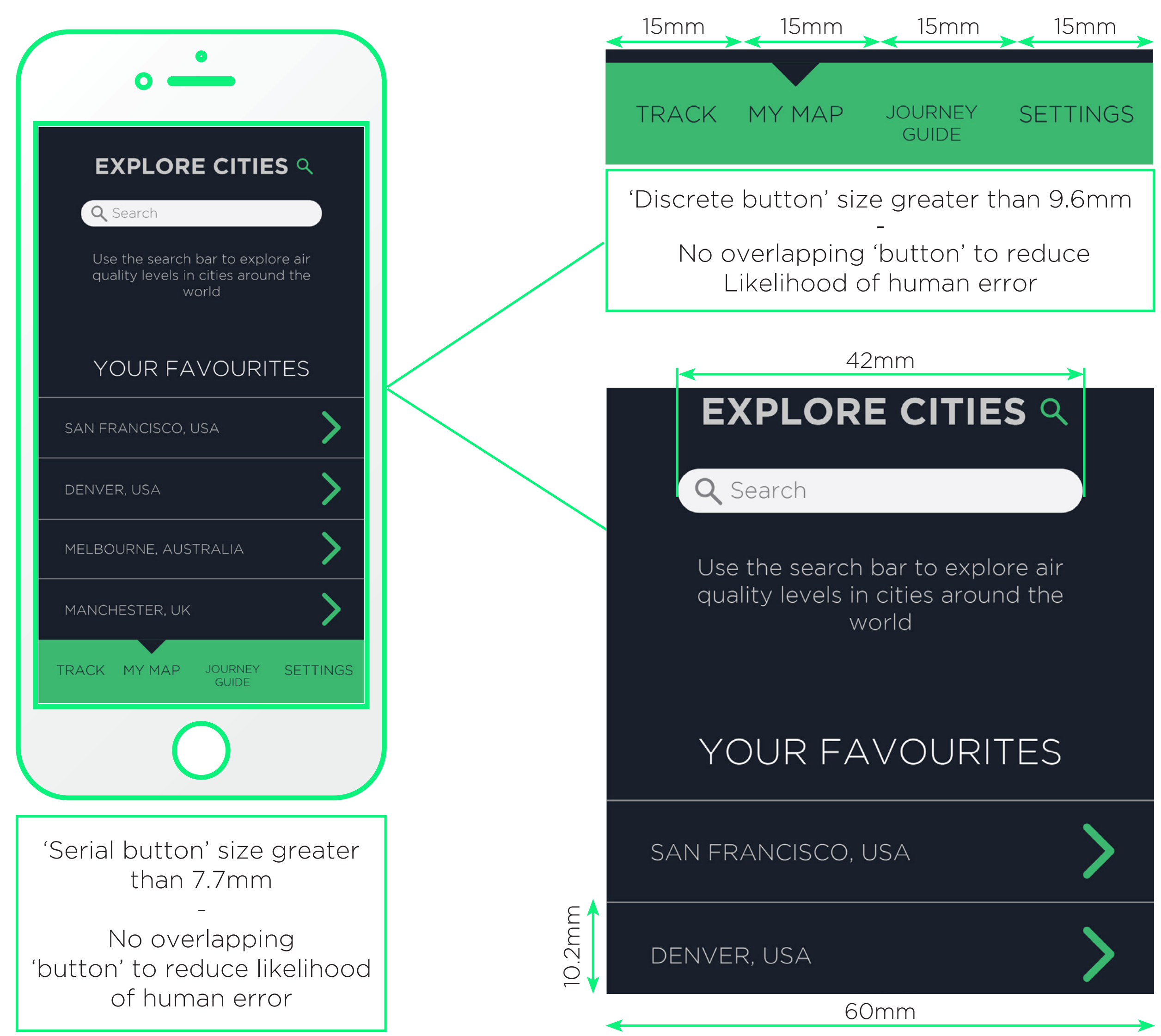
To ensure this did not happen with the interface being developed a 'prevention' design approach was taken. This makes the design of the product difficult, but not impossible to commit an error with when using (Sanders & McCormick, 1993). Though making error impossible would be ideal for an app it is not practical. With the knowledge that user errors declined as the target size increase (Microsoft, 2016); reduction of human error was implemented into the interface design through the use of enlarged button sizes to reduce the precision of a users finger needed to complete a task. Ensuring buttons were not over lapping also reduced the likelihood of the user selecting the incorrect action.

ANTHROPOMETRICS

To reduce the precision needed by the user, and therefore reduce human error, anthropometrics of the thumb and 'button' sizes on the screen were considered.

When a user touches a screen with their thumb is spread across the surface, and as such the generic anthropometric data for thumb diameter is less useful as in this case it is a dynamic measurement. The correct measurement will be when the users thumb is engaged in pressing on the screen.

A study by Microsoft (2006) suggested that the optimal width measurement for a 'target' measured 9.6mm for discrete tasks and 7.7mm in serial tasks with no significant difference in error rate. Xiong & Muraki (2014) suggested a similar measurement of 9mm for discrete tasks. Images to the right show how this data and a preventative design was adopted.



AFFORDANCE & SEMIOTICS

AFFORDANCE

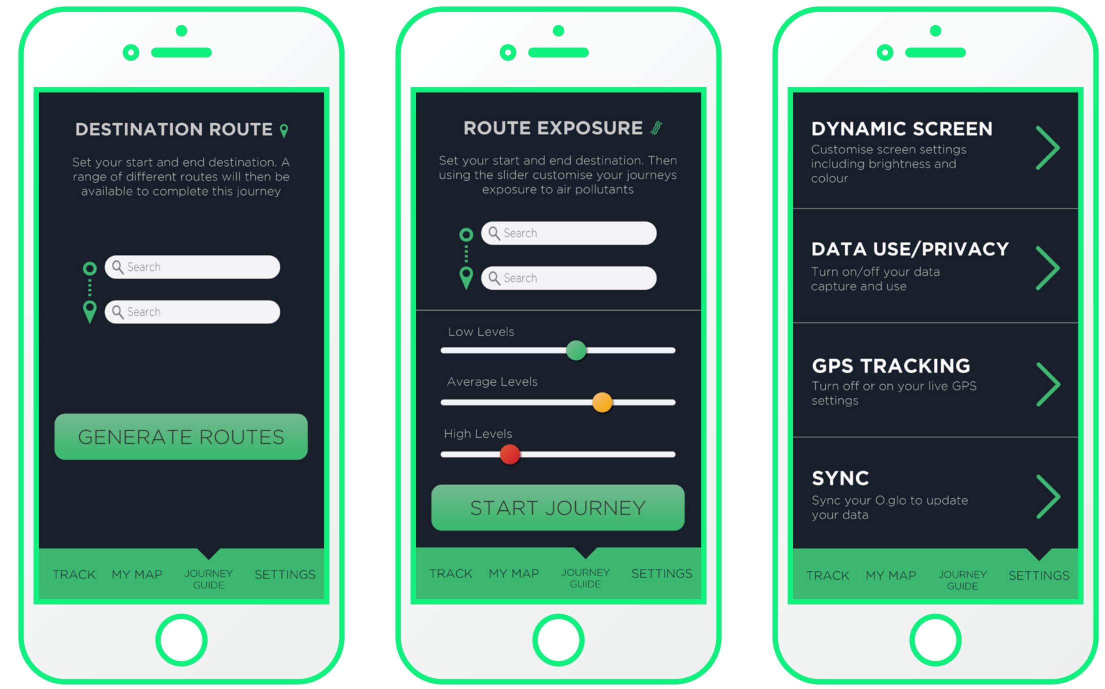
Use of digital affordance through the app interface will reduce cognitive load on users when using the app. To navigate through the developed interface, different types of affordance have been used. Negative Affordance has been used throughout by use of colour (loungelizard.com, 2015). Colour has been used to highlight 'soft buttons' that the user can click. These can also be seen written in white text. Text written in light grey is read-only and cannot be interacted with.

Metaphorical affordance refers to 'imitations of real objects, to communicate'(webdesignerdepot.com, 2015). Use of this can be seen through 'check boxes' by the use of ticks. Using check boxes is a common task and is associated with selection of a response to a question. The question in this case is '*would you like the light on or off?* . Metaphorical affordance has also been used to communicate buttons for the user to 'press', similar to that or a remote. The drop shadow and gradient add the 3D effect to make the object look like it must be pushed to work.

SEMIOTICS & SEMANTICS

Semiotics performs the same function to reduce cognitive load as affordance through the use of the users long term memory. It is preferable over verbal/written communication as it depicts visually what a function represents (Sanders & McCormick, 1993). Through the use of semantics in the users long term memory, symbols can be associated with a meaning which acts as an instruction as to what the screen/interaction is for (Sanders & McCormick, 1993).

The symbols to the right are examples of icons that have been selected and use in the app to pair a function to an image/symbol that can be easily understood and interpreted by the user to what the desired outcome/function is. For example a padlock symbol has been used to represent the apps option to control data sharing. The padlock represents that the user can keep this information safe 'under lock and key'. The symbols used are metaphorical representations of the function available to users.



Button with 'click-able' graphic design
-
Search icon with widely recognised search bar & symbol

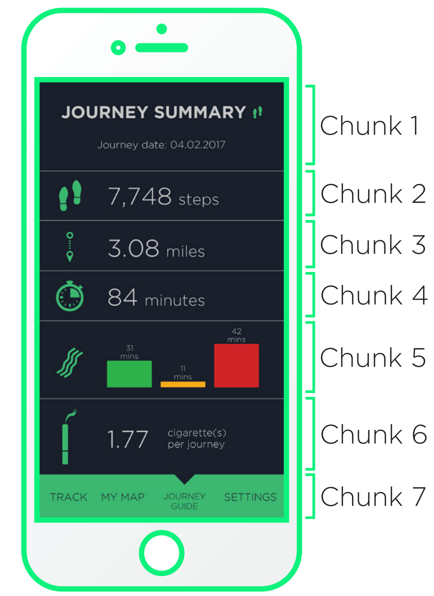
Instinctive slider designed
-
Brightness depicted by the change in symbol size and colour

Different colouring of text to show where interaction is available
-
Use of arrows to aid as 'pointers' for interaction

INFORMATION CHUNKING

The working memory has a capacity to process 7 ± 2 pieces of information at one time (Miller, 1956). As such, each screen of the app therefore does not exceed 7 pieces of information. Though the maximum is 9 pieces of information, 7 pieces per screen was used due to the fact that whilst using the app the users will also be perceiving other information through their everyday interactions. These could include walking, eating or opening a door.

Miller suggests Chunking as a method of defining 1 piece of this information. Chunking for UX design refers to group of different menus into a group no larger than 7-9 options (Sutcliffe, 1995). The screen examples to the right show how chunking has been used to ensure that there are no more than 7pieces of information per screen. The design has also used lines/sectioning to define different area of information to further reduce the cognitive demand on the user, thus improving usability of the product. Reducing the amount of text per screen to no more than 40 characters per line also reduced the cognitive demand and of the interface (usertesting.com, 2016). Presentation of less information to the user will reduce the stress levels they experience whilst using the app and prevent them from feeling overwhelmed.



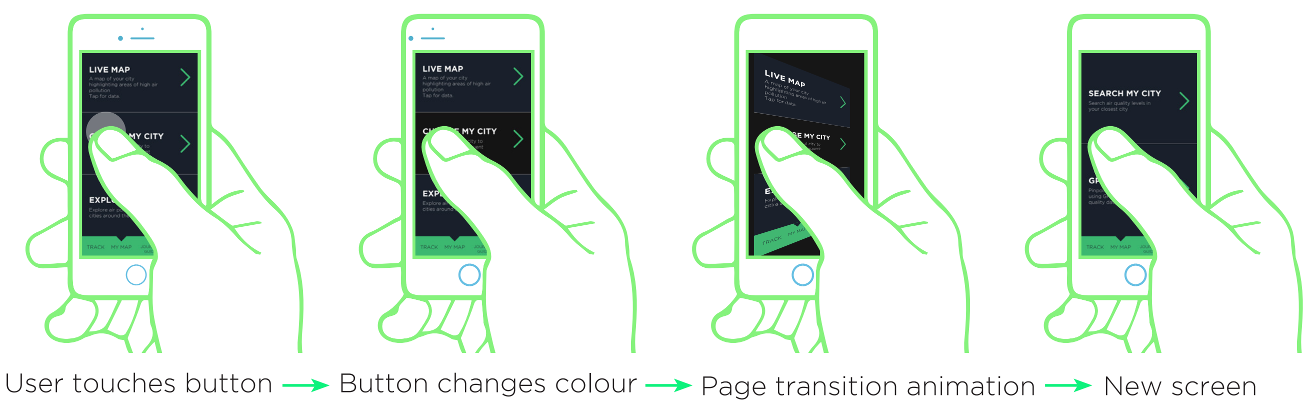
LAYOUT

Enhancement for layout communication must consider the use of vertical rhythm. Sensible usage of size and spacing between content sections was used to create a good vertical rhythm through hierarchical content (UXbooth.com, 2017). To promote logical access paths menu's should be organised in hierarchy, which in turn will make the menu more intuitive and again reduce the cognitive demand of the user (Sutcliffe, 1995). The vertical rhythm of the app has been designed so that importance of tasks is hierarchical. The layout of the menu bar reading from left to right is also hierarchical of importance.

Moreover 'to improve pathway tracing, backtrack facilities are helpful so user can return to the last menu' (Sutcliffe, 1995). As such screen designs use a menu bar with a visual tab to locate where the user is on the app and a 'swipe back' option to return to the previous screen.

HAPTIC FEEDBACK

Learning a system to reduce cognitive stress can be supported through haptic feedback (inclusivedesigntoolkit.com, 2017). Digital Haptic feedback looks to recreate the sense of touch through motion (mobileburn.com, 2013). This has been applied to the interface design. The screens to the right show colour change when selecting an option, and a 'transitioning' sequence to the selected page to inform users that a task has been completed. The use of haptic feedback informs the user that they have completed an interaction and reduce stress levels knowing that the app is reacting.



ANTHROPOMETRICS

PRODUCT BODY

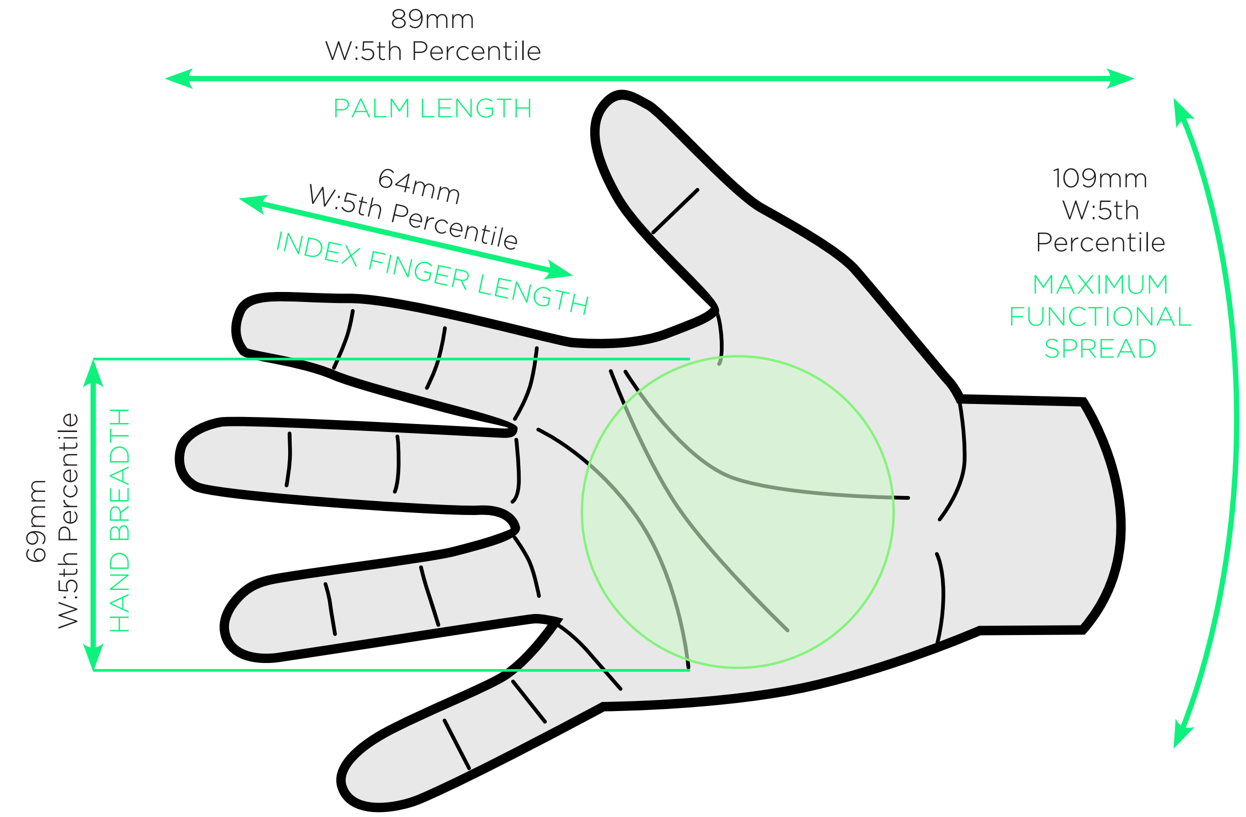
The design of the physical product up until now did not make use of anthropometric data to help ensure the product felt comfortable throughout use. Even with the limited interaction with the physical product, the dimensions needed to ensure the product would sit easily in the users palm and that when attaching it to a bag the users grip diameter was not stretched too far. *Key* measurements that would ensure the product would comfortably fit in the palm of the users hand were:

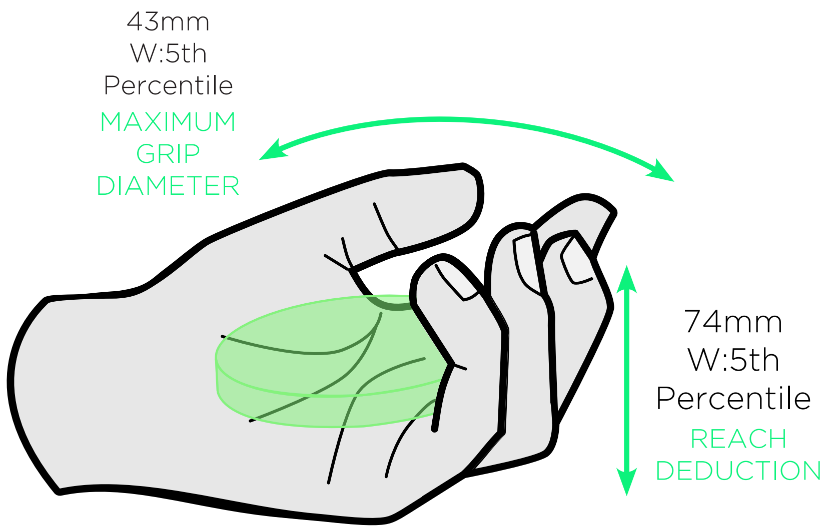
- Palm Length
- Hand Breadth
- Maximum Functional Spread (Pheasant, 2013)
- Maximum Grip Diameter (DTI, 2002)

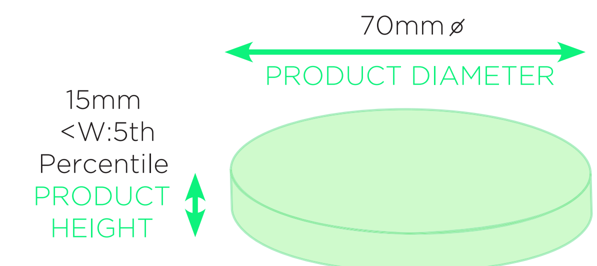
The 5th percentile measurements of women were applied to all measurements, if the product was any larger than the 5th percentile, the product could not be held by users with a 5th percentile hand measurement. The 5th percentile womens hand measurements were chosen as it would also mean an inclusive design for mens 5th percentile hands too. Designing to the 5th percentile of women also ensured that users all through the 95th percentile would be able to hold the product with no discomfort.

3 prototypes were produced of varying diameter (60mm, 70mm, 80mm) using the above anthropometric data. User testing was conducted were users were asked to comment on how comfortable the shape was in their hand and how it 'felt' to hold. User suggested the design of 80mm was too large to fit in the palm of the hand comfortably, and in all likelihood would stand out too much attached to the their bag. The results for the 60mm design were the reverse of this, that the product was too small and that even if it did light up it's effect would be easy to miss. The design with a dimension of 70mm received the most positive feedback, Feedback stated that the product sat well in the palm of a users hand and was also easy to grip around when it needed to be attached to a bag. Although 70mm was slightly over the Hand Breath measurement of 69mm, when taking into account a standard deviation of 4mm it still fell within an acceptable range of comfort for users to hold.

The height of the product would largely depend on the components needed. From a human factors perspective the two most appropriate pieces of data to ensure users could grip the product were: Optimum Grip Width and Finger Reach Deduction. A cylindrical grip will be used when holding the product, as such use of the Optimum Grip Width for grip design would determine the maximum height the product could be. Taking the womens 5th percentile measurement, the maximum height the product could be was 38mm (Tilley & Henry Dreyfuss Associates, 2002). Combining this measurement with the 5th percentile woman's Finger Reach Deduction of 74mm (Tilley & Henry Dreyfuss Associates, 2002) suggested that the maximum height of the product could not exceed 38mm (approx. half of the Finger Reach Deduction Measurement for when finger are flexed around an object). To promote a greater social and physio pleasure when holding the product, inspiration was drawn from smartphone design. The average height of a smartphone measures at 8.9mm. In a western culture where thinner technology is more in demand and seen as more technically advanced and more desirable (Ess et al. 2001) the height of the product was dimensioned at 15mm rather than 38mm. This height is well within the users capabilities to hold, but also will ensure the users has a more desirable product to hold.





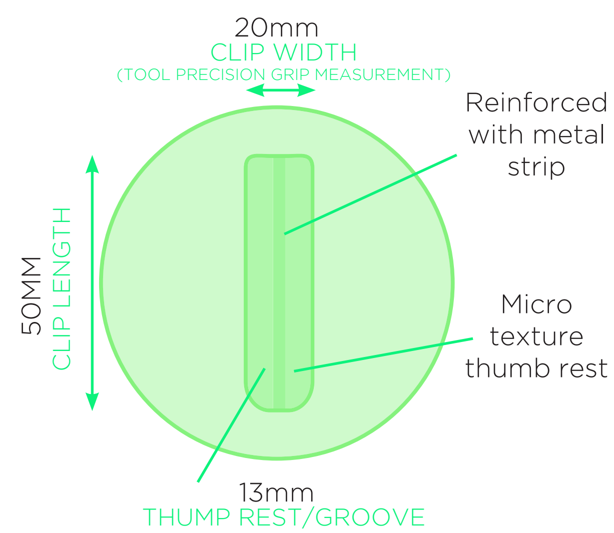


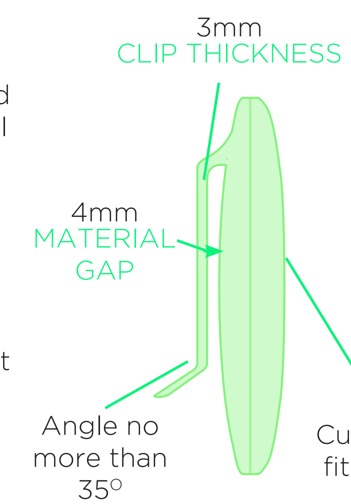
PRODUCT CLIP

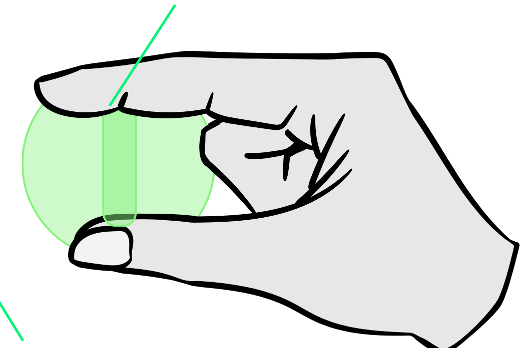
The clip length was determined through measuring the width of various bag shoulder straps. The approximate 50th percentile of these measurements was 50mm, thus the clip was made 50mm long. Due to the enormous range of bags and the different places to clip the product on a bag this estimate will cater for a large range of designs. This height also ensured the design could be attached to belts with a measured average height of 39mm (apparelillustrated.com, 2016).

To ensure ease of use when detaching the clip, a 13mm thumb rest with a rubber micro texture has been applied to the clip. The 13mm sizing was determined through the optimal size of Push Button design for thumbs (Tilley & Henry Dreyfuss Associates, 2002). A micro texture was applied to then further increase the users grip on the clip when detaching from their bag and to also act as a form of haptic feedback to ensure correct use of the clip.

To reduce the likelihood of the clip failing and to reduce the need to re-attach the product regularly; the clip will be reinforced with a metal strip running through the centre. The metal will be pre-bent towards the product body. This ensures when the product is clipped to the users bag there will be a strong hold between the clip and bag material. This feature has been used in a number of personal fitness clips such as Fitbit.







DISPLAYING INFORMATION

ORIGINAL DESIGN

The original design of the product drew influence from the elemental symbol for Oxygen 'O', which for humans is the vital element in the air we breathe. The design incorporated the 'O' shape through the use of a glowing ring. Dependent on the quality of air the ring would change colour as the graphics to the right show.

Through peer evaluation and talking to users it was suggested that the shape of the product was not only impractical with a hole through the middle, but also would make users feel they owned a product that was making too much of a statement and drawing unnecessary attention. Furthermore it became obvious that the way the information of air quality was displayed (through a glowing ring) did not make the user aware of what the product actually did. The use of the colour blue also added confusion as many users naturally assumed low air quality would be represented by the colour green. Comparisons were made that the product would be seen as a bike light rather than an environmental personal tracker.

Comparing these comments against the URS prompted the need to amend the form of the product, but also a way to display information whilst relating the product to its function.

RE-DESIGN

The redesign to display air quality drew influence from users ideological values of being environmentally & health conscious. Dependent on the concentration of PM2.5 in the users environment the screen will display the green, orange or red leaf. Within each colour are a differing shades. As the shades turn darker it symbolises that the quality of air is getting lower and if it continues the leaves will change to the next colour representing higher PM2.5 concentration.

The information displayed has remained entirely visual whilst making use of metaphorical affordance & semiotics. As the images to the right show, the metaphor used is the growth of plants over the summer, autumn and winter months. As stated semiotics was used to create a visual means of displaying air quality whilst also relating the products primary function to air, the environment and health. Plants (and specifically leaves) were used to create this metaphor as not only are leaves inherently associated with nature and the environment but through research conducted by NASA they have been found to be the most effective and efficient way to filter PM2.5, releasing fresh air (NASA, 1989). Various leaf shapes were looked at before a simplified graphic of a Clover leaf was settled on. The leaf shape designed can be instinctively identified as a leaf through the use of shape affordance and the colours used.

Dependent on PM2.5 concentration, the colour of the leaves will change. When the user is in areas of cleaner air the colour scheme will be green. This mirrors the colour of leaves when they are healthy. Furthermore the colour green is often paired with nature and well-being as well as the colour for 'go' (Tilley & Henry Dreyfuss Associates, 2002) which in this case prompts user to breathe more freely. As users move to areas of lower air quality the leaf will gradually transition into shades of orange. Again orange is associated with caution and warning (Tilley & Henry Dreyfuss Associates, 2002) which in this case suggests to user that they should try to move to areas of better air. If users move into an area with dangerous high levels of PM2.5 (65% +) the leaves will fade into a red colour scheme. Red is associated with serious danger and that a task should be stopped (Tilley & Henry Dreyfuss Associates, 2002), in this case moving to a different area immediately.

The colours not only have this more practical use but also represent the natural change in the colour of leaves. The green represents a healthy plant that is new and flourishing, then over time all leaves begin to lose their colour and turn orange and on to red. This represents the life cycle of a health leaf to an unhealthy dying leaf. This use of biomimicry along with the 'blooming' effect created by each leaf gives the product an air of life that users will be more inclined to want to nurture as the health of the leaf is truly a reflection of the users health. On an ideological levels users will be more motivated to keep their leaf looking green and health as it will offer and intrinsic reward.

*The re-design did not have the hole running through the centre of the product. This reduced the likelihood of finger entrapment whilst increasing the products aesthetics appeal.

EMOTIONAL DURABILITY

The emotional durability of the product has been greatly increased through the use of nature as a metaphor. This use of nature embraces the idea 'that attachment to nature, and specifically to 'life and lifelike processes' (Anusas, 2006) evoke innate eco-emotions through mimicry in technology (Anusas, 2006). The design also increases user empathy towards the product which in turn begins to form 'intimacy' and feelings of care towards the product (Chapman, 2015). The way the product is reactive to it's environment gives an impression of consciousness and becomes easier to understand through more interaction with the product (Chapman, 2015). All these features of the re-design help to emotionally bond the user to the product in such a way that through care of the product they in fact will be caring for their own body. Keeping their plant healthy will not become a task or chore, but a want to use the product.

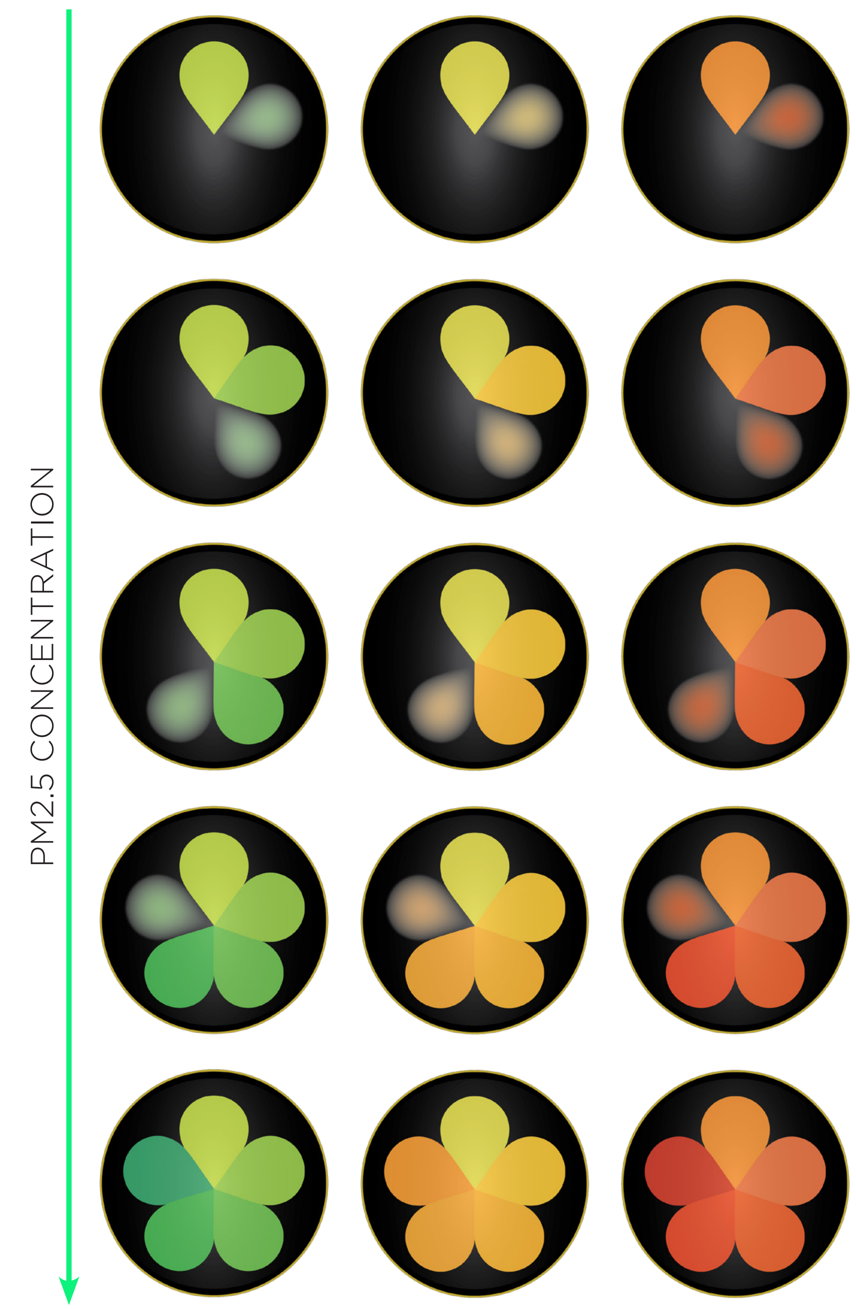
INITIAL 'O' DESIGN

OXYGEN SYMBOL

PM2.5 CONC. 0-30%

PM2.5 CONC. 30-65%

PM2.5 CONC. 65-100%



SCREEN DISPLAY VS. AIR QUALITY

The diagram below shows which graphical display corresponds to what concentration of PM2.5 particles in the air. When the air quality monitor identifies a concentration percentage, it will then convert this to a digital output value. The digital output value will then correspond to a specific graphic element being displayed on the AMOLED screen.

DEVELOPMENT

DESIGN FOR MANUFACTURE

SUMMARY

COMPONENT SELECTION

FUNCTIONAL SPECIFICATION
Prior to selecting the specific components the product required, a Functional Specification for the product firmware system was produced. The specification highlighted the primary function(s) that the firmware would be responsible for producing in the product. Each of these functions where then given a unique specification as to their requirements in terms of the overall system. These specs. were derived from the PDS.
Selection of components would impact the rest of the products designs. Through Human Factors the ideal dimensions of the product measured 70mm (diameter) x 15mm (height). However to ensure the product could function, key components had to be selected. As will be discussed, the total component dimensions were far larger than the 15mm height specified and therefore prompted changes to the overall dimensions of the product when designing the product hardware.

AIR QUALITY SENSOR
Accuracy of the Air Quality Sensor was crucial. Initial research identified that Air Quality Sensors typically use two different methods to detect PM2.5 concentration. The first method being Laser Optic Scattering. The sensor fires a concentrated beam of light on to a photo-transistor. When PM2.5 particles fall into the concentrated beam of light, it breaks up the beam and staggers the time it takes for the light waves to hit the photo-transistor. The frequency of light hitting the photo-transistor is then calculated as a percentage of PM2.5 in the air. The second method used to identify and measure PM2.5 is through the use of Electrical Low Pressure Impactors (ELPIs). This method makes use of plates with electrical current being passed through. When particles fall upon the plate it is recorded as a change in current. PM2.5 concentration is indicated by the number of changes in current in any given time.

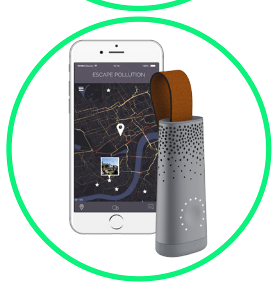
Each sensory method has pros and cons. The ultimate decision was based upon which method was more accurate. Through component research and literature reading the decision to use Laser Scattering sensors was taken. The primary reason for this was that Laser Scattering has a higher PM2.5 accuracy and also ELIP sensors have greater difficulty detecting particles below 3 microns (PM3) which would mean that the products primary function of detecting PM2.5 would not be met (fy.chalmers.se, 2017).

Having established the type of Air Quality Sensor to use in the product it was then a case of comparing a number of these sensors against the specification defined by the PDS and Functional Spec. Initially the sensor had to have an accuracy of 10% (although this was modified to 12.5% due to limitations of current technology), work within a temperature range of -15^{o}C to 50^{o}C and have dimensions of no more than 30m x 30mm x 15m.To Identify the Laser Optic sensor that most closely fitted these specifications a table was drawn up to compare a number of different sensors. After researching various different sensor models from different manufacturers the sensor that best fitted the specification was the SDS021 Laser Sensor.

ATMOTUBE

TZAO TRACKER

PLUME FLOW

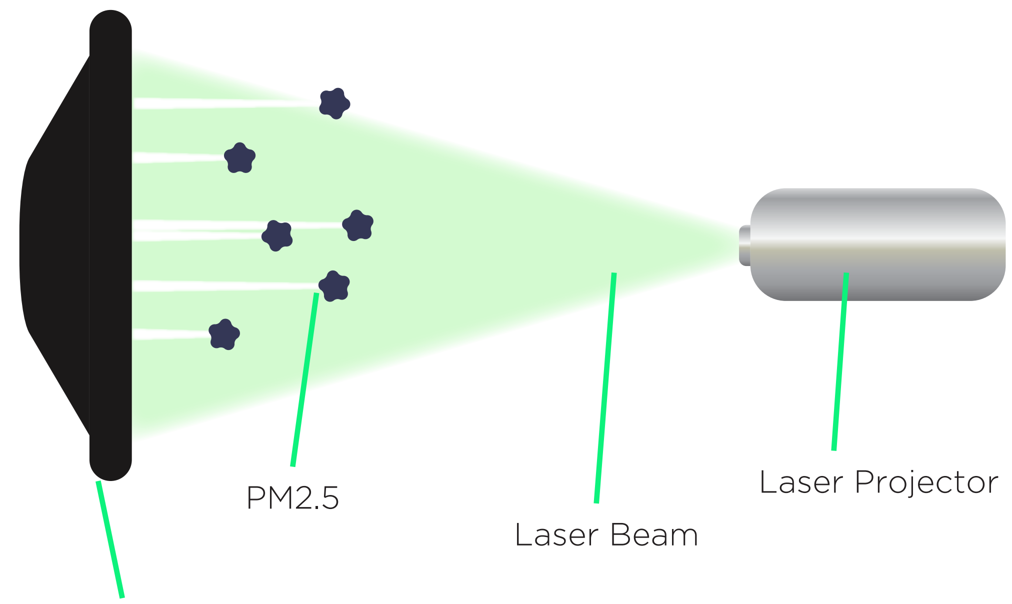


AIR QUALITY SENSOR - FUTURE DEVELOPMENTS
Though component research identified the most appropriate air quality sensor *widely* available on the market today, it did not necessarily identify the latest technology available. Research was conducted into products available to consumers that tracked PM2.5 concentration. The results showed that many of the products deliver similar functions whilst also having a reduced overall dimensions in comparison to the product being developed. As will be highlighted in the coming pages, many of the other components used take up minimal space inside the product itself, and as such the air quality sensors being used must inevitably be the largest component.

Since all the products being sold currently had smaller overall dimensions than the product being developed, it was justifiable to assume that each product available on the market today had custom designed or patented technology to detect PM2.5 concentration that were far smaller than the SDS021 Laser Sensor, available to the general market today. An example of these smaller sensors is the Micro PMT, measuring at 15 x5 mm that measures PM2.5 and is currently in development for widescale distribution (techon.nikkeibp.co.jp, 2013).

When launching the product the R&D to make these sensors would increase cost and production time; however at this stage assuming that a Sensor with reduced dimensions is possible was entirely justifiable. Whilst using the same sensor identified against the PDS, reducing the component's dimensions would give a more realistic indication of the spacing needed to house the component. The dimensions of the SDS021 measured 42.5 x 32 x 18mm; however with the new knowledge gained a new conservative estimate of dimensions was used. The dimensions taken forward were: 30 x 22 x 11mm. All 3 companies were contacted regarding information about the sensors they used, all three companies declines to share any details

LASER OPTICS SENSOR

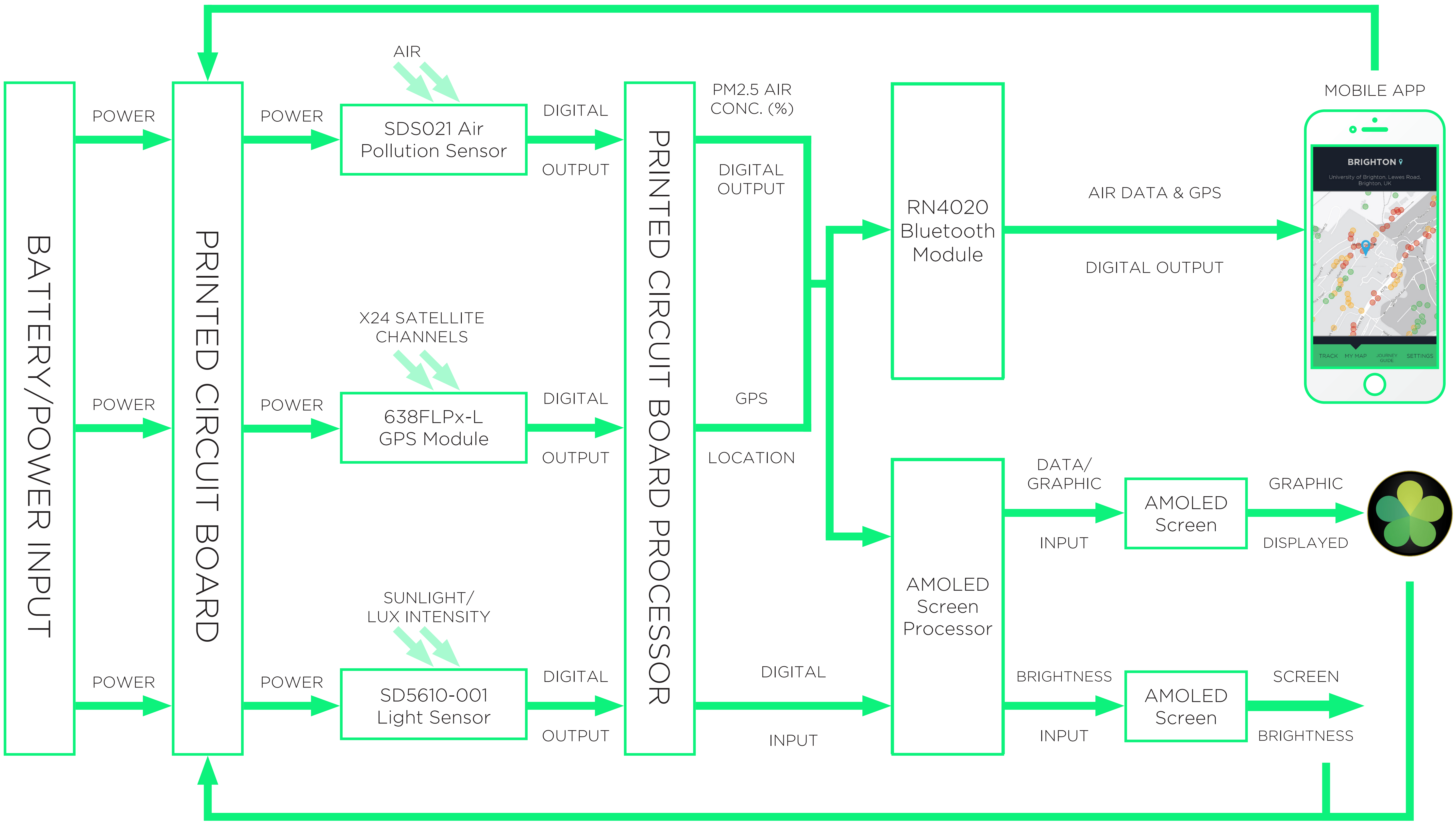


SDS021 LASER SENSOR

Accuracy: 12.5%
Dimensions: 42.5 x 32 x 18mm
Working Temperature Range: -10 to +50^{o}C
Response Time: 1 second
Digital Output: Yes
Voltage: 3.3v
Current: 60mA
Mass: 20g (estimated)

CIRCUIT BLOCK DIAGRAM

Production of the functioning PCB & components along with the app will more than likely be outsourced for manufacture and assembly. In order to ensure that the components supplied would interact in the correct way the circuit block diagram below would be sent to the supplier/manufacturer. The diagram represents how each of the components must interact with one another in order to bring about the desired outcome, which in this case is the correct graphical element being displayed on the AMOLED screen. The block diagram shows the information that each component will have as an input (which may be external e.g. air) and the output which will determine the functioning of the next component(s).



DESIGN FOR ASSEMBLY

PCB & COMPONENT SIZING

As stated earlier, to ensure the product would be able to function it was important to firstly establish an exact list of the components that would be used in the product. With the established list of components and their dimensions the next step was to arrange this into a formation to be attached to a PCB. The primary components such as the air quality sensor, Bluetooth module and GPS module would sit atop the PCB to be soldered in place when being manufactured. The battery would be placed below the PCB with wiring leading through to the components through the underside of the PCB. This would also ensure that the width of all the components together was reduced. PCB thickness can range from as little as 0.5mm through to 3.2mm thick (4pcb.com, 2017). As such an estimated PCB thickness of 2mm was used. As the diagram to the right shows, in total this gave the PCB and components a height of 18.5mm (already 3.5mm taller than the total height of the Human Factors design). To accommodate the shape of the designed product, a round PCB board will be used with a diameter of 48mm. This diameter was chosen to accommodate all the components on to the PCB surface.

To produce a functioning product, the ideal dimensions of the product derived from human factors (50mm diameter and 15mm high) had to be adjusted. To allow enough space for the screen, PCB and Lower Housing case the height of the produce (minus clip) was increased to 35mm. To accommodate for the size of the PCB and components the overall diameter of the product was increased from 50mm to 70mm.

ASSEMBLY

The assembly of the product would significantly impact the design of the various parts of the product. Therefore establishing a 'base' assembly process would focus the design of the parts during DFM. The reverse engineering of the Amazon Echo provided an insight into how various components could be assembled in this product. The final design reduce assembly time of the parts, increases ease of assembly whilst also ensuring strong joints between surfaces that required high water resistance. The assembly is made up of 3 sub assemblies that will need to be assembled before putting together the final product.

21 MINUTES (ESTIMATED)

SUB-ASSEMBLY 1

Manufacture and assembly of the PCB and components will most likely be an outsourced requirement. Providing a manufacturer with the firmware BOM and assembly diagram of the product will allow for ready made electrical components to be installed directly into the product. Due to the detail of the PCB, it is estimated to take 20 minutes to solder and finish 1 PCB with components attached. When being assembled to make the final product the PCB will be screwed into non-threaded holes in the lower housing. The holes present on the PCB allow for alignment when being placed into the lower housing. 4 threaded screws will then secure the PCB into place. This completes Sub Assembly 1. It is important to note that Sub Assembly 1 is dependent on assembly of the outsourced PCB and electrical components.

15 SECONDS (ESTIMATED)

SUB-ASSEMBLY 2

Assembly of the clip to the lower housing is one of the quicker joining processes. As discussed earlier the clip will be Ultrasonically Welded to the Lower Housing of the product. Ease of alignment and therefore joining has been achieved by the use of a locating channel on the surface of the two mating faces which will also ensure a consistent joining across multiple parts. Couple this with an estimated average weld time of 3.6 seconds per piece (1000 pieces can be joined in an hour (Granta CES Edupack, 2016), the assembly process to join these two parts should be very small. The second stage of this Sub Assembly is positioning the second O-Ring in the groove present on the Lower Housing. Again the groove acts as a means of alignment and location for the O-Ring and as such will reduce assembly time. Lastly the External Body ring is slid over the lower housing shaft and will be positioned in place using Sub-assembly 3. Sub-assembly 3 took influence from the lid of the Amazon Echo. Dependent on the accuracy of the injection moulded part and the milled body ring and after initial testing, an epoxy resin may need to be applied between the two surfaces which would increase the assembly time by 8 minutes (masterbond.com, 2017) to allow the epoxy to set.

45 SECONDS (ESTIMATED)

SUB-ASSEMBLY 3

Sub Assembly 3 consists of the AMOLED Screen, an O-Ring, the snap fit cover and 4 M2x6mm screws. The assembly will start by placing the O-Ring in the provided groove on the surface of the snap fit cover. Secondly, wiring coming from the AMOLED screen will need to be threaded through hole in the centre of the snap fit cover. Once this has been done the 4 screws will be placed in the screw holes on the snap fit cover and lined up with the screw inserts on the underside of the screen. Screws will need to be tightened to ensure O-ring compression occurs to prevent water entering the product.

10 MINUTES (ESTIMATED)

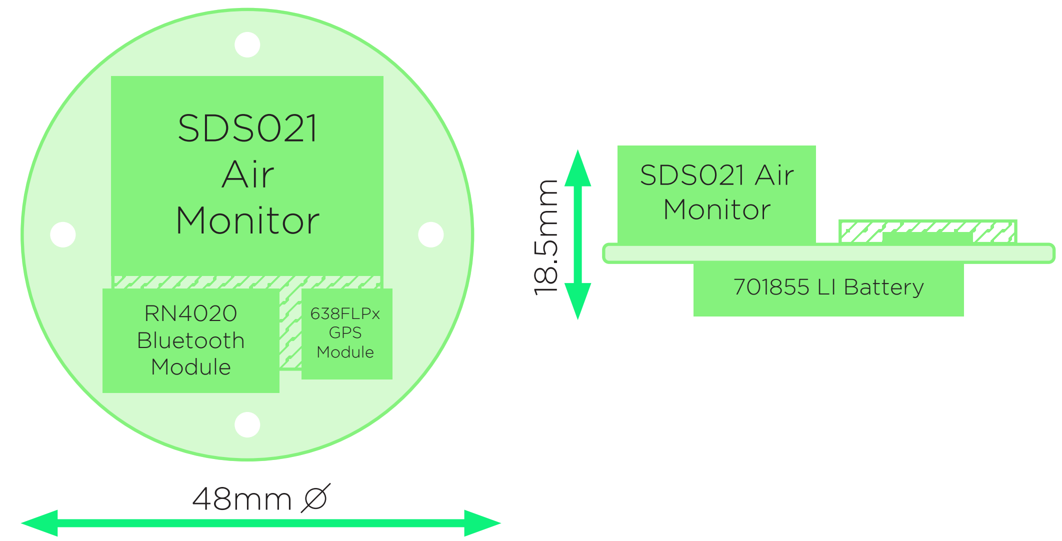
FINAL ASSEMBLY

Once all sub assemblies have been completed the final assembly of the product is very quick. The first step is attachment of the screen wiring to the specified ports of the PCB and components. Most likely this will make use of pins and not be soldered which will further reduce assembly time. When the screen wires has been successfully attached, Sub-assembly 3 will be pushed into place concentric to the Lower Housing. This will in turn secure the External Body Ring whilst also making disassembly of the product impossible for users. This will then complete the assembly of the product.

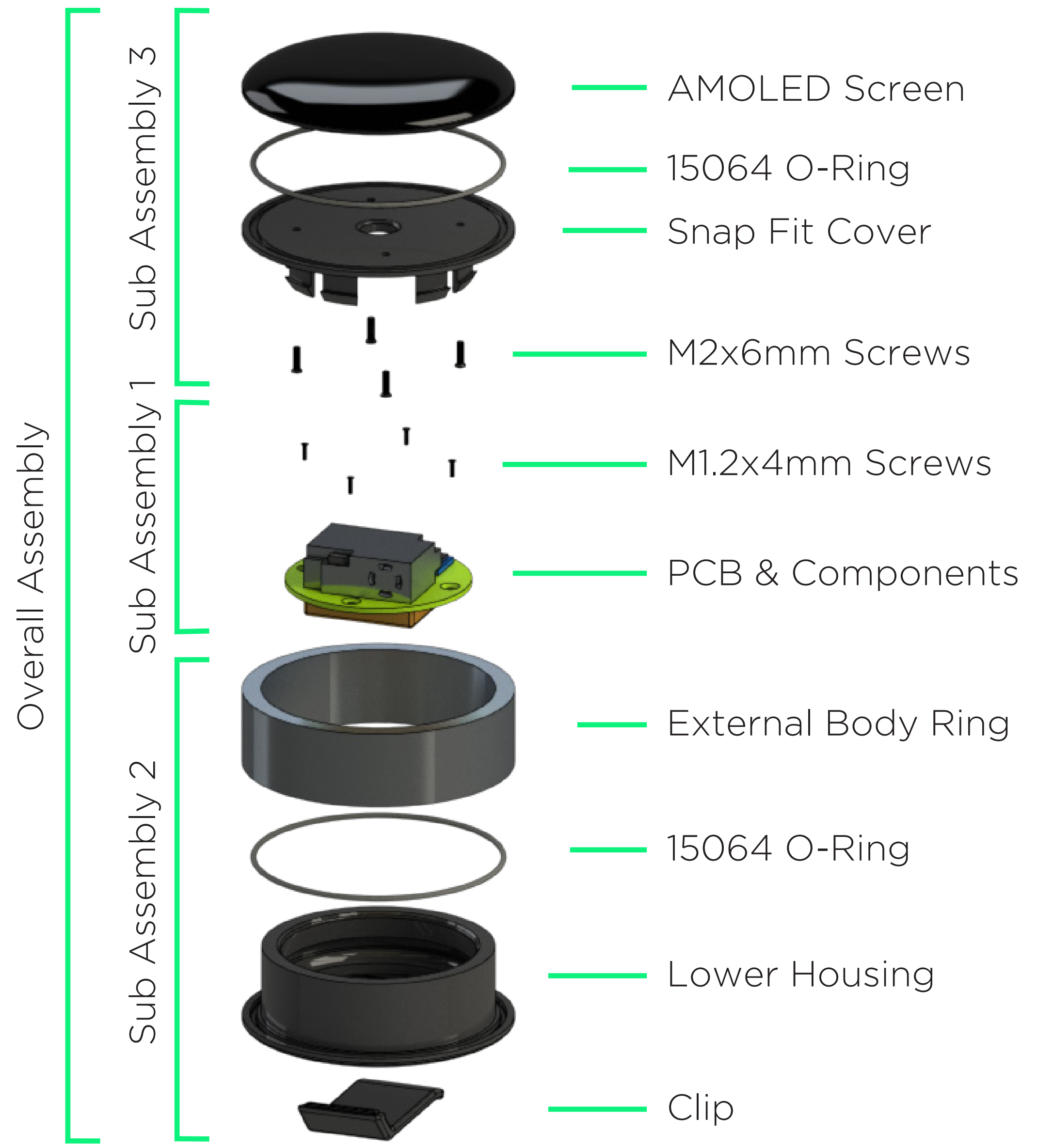
WORST CASE **- ESTIMATED TOTAL TIME FOR ASSEMBLY =** 32 MINUTES

BEST CASE **- ESTIMATED TOTAL TIME FOR ASSEMBLY =** 10 MINUTES

PCB BOARD DIMENSIONS



ASSEMBLY AND SUB-ASSEMBLIES OF THE PRODUCT



PART DESIGN - SNAP FIT COVER

SNAP FIT ASSEMBLY
The original design for assembly had been to make use of a threaded aluminium ring and threaded shaft of the Lower Housing. As discussed, this design was not cost effective nor did it make assembly of the product easy. To secure the aluminium ring in place whilst protecting the electronic components, and provide a mounting surface for the AMOLED screen, a snap fit design was chosen. The snap fit cover drew inspiration from a similar part design of the Amazon Echo 'Snap-fits are the simplest, quickest and most cost-effective method of assembling two parts' (BASF, 2007) whilst also being the most environmentally friendly form of assembly. Use of snap fit would also reduce the part count. The cantilever design would have to ensure that the snap fit cover could be pushed into the grooves in the Lower Housing during assembly and provide a secure fit that could not be disassembled after.

MATERIAL SELECTION
Snap fits can be designed using a number of materials, but by far the most appropriate materials are polymers. Thermoplastics are preferable than thermosetting plastics due to their high flexibility, high elongation properties, low coefficient of friction, high strength and ability to be moulded into complex shapes (BASF, 2007). When selecting a material for the snap fit cover to be manufactured from, various thermoplastics properties would have to be put through a series of equations to determine their suitability.

SNAP FIT DESIGN
Due to its high strength values when bending, a Cantilever snap fit design was used. *When designing the snap fit and testing materials through equations, the BASF industry standard Snap-Fit Design Manual (2007) was used.* Prior to material/design testing a base design was created, shown to the right. These dimensions were estimated through CAD modelling and tested through prototyping to determine if any dimension changes would be needed and to see which material to use to prevent failing of the snap fit.

The BASF manual provided a list of recommended thermoplastics for snap fits along with their Allowable Strain Value (e) and Coefficient of Friction. The three materials chosen from this list to evaluate were PET, PC and ABS due to their high yield strength, good mouldability and low cost. To test the suitability of each of these materials against the snap fit design dimensions, three factors needed to be determined: Maximum Deflection of Snap, Mating Force and If the Snap Fit is Acceptable for use. The equations used were more accurate than conventional bending beam equations as these tend to 'underestimate the amount of strain at the beam/wall interface' (BASF, 2007) as they assume the wall the snap fit is attached to be completely rigid. These equations only represented this theory when the ratio of beam length to thickness is 10:1, which in this case was not true (3.5:1.75) (BASF, 2007). The equations suggested by the BASF standard used a Q Deflection-Factor to determine the true strain on the snap fit. A Q Deflection-Factor of 2.2 was determined through the use of the BASF Manual and the style of the cantilever. The table below shows each value for the 3 polymers being tested against the cantilever design shown in the diagram to the right.

	Max. Deflection (mm)	**Mating Force** (N)	**Strain Limit** (%)	**Safety Factor** (Allowable Strain/ Strain Limit)
PET	2.4	183.2	3.1 *(Allowable strain value: 5.8)*	*1.8*
PC	3.4	148.9	3.1 *(Allowable strain value: 9.2)*	*2.9*
ABS	2.9	275	3.1 *(Allowable strain value: 7)*	*2.3*

As the table shows, all of the materials had a maximum allowable deflection (mm) that was above the true deflection value (Y) of 1.25mm ensuring that each plastic could deflect the required amount. Due to the dimensions of the design, all strain limits for each material measured 3.1%. These were compared against the Maximum Strain Values for each of the plastics given in the BASF Manual. All materials passed this test, which ensured that when deformed under pressure all the plastics would return to their original shape and not pass their elastic limit. The mating force for each design varied considerably. This was the force required to push the snap fit cover into place. ABS would require a force of 275 Newtons to simply push the snap fit cover into position, since the force required was so high it would most likely make the assembly process harder and more time consuming. Even with adjustments to the cantilever dimensions it would not bring about enough change to ensure ease of assembly. PET also had a relatively high mating force of over 183.2N. When mating force is too high it often means that assembly of the product is much harder and if the full force is not applied directly through the centre of the cantilever beams, can result in part failure (BASF, 2007). The assembly needed to be easy whilst making disassembly by users very unlikely. Polycarbonate provided the lowest mating force that was also close to an acceptable force of 100 Newtons (or 10kg) to assemble the product whilst also having a high strain value (BASF, 2007).

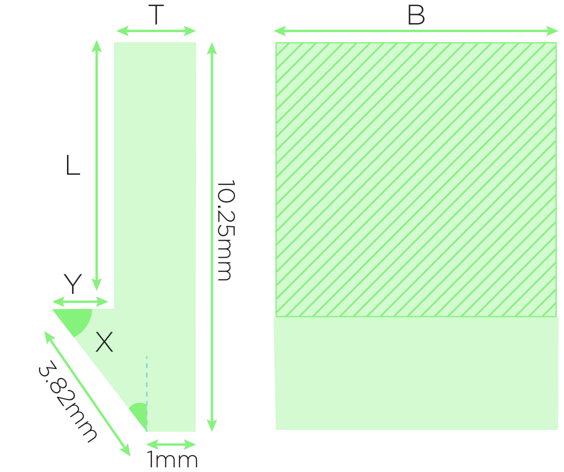
To reduce the mating force required during assembly to be closer to 100N it meant adjusting dimensions of the cantilever design. The three dimensions changed to reduce the mating force were the Lead Angle (X) due to its direct involvement in the equation for Mating Force. Reduction of this angle would reduce the overall outcome of the equation, and therefore the force. Reduce of length T would also have an indirect change to the mating force. Perpendicular Force (P) is used to determine the Mating Force (W). P is determined using the equation (B)(T)^2(E*e)/6*L. Thus reducing T would reduce the overall of P, again reducing the resultant Mating Force. Lastly measurement L was increased by 1mm as an increased length of cantilever would result in the same perpendicular force being applied over a longer/larger area, ultimately reducing the mating force. P was reduce to 1.5mm, T to 8mm and the Lead Angle was reduced to 25^{o}.

With these new dimensions applied, the required Mating Force to push the snap fit cover in place was reduced to just above 105 Newtons. The reduced mating force would ease the process to push the snap fit cover into the Lower Housing whilst also providing a strong assembly joint to prevent user disassembly. The redesign also reduce the gave the design an increased safety factor of 4.8.

CANTILEVER 'BASE' DIMENSIONS

T = 1.75mm
B =9.75mm
Y = 1.25mm
L = 7mm
X = 31^{o}
Q= 2.2

*Q - Deflection Factor



EXAMPLE OF EQUATIONS TO DETERMINE SUITABILITY OF PLASTICS (ABS)

Mating Force (W)

$$W = P\frac{\mu + \tan\alpha}{1-\mu\tan\alpha}$$

124*(0.6 + tan31^{o})/(1-0.6)(tan31^{o}) =
124*(1.2*0.24) =
124*5 =
620 Newtons

Maximum Deflection of Snap Fit (Y_{max})

$$Y_{max} = \frac{\epsilon_o L^2 Q}{1.5\,t}$$

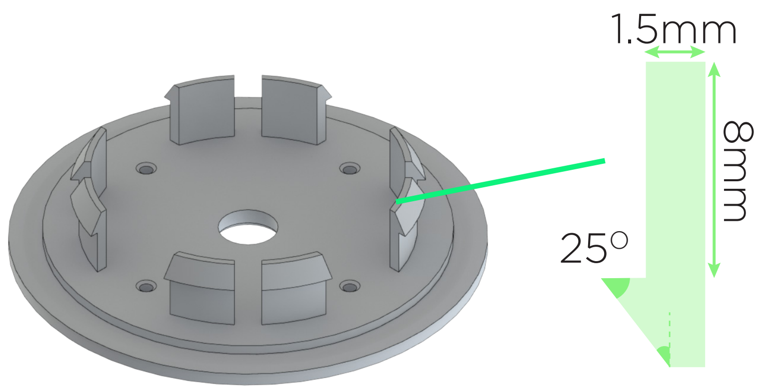
(0.07)(7)^2(2.2)/(1.5)(1.75)=
7.5/2.63 =
2.9 mm

Strain Limit (e)

$$\epsilon = 1.5\frac{tY}{L^2 Q}$$

1.5*(1.75*1.25)/((7)^2*2.2)=
1.5*(2.2/107.8)=
1.5*0.02=
3.1%

RE-DESIGNED CANTILEVER



PART DESIGN - LOWER HOUSING

THE PART

The Lower Housing part would be the main part for all other components to be fitted to. It provides a place to safely house the electronic components whilst also providing a surface for the external body ring and snap fit cover to attach to. As a Prima Selection Matrix showed there were a number of manufacturing processes this part should consider using.

DESIGN FOR ASSEMBLY

As discussed the external body ring slots on to the shaft of the Lower Housing. This in turn will then be secured in place through the snap fit cover. The overall time for this assembly was less than 5 seconds, however housing of the PCB and components would be a separate assembly into the Lower Housing. The original design shown to the right was to simply glue the underside of the PCB and components to the surfaces of the battery recess. Three main issues arose from this design. Firstly the use of a glue or resin may over time fail and cause the PCB to come loose; if this were to occur it may damage the components and stop their functioning. The second issue was the time needed for any epoxy/glues to set which would further increase assembly time, and finally us of epoxy on to PCBs =often cause failure of the PCB due to the temperature at which the epoxy is applied. The initial design also used high a high quantity of material.

The re-design shows how self-tapping screws will be used to secure the PCB. Through the use of ribbing the quantity of material needed to secure the PCB was significantly reduced. The ribbing also offered structural support (Quickparts, 2017) for the screw hole bosses. The bosses for the screws would use the Nominal Bore measurement of the screw used. A Type AB, Self Tapping M1x4mm screw with flat 100° was used to secure the PCB in place. Use of a Self Tapping screw rather than Self Binding Inserts and screws not only reduce the part count of the product, but also the overall cost of production. Counter sinking would be accounted for on the PCB itself. To ensure a H7 Transition fit (ISO 286:2) would occur when inserting the self tapping screw the metric nominal bore of the screw diameter was used. The hole diameter needed to ensure the M1.2x4 screw would be secure and would thread into the material was 0.95mm (trfastenings.com, 2017).

Other DFM practices used were ensuring that the Boss Diameter (4mm) was at least 2-2.5 times bigger than the Hole Diameter (1mm) (BASF, 2007). Counter Sinking of at least 0.5mm was adhered to on the PCB along with a draft angle of 1° on the inner core hole surfaces (BASF, 2007). Both these design inclusions would ensure a secure screw fit along with a reduced likelihood of the boss cracking/failing.

MATERIAL SELECTION

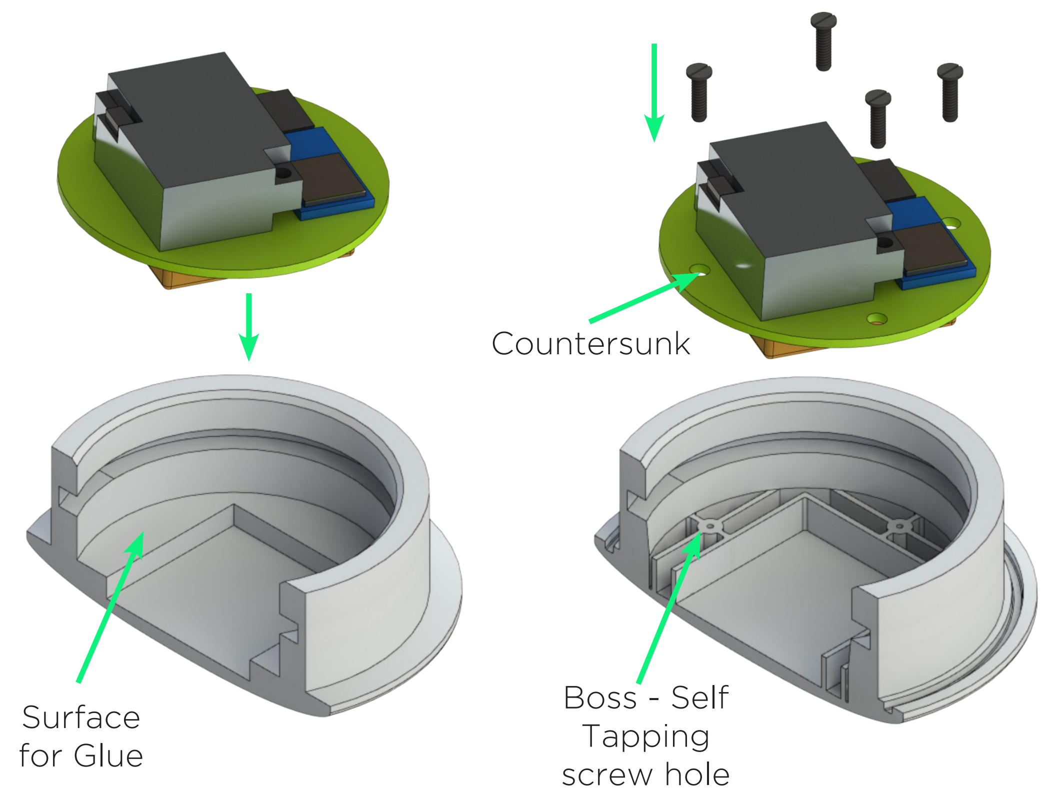
When choosing a material for the Lower Housing many properties were considered. To ensure that water/rain would not damage the part high durability and water resistance was needed. The Lower Housing also provided the largest surface of the outercasing of the product and as such would be subject to repetitive impacts, drops and general wear and tear. To ensure any damage occurring was simply cosmetic a high impact resistance and Hardness Vickers rating was required. The part would have multiple forces acting upon it from the snap fit cover and the clip. Ensuring the material would not fail by also taking into account Yield and compressive strength of the material was important too. The material chosen had to have all these properties whilst also having good mouldability due to the complexity of shape being produced. To narrow down to a selection of Polymers, a graph plotting Tensile Strength against Mouldability (level 3 and above) was produce. Below is a section of the materials compared for the Lower Housing.

PROPERTY	ABS	POLYCARBONATE	POLYSTYRENE	PA NYLON	POLYETHERETHERKETONE
Durability / Scratch Resistance	High	Very High	Average	High	Very High
Cost (GBP/kg)	1.75 - 2.1	2.62 - 2.85	1.33 - 1.89	2.6 - 2.92	64.9 - 69.5
Yield Strength (MPa)	27.6 - 55.2	60 - 72.4	35.9 - 56.6	90 - 165	70 - 103
Hardness (Highest - Vickers)	15.3	21.7	16.9	28.4	28.5
Mouldability Rating (1-5)	1	3	2	2.5	1

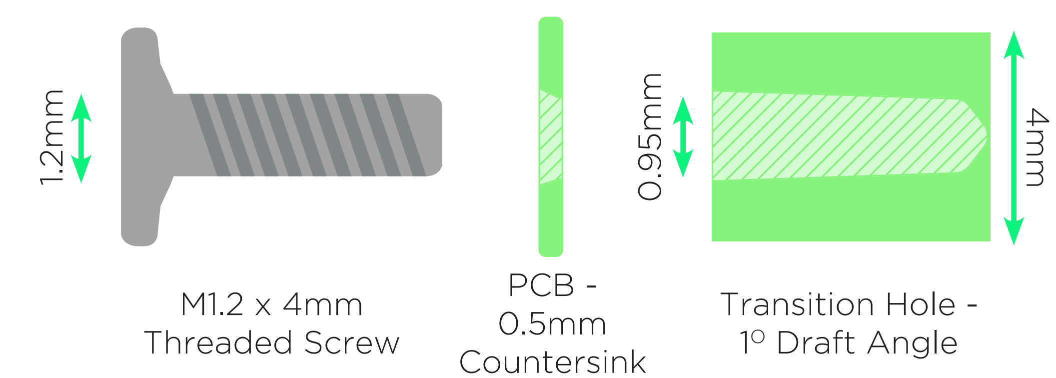
(Granta CES Edupack, 2016)

The two materials that suited the requirements of the Lower Housing best were ABS and Polystyrene. Though Polystyrene was cheaper than ABS and had a greater yield strength, it is also a very ductile material and upon impact is very prone to cracking (Granta CES Edupack, 2016). Furthermore when moulded it can be relatively expensive to colour Polystyrene and get a consistent opaque finish. ABS was the most suitable material to make the Lower House part from. It offered high durability and fresh water resistance, was low cost and had good suitability for moulding, with high precision of up to 0.1mm for complex moulds (Swift & Booker, 2013). Though other materials such as PEEK did have higher mechanical properties these were over-specing the product and would provide a level of strength not needed along with drastically increase material cost. ABS has added benefits of being light, high-gloss finishing applied directly in-mould, coming in a range of colours and most importantly had the "highest impact resistance of all polymers" (Granta CES Edupack, 2016).

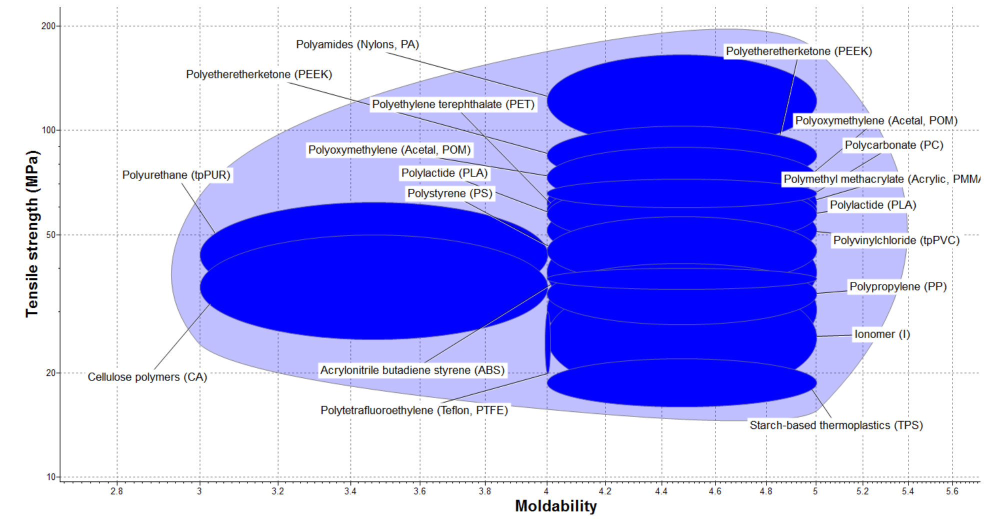
INITIAL VS. REDESIGNED PCB ASSEMBLY



THREADED SCREW AND HOLE



TENSILE STRENGTH V. MOULDABILITY OF THERMOPLASTICS



PART DESIGN - LOWER HOUSING

MANUFACTURING METHOD

When selecting the manufacturing of the Lower Housing, the PRIMA Selection Matrix was consulted to select a process that could use the desired material (ABS) and would also produce high quantities at a low investment. The complexity of the part to be made was another factor in determining which process to use when manufacturing. The Lower Housing had many under cuts and some wall thickness as small as 0.5mm. Due to the complex shape, the high gloss surface finish required and the need for tight tolerances, the choice was made to use MuCell Injection Moulding. MuCell Injection Moulding was chosen over regular injection moulding as the process produces parts with greater strength than regular injection moulding, at roughly 30% less weight (Leferti, 2015). This process also offers greater detail to complex parts, and due to the use of nitrogen gas in the mould, the parts created have increased flat profiles where required with less potential for warp (Leferti, 2015). MuCell Injection Moulding was also suitable for ABS due to the materials low melting point which would ensure good mouldability, and production of high quality parts. Designing parts for MuCell Injection Moulding are to the same requirements as regular Injection Moulding.

DESIGN FOR MANUFACTURE

As touched upon earlier, the design of the Lower Housing made use of Ribs and Bosses. Their inclusion performed two main functions. Firstly the use of ribs significantly reduce the cost/quantity of material needed to produce the part. Secondly, thick/large sections of plastic walls tend to result in warpage or shrinkage when injection moulded (engineeringexchange.com, 2017). Through the use of ribs not only does the plastic part have an increase in bending stiffness, but is also much less likely to have surface imperfections that undermine aesthetic value of the part (stratasysdirect.com, 2017). The use of ribs in injection moulding came with certain rules that had to be followed to ensure good design.

To ensure the easy ejection from the mould, a draft angle of 1° was applied to all ribs. The maximum rib depth could be no greater than 10 times the width of the rib wall (Quickparts, 2017), which in this case has been followed (1mm thickness and 6mm height). Furthermore guidelines suggest that rib thickness at its base should be no more than 0.6 times of the nominal wall thickness of the part (engineeringexchange.com, 2017). As shown in the model to the right, the nominal wall thickness measured 2.4mm at its widest point. 2.4mm x 0.6 = 1.45mm, meaning that the rib thickness could be no greater than 1.45mm. As such all rib walls have been made 1mm thick. This design not only increased stiffness but also reduced the chance of the part shrinking.

The second important requirement when designing ribs was to ensure that there were no sharp corners. Sharp corners in rib design can lead to increased stress concentration and the ultimate failure of the part (stratasysdirect.com, 2017). Other issues that occur with sharp corners are poor flow of material and an increase in mould wear. When adding a radius to ribs, a suggested radius of between 0.5-0.9mm should be applied (Hasenauer *et al.*, 2007), again the model to the right demonstrates this use of radii on corners of all ribs. The principle of sharp corners when injection moulding applied not only to ribs, but also to the whole part structure. Due to the complexity of the part being made not all edges could be radiused (e.g. snap fit over hang), however where possible radius edges and gradual decrease in wall thickness were applied to sharp corners.

Another area that had to be considered when injection moulding the Lower Housing was wall thickness. For unfilled polymers, the guideline wall thickness consistency is between 0.3 and 5mm (engineeringexchange.com, 2017). Where possible this rule was kept to, but due to the complexity of the shape this rule could not always be followed. Though it is suggested, a consistent wall thickness is not essential. Due to design limitations, wall thickness could not be kept uniform, but to combat this the change from slightly thicker to thinner walls has been made as gradual as possible. Again for the snap fit overhang this is less consistent.

Lastly, to ensure ease of ejection from the mould draft angles have been applied to all vertical faces. A suggested minimum draft angle for vertical faces is 1°, with an optimum being 2° (Quickparts, 2017). A draft angle of 2° was applied to all vertical faces, including the shaft, though this angle will likely return to 1° when ejected from the mould due to cooling and through the use of a parallel mould opening (stratasysdirect.com, 2017). Due to the complex shape being constructed not all 'best design' rules could be followed for this part. Prior to machining of moulds pieces, a Rapid Injection Mould prototype would be produced and tested to allow for inspection of the part for any modifications needed. This would initially increase costs, but in the long term may save large investments into moulds that may potentially produce faulty parts.

FINISHING

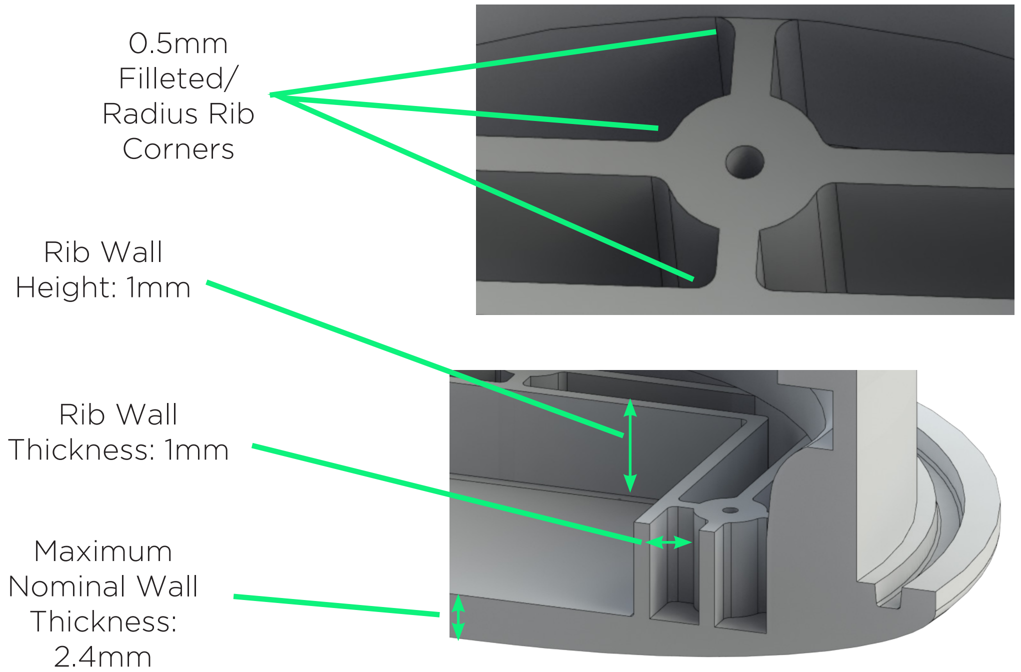
The finish deemed most desirable for this product from Human Factors was a high gloss, black finish. To selected the colour of the part produced would be a simple process that involved selecting the ABS granules dependent on the desired part colour.

Ensuring a high gloss finish would be down to the mould cavity used. MuCell Injection Moulding can produce parts of very little surface roughness (0.2 -1.6 μm) and often with a Surface Roughness rating of A. Though this would produce a smooth finish, it may not be to a high enough gloss standard. To ensure this aesthetic requirement would be met the mould produced would have a SPI-A2 - Diamond Buff which can be hand polished or textured to the interior of the mould, whilst also ensuring the mould was made of a high polished steel (protolabs.co.uk, 2017).

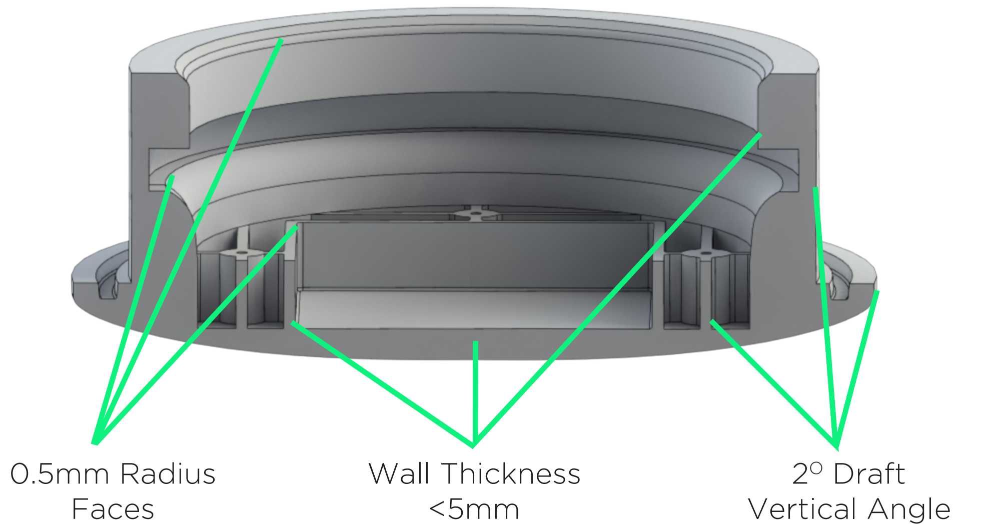
Another area to address was the issue of ejector pin and the Sprue (material injection) location. Incorrect positioning would leave a mark on the surface of the product that would severely reduce the aesthetic value of the product. To ensure that any marks left behind from the injection moulding process could not be seen, the mould would be designed to ensure that any marks left were along the top surface of the shaft. The surface would not be seen on the external and fully assembled product.

Finally, the Lower Housing would be finished with a Liquid-Repellent Coating. The coating would increase water resistance of the product by placing the finished part in a vacuum chamber whereby a nanometer-thin liquid-repellent monomer would be applied to the surface. This process works well on complex shapes as it is applied in the vacuum chamber and is used regularly ion phone casing (Lefteri, 2015).

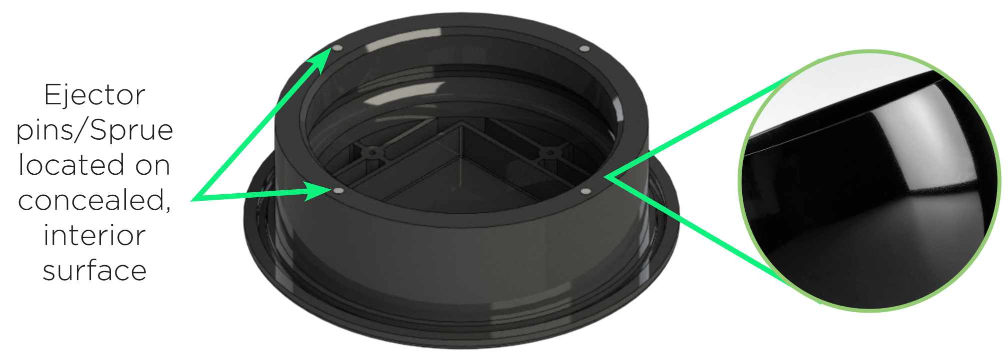
RIB DESIGN



DRAFT ANGLES AND WALL CORNER FILLETING



INITIAL VS. REDESIGNED PCB ASSEMBLY



SPI-A2: Grade #2 Diamond Buff, 1-2 Ra - Black Gloss Finish

INGRESS PROTECTION - O RING DESIGN

The previous page detailed how Ingress protection would be used to ensure that the product's internal functioning was made water resistant. Preventing water entering the product in the first place would ensure greater long term protection, ultimately reduce the risk of losing product functioning and potential injury to the user. The nature of the design and assembly meant that there would be two main points for water to access the inner components. These were the screw fix between the AMOLED screen and the snap fit cover. The other being where the External Body Ring meets the outer lip of the Lower Housing. Though the snap fit would provide sufficient force to keep the aluminium ring in place, the force would not be sufficient enough to guarantee a water tight seal. This was also the same for the screen and snap fit.

The most effective way to make a seal between two meeting surfaces water resistant is through the use of O-Rings. O-Rings are low cost, do not require intricate part assembly, can compensate for tolerance runout, allow for seal in any direction and are lightweight (hydraulicspneumatics.com, 2017). There are many different check-boxes that an O-Ring must fulfil in order to provided a high quality seal. These are detailed below.

DETERMINING THE APPLICATION

There are two main types of O-Ring applications. These are Dynamic and Static. Dynamic O-Ring application focuses on when there are high levels of vibrations between surfaces, or even mechanical movement between the surfaces. Static is where there is no vibration. The environment in which the product will be used will causes small vibrations, and as such Pseudo-Static seal will be needed. This results in the O-Ring application to be radial-static. When designing the groove for the O-Ring to sit, this was taken into account.

MATERIAL SELECTION

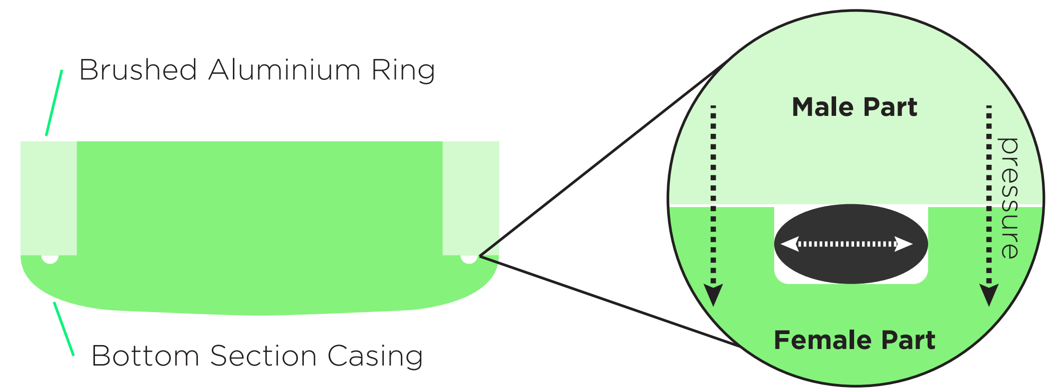
The material selection was determined by the environment in which the product would be used. Whilst also considering a Pseudo-Static application, the O-Ring would be subjected to weather conditions such as rain, snow, and differing temperatures. Ensuring the material had low conductivity would also reduce the change of short-circuiting or user injury. Another important aspect to be considered was the material's permeability to gas. Due to air being a gas, a low impermeability level would be needed to allow entry for air into the product to be analysed for basic functioning of the product.

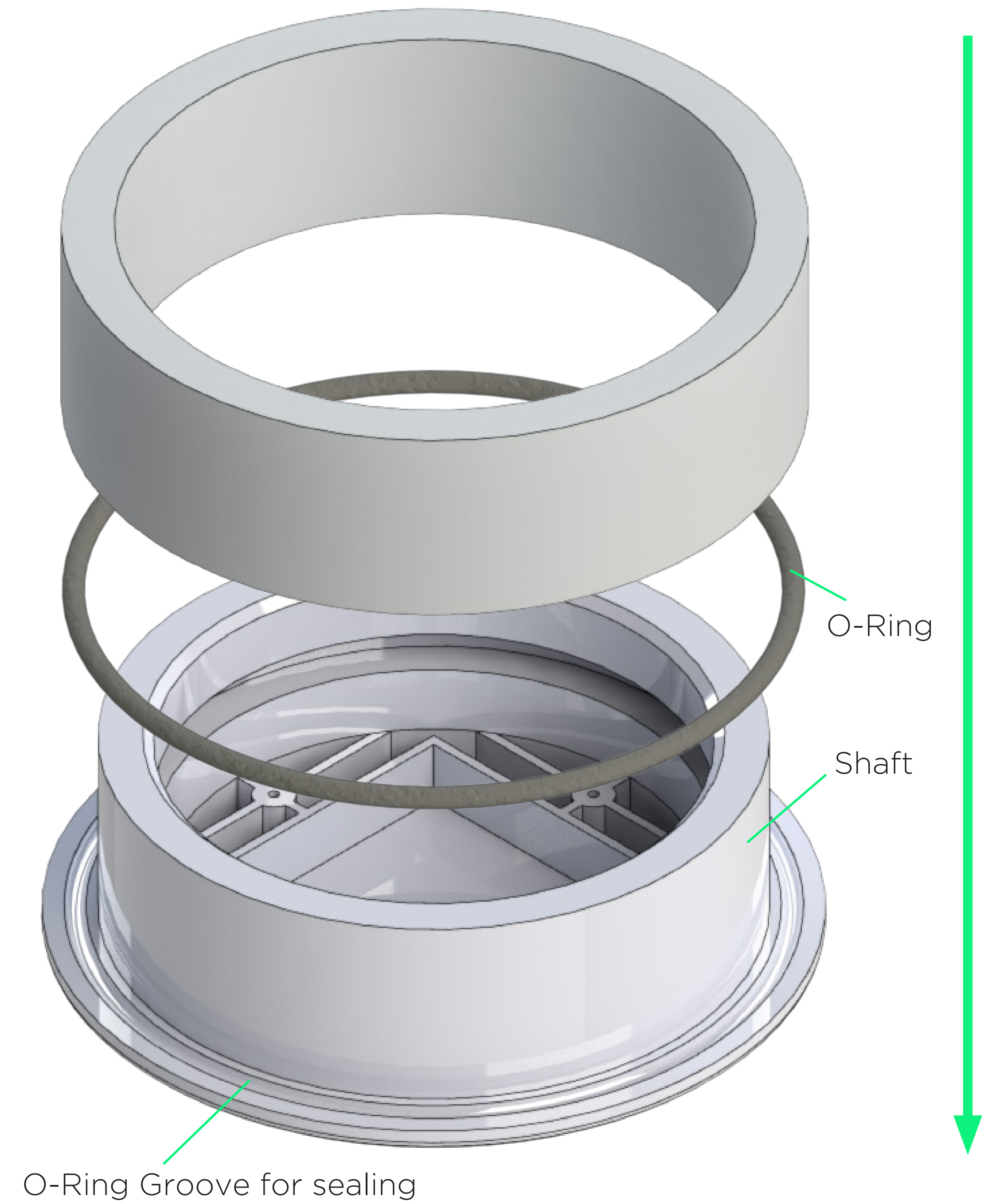
When determining the O-Ring material other factors that were considered included water resistance, Elongation Percentage, type of fluid resistance, functioning temperature range and hardness. All of these criteria had to be met whilst also ensuring the material was low cost. Below is a simplified version of the material comparison table conducted for the O-Ring material. The material chosen was Ethylene Propylene was due not only to it's high water resistance but also ability allow oxygen/gas t pass through it.

MATERIAL	COST	MAX ELONGATION	WEATHER RESISTANCE	GAS IMPERMEABILITY	TEMPERATURE RANGE	OVERALL SUITABILITY
Buna-N (Nitrile)	1	600%	3	1.5	-40 to 250°C	2
Butadiene, Styrene Butadiene	1	600%	3	2.5	-50 to 212°C	3
Ethylene Propylene	1	600%	1	2	-60 to 260°C	1.5
Silicone	3	800%	1	4	-100 to 450°C	3
Polyacrylate	3	600%	1	1	-25 to 300°C	3

1 = Excellent 2= Good 3=Fair 4=Poor

STATIC RADIAL O-RING SYSTEM





INGRESS PROTECTION - O RINGS DESIGN

O-RING SELECTION

The material selected for the O-Ring through material comparison was Ethylene Propylene. Though it had poor permeability to gases compared to the other materials; the primary requirement to keep water out along with costing meant the material was most appropriate. With the material of the O-Ring selected the next step was to select the size of the O-Ring required. All O-Rings used must conform to standard ring dimensions outlined in ISO 3601-03:2005. Conforming to this standard would ensure that O-Rings could be bought as standard pieces, reducing manufacturing cost of custom ring sizes. The ISO also ensures that correct application of groove dimensions and tolerance will prevent leakage.

The outer diameter of the product measured 70mm, and the diameter of the shaft (labelled on the previous page) measured 60mm. The O-Ring would sit between these two edges of the design, and as such this meant the O-Ring dimension had to be within this 10mm range. The O-Ring chosen was the (ISO) 15064 ring. As detailed in the graphic to the right; the ring had an Inner Diameter of 64mm well within the range required, and a Cross-Section of 2mm. If a ring had been chosen with a Cross-Section greater than 2mm, the required groove located on the top edge of the Snap Fit section would be greater than the thickness of the part. Choosing an O-Ring with a smaller Cross-Section would also decrease the overall weight of the product to further help conform to the PDS. Other advantages of a smaller Cross-Section O-Ring were a reduce cost, less machining required to parts and also more resistance to explosive compression e.g. dropping or stepping on the product (Hi Tech Seals Inc., 2017).

GROOVE DESIGN

The design of the groove for the O-Ring to sit in would be determined using the Stretch Factor for static applications whilst also taking into consideration the Compression Squeeze acting on the O-Ring. In this particular application the pressure acting upon the O-Ring was not needed as the O-Ring would not be acting upon any internal or external pressure due to the nature of use (not holding in or out a constant PSI).

When determining the depth the groove needed to be, an important requirement was the stretch of the O-Ring. Stretch helps to 'fill out' the groove and allow for a tighter seal. The recommended stretch for static applications is between 2-8% (Hi Tech Seals Inc., 2017). Due to the material selected having good elongation and yield properties, a higher stretch value of 7% was chosen to determine the depth of the groove. To determine the depth of the groove the following equations were required:

Equation 1: **O-RING STRETCH PERCENTAGE = (COMPRESSION SQUEEZE / CROSS SECTION) X 100**
Equation 2: **COMPRESSION SQUEEZE = CROSS SECTION - GROOVE DEPTH**

Inputting the Cross-Section data along with the desired stretch percentage into Equation 1 produced a Compression Squeeze value of approximately 0.1mm. Substituting this value into Equation 2 along with the Cross Section of the O-Ring gave the following equation 0.1 = 1.5 - Groove Depth. Rearranging this gave a Groove Depth value of 1.4mm. The determined Groove Depth would allow for the O-Ring to be compressed to a high enough level to provide a sufficient water resistant seal whilst also ensuring the material would not yield/deform past its elastic limit.

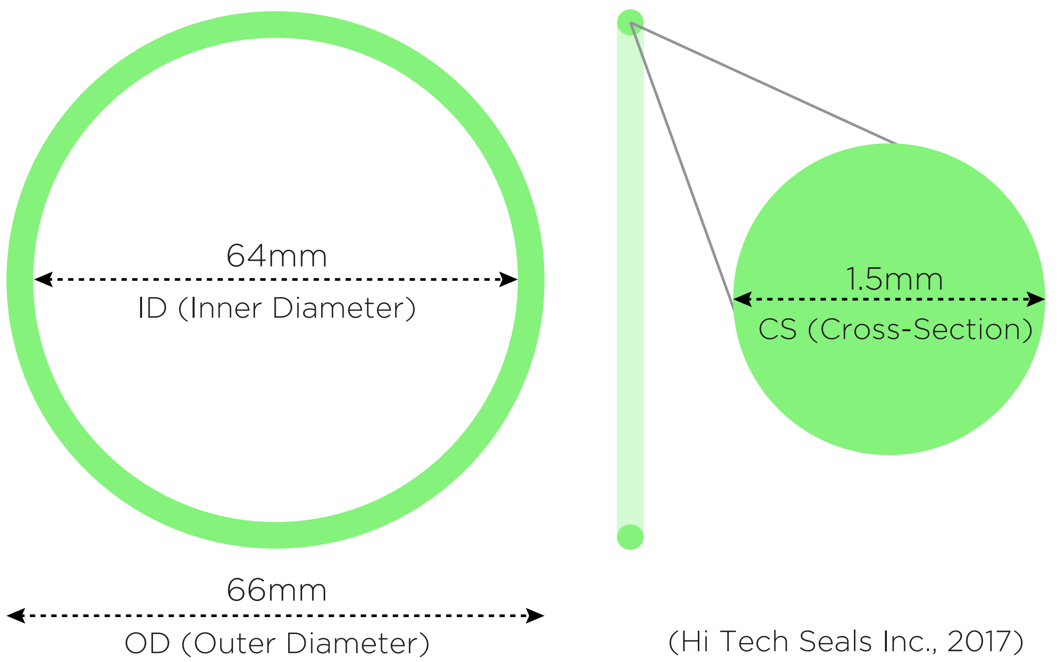
OTHER DESIGN FACTORS

To further ensure the O-Ring application would provide water resistance the correct surface finish needed to be applied. Use of an incorrect surface finish would lead to tearing, abrasion and a shorter O-Ring life. A recommended surface finish for static mating applications of at least 32Ra will be applied to the O-Ring Groove to provide a water resistant seal (marcorubber.com, 2017).

To reduce the likelihood of O-Ring damage during assembly, and to ease assembly, fillets were applied to the inner corners of the groove along with a 5° entry angle (marcorubber.com, 2017).

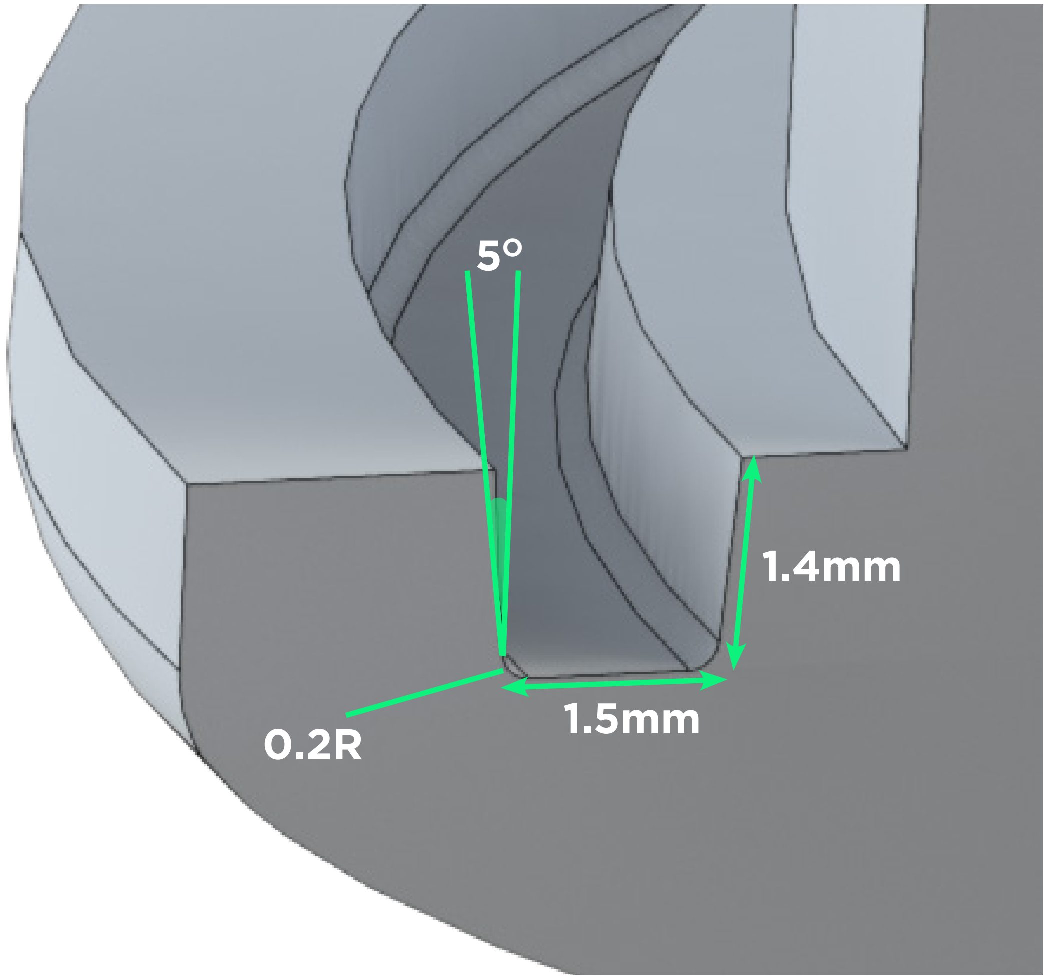
Application of following O-Ring tolerances will also ensure ease of assembly, and also reduce the rate of abrasion.
CROSS SECTION: 0.8-3.15mm = ±0.08mm
INSIDE DIAMETER: 58.43-66.5mm = ±0.51mm
(Hi Tech Seals Inc., 2017)

15064 O-RING DIMENSIONS



(Hi Tech Seals Inc., 2017)

O-RING GROOVE DESIGN



INGRESS PROTECTION - LOUVRE TESTING

IP 43

LOUVRE DESIGNS VARIATIONS

The CAD models to the right show the four different Louvre design variations. Each design conformed to the Free Area Percentage measurements required whilst also varying in angles between 25-30°. For each design either the number of Louvres or their position varied. Testing this range of designs would allow for selection of the most appropriate design for the application to this product. Below is each Louvre Design detailed. Each Louvre design was 3D printed, which may have been a draw back to testing as the accuracy of 3D printing can be problematic and could thus have made the free area percentages of each design different to the designed percentages.

	No. of Vents	Free Area Percentage (%)	Other Info.
DESIGN 1	3 Vents	36	Located under clip
DESIGN 2	4 Vents	29	Located under clip
DESIGN 3	10 Vents (2x5)	44	Two columns of vents split either side of clip
DESIGN 4	6 Vents	39	Non-Filleted outer edges

LOUVRE TESTING

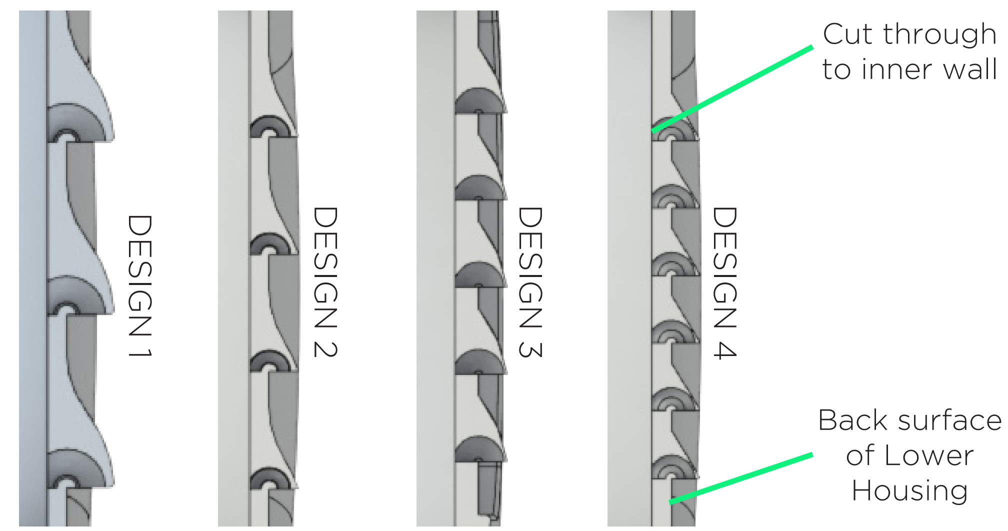
When setting about testing each Louvre design the IP level had to be taken into account. For water IP the level given was 3, meaning that the product should be 'Protected against direct sprays of water up to 60° from the vertical' (engineeringtoolbox.com, 2017). To ensure each Louvre was tested against the IP level, the flow of water had to be set up at the 60° angle given, and would need to be a 'spray' of water rather than a single jet. The diagram to the right shows the test set up and the actual test set up is shown in the picture below this.

Each Louvre design to be tested was 3D printed. Each Louvre design was then attached to a container that would act as a means to catch any water that penetrated the vents on the surface. To ensure that no water entered the container through the surface meeting, a rubber sealant was placed over the mating surface; this would ensure that the tests carried out were valid and not presenting false data. Each Louvre design would be placed at 60° to spray of water and subjected to the spray for 2 minutes. The spray style chosen was that best simulated the effect of rainfall. The graphic below shows the volume of water each design allowed to pass through the vents.

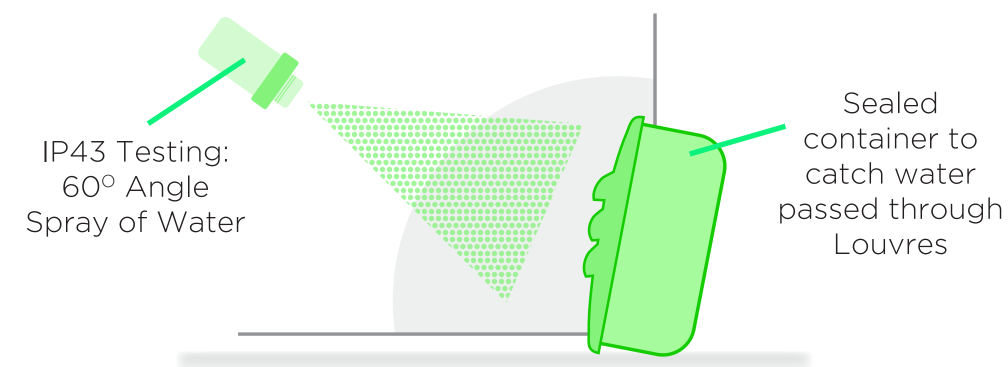
The results above firstly highlighted the fact that very little water could enter each design which was a positive. Design 1 offered the greatest water/rain protection by only letting in 2ml of water. Positively Design 1 made use of the largest Louvre vent design angles and size, whilst also having the smallest number of vents. Reducing the number of vents required and with a large size would ultimately reduce the complexity of the mould required in manufacture, thus reducing manufacturing costs. Though other designs did make use of more vents, and therefore allowed a greater volume of air to diffuse into the product, the primary goal was to prevent any water from affecting the electrical components.

Whilst Design 1 did not offer 100% water/rain protection this would be combated through other methods rather than further adjustment to the vent design. The positioning of vents on Design 1 were as such that when the product clip was also attached, the vents would be on the underside of the clip, which in turn would offer the vents more protection from direct water/rain exposure. The Ingress Protection test also required water to be sprayed directly at the Louvre vents when in reality the vents would no be facing 'outwards' when attached to the user's bag and as such would not be subject to the full force of any rain.

LOUVRE VENT DESIGNS

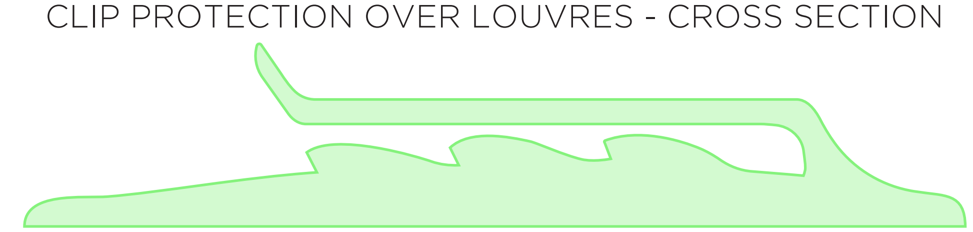


IP LOUVRE TEST DIAGRAM



IP LOUVRE TEST SET UP

CLIP PROTECTION OVER LOUVRES - CROSS SECTION

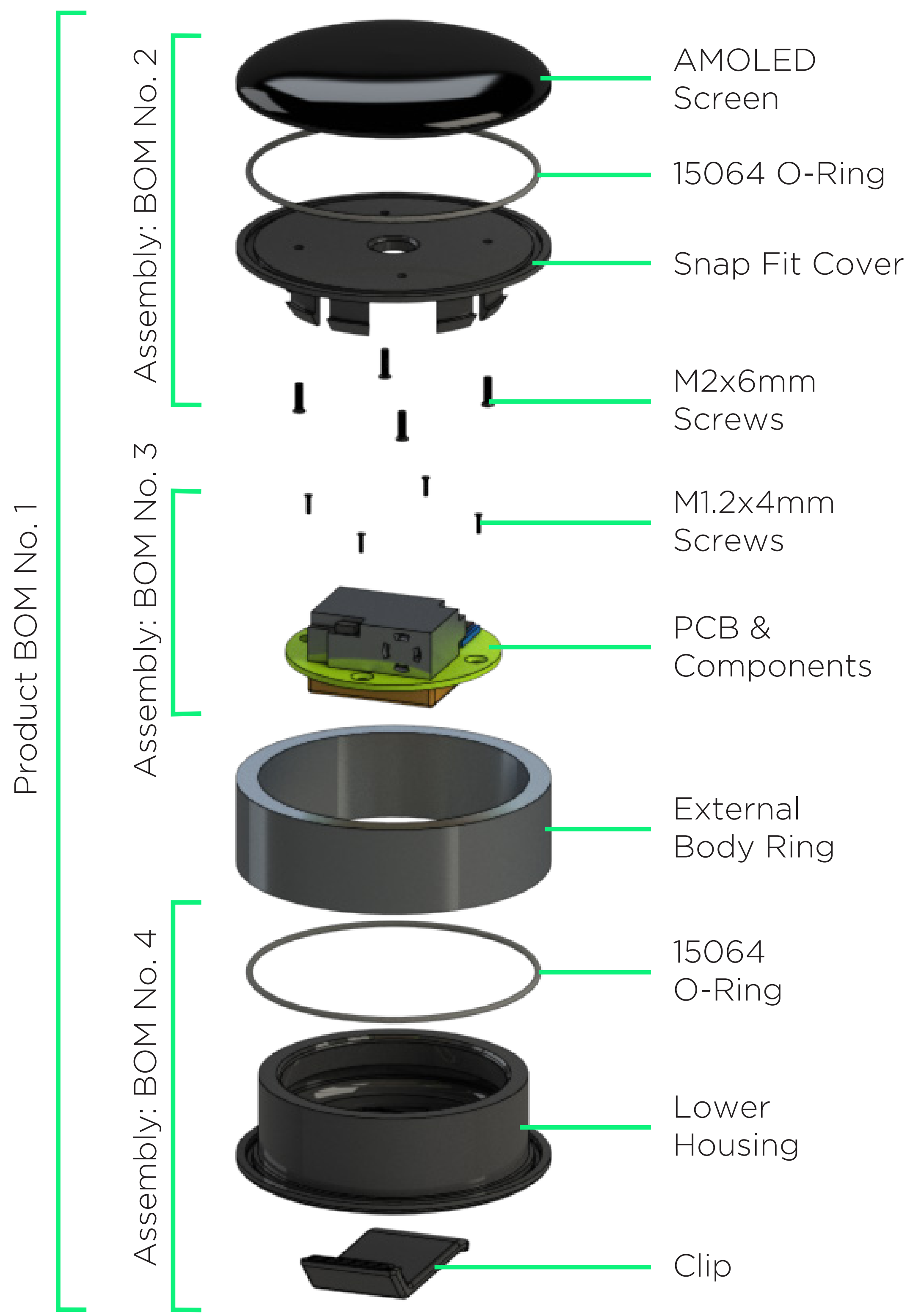


FINAL BILL OF MATERIALS

To the right shows the complete Bill of Materials to produce one working product for both the hardware and firmware functioning of the product.

Accompanying the hardware BOM will be part technical drawings.

The app would be created using the Flow Diagram and Interaction Document.



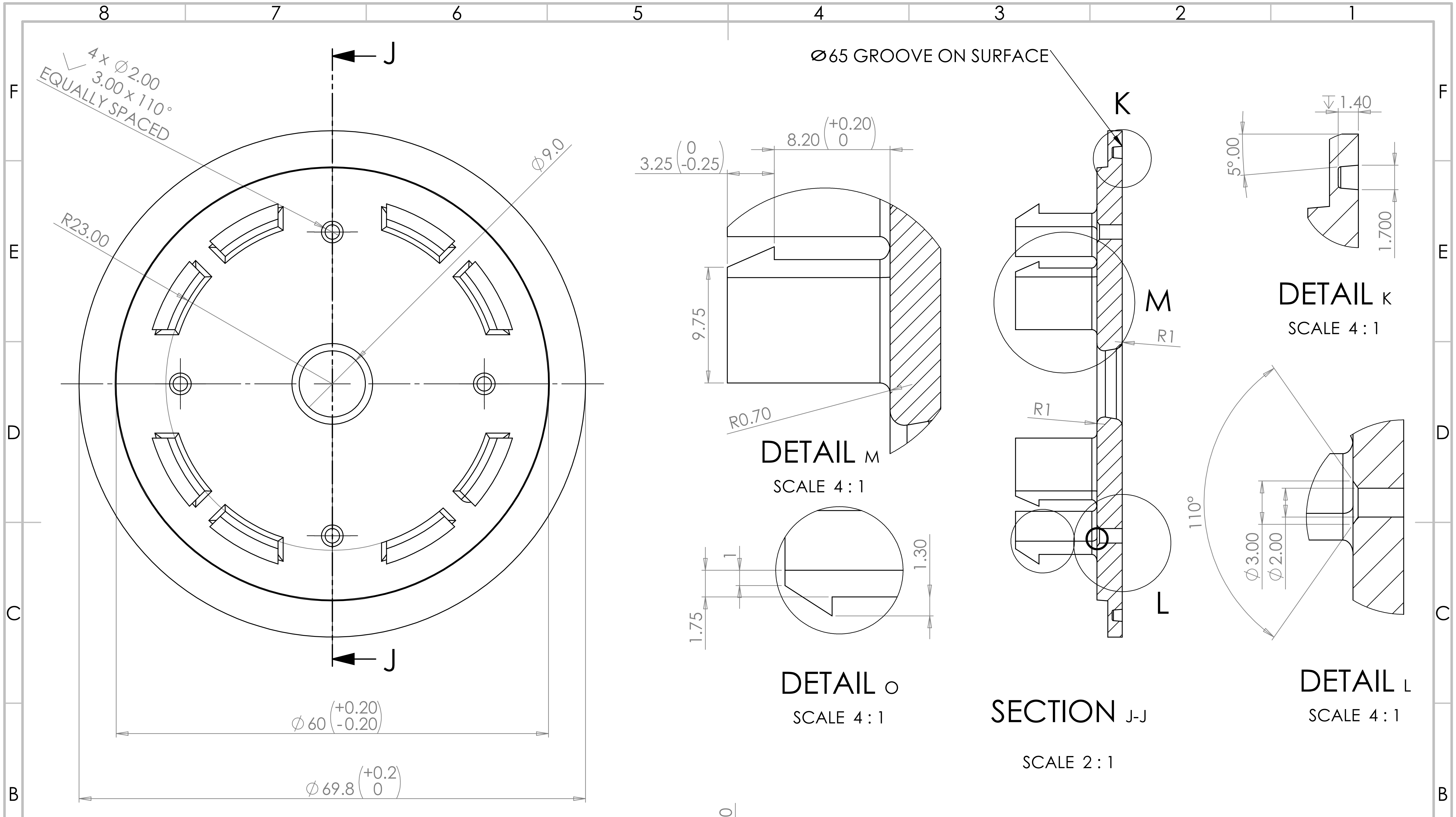
HARDWARE BILL OF MATERIALS

BOM NUMBER	PART NUMBER	PART NAME	FUNCTION	QUANTITY	MASS (g)	MATERIAL	PROCUREMENT	PROCESS	FINISH
4	1	Clip	Joins to part 2 underside	1	4.2	ABS	MTS	Injection Moulding	SPI - A2 (Black)
4	2	Lower Housing	Site for parts 2 & 3 joining and part 5 mounting	1	26.8	ABS	MTS	Injection Moulding	SPI - A2 (Black)
1	3	External Body Ring	Slides over part 2 shaft	1	54.7	Aluminium	OTS & MTS	Milling & Mechanical Polishing	Brushed Satin
2 & 4	4	(ISO) 15064 O-Ring	Water resistance at assembly joins	2	1.36 (total parts)	Ethylene Propylene	OTS	N/A	N/A
3	5	PCB & Components	*SEE FIRMWARE BOM*	*SEE FIRMWARE BOM*	*SEE FIRMWARE BOM*	*SEE FIRMWARE BOM*	*SEE FIRMWARE BOM*	*SEE FIRMWARE BOM*	*SEE FIRMWARE BOM*
3	6	M1.2 X 4mm Screw	Secures part 5 to part 2	4	0.16 (total parts)	Stainless Steel (AISI 316)	OTS	N/A	N/A
2	7	M2 X 6mm Screw	Secures part 9 to part 8	4	0.68 (total parts)	Stainless Steel (AISI 316)	OTS	N/A	N/A
2	8	Snap Fit Cover	Attachment site for parts 3 & 9	1	15.1	Polycar-bonate	MTS	Injection Moulding	
2	9	AMOLED Screen **(Blackbox)**	Displaying Graphics & part 8 joining	1	55 (estimated)	N/A	OTS & MTS	N/A	N/A

FIRMWARE BILL OF MATERIALS

BOM NUMBER	PART NUMBER	PART NAME	FUNCTION	QUANTITY	MASS (g)	MAX VOLTAGE (v)	PROCUREMENT	DATA SHEET
3	10	SDS021	PM2.5 Sensor	1	15	3.3	OTS	goo.gl/HtHcDb
3	11	RN4020	Bluetooth transmitter	1	6	2.8	OTS	goo.gl/uyXRAR
3	12	VENUS 638FLPx-L	GPS locating module	1	2.5 (estimated)	3.1	OTS	goo.gl/PHT1TW
3	13	SD5610-001	Ambient light sensor	1	1 (estimated)	3.7	OTS	goo.gl/6L2BKV
3	14	Li-Re-chargeable. Battery	Provides power	1	19	3.7	OTS	goo.gl/DaptjZ
2	15 *(See Part 9 Hardware BOM)*	AMOLED Screen **(Blackbox)**	Displaying Graphics	1	55 (estimated)	3.5	OTS & MTS	goo.gl/yl1gTM

SNAP FIT COVER DRAWING



DIMENSIONS ARE IN MILLIMETERS TOLERANCES UNLESS OTHERWISE SPECIFICED: x.x - ± 0.2 x.xx - ± 0.01 x.xxx - ± 0.07	FINISH: SPI - A2 DIAMOND GLOSS (Black)	HOLE TOLERANCES: ISO 286:2	REVISION: 1 University of Brighton School of Architecture and Design TITLE: SNAP FIT COVER

	NAME	SIGNATURE	DATE
DRAWN	Arun Joshi	AJ	18/4/17
CHK'D	Arun Joshi	AJ	18/4/17
APPV'D	Arun Joshi	AJ	18/4/17

MATERIAL: POLYCARBONATE	DWG NO. 1		A3
WEIGHT: 15.1g	SCALE: 2:1	SHEET 1 OF 1	

LOWER HOUSING DRAWING