Major Project Technical Report:

# Designing For The Homeless

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# Executive Summary

It was identified that the Glasgow housing crisis is particularly affected by two key issues; a negative perception of the homeless by the public and the widespread concern of homeless sleep deprivation. This major project aims to address this to the extent of improving the short-term quality of life of the homeless, whilst providing opportunity for them to transition to a life off the streets.

A product and associated service was eventually designed to offer the homeless a greater source of monetary donations, access to support services and relief from noise pollution that contributed to their poor sleeping patterns. It made use of pre-existing technologies in RFID and white noise sleep therapy.

The technical objectives for the project were as follows:

- Human-centred research and justification of key design decisions.
- Preliminary functional analysis
- Component selection
- Casing and Mounting design with utilisation of anthropometric data
- Design optimisation for manufacture
- Design optimisation for assembly
- User Interface Design
- Transactional System Design

Communicating with the British Sleep Society and a commercial bank heavily involved in charitable operations ensured that the product and service concept was rooted in realism. Storyboarding and persona analysis preserved the human factors approach for the design process.

Components were selected based on their potential relationships between each other and amongst other criteria such as cost, performance and space efficiency. CES was used to select materials for manufactured components. UI was designed using an online open-source tool in Figma. Fusion360 was used for component design and draft angle analyses for manufacturing capabilities.

Although the product incorporates pre-existing technologies, it is a pioneer in terms of combining them in the public environment adopted by the homeless.

# Contents

## 1. Background

Homelessness has plagued the UK for centuries. Glasgow particularly was rife with overcrowding and poor living conditions, with the 1961 census indicating there were 11,000 homes unfit for habitation. Despite the eventual introduction of the 1977 Housing Act, the recession of the 90s still saw 70,000[1] repossessions a year.

The combined efforts of the UK government as well as numerous organisations such as Shelter Scotland have proved to be insufficient in the mission to eradicate homelessness, with a household becoming homeless every 18 minutes in the present day. Applications for temporary accommodation rose by 11% in just 6 months in 2019. [2]

Living experiences can be categorised into the following; rough sleepers are those who are bedded down in the open air or places not built for habitation. Other homeless individuals may utilise shelters offered by humanitarian organisations and the council, whilst there is a subset of people who cannot or choose not to accept aid and in turn are excluded from official statistics.

2019 saw 54% of statutory homeless applications come from males, and 57% from people under the age of 35.[3] The ethnic profile of the homeless population is also becoming increasingly diverse; a survey of London Winter shelters in 2004 found 30 nationalities represented.[4]

Shelters are often only open during the winter months, and even then, many rough sleepers choose to forgo temporary shelter in order to preserve their anonymity, privacy, freedom, and peace of mind. The abundance of organisations that provide aid results in an ambiguous service structure.

Aside from the basic needs such as food and shelter, the homeless face difficulties accessing healthcare services, registering with GPs and getting holistic support.[5] Civilians tend not to directly donate for a variety of reasons; guilt, lack of change, fear and a desire to not enable addictions.

## 2. Concept Development

After compiling a thorough user profile of UK rough sleepers, design ideas were developed to address the prominent problems they faced. The obvious starting point was shelter design – something lightweight and easy to construct that would serve as short-term protection from the elements. However, this sector has already given birth to numerous design concepts and the conclusion from these executions was that it is difficult to implement a one-size fits all shelter due to the drastically different urban environments they are made for. It was also considered to make a tool to help rough sleepers manage their limited resources and amenities. Another direction was the administration of drugs and designing for the drug crisis.

**Figure 1: Storyboarding User Experience**

However, I experienced a breakthrough in my design process after developing my persona (having used a variety of online interview resources such as Invisible People and St Mungo's).[6] I realised that a root cause of the homeless not receiving enough help was the social barrier formed between them and the public, which prevents pedestrians from walking up to someone and offering their support.[7] I sought to implement more compassion in the relationship between beneficiaries and members of the public. Storyboarding with this in mind led me to develop an initial concept which addressed three key issues – sleep deprivation, insufficient donations and a difficulty in communications with services.

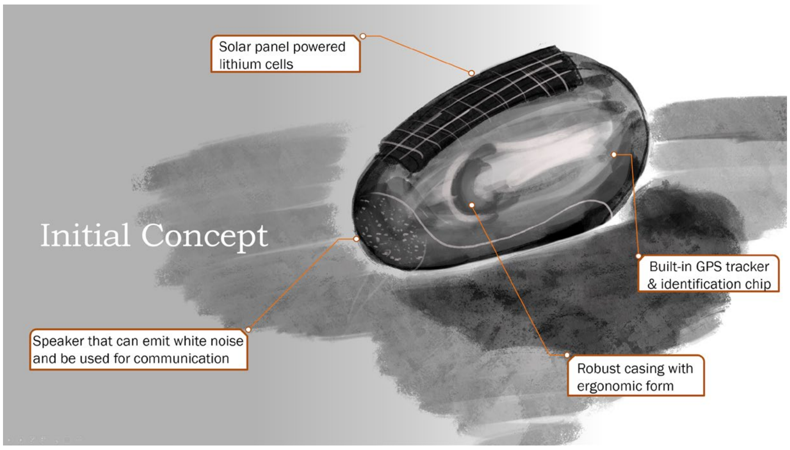



**Figure 2: Initial Concept**

Further research led me to justify omitting the telecommunications feature I intended to add to the device. I also confirmed the impracticalities of making the device solar-powered as originally conceptualised. Communicating with the research subcommittee of the British Sleep Society informed me that the use of white noise in a public environment is unprecedented research. I was given a dB range of 60 to 90 to work with and was advised that even though the response to white and pink noise differs between individuals, it would be a promising solution for the majority of users.

## 3. Functional Analysis Screening Tool

After establishing that incorporating telecommunication would be surplus to user requirements, the two main features were as follows; the facilitation of contactless donations and assistance with the challenge of sleep deprivation faced by rough sleepers.

When initially approaching contactless donations the following considerations were made. It was important to increase the exposure of rough sleepers to pedestrians. The current precedents in society leads to pedestrians avoiding contact with rough sleepers for a variety of reasons. The social disparity also leads to the homeless occasionally choosing to keep a low profile, thus making the nearby public unaware of their immediate need for donations. Cashless donations will therefore be made possible via a mobile application that sends push notifications to nearby members of public. The user interface will kickstart an emotional investment in rough sleepers within the user's proximity by displaying information about them; a name, age and personal goals which are details that they would otherwise not know by simply passing the rough sleeper on the street. The pedestrian would be notified of a rough sleeper's presence with the assistance of a GPS module incorporated into the product that they carry.

The product in question will also be used by rough sleepers to facilitate contactless transactions. This requires the use of an RFID chip and an integrated antenna that would use electromagnetic waves from a card reader to temporarily activate the chip and communicate with the reader. The activation of this chip should be indicated to the user, potentially via an LED.

The device will have to be made transportable; this involves a robust and lightweight casing construction, with charging facilities and perhaps a keychain to improve ease of carry. The rechargeable battery would not be used for the contactless system but rather the white noise feature.

The white noise feature was arrived at after an exploration of sleep deprivation solutions. A study of the effect of white noise on the sleep of subjects exposed to ICU noise was evaluated.[8] Polysomnographic technicians employed EEG, EOG and EMG to monitor arousal states during REM and non-REM sleep. The mean arousal index of 0.01 for White Noise testing was significantly lower than that of recorded ICU noise, allowing proof of concept. Although the auditory arousal threshold was higher in stage 3-4 NREM compared to 1-2, the mean increase in noise from baseline to peak remained the same across sleep stages. This meant that arousals are typically triggered by a relative rise in noise levels, highlighting the value of a baseline white noise machine. It will be controlled using a microcontroller which will use its RTC to regulate its activation periods.

## 4. Product Design Specification

| *Specification* | Justification | Further Details |
|---|---|---|
| *Must be easily carried* | Rough sleepers tend to be on the move and the product should not deter them from that lifestyle. It must be lightweight and compact enough to fit in pockets of clothing and bags. | Should have dimensions that comply with average trouser and coat pocket volumes. Must comply with mass figures from anthropometric data for handheld devices |
| *Must be durable* | Must have a suitably long lifespan and withstand expected stresses. | HALT/HASS should be developed for the product after prototyping to ensure the product has a guaranteed lifespan of at least 5 years. |
| *Must be reliable* | The product and its electronic components must not be prone to failure (which may be caused by ionising radiation, excess temperature or mechanical shock). It must have a 99.9% success rate with performing contactless payments. | The antenna must be tested for reliability in appropriate conditions (exposure to EM waves at a frequency emitted by card readers). Preliminary electronics testing must be carried out using multi-meters. |
| *Must streamline donation process* | Must have a user interface for members of the public that allows them to donate without the use of cash. Donations must be quick to make and users must get feedback for instant gratification. | It must take less than 30 seconds to complete a donation within being notified of a rough sleeper in proximity. |
| *Must help improve the perception of rough sleepers* | There is a popular attitude amongst members of the public that associate rough sleepers with drugs and crime, which makes them undeserving of donations. | The product must incorporate a user interface that helps to challenge and reorient the general negative perception of the homeless. It should also be clearly trustworthy. |

| | | |
|---|---|---|
| *Must be shock resistant* | The product is used by someone who will frequently travel, and it is therefore prone to being dropped on hard surfaces. | HASS can also be used for this purpose to ensure the casing and internal parts can withstand repetitive shock. |
| *Must be ergonomic* | As a hand-held device, the product must be comfortable to hold | Anthropometric data must be used to justify dimensions |
| *Must be cost effective* | The product must be cheap enough for a charity to distribute | A cost analysis can be performed to minimise expenses |
| *Must have contactless transactions* | Must provide beneficiaries with a way of spending their electronic donations | May include a mechanism such as RFID, NFC, Digital Wallet |
| *Should assist with issue of sleep deprivation* | Sleep deprivation is a persistent issue for rough sleepers due to inconsistent noise pollution in their proximity. | Noise cancelling or use of white noise is a possible solution. |
| *Should reduce the need for begging* | The addition of a reliable donation stream should reduce the need for donating in person. | Another effect of the contributor user interface is to encourage donations in person once they are emotionally invested in the beneficiary. |
| *Should be energy efficient* | As the product must be cost effective and transportable, it cannot house large batteries. | It must sustain its electronic features throughout the duration of a day as rough sleepers must go out of their way to use charging facilities. |
| *Should have a digital footprint for identification* | Identification is necessary for the bank's virtual account system, for security purposes. | Use of a GPS module for tracking. Each device has a unique code associated with it. |
| *Should be recyclable or repurpose-able* | Where possible, recyclable materials must be used for custom parts due to their inability to be repurposed. | Refer to the 7 plastic codes for recycling guidelines.[9] |
| *Should be waterproof* | The product is to be used outdoors and must therefore be sealed well enough to withstand rainfall and dilute chemical erosion. | Material selection will impact the product's chemical resistance. |

**Table 1: Design Specification**

# 5. Component Selection/ Design

## 5.1. RFID Tag

Radio Frequency Identification (RFID) is a technology that has been used for approximately 50 years, and has been cost effective enough in the last 10 years to be involved in mass production.[10] They have been particularly adopted in debit and credit cards as an alternative to the magnetic strip, making transactions more consistent, fluid and adaptable. Users have the liberty to activate a transaction from any angle as opposed to being constrained to the unidirectional swipe of a magnetic strip.

The technology works as follows: read-only or read-write data is stored in an RFID tag (Figure 3). The tag itself is either powered by a battery (active) or relies on wireless power from a reader to operate (passive). Once the tag (which typically has its own integrated antenna) is within an appropriate proximity to a scanning antenna, EM energy causes the tag to commence transfer of data using radio waves. The antenna receives these radio waves which are subsequently decoded by the reader.

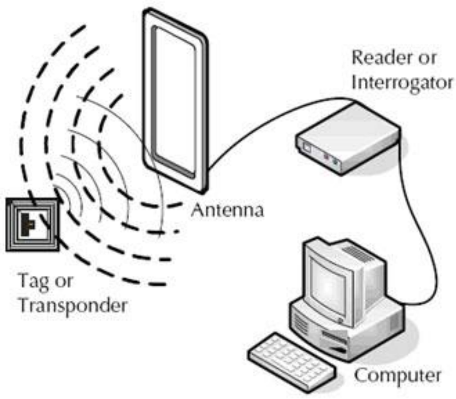



**Figure 3: RFID System Architecture**

The first decision to be made is the nature of the RFID tag. Whilst the product will have a battery for the white noise element, the relatively larger footprint, increased costs and demand for maintenance results in passive being the most appropriate option. Active tags are usually opted for when a large gain is required to communicate with a reader over longer distances, however for the purpose of making contactless payments, a shorter distance is preferable for security.

RFID tags are also subcategorised by generation and class.[11] Gen-2 will be chosen for the faster read speeds, added security and adaptability (being a global standard) despite the insignificant extra cost. Class 2 will be selected as read-write tags offer the flexibility of storing current transactional information on the tag (Figure 4).

| | |
|---|---|
| Class 0 | UHFI read-only, preprogrammed passive tag |
| Class 1 | UHF or HF; write once, read many (WORM) |
| Class 2 | Passive read-write tags that can be written to at any point in the supply chain |
| Class 3 | Read-write with onboard sensors capable of recording parameters like temperature, pressure, and motion; can be semipassive or active |
| Class 4 | Read-write active tags with integrated transmitters; can communicate with other tags and readers |
| Class 5 | Similar to Class 4 tags but with additional functionality; can provide power to other tags and communicate with devices other than readers |

**Figure 4: RFID Tag Class System**

## 5.2. Antenna

For antenna design I first looked to the antennas used in credit and debit cards. Despite the conformity in dimensions of cards from manufacturer to manufacturer, the antennas used tend to differ significantly due to varying applications.

RFID systems operate in two frequency bands: 13.56MHz or 125kHz.[12] The antenna must therefore be designed to accommodate one of these two frequencies. The materials surrounding the antenna will have an impact on the frequency of the antenna. For instance, a paper exterior and adhesive surrounding an RFID tag would reduce the antenna frequency by approximately 300kHz, which would need to be compensated by tuning the antenna 300kHz higher.

Non-destructive analysis was done on single-use paper Glasgow Subway tickets which use RFID technology. Shining a flashlight through it revealed the silhouette of the antenna and the position of its RFID tag; it was noteworthy that the tag was not ‘melted’ onto the antenna as they typically are in credit cards.


**Figure 5: Disposable Glasgow Subway RFID**

Acetone was then used to dissolve the plastic coating of a credit card to reveal the RFID structure embedded in it (Figure 6). The antenna was made of enamelled copper wire, and its ends were meandered. These meandered end points allow for positional adjustment of the RFID tag whilst providing a large surface area onto which the tag can be attached to, by means of flux and conductive adhesive or solder.

**Figure 6: Dissolving a contactless debit card in acetone**

I proceeded to research NFC (Near Field Communications), a subset of RFID technology that is used in mobile devices particularly; services such as Apple Pay and Google Wallet. NFC has the added advantage of being able to be utilised as a reader for passive RFID tags, making it possible to perform transactions from smartphone to smartphone. Analysing NFC antenna properties revealed that they operate with low frequencies and relatively large wavelengths; the antenna's linear dimensions are hence confined to 0.5% or less of a wavelength.[13] This results in the antenna not projecting any radiation, and having a radiation efficiency close to zero. Radiation efficiency, being the ratio of power delivered to the antenna to the power radiated by the antenna:

$$\varepsilon_R = \frac{P_{radiated}}{P_{input}}$$

Therefore, it is fair to neglect conventional antenna parameters when dealing with them on the scale of a handheld-device; radiation pattern and antenna gain becomes irrelevant. The performance criteria that does matter, however, is inductance. The larger the inductance provided by the antenna, the better the RFID tag will communicate with the reader. Inductance levels depend on the antenna's geometry and correlate to the number of turns in the antenna's coil, the thickness of the wiring and the distance between the turns.

The relationship between RFID tag and its antenna can be modelled as the circuit as shown in Figure 7 [14]. The tag has its own internal resistance and tuning capacitance represented by $R_{chip}$ and $C_{tun}$ respectively. The integrated antenna has stray capacitance, resistance loss and self inductance represented by $C_{ant}$, $R_{ant}$ and $L_{ant}$. Research has shown that NFC devices typically have antenna with at least 1µH of inductance.

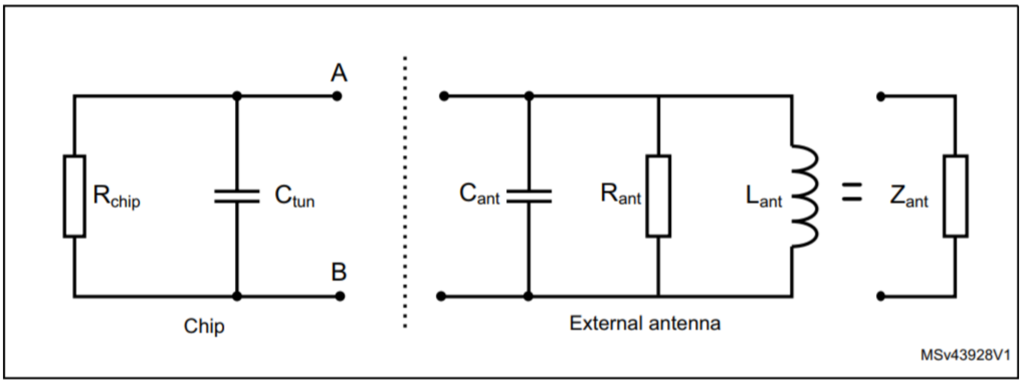



**Figure 7: Relationship Between RFID Tag and Antenna**

Inductance can be calculated once the shape of the antenna is determined; the three most common types are circular, spiral and squared antenna. Squared antenna can further be subcategorised into various layouts, including square, octagonal and hexagonal. The geometry of the antenna largely depends on how much space is available in the product it will be mounted into, and its performance can be finetuned by adjusting the other mechanical parameters as listed before. A squared antenna with a square layout was chosen for this product as it was deemed most appropriate in relation to the rest of the design. The formula for calculating the inductance of squared antennas is as follows:

$$L_{ant} = K1 \times \mu_0 \times N^2 \times \frac{d}{1 + (K2 \times p)}$$

Where $L_{ant}$ = Self Inductance

$\mu 0$ = $4 \pi \cdot 10^{-7}$ H/m

N = number of turns

d = average diameter in mm [($d_{out}$ + $d_{in}$) / 2]

K1, K2 = 2.34 and 2.75 respectively (for square coils)

An antenna performance tool that uses the above formula developed by ST Microelectronics [15] was used to adjust geometric parameters until a desirable inductance was achieved. The final antenna dimensions are 5 turns of 0.22mm diameter conductive material, spaced 0.5mm apart. The overall antenna will measure 40mm x 13mm and it will have a self-induction of 1.08µH.

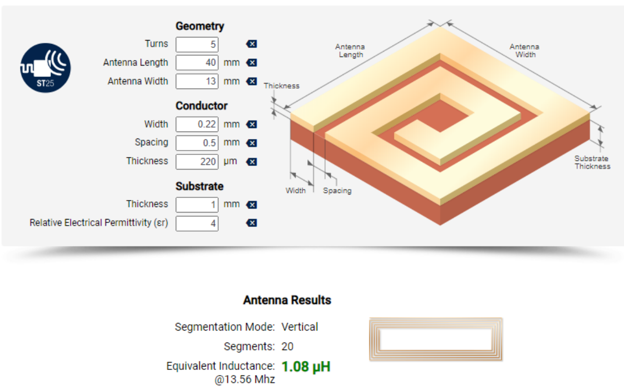



**Figure 8: Antenna Calibration Tool**

## 5.3. LED

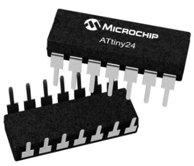
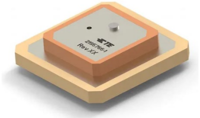
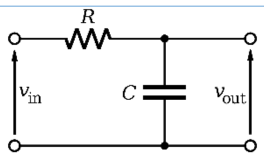
The importance of an LED was made apparent when experiencing the contactless payment system first hand. Debit/credit cards do not offer any indication of the completion of a contactless transaction however electronic devices with NFC capabilities such as the Apple iPhone 11 offers a specific UI for contactless payments, as well as an auditory response in the form of a beep. Card readers such as the one in Figure 9 provide an approval message and an audio response as well at the end of a transaction. However, trust in the transaction from both parties (the customer and the merchant) is boosted if the electronic NFC device provides some apparent confirmation. Incorporating an LED and utilising the white noise speaker would help address this concern. The LED would be powered by the battery that powers the speaker sub-assembly.

**Figure 9: Portable Card Machine[16]**

A magnetic proximity sensor would be used to detect the relative rise in self induction in the antenna. It will be positioned 1mm above the antenna and should be able to discern the difference between it being activated and deactivated. The sensor will need to be appropriately calibrated in order to do so.

## 5.4. PCB

There are a series of electronic components that will be mounted on a PCB (printed circuit board). They are as follows:

| Image | Component | Function |
|---|---|---|
|  | ATMEL AVR 8 bit 14 pin Microcontroller, 20MHz, 2kB Flash | A microcontroller will be needed to operate the white noise emitter, LED and GPS module. |
|  | TE Connectivity 2195766-1 GPS Module | Needed for security and for contributor UI app to detect nearby devices . |
|  | Magnetic Proximity Reed Switch | Used to detect the relative rise in self induction in the antenna and instruct AVR to direct power to LED. |
|  | Low Pass Filter (resistor and capacitor) | Resister and capacitor used to smooth the output and lower volume to the desired dB level. |

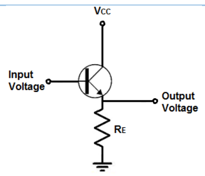
| | | |
|---|---|---|
|   | Buffer Transistor | Required as the AVR microcontroller cannot drive the low impedance load directly. [16] |
|  | DC Blocking Capacitor | Connected in series with the speakers to avoid unnecessarily heating and saturating them with dc current. |

**Table 2: PCB Components**

## 5.5. Speaker

The original approach with creating a white noise feature involved storing a compressed .wav file of a white noise sound clip on a microSD card, which would be subsequently read by a microcontroller. I had planned on using a 2GB microSD card with white noise audio files stored on it after being converted to a .wav format with 8-bit depth and a 44.1kHz sample rate for consistency. A script would then have been written to rescale the data to an 8-bit unsigned integer. However, this method was evaluated as being too inefficient and expensive compared to the alternative method; generating white noise using a pseudorandom binary sequence.

I initially explored generating white noise using PWM (pulse-width modulation), but the fact that an 8-bit PWM has a 62.5kHz period that would need to be filtered out led me to avoid this option. Leaving the period in would otherwise cause breakages in the sound quality. Instead, a GPIO (general purpose input output) port will be controlled with a 1-bit pseudorandom number generator by means of an interrupt routine. The AVR microcontroller chosen has been clocked to 20MHz; using a 30kHz timer interrupt provides 667 cycles. Assuming 20 cycles for rand (which is not particularly optimised) and 20 cycles of interrupt overhead, the cycle count of 667 is sufficient.

The code itself will utilise an LFSR (linear feedback shift register). [17] This is a way for the AVR to rapidly generate a nonsequential list of numbers. The operations used will consist of a right-shift operation and an XOR operation. The LSFR will be defined by its polynomial – an $n^{th}$ degree polynomial has $2^n$-1 different states, and therefore every number between 1 and $2^n$-1 will occur in the shift register before it repeats. The states are $2^n$-1 because an LFSR can never have a value of 0, since all shifts of a zero value will be left at zero. Therefore, the LSFR is seeded to a non-zero integer i.e. 1.

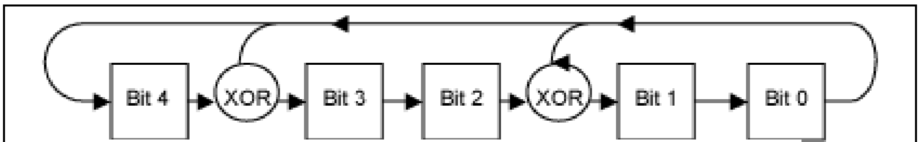



**Figure 10: LFSR Operation**

The speaker chosen is a RS PRO 8Ω 0.15W Miniature Speaker, with a thickness of 2.8mm and an external diameter of 10mm. It was chosen for its compact size and ability to produce up to 82dB, which is sufficient for the product's environment. Two speakers will be used, creating a left and right channel for noise.

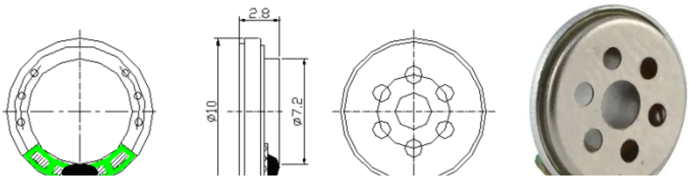



**Figure 11: Miniature Speaker Selection**

## 5.6. Power

My initial direction, influenced by the desire to make the product self-sustainable, was to power the electronics with a photovoltaic cell. However, this decision was redacted for several reasons; the surface area of the device is insufficient, the device is not expected to be exposed to sunlight for the majority of its lifespan and the cell itself would be too inefficient. Instead, the unit will be powered by a Lithium Ion cell which is rechargeable via MicroUSB.

A MicroUSB port with an integrated circuit (IC) will be mounted into one end of the device. Micro-USB was selected as it is the current standard for mobile and portable devices, as opposed to the other popular connecters (Type-A, Type-B and Mini-USB). Micro-USB phone chargers are frequently freely distributed by charities to rough sleepers in Scotland and are readily available.[18] InLink Kiosks in Glasgow also provide free USB charging services[19] (much like other smart kiosk initiatives globally), allowing rough sleepers to charge their devices using Micro-USB to USB cables.

**Figure 12: InLink Kiosk**

The Micro-USB port will have a built-in IC whose purpose is to protect the port and battery from excessive charge. A pre-assembled 5 pin Micro-USB IC stock part will be used (an example of which is shown in Figure 13)

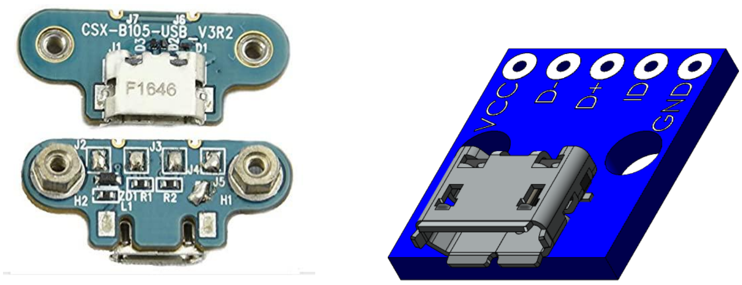



**Figure 13: MicroUSB port**

I initially considered using an 18650 Li Ion cell, which is typically used in laptop computer batteries, LED flashlights and e-cigarettes amongst other handheld devices. Unfortunately the design constraints led to the dimensions of this particular cell being too large. A smaller Li coin cell could have been used which would deliver similar capacity levels however the mounting for these are bulkier due to the greater surface area demand for wiring contact points. I compromised by selecting another lithium ion battery, comprised of two 10280 cells. These rechargeable cells can be charged for 1000 cycles, a capacity of 200mAh, an external diameter of 10mm and a depth of 28mm. Two cells will be connected in series to compensate for the relative drop in capacity per cell, as width wasn't the limiting dimension in my design, but rather depth.

**Figure 14:**

**Li Ion Cell selection**

## 5.7. Switch

An on-off switch was selected due to product space constraints. Choosing a more space efficient antenna field detection system (as opposed to the relatively large magnetic proximity sensor) would provide enough space to install a potentiometer control system as originally intended. The switch chosen is a standard part; the Mini Rocker SPST PPW01080. It has the universal symbols for on and off printed on it, which makes it intuitive to use.

**Figure 15: Switch selection**

## 5.8. Keychain

User research and storyboarding revealed that rough sleepers tend to rely on compact tools and devices built for transportation. Most carry rucksacks for personal belongings and mobility, and this observation led me to incorporate a keychain feature into my design. After exploring several design options including carabiners and more conventional key chain designs, it was opted to use a mobile phone 'charm', taking inspiration from the charms found on HSBC secure key fobs (Figure 16). These are sturdy, inexpensive and lightweight chains made from a lariat cord. The fabric will loop around itself and an anchor on the casing of the device, with its other end free to use as a connecter to a larger keychain


**Figure 16: Mobile Charm Integration**

## 5.9. Casing

### 5.9.1. Concept Sketching

Casing design initially stemmed from a focus on ergonomics. Market research was conducted on various handheld devices and the form of their casing was scrutinised. It was clear that complex structures were to be avoided for inclusivity of a range of hand sizes. The nature of a handheld device's purpose means that it is to be comfortably held in several orientations. The reason mobile phones have retained the conventional rectangular geometry despite the recently popularised curved screen technologies is because of the versatility a rectangular prism provides to the user. It can be shifted up and down the user's palm with ease and without loss of balance.

On the subject of balance, weight and centre of mass was also considered in the design of the casing and the components within it. They would have to be slightly bottom heavy as the device is designed to protrude from the top of the user's hand (where the RFID tag is located) and therefore the product would need to be sufficiently counter-balanced to prevent it from easily tipping over and out of the user's hand.

With the concepts of balance, orientation and comfort considered, I started by sketching some concepts of casing forms inspired by existing handheld devices.

**Figure 17: Casing Concept Sketching**

I noted that the more organic looking forms with curved geometry fit the message that I wanted to get across – a trustworthy benefactor with no 'corporate' undertones. Rough sleepers are a justifiably sceptical population when it comes to new products in their lives and the design should illustrate that it is there to help them primarily.

## 5.9.2 Clay Modelling

With an organic form in mind, I proceeded to make some models for the casing out of air-drying clay. I used plasticine to place screens and buttons to understand which positions offered more comfort. I also made indents to signify the position of the speaker. The model in Figure 18 was the most ergonomic, with its form-fitting features making it feel like a natural extension of the hand. However its lack of space efficiency aesthetic appeal made it an unviable option.

**Figure 18: Clay Model 1**

This stopwatch-esque form was also ergonomic and its balance was optimised; it was bottom heavy and comfortably sat in the palm. However, it was relatively unstable when placed on the ground and it too lacked space efficiency for components. Another fault of this design was how it was only useable in one orientation and it was consequentially only suitable for right-handed users.

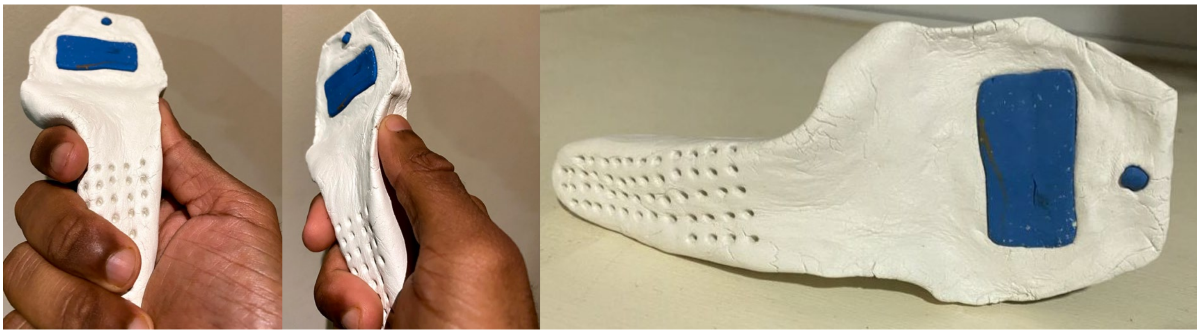


**Figure 19: Clay Model 2**

**Figure 20: Clay Model 3**

The form in Figure 20 has an eye catching structure which stands out as a blend of sleek and natural. Aesthetically, it was an improvement to the previously mentioned models due to fewer curvatures and a simpler design. However, this was not executed well enough as the model was somewhat uncomfortable to hold and did not fit well into pockets.

**Figure 21: Clay Model 4**

The final model I made proved to be the one that would inspire my final design. A much simpler geometry that incorporated curvatures that allowed the product to fit nicely into the user's hand with two degrees of freedom. The 'lips' on the edge of the model provided sufficient grip to even pinch the product by one of its ends and keep it upright without discomfort. I replicated this model at different scales (lengths of 90, 100, 110, 120mm) and found from a user group of 10 random individuals that 110mm was the most comfortable to hold and manipulate.

## 5.9.3. CAD Modelling

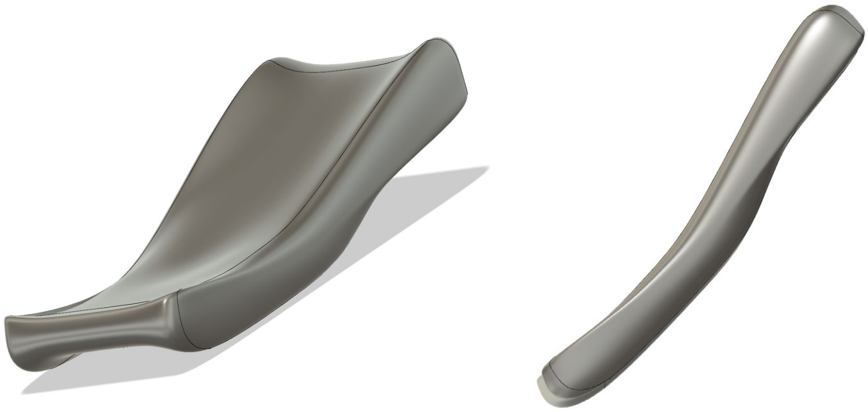


**Figure 22: CAD V1**

The next step was to translate my concept into a more precise CAD model. I used the sculpt tool in Fusion360 to reproduce some of the organic geometry that I made when clay forming. The first version of the casing had more pronounced corners for better grip, however it was apparent that it would not have sufficient capacity for the components I required.

**Figure 22: CAD V2**

The second and final version of the casing CAD model had a similar side profile to the first, whilst having a more ovular structure which complements the user's thumb position (which is naturally a few centimetres adjacent to where the product would sit on the user's palm).

## 6. Anthropometry

One of the key focuses for a handheld device is how ergonomic it is, since it is frequently handled for potentially long periods of time. Several qualifying anthropometric-based criteria were stipulated at the start of the design process;

- *The user should be able to carry, pocket or wear the product in order to leave at least one hand free for other operations:*
  The casing was designed for one handed operation. The decision to make its widest profile 110mm by 42mm was influenced by the lowest 5$^{th}$ percentile for palm size. This value was 99.07mm, which covered 90.1% of the product's length. Taking into account the additional data concerning metacarpal to joint lengths, these dimensions were considered inclusive enough for almost all of the user population.

- *Straps and/or chains must be compatible with accessories and clothing:*
  A versatile phone charm strap was designed with a 4.8mm diameter keyring on one of its ends. This can be chained to a larger keyring according to the user's personal requirements. The volume of the casing also did not exceed standard pocket dimensions for trousers and coats.

- *The product must not pose a snagging hazard*
  There are no sharp edges or corners on the exterior of the product, and the two casings are flush with each other where they are split into segments. The product is therefore snag-proof.

- *The product must be able to survive its expected thermal, chemical and physical environment*
  The material selection for the casing will reflect the product's ability to deal with its environment.

- *The product must be ergonomic enough to hold so that the user is free to focus on functional operation instead of figuring out a more comfortable way to hold the device.*
  For portable devices to be comfortably carried with one hand, the maximum dimensions are 1000mm by 150mm by 450mm. The maximum external dimensions of the product comfortably falls within this range. The 5$^{th}$ percentile weight for one handed carry of a portable product is 4.4kg; weight analysis must be done to ensure this guideline is adhered to. [20]

- *The product must be stable when put down, with the white noise emitter exposed to the user.*

The speakers were positioned to face the longer edge of the casing so that it could be laid on the ground on either of its large surfaces without obstruction to sound. The 'lipped' edges of the faces and symmetry of design will ensure that the product will be stable and balanced when placed on the ground. This is subject to weight distribution analysis.

- *The interface must be intuitive to operate with labels used where required.*
  A retroactive decision was made to laser engrave the top casing with the identification number for the product. This is a critical piece of information that the user will need to know in order to liaise with the charity and banking services. It was originally proposed to be implemented via a sticker, however even laminated stickers are not durable enough for the environment and weathering the product will be exposed to. It is possible to laser-engrave polypropylene (the material chosen for the casing) with a CO2 laser.

- *Buttons must be appropriately sized and positioned so that they are not accidentally pressed.*
  Thumb reach data was utilised here. The form was adjusted according to the values of thumb reach at different angles. It was deemed that the most comfortable angular displacement for the 5$^{th}$ percentile was 33° and the thumb reach at the same angle was 57mm. The switch position was therefore determined according to these anthropometric constraints. [21]

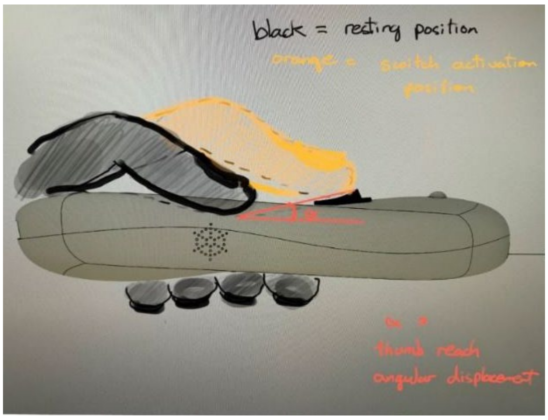



**Figure 23: Thumb Displacement**

# 7. Materials

## 7.1. Casing Material Selection

When considering the material selection for the casing there were several factors to consider. It has to be robust, hard and strong to withstand damage from being dropped onto a hard surface from chest-height. Interference is another factor to consider; the probability of the RFID tag being read by the scanner depends on the electrical permeability of its surrounding environment. Apart from material selection, RFID performance is also affected by interference from other RF emitting sources (not an issue in this particular case as the integrated antenna does not emit its own radio frequency), the line-of-sight between the tag and the reader, and the presence of a potentially ‘dirty’ power supply. Line of sight will not be an issue as the antenna will be powerful enough to facilitate data transfer from any angle within the useable range. As for the risks associated with power, a clean OEM (Original Equipment Manufacturer) charging IC will be chosen.

The complex geometry of the casing and the requirement for mounting structures to be attached to it in the internal surface means that it will be preferable to injection mould the casing in two halves. It would not be possible to choose metal based on the results of several studies that explore the effects of metal structures on RFID performance. One such study explored tag recognition for aluminium beer cans and how they were affected by the introduction of a corrugated card spacer. [22] The spacer proved to significantly boost the read probability due to its insulative properties.

| Tag visibility | Product | Spacer | Read probability | |
|---|---|---|---|---|
| | | | Side panel | Top panel |
| Visible | None | No spacer | 1.000 | 1.000 |
| | Alumnum beer can | No spacer | 0.927 | 0.250 |
| | Alumnum beer can | On the back | 1.000 | 0.768 |
| | Alumnum beer can | On the back and front | 0.972 | 0.720 |
| Invisible | None | No spacer | 0.997 | 0.998 |
| | Alumnum beer can | No spacer | 0.087 | 0.031 |
| | Alumnum beer can | On the back | 0.013 | 0.024 |
| | Alumnum beer can | On the back and front | 0.063 | 0.103 |

**Table 3: Results from RFID Study**

Antennae are generally insulated by materials that are moisture-resistant (i.e. not porous). This means ceramics are regarded as the best insulators. However, their fragility and cost means that I restricted the material selection data set to polymers and elastomers, which are also considered to be effective for this purpose.

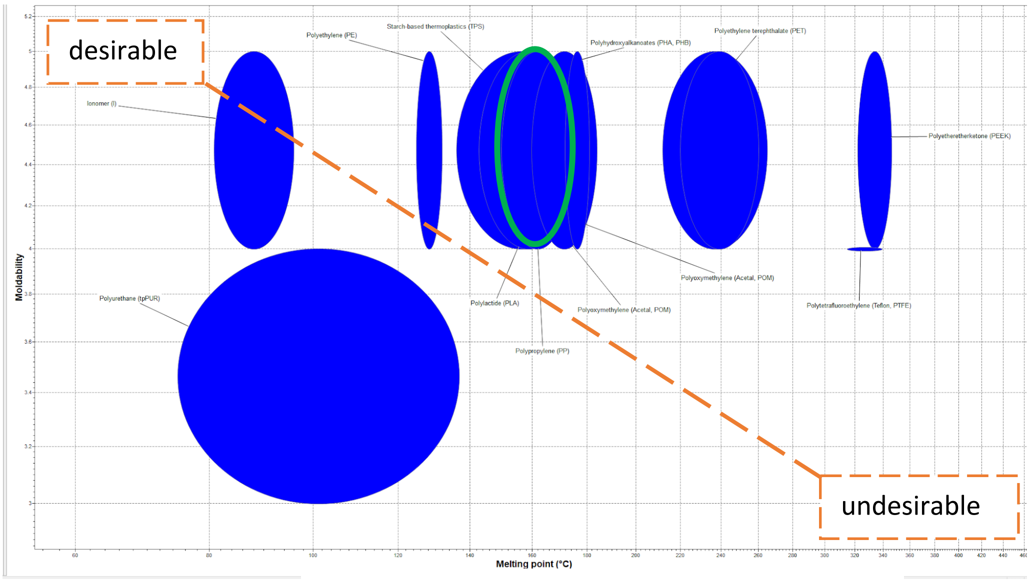



**Figure 24: Mouldability vs Melting Point**

The Cambridge Education Suite Edupack was used to compare relevant parameters for polymers (in dark blue) and elastomers (in light blue). The first chart was used to order the materials in suitability for injection moulding. Mouldability (which correlates to viscosity when molten) and melting point were the chosen axes. The casing material should be as mouldable as possible due to the complexity of the casing mould; there are some relatively small cavities for mounting points into which the molten material should comfortably flow into. A lower melting point would result in lowering the manufacturing costs due to less cooling time and lower energy requirements.

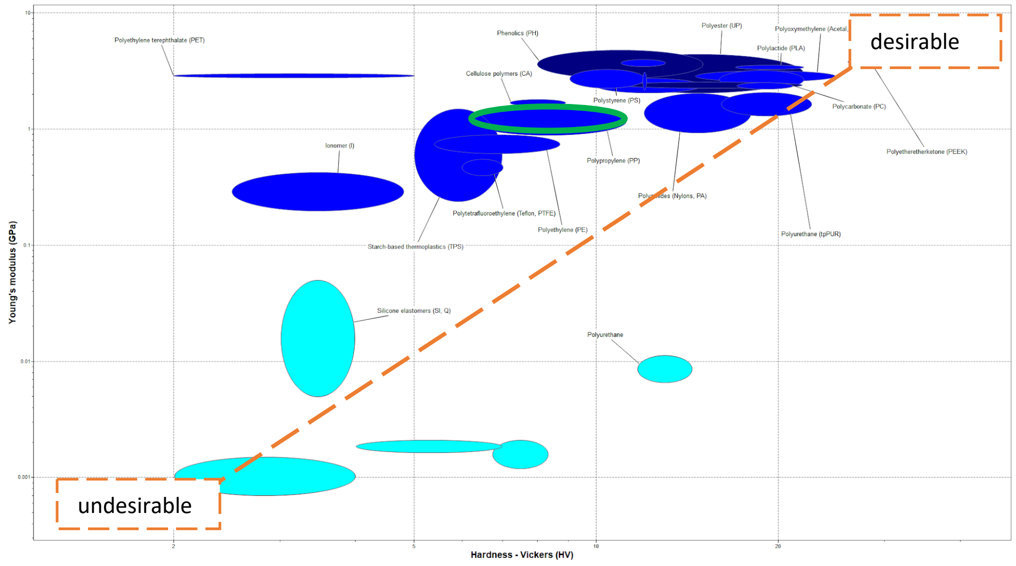



**Figure 25: Young's Modulus vs Hardness**

The next chart plotted Youngs Modulus (for strength and toughness) against hardness. Hardness was evaluated because of the requirement for fracture and scratch resistance from rough surfaces such as pavement stone.

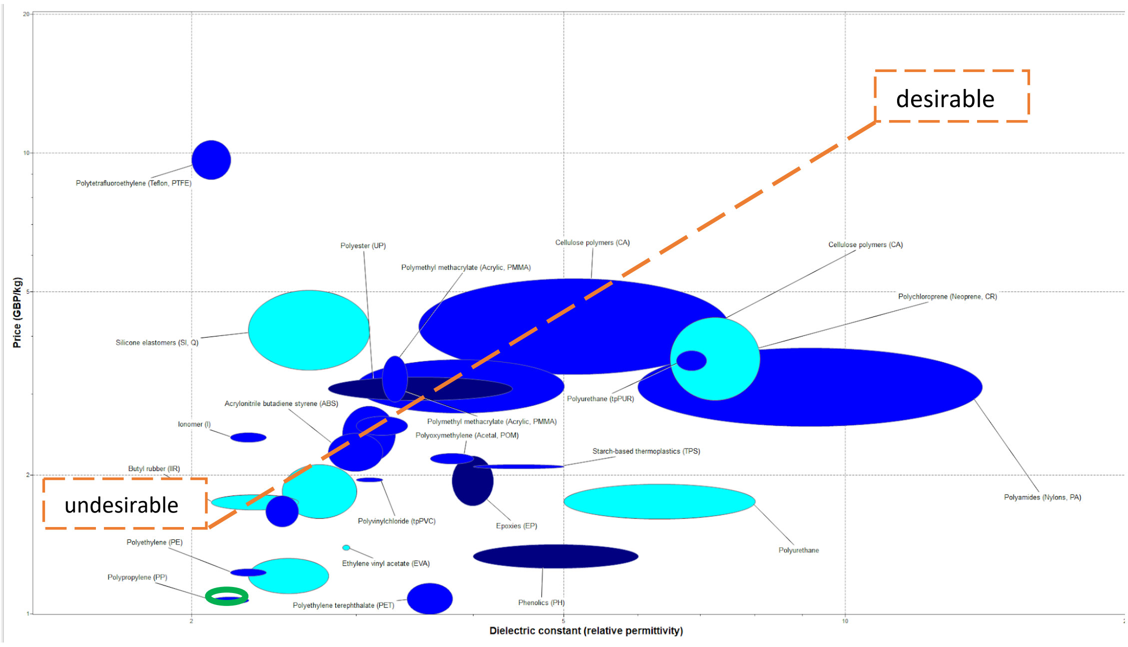



**Figure 25: Price vs Dielectric Constant**

The final chart considered two more important factors; electrical permittivity and price. A lower relative permittivity, or dielectric constant (the ratio of the capacitance of a capacitor using a material as a dielectric to the capacitance of the same capacitor using a vacuum) signifies a material with more insulative properties.

The results of the three charts were compared and it was concluded that the most desirable material was Polypropylene (PP – circled in green on each chart), followed by Polyethylene (PE). Despite its semi-crystalline properties, PP has a high processability rating. It is easy to injection mould due to a low melt viscosity. PP is also a pseudoplastic which reduces viscosity at high shear rates.

It has chemical excellent resistance to dilute acids and alkalis. However, it is prone to high mould shrinkage, thermal expansion and creep. Injection moulds and the injection process will have to be appropriately designed to address this.

## 7.2. Other materials

The other bespoke parts to be manufactured for this product is the antenna, antenna mount and battery mount. Everything else will be stock parts ordered in from other manufacturers (such as LED's, switches and other electrical components). The antenna will be manufactured from enamelled copper wiring, the industry standard for RFID antennae. The antenna mount cannot be made from PP as this material oxidises at a faster rate when in contact with certain metals such as copper. The antenna will be embedded into the antenna mount, which will be manufactured from PVC.

## 8. Design for Manufacture

The casing will be injection moulded and its design had that taken into consideration. A uniform wall thickness of 2mm was implemented for the majority of the shell. Where modifications were made for mounts, ribs and divots were added to keep wall cooling rates consistent. Figure 26 shows how the keychain mount, a hemispherical cavity in one end of the shell, had an equally large hemisphere designed into the internal surface to maintain wall thickness. Section thickness was minimised to 2mm as the square of the thickness is proportional to cooling time, which increases costs.

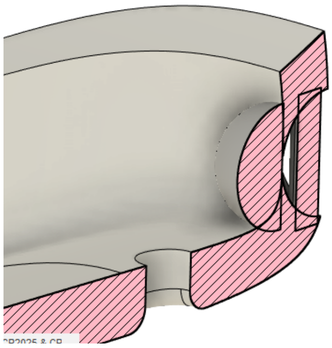


**Figure 26: Section of Charm Mount**

The casing has a varying draft angle, as indicated in Figures 27 and 28. Apart from the very ends of the case where the walls start to approach 70°, the majority of the casing has a positive draft angle between 92° and 100°. The fact that there only curves in the geometry as opposed to straight edges means that the structure is a lot more forgiving to the mould removal process. There are also no sharp corners in the design in order to avoid stress concentrations and obstructions of PP flow.

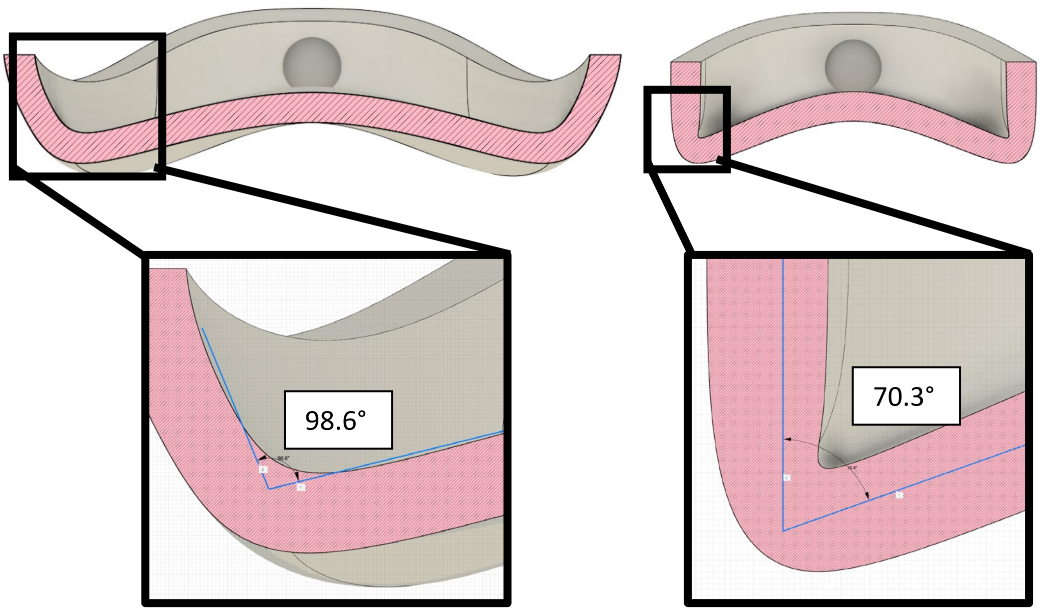



**Figure 27: Section of Casing**

As the antenna mount is cantilevered, I added two rectangular ribs on either side to prevent sagging. The rib thickness and height is 1.2mm, which is 60% of the wall that it supports in order to prevent voids and sinks.

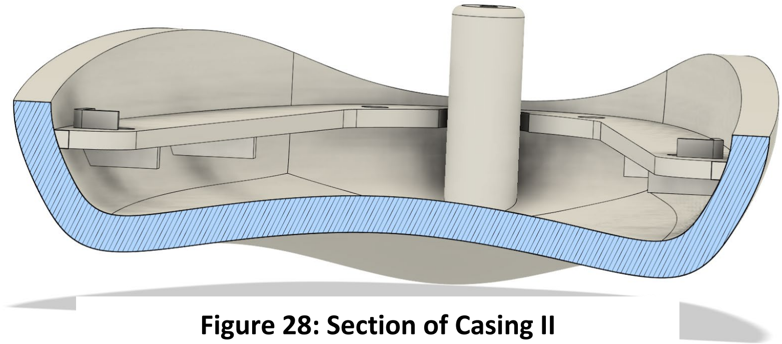


**Figure 28: Section of Casing II**

The antenna will be batch produced using a popularised manufacturing process for RFID assemblies. The custom shape of the PVC inlay will not be an issue for RFID manufacturers as there are already systems in place for the manufacture of customised key fobs that stray from the traditional rectangular card design. A CNC machine will circle the coil directly onto a prepared PVC sheet inlay. The RFID tag will then be fused to the antenna by melting the contact points. The assembly will then be secured between two other sheets of PVC using high temperature pressing. A customised cutting tool will stamp the RFID unit out into the profiles shown in Figure 29. A draft angle analysis on the antenna coil proved that a CNC machine with a ± 2° tolerance would not have any issues printing the antenna from a vertical direction.

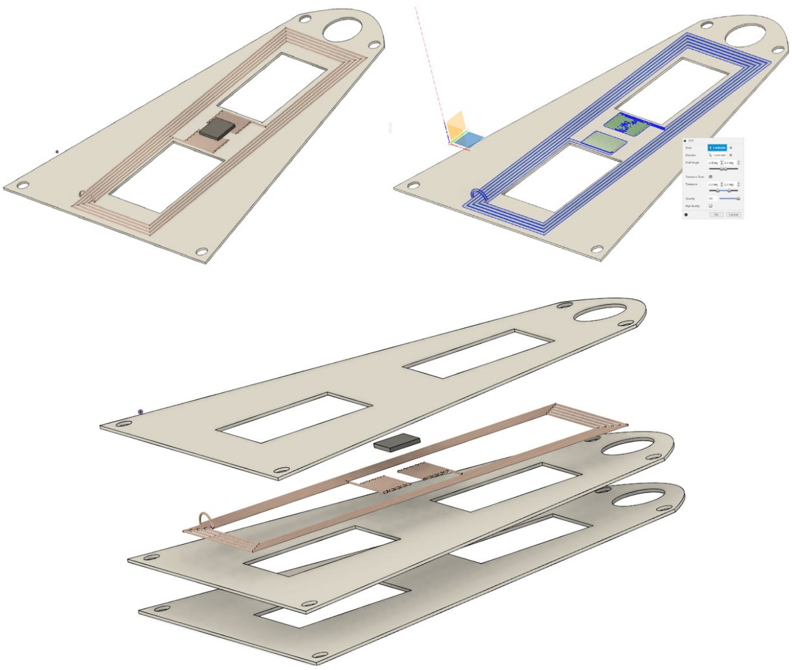


**Figure 29: RFID Installation**

The battery casing is to be injection moulded and will also be made from polypropylene. One modification made late in the design process was to include a 2.9° draft angle to the mounting slot at the bottom, which would allow the mould (split into two parts) to comfortably release it. The male counterpart of the mount situated on the casing was also appropriately adjusted to match.

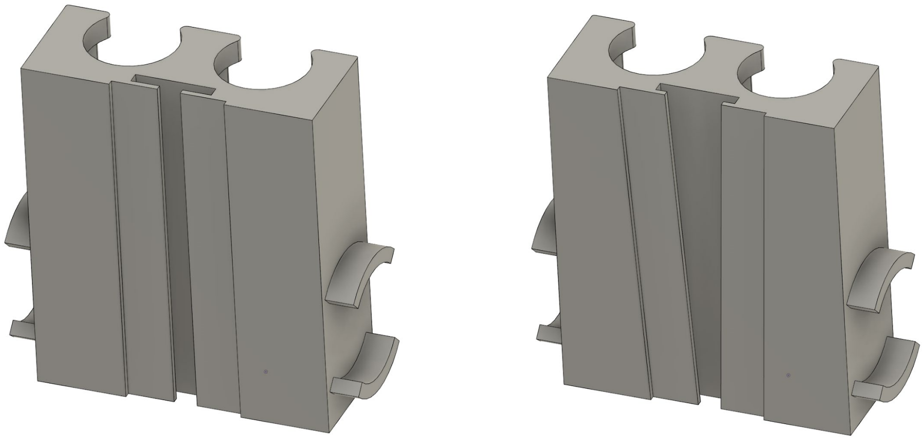


**Figure 30: Battery Mount**

## 9. Design for Assembly

Part count was minimised where possible to reduce assembly time. Almost all mounting components were designed into one half of the casing. Stock parts were also standardised to reduce part variety; there are two diameters of screws used in the product, an M2 and an M1.5. Grooves and draft angles not only help with mould removal but also serve as guidelines for part insertion, which is especially useful for parts with one degree of freedom such as the battery mount. Holes will be threaded to avoid the need for nuts, requiring only screws and washers installed from one side. User assembly was also considered, with the casing having mating feature for the MicroUSB slot. The assembly process is designed to be done entirely top-down, and there needs to be no re-orientation of the assembly apart from the switch installation at the beginning.

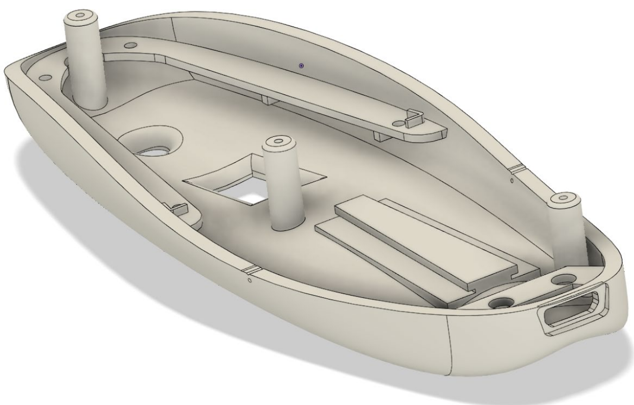
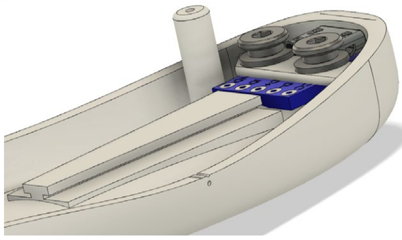
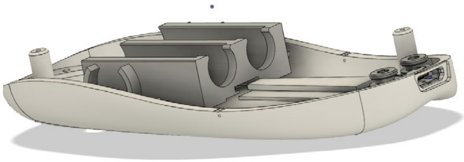
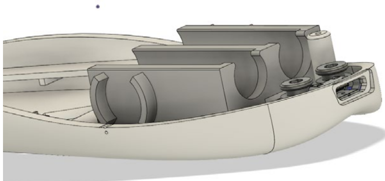
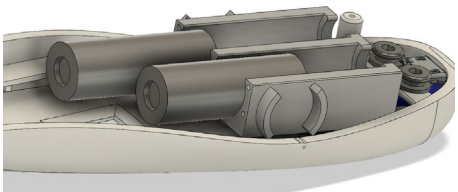
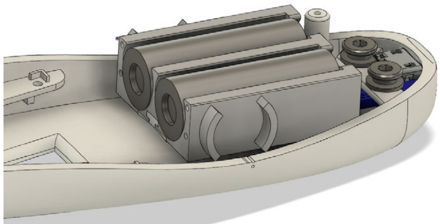
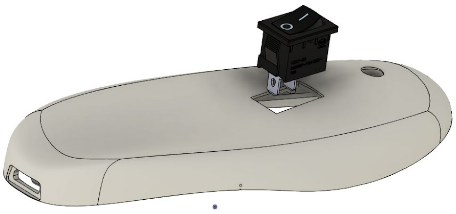
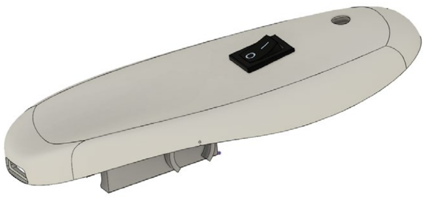
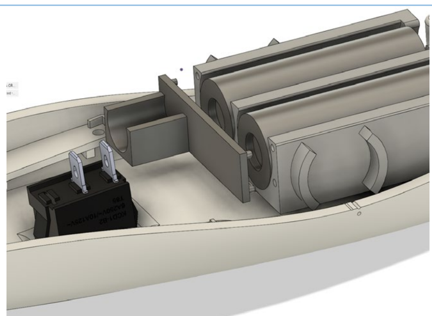
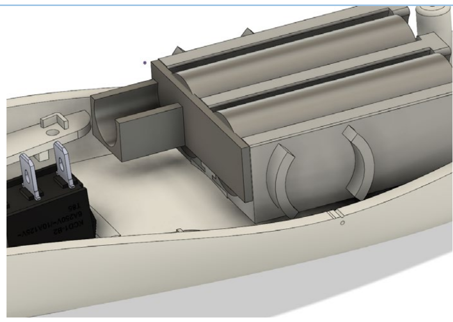


**Figure 31: Upper casing design**

## 9.1. Assembly Sequence

| ***Before*** | ***After*** | | ***Procedure*** |
|---|---|---|---|
|  |  | 1 | Insert MicroUSB IC and secure with one-sided screws & washers |
|  |  | 2 | Slot battery mounting unit into top half casing. |
|  |  | 3 | Slot Li Ion cells into battery mounting unit. |
|  |  | 4 | Apply PP adhesive to switch and insert |
|  |  | 5 | Push-fit sensor mount into the battery mount after aligning the 4 pins. |
|  |  | 6 | Place RFID assembly (antenna, tag and PVC layers) into position |

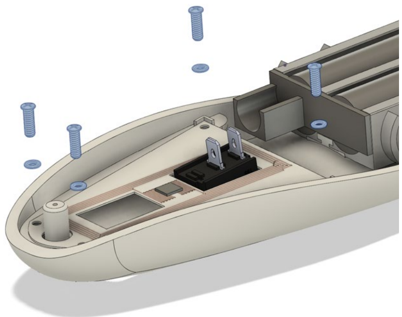
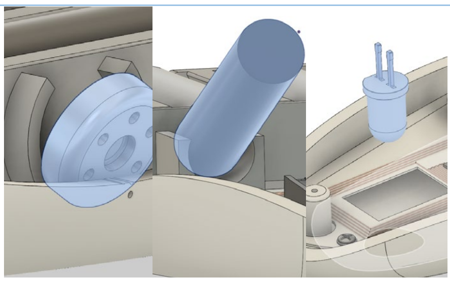
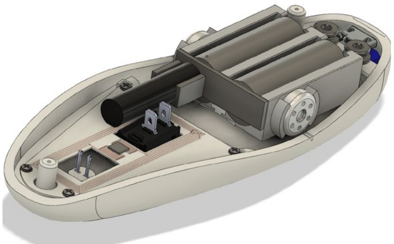
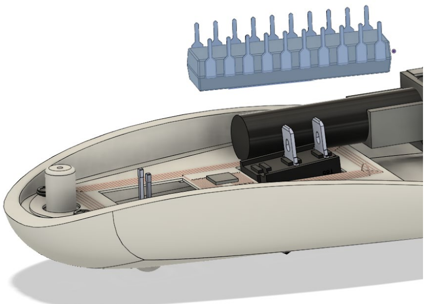
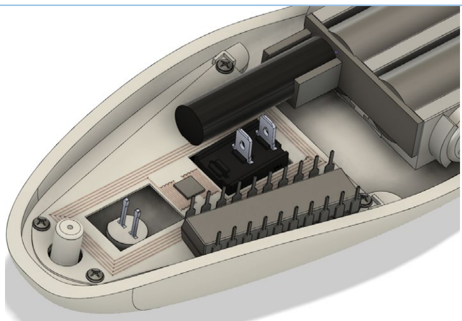
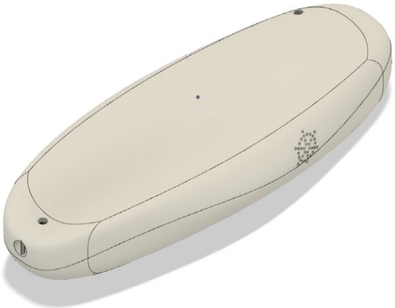
| | | | |
|---|---|---|---|
|  |  | 7 | Secure the RFID unit with screws and washers from one side. |
|  |  | 8 | Push-fit speakers & sensor to mounts and glue LED to slot. |
|  |  | 9 | Attach AVR microcontroller and PCB (which includes the GPS unit) |
|  |  | 10 | Secure bottom half of casing to the rest of the assembly using countersunk bolts. |
|  |  | 11 | Loop charm around itself and the charm housing to temporarily secure. |

**Table 4: Assembly Sequence**

## 10. User Interface Design

I started the UI design process by determining what information the user needs to see. I also listed information that the company needs from the user.

The user needs to know:

- How the application works
- Proximity of the rough sleeper to them
- Miscellaneous items that the rough sleeper may need
- The profile of the rough sleeper including name, age, aspirations
- Donation options
- Customisable donation options (custom amounts and standing orders)
- The logo, and company behind the service
- Contact details for the company

The company will need the user to assign themselves an account on their system and verify it with their phone number. The user will also need to accept push notifications from the application.

I proceeded to group these criteria into different interface screens. It is important to minimise navigation to make the donation process as fluent and rapid as possible. After sketching out a storyboard for the application user journey (examples of which are shown in Figure 32), I used the open-source Figma software to draft a design.

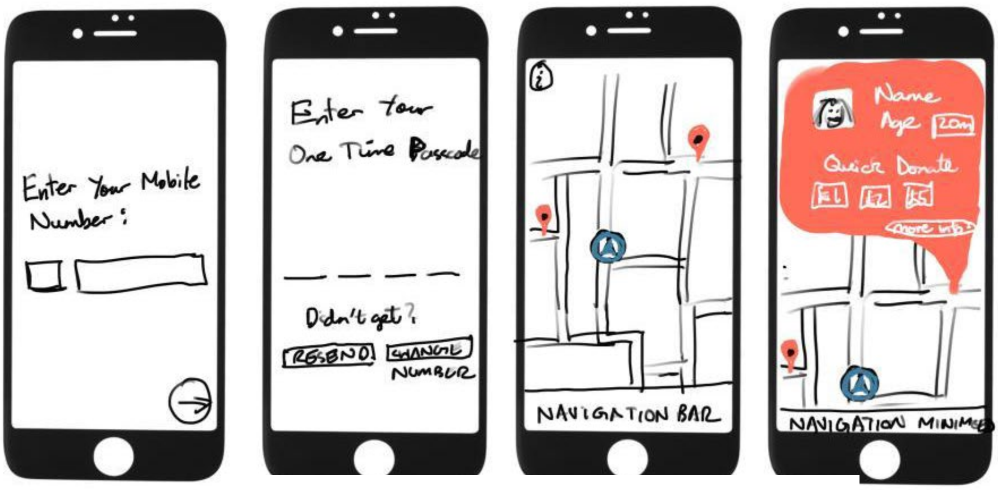



**Figure 32: UI Design**

The dark blue colour scheme was chosen for an image of professionalism and trust, whilst yellow was chosen as a complimentary colour that implies sentiments of hope, energy and happiness. The majority of the app is monochromatic except for the homeless profiles which are designed to stand out.

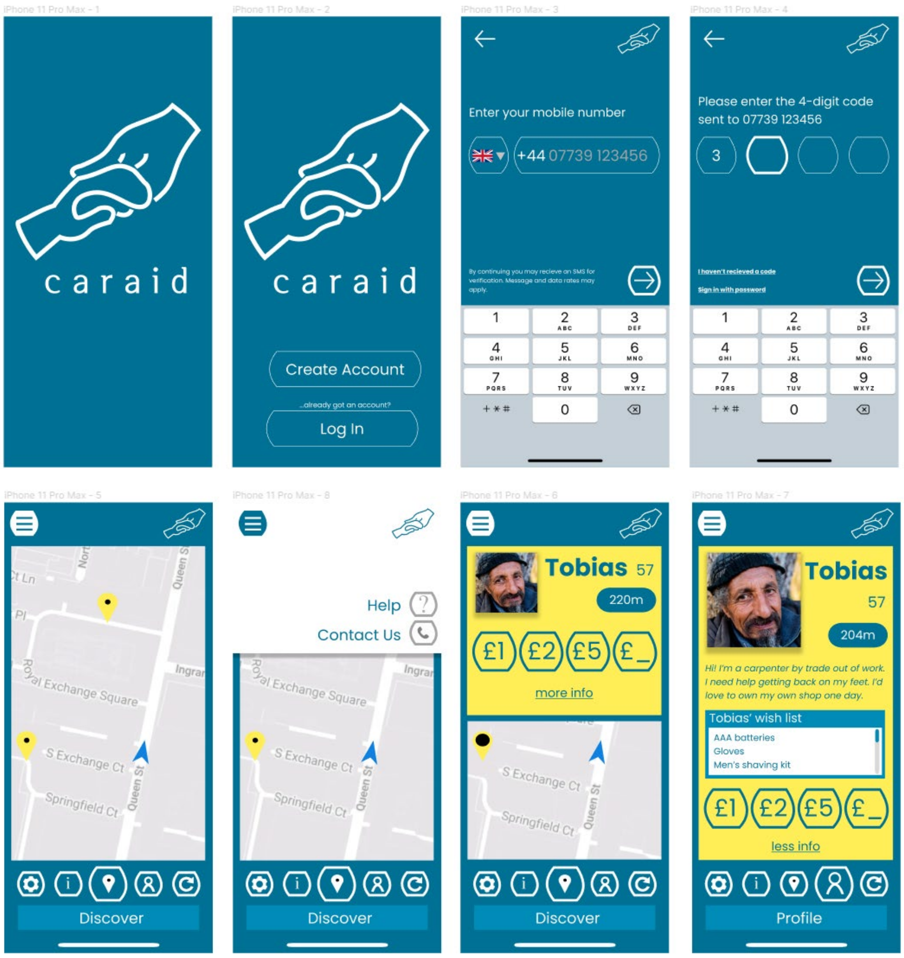



**Figure 33: Figma UI Design**

The features of the final UI is as follows:

- Start-up Screen
- Account creation with SMS verification, account merging with social media platforms
- Navigation ribbon at bottom of the screen with 5 tabs
- Menu icon on the top left with access to application help and contact details
- Discover tab with real-time map, user location and rough sleeper locations
- Information tab on how to donate further and set up standing order donations.
- Settings tab for account management and payment set-up.
- Profile tab for a list of nearby profiles for the user to sponsor
- Donation history tab
- User can quick donate on the discover tab, or can choose to go to their profile which will have more profile information and a customised wish list.
- User can accept push notifications from the app. When they come within 200m of a rough sleeper using the service, clicking on the resulting push notification will redirect them to their full profile.

## 11. Transactional System

I contacted a commercial bank who offers services to charity, in order to devise a transactional system that involves the charitable company, public donations and rough sleeper expenditure.

The charity initially opens a main account with the bank for a particular region. The charity then segregates this main account into beneficiary virtual accounts. These virtual accounts are all under the charity's name and the charity has the liberty to organise cashflow between them. These virtual accounts will then be assigned to an account associated with a rough sleeper device.

The device will have a unique ID tied to a GPS tracking module, that will not only allow contributors to identify nearby beneficiaries, but also provide the bank with assurances that malpractices such as fraud and/or money laundering is taking place. Contributors will be able to donate through their own banks via online payments and the Caraid application. Payments will pass through the Central Bank Clearing system to the charity bank, where the funds will be deposited into the main account. The charity will then distribute the donations accordingly.

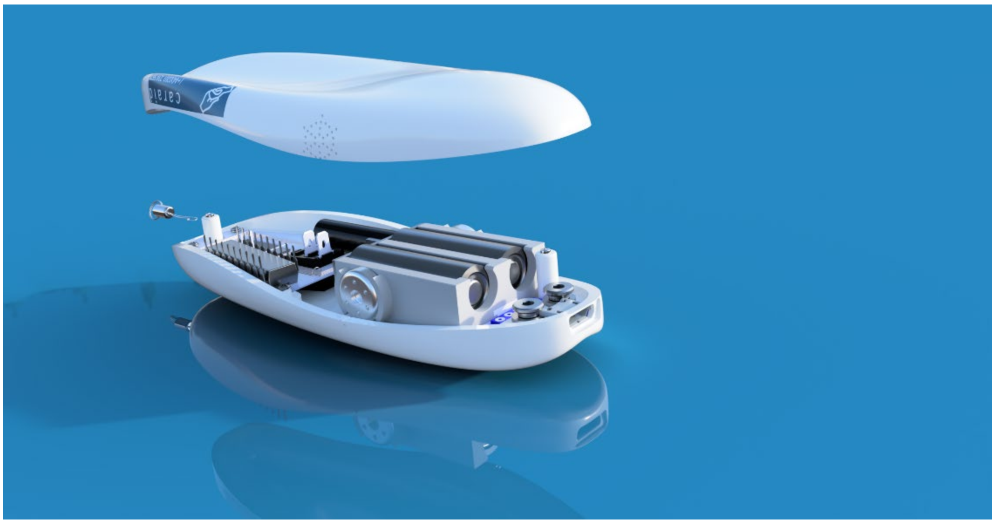
The beneficiary will be able to make contactless payments with RFID technology linked to the VA, albeit with restricted usage. Restrictions for contactless payments in the UK have recently been lifted from a maximum one-time contactless spend of £30 to $45 due to COVID-19.

There are several services that the beneficiary may require that will be organised by the bank and charity. The rough sleeper can call the charity and dial their device ID as an extension. They will then be able to access a variety of services offered by the charity, such as account balance information, and homeless shelter information etc. Account balance can also be messaged to the rough sleeper via SMS on a daily basis. The product will work similar to prepaid cards, where each device will be loaded with funds; there is therefore no capability for overdraft in this system.

If the device is lost or stolen, the charity hotline can be contacted to report the device missing, upon which the RFID tag can be immediately deactivated.

## 12. Conclusions and Further Work

A thorough design process grounded by the study of user experiences and human factors has delivered the design of an effective technology for homeless individuals. It has been developed hand-in-hand with a system that has potential to provide them with a steady stream of revenue which they can use in the long run to reintegrate themselves into society. The device will be a contact point between them and support services. By accepting themselves into a system designed to help them, rough sleepers will be taking the first step in a challenging task to find a life off the streets.



A few more processes and considerations must be undertaken before being able to take this product and service to market. The effect of different colours of noise must be systematically tested on the target user group in a simulation of the public setting they are expected to use the product in. A potentiometer must be integrated into the design as audio customisation is an important feature to accommodate all users. The product is sealed well but is not waterproof. Even though the casing has speaker grilles impervious to rust and corrosion, it does not have a secondary mylar diaphragm to weatherproof it.

An assembly analysis using Boothroyd and Dewhurst methodology must be conducted, and the results from this used to redesign parts for assembly purposes. Consequentially, a cost analysis must be undertaken once the PCB has been designed. A fully functional prototype made of 3D-printed parts can be produced (at the expense of injection moulding), and a final prototype can be made after Finite Element Analysis. The prototype must undergo HALT and HASS after a final prototype is manufactured, before controlled user testing can commence. The product will likely have several design iterations as the concept is new to market and may require finetuning based on user behaviour.

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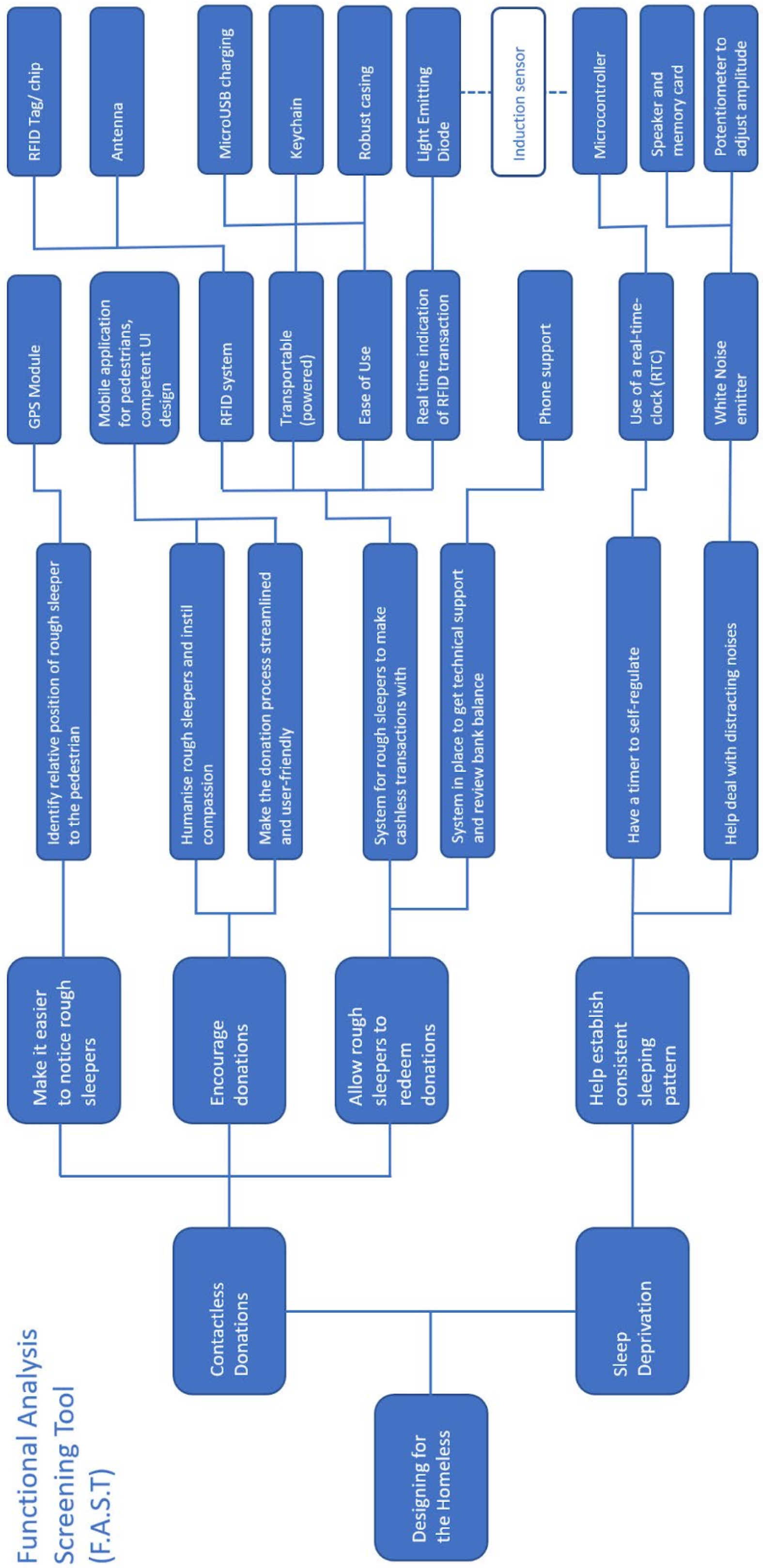
## 14. Nomenclature

| | |
|---|---|
| Rough sleeper | The most visible form of homelessness, sleeping on the streets |
| Statutory homelessness | Legally defined as homeless by local authorities |
| GP | General Practitioner |
| LED | Light Emitting Diode |
| ICU | Intensive Care Unit |
| Polysomnography | Sleep Study |
| EEG | Electroencephalogram, detects electrical activity in brain |
| EOG | Electrooculography (eye tracking) |
| EMG | Sub-mental electromyogram |
| REM | Rapid Eye Movement (dream state of sleep) |
| NREM | Non- Rapid Eye Movement, comprised of 4 states |
| RTC | Real Time Clock |
| RFID | Radio Frequency Identification |
| NFC | Near Field Communications |
| $\varepsilon_R$ | Radiation Efficiency |
| $L_{ant}$ | Self inductance |
| LFSR | Linear Feedback Shift Register |
| OEM | Original Equipment Manufacturer |
| FEA | Finite Element Analysis |
| HALT | Highly Accelerated Life Test |
| HASS | Highly Accelerated Stress Screening |

# 15. Appendices

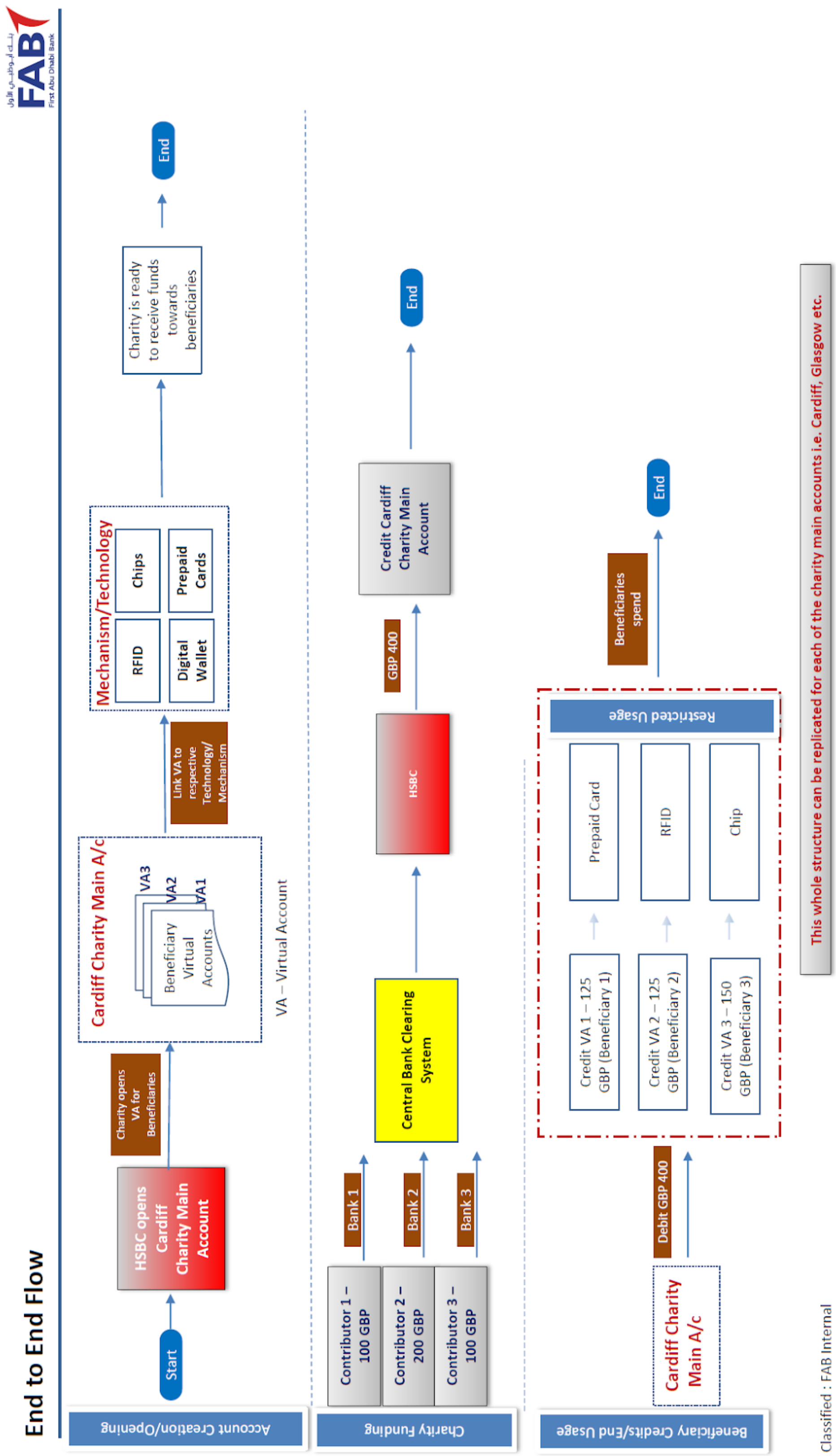
## 15.1 Appendix A: F.A.S.T



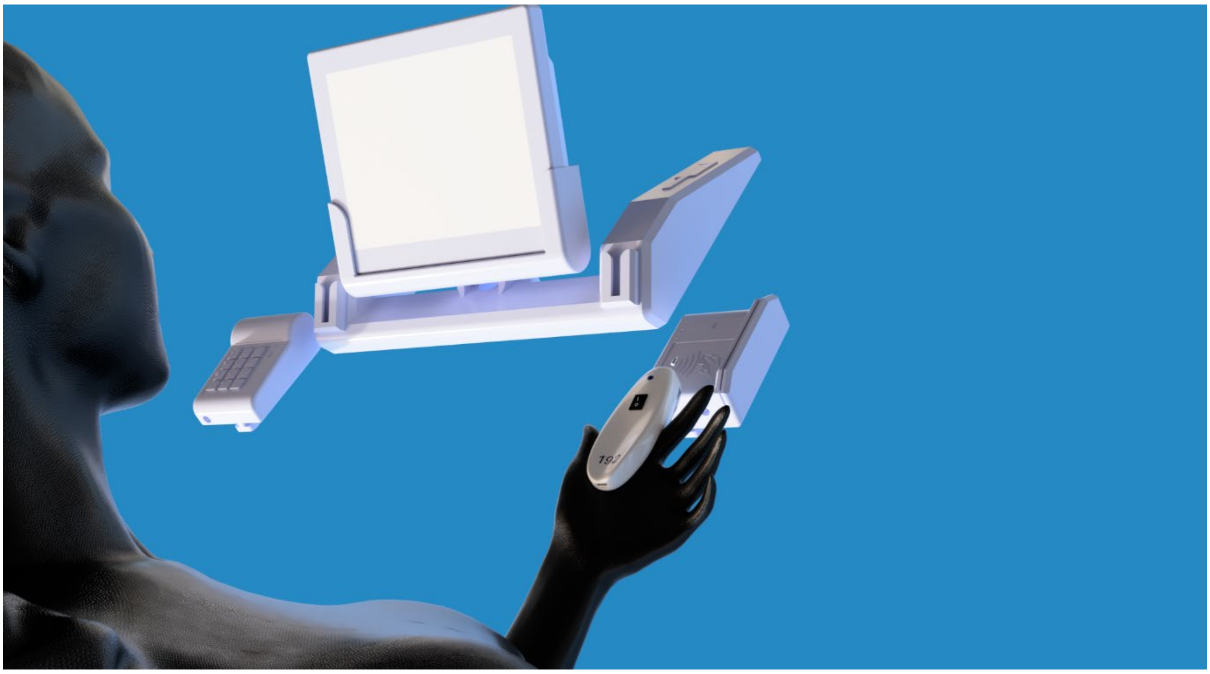
## 15.2 Appendix B: Anthropology

| | Percentile | | | | | |
|---|---|---|---|---|---|---|
| | Right hand | | | Left hand | | |
| Dimension | 5th percentile | 50th percentile | 95th percentile | 5th percentile | 50th percentile | 95th percentile |
| Hand length | 178.33 | 192.50 | 206.66 | 179.13 | 192.98 | 207.71 |
| Palm length | 99.07 | 110.68 | 119.87 | 99.31 | 110.89 | 121.11 |
| Hand breadth at thumb | 91.60 | 102.54 | 112.82 | 91.79 | 101.95 | 112.05 |
| Hand breadth at metacarpal | 79.44 | 87.05 | 96.51 | 78.55 | 86.25 | 95.25 |
| Grip diameter | 50.00 | 65.00 | 85.00 | 50.00 | 65.00 | 85.00 |
| Fist circumference | 245.00 | 271.00 | 300.00 | 241.0 | 269.00 | 296.50 |
| Hand circumference | 215.00 | 238.00 | 261.00 | 214.00 | 236.00 | 260.00 |
| Wrist circumference | 146.00 | 163.00 | 181.00 | 146.00 | 163.00 | 181.00 |
| Arm length | 700.00 | 755.00 | 810.00 | 700.00 | 755.00 | 810.00 |
| Elbow length | 431.87 | 468.43 | 504.11 | 433.23 | 466.30 | 503.78 |
| Elbow flexed | 235.00 | 270.00 | 311.00 | 236.00 | 268.00 | 310.00 |
| Fingertip to root digit 1 | 49.03 | 57.37 | 70.80 | 47.57 | 56.51 | 70.21 |
| Fingertip to root digit 2 | 63.35 | 72.76 | 79.51 | 63.01 | 73.18 | 80.19 |
| Fingertip to root digit 3 | 69.17 | 79.37 | 87.78 | 68.73 | 79.58 | 87.56 |
| Fingertip to root digit 4 | 62.20 | 73.77 | 81.52 | 61.66 | 72.88 | 80.71 |
| Fingertip to root digit 5 | 50.58 | 59.46 | 67.16 | 49.51 | 59.43 | 65.90 |
| Breadth of first joint of digit 1 | 18.65 | 22.08 | 25.17 | 18.60 | 21.50 | 24.59 |
| Breadth of first joint of digit 2 | 17.34 | 20.04 | 22.68 | 16.90 | 19.75 | 22.39 |
| Breadth of first joint of digit 3 | 17.26 | 20.00 | 22.30 | 17.00 | 19.64 | 22.05 |
| Breadth of first joint of digit 4 | 16.05 | 18.68 | 21.11 | 15.74 | 18.38 | 21.04 |
| Breadth of first joint of digit 5 | 13.95 | 16.98 | 19.24 | 13.62 | 16.58 | 19.41 |
| First joint to root digit 2 | 39.42 | 47.34 | 53.50 | 38.30 | 47.07 | 53.61 |
| First joint to root digit 3 | 43.10 | 52.55 | 60.34 | 42.56 | 52.13 | 59.33 |
| First joint to root digit 4 | 38.20 | 46.52 | 53.82 | 37.73 | 46.39 | 53.35 |
| First joint to root digit 5 | 27.71 | 35.12 | 41.51 | 27.37 | 35.20 | 41.55 |
| Second joint to root digit 1 | 17.39 | 23.16 | 31.01 | 17.76 | 22.74 | 29.97 |
| Second joint to root digit 2 | 19.40 | 24.11 | 27.68 | 19.29 | 23.90 | 28.06 |
| Second joint to root digit 3 | 21.34 | 26.35 | 30.58 | 20.57 | 25.86 | 30.43 |
| Second joint to root digit 4 | 17.40 | 22.75 | 27.18 | 17.40 | 22.43 | 26.84 |
| Second joint to root digit 5 | 13.59 | 18.10 | 21.88 | 13.71 | 17.87 | 21.35 |

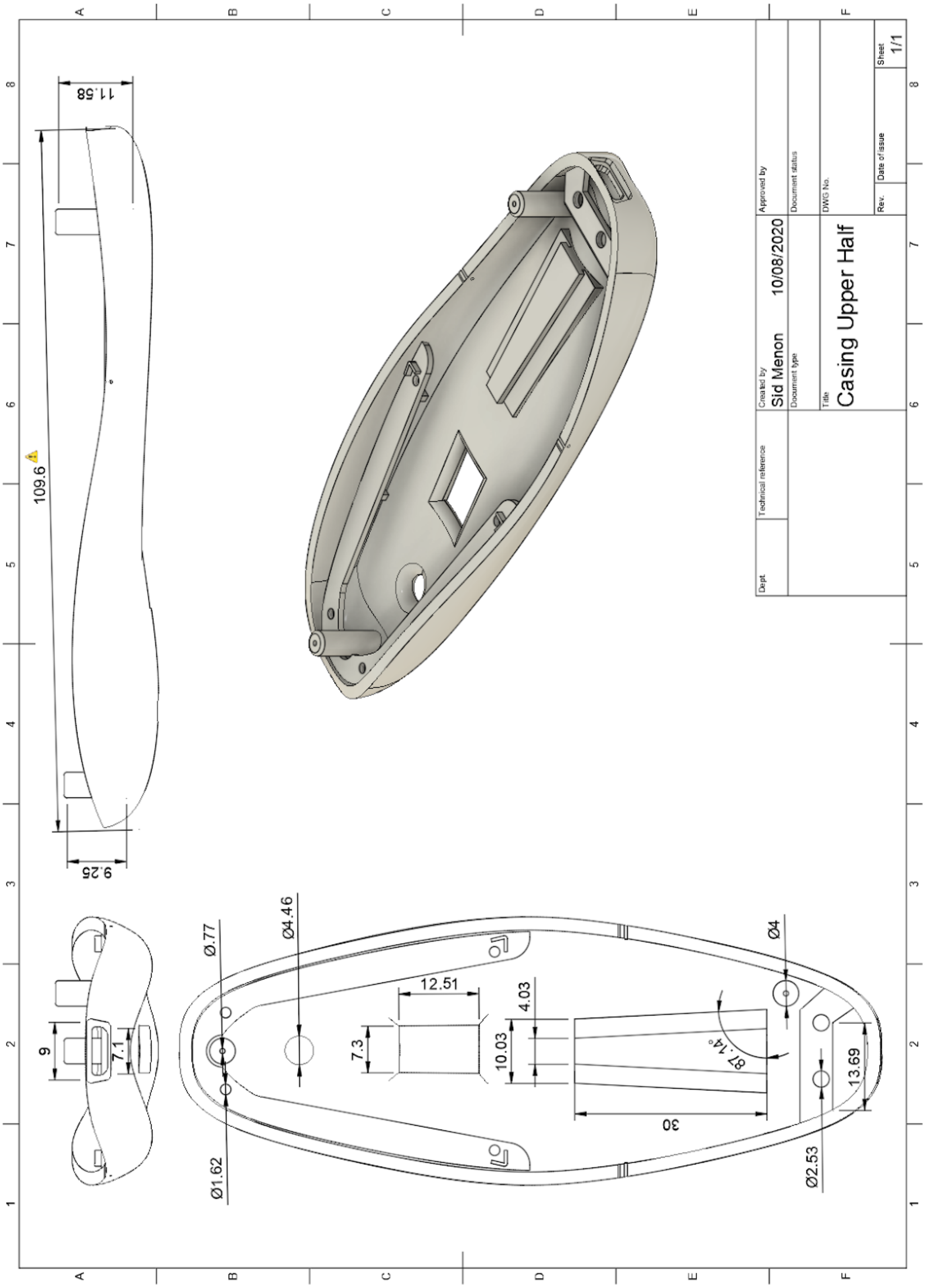
## 15.3. Appendix C: Transactional Layout



## 15.4. Appendix D: Final Renders

## 15.5 Casing Profile



## 15.6 Casing Profile II