MIDP Final Design Report

Digital Product Passports

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Abstract

This project focused on improving the accessibility of the Digital Product Passport concept by developing a prototype for a passport that not only fulfils the needs of a DPP, but also conveys information easily to users. This work builds upon the exploratory work completed in the previous semester where RFID was chosen as the method of data communication.

Initially, a user testing session was conducted where participants interacted with RFID tags. The insights generated from this suggested that introduction of a GUI would be beneficial as well as simplifying the interaction. This led to an Eco-Audit which validated that the concept chosen as part of the testing was the best environmentally. A second user testing session, with a broader demographic, was then conducted where participants aided in the selection of communication methods to ensure that the final concept would be easy to understand by all stakeholders of all ages. This final concept was analysed and designed in detail using typical material selection techniques and finite element analysis. The final design was then evaluated against the design specification as well as other alternative eco-conscious products to ensure that the correct design decisions had been made. When compared against the environmental impact of manufacturing and using a simple toaster the DPP falls short with just 31% of the equivalent impact. This proved that the concept has the potential to greatly reduce energy usage and carbon emissions. Finally, future works were suggested that would aid in enhancing the functionality of the prototype or further validate its design.

Acknowledgements

Throughout this project, support and resources were received from many parties which proved vital to the completion.

Firstly, I would like to greatly thank Anna Chatzimichali for her continued and dedicated support and guidance throughout the project as my supervisor. I would also like to thank Rod Valentine for assessing this project as well as the invaluable points made during meetings. I am also grateful to Gary and Josh in the Rapid Prototyping Lab for their expertise in producing prototypes. Thanks also to all the participants of the user studies without whom this project would not have been possible. Finally, thank you to my family, friends and the IDE 2024 cohort for the care and support throughout the last year for which I am very grateful.

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ABS	Acrylonitrile butadiene styrene	NFC	Near Field Communication
AI	Artificial Intelligence	P2P	Peer to Peer
CE	Circular Economy	PC	Polycarbonate
DBP	Digital Battery Passport	PCB	Printed Circuit Board
DPP	Digital Product Passport	PHA	Polyhydroxyalkanoate
E-Waste	Electronic Waste	PVC	Polyvinyl Chloride
EU	European Union	QR	Quick Response
FEA	Finite Element Analysis	RFID	Radio Frequency Identification
GUI	Graphical User Interface	SCL	Clock Signal
HDPE	High-Density Polyethylene	SDA	Data Signal
I2C	Inter-Integrated Circuit	TPU	Thermoplastic Polyurethane
LCA	Lifecycle Assessment	UART	Universal Asynchronous Receiver-Transmitter
LCD	Liquid-Crystal Display	UK	United Kingdom
LDPE	Low-Density Polyethylene	UV	Ultraviolet

1 INTRODUCTION

Internationally there is a growing demand for more sustainable business and design practices (Bartlett, 2012). To address this the European Union (EU) implemented legislation that enforces a shift in business models from the more traditional linear model, Figure 1, to a Circular Economy (CE) (European Commission, 2020), Figure 2. In a CE materials and products are treated as more of a service than a purchase and, at the end of a products life, waste is recovered, recycled, and reused in the manufacturing process (European Parliament, 2023a). This helps not only to reduce the amount of raw materials being used, therefore benefiting the environment, but also helps retain the value of materials meaning there are economic benefits as well (Steinbrecher, 2021).

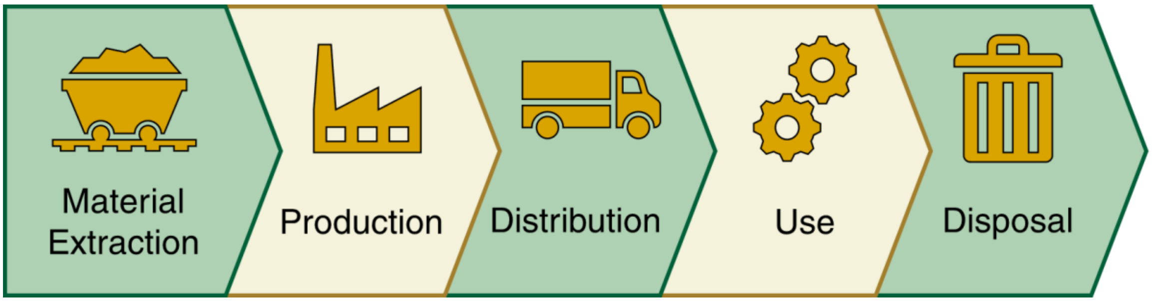


Figure 1: A diagram depicting the stages of a product's life within a linear economy.

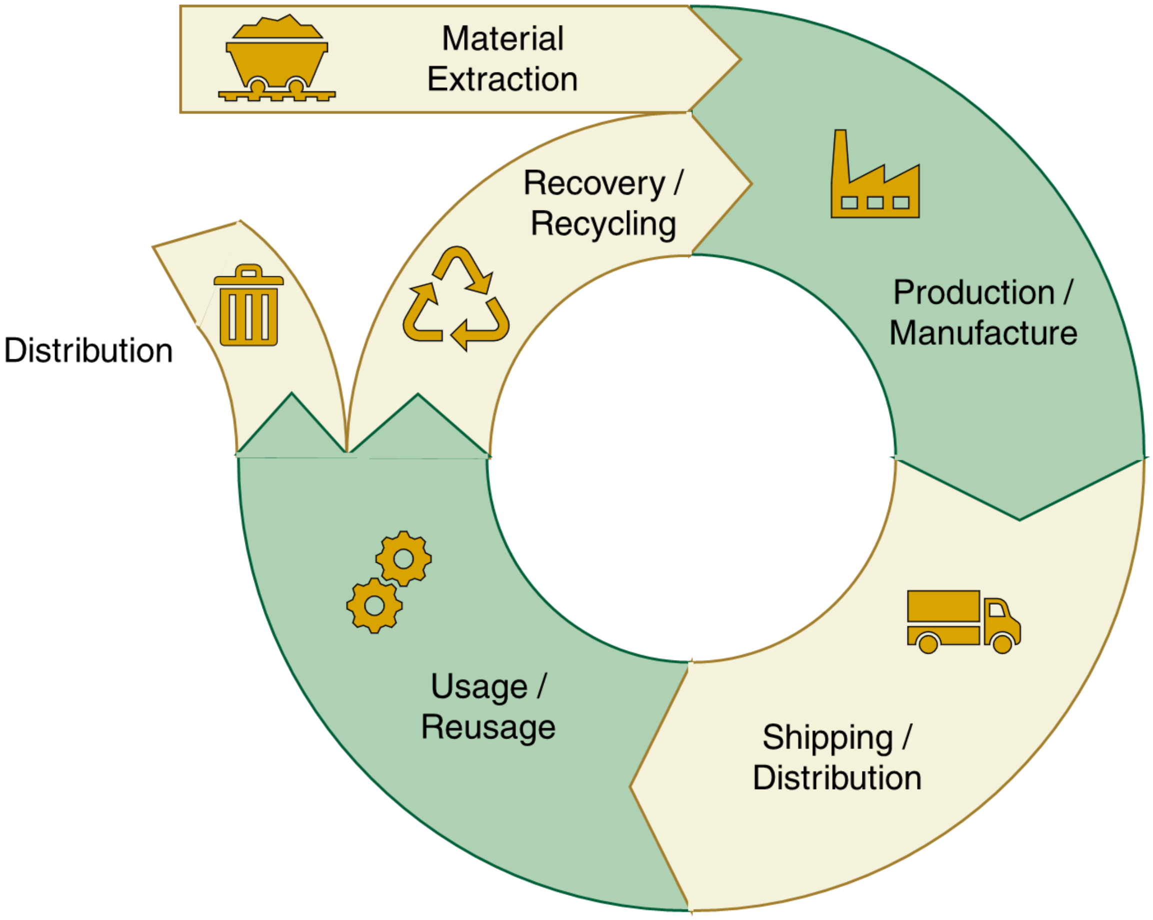


Figure 2: A diagram depicting the stages of a product's life within a circular economy.

Digital Product Passports (DPPs) are one method that the EU are in the process of rolling out that could greatly contribute to the CE effort (Berger et al., 2022). A DPP is widely considered to be a “digital twin” of a physical product that contains data relating to the origin, manufacture, material, usage, maintenance, disassembly and recyclability (European Parliament, 2023b) (Steinbrecher, 2021). The usage data about a product is especially important as it would allow the product to be reused for a longer period of time.

Unfortunately however, the policymakers within the EU parliament are currently only focusing on data. Their main concerns are the structure of large datasets and how the data in DPPs will be communicated between big parties (Gayko, 2024). This means the human element to the passport is being lost, such as how users will interact with it in their homes. Therefore, alongside fulfilling the functionality a DPP requires, this project looks to incorporate stakeholder needs from all areas of the lifecycle ensuring that the passport created is one that users will be happy to have in their homes and will be easy for them to use.

This also comes at an important time as currently the DPP is in its infancy, so by integrating the typical consumer needs now, it sets the stage for this to become the benchmark for how consumers will interact with the DPP concept.

The DPP concept has already been implemented in some form for the worst polluting product groups such as batteries and textiles. The EU is looking to expand this coverage to other products, so a focus for this project was chosen being electronics as E-waste is the fastest growing waste stream in the world with an annual output of 53.6 Megatonnes (Forti et al. 2020).

The aim for this project therefore is to develop a novel method for conveying the information contained within a DPP, with a focus on electronics.

This report starts with a recap of work that has already been completed and that contribute towards the project. This is followed by a user testing session where participants were asked to interact with radio frequency identification (RFID) technologies as well as decide between two concepts. An Eco-Audit of two concepts came after to ensure that the right choice was being made environmentally. After this a second user testing session was completed where participants helped finalise some of the design choices. These choices were then acted upon with a final user interface being created and a protective box was designed and evaluated. Finally, the report looks to validate the design by comparing to goals, specification points as well as alternative eco-conscious design methods.

It is also important to note that for this project there are some elements that are being disregarded. Firstly, the actual data stored on the tag will not be considered and any suggestion of the data that is stored on the tag is for explanation purposes and is not meant to represent the information that may be included within a passport. Secondly, the privacy of users data will be ignored. Both of these are being ignored as the scope of work that would be needed would extend the timeline for the project past the dates for submission and out of the timeframe the project needs to be completed within.

2 Concept Evolution

2.1.1 Mini Study 1 – Technology Audit

The first mini study consisted of a Technology Audit alongside exploration of the current practices being used in product passports for batteries. This helped inform some of the choices that needed to be made regarding the technology used for conveying information as well as the information it may need to convey.

The exploration of Digital Battery Passports (DBPs) highlighted key pieces of information that might need to be held within a DBP found through analysing important stakeholders (Berger et al., 2020). This process was repeated for the DPP and a template of the types of information that will need to be contained was created, Figure 3. This helped inform the following technology audit.

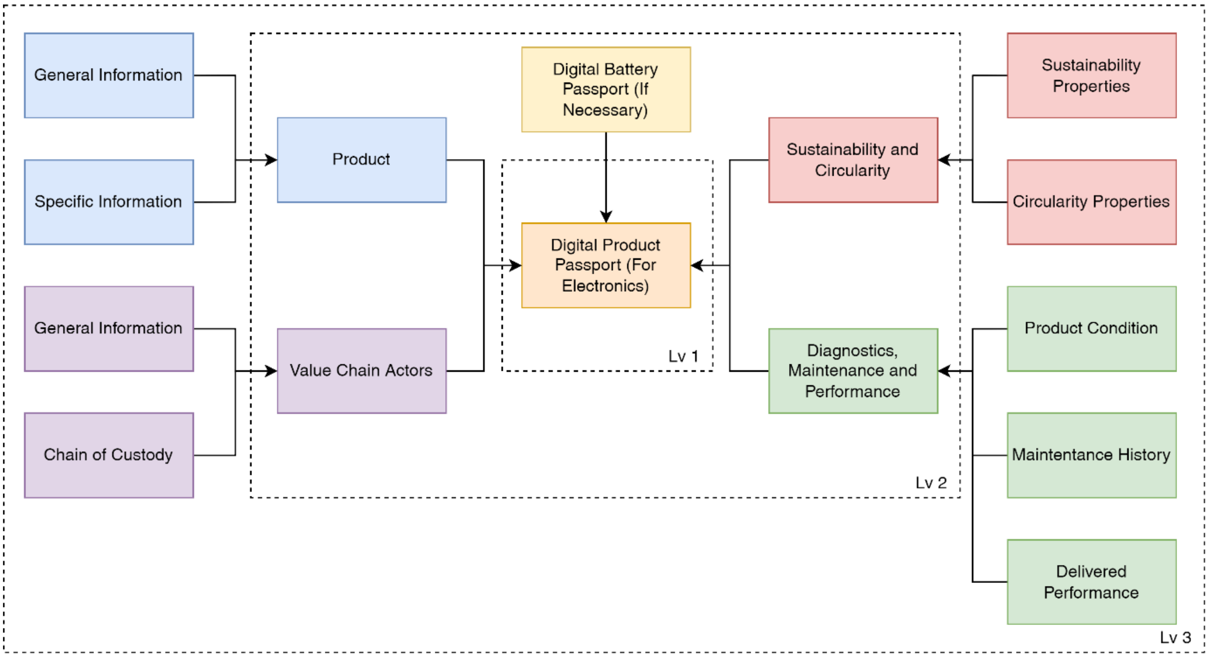


Figure 3: A template of the types and scale of information a DPP might contain.

The technology options considered were SmartTags, RFID, Artificial Intelligence (AI) Image Recognition, and Icons/Labelling.

- SmartTags – SmartTags, while lacking in customisability and automatic tracking, highlighted a very niche point that some of the changes can be visually spotted by the user without the need for any additional technology.
- RFID – With automatic data tracking, RFID shows a lot of promise and coupled with a fast information transfer speed appears to be a very good option. However, retrofitting of supply lines and redesign of products is required to make it work efficiently.
- AI Image Recognition – During testing it was found that while AI was very good at detecting the specific model of products in good camera conditions it struggled when visibility or lighting was poor. It also requires an online database, something that should be avoided.
- Icons and Labels – Both Icons and Labels can be very familiar for users and can easily convey any information. When the product is manufactured however they are locked into that state so cannot track information and could easily become outdated.

In conclusion, the exploration of DBPs allowed for identification of information that would need to be contained within DPPs. Technological options for conveying this information were explore with RFID seeming to provide the most promise, however others were not disregarded at this stage.

2.1.2 Mini Study 2 – User Needs Research

The focus for Mini Study 2 was incorporating the needs of potential users into the concepting of the DPP. This was considered important as, for DPPs to be effective in reducing waste and contributing to a CE, users need to be interacting with them and using them. One of the best ways to ensure this is the case is to make them easy to use and efficient.

Incorporating stakeholders from across the entire life cycle of a product is important as they are all likely to be interacting in some way with a DPP. To identify these stakeholder groups a tool, known as SCOPIS, was used (Morgane et al., 2018). The groups identified were Recycling Contractors, Manufacturing Engineers, Supply Chain and Logistics Experts, Sustainability Engineers, Product Users, and Product Life Cycle and CE Experts.

Semi-structured interviews with stakeholders were conducted to reveal insights into various aspects of DPP implementation. The findings from these interviews highlight several key considerations:

- Safety: Concerns about data confidentiality and protection were raised, emphasising the importance of addressing privacy concerns.
- Data and Information: Automatic data collection is preferred for reliability and real-time analysis. Ensuring it is kept in a raw form is also important so that data doesn't get corrupted. Data accuracy and accessibility are crucial for stakeholder trust in DPPs.
- Increasing Adoption: Cost, Data Ownership, and Legislative compliance influence various stakeholders' willingness to adopt DPPs. Retrofitting DPPs economically and demonstrating benefits to companies are essential.
- Interaction: Ease of use, simplicity and familiarity are critical for user acceptance. Visual feedback and ergonomic design were emphasized for efficient interaction.
- Targeting: Two interviewees mentioned that typically when regulations come into force in the sustainability industry the most impactful products are targeted first. This was applied to this project where small electromechanical products were chosen.

Overall, stakeholder engagement and user-centric design principles clearly make up much of the requirements for users. The insights gained in this study could be used for concepting of DPPs and generating quantifiable requirements based on the needs of users.

2.1.3 Design Specification

With needs of users identified and potential technologies explored, a cohesive design specification could be developed. This can be found in Appendix A. Some of the most important points are explored briefly below:

- Data Transfer Speed **–** The data held within the passport should be transferred from or to the passport in less than a second. This is due to final assembly lines of electronic devices are typically continuously moving, at approximately 0.1 metres per second (Roser, 2023).
- Ease of Use **–** It is hard to define goals when making a product easy to use, however, for this project it has been decided that a 10 second limit to daily and normal interactions will be set. This is within Nielsens limit of absolute focus (Nielsen, 1993) and therefore should ensure the passport is easy to use.

- Passport Cost **–** The cost of a passport is important when considering the variety of products it could be placed in. To ensure that it is a profitable endeavour for manufacturers to implement the passport should be no more expensive than £4.08 as this is the recoverable material cost from the simplest device being considered, a toaster (Massachusetts Institute of Technology, n.d.).

2.1.4 Design Concepts

Even though thorough exploratory work had been completed the potential design space for the project was still broad, as constraints had been set but a design direction had not. Using a design tool, known as an opportunity lollipop and seen in Figure 4, an opportunity was identified which was directly traceable back to the research already completed.

Figure 4: An opportunity lollipop depicting how research was used to generate an opportunity.

This design opportunity was "To create a simple and easy to use passport for everybody to use that only targets certain products." With the path for the project identified, concept ideas could be generated, Figures 5, 6 and 7.

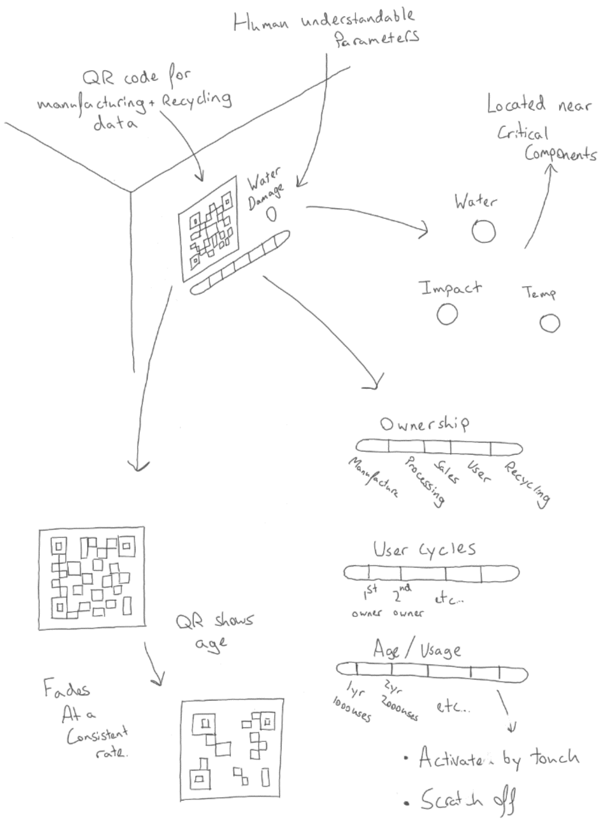


Figure 5: A concept drawing for a DPP with human readable elements.

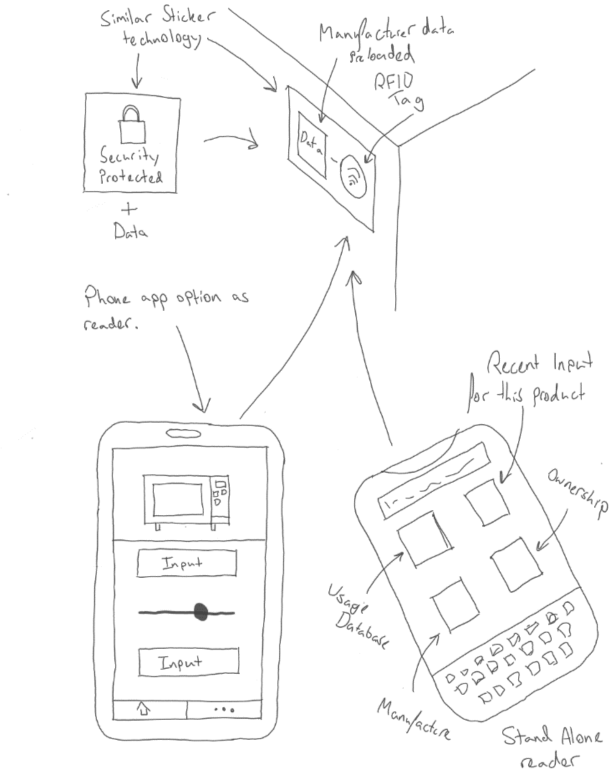


Figure 6: A concept drawing for a simple DPP with a standalone reader.

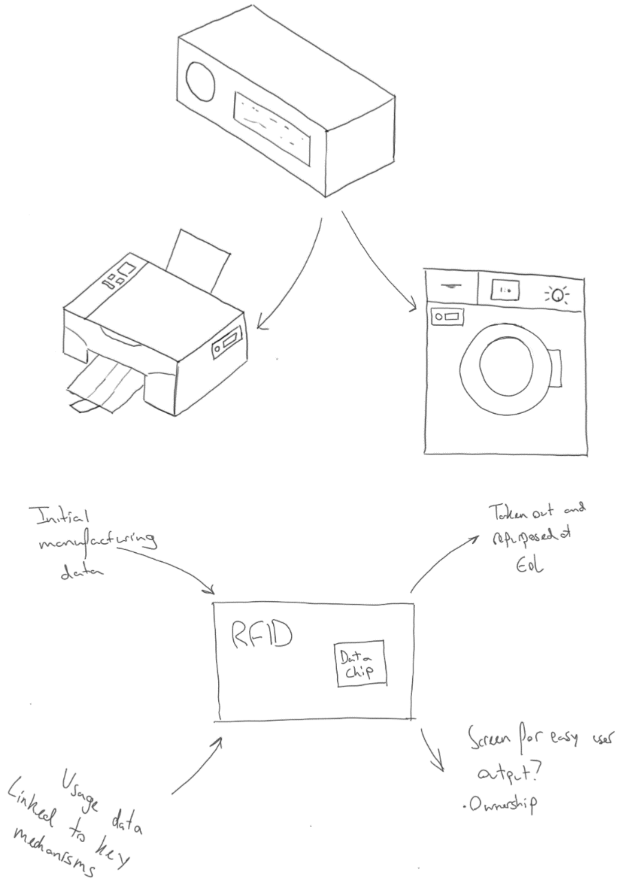
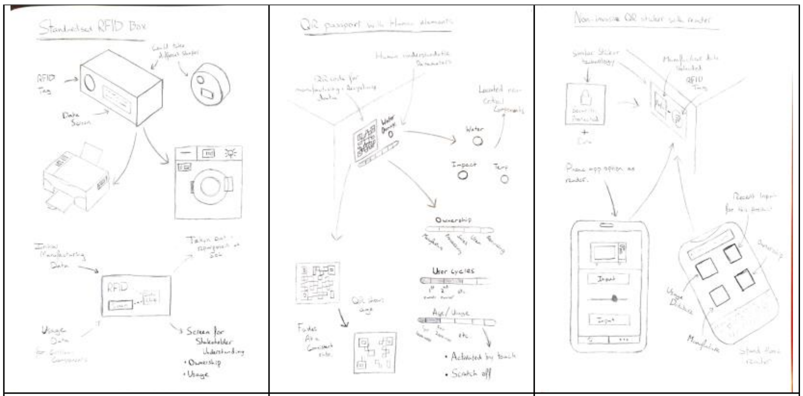


Figure 7: A concept drawing for a DPP which resembles a black box for information storage.

With concept ideas created, using a variety of technologies identified in Mini Study 1, they could now be evaluated to identify which was the most suitable to take forwards. Using a Harris profile, Figure 8, the RFID black box was chosen, with the quick response (QR) code passport being a suitable replacement should the prototyping of the RFID option deem it to be unsuitable.



		Concept 1 - Standardised RFID Box				Concept 2 - QR Passport with Human elements				Concept 3 - Non-invasive RFID sticker with reader			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Data	Adaptability												
	Tranfer Speed												
	Visual Feedback												
	Production Line Equipment												
Cost	Maintenance												
	Material												
	Value												
Geometry	Flexibility												
	Size												
	Need for Redeisgn												
	Accessibility												
	Complexity												
Interaction	Customisability												
	Simplicity												
	External Equipment Requirements												
Other	Future Proofing												
	Durability												
	Total	8				6				0			

Figure 8: A Harris Profile comparing potential concepts that could be taken forwards.

A more life-like drawing of this choice can be found in Figure 9.

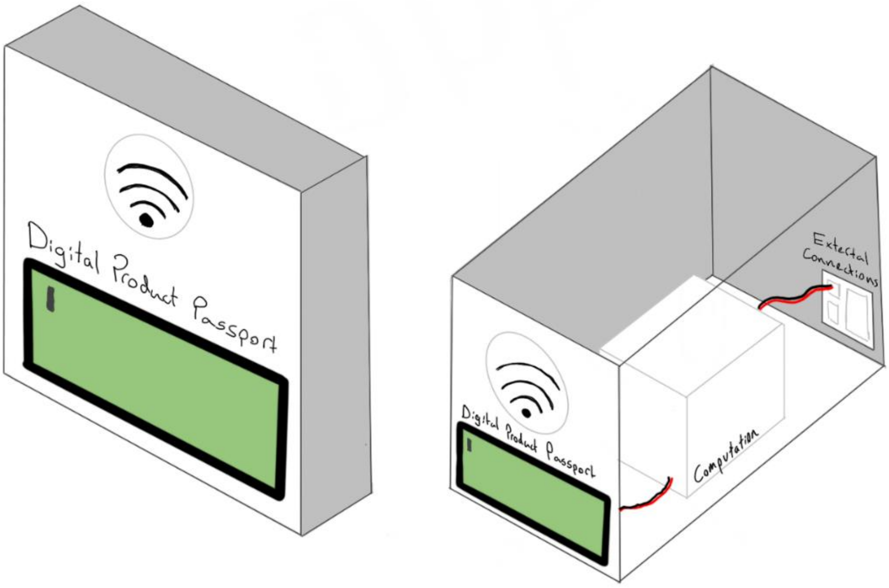


Figure 9: A drawing of the RFID Black-Box Digital Product Passport concept.

3 CONCEPT RECONSIDERATION

This final chosen concept however needed to be reconsidered as after a short break from the project it was realised that this concept may add more to the E-waste problem than it reduces. For this reason, a Low-Tech option, Figure 10, with no electronic elements that draw power should be considered alongside. This concept still uses RFID tags as the main form of data storage and communication.

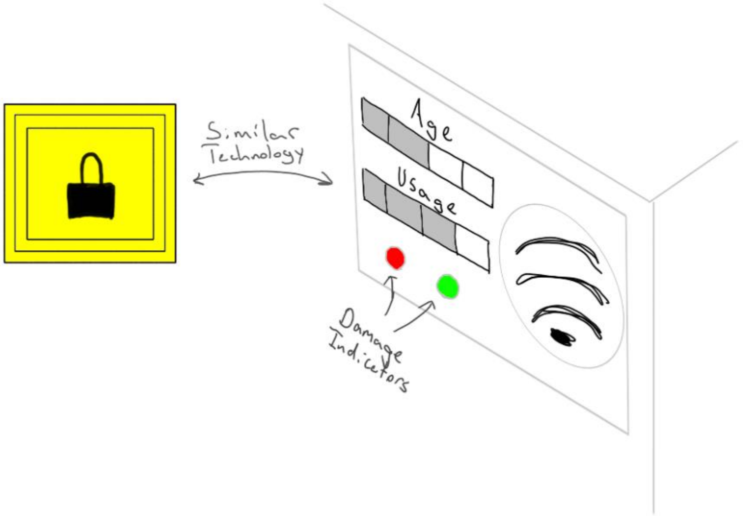


Figure 10: A drawing of a potential design for a Low-Tech DPP.

As the goal for the project is to convey information easily to stakeholders and this choice mainly affects the consumers of the products, the concepts should be decided between during a user testing session by potential stakeholders.

4 TECHNOLOGY TESTING: RFID

4.1 CHOICE OF CHIPSET

For the RFID technology there were multiple options of chipsets that could be used, mainly RC522 and PN532. As the exact functionality of the passport had not been clearly defined yet it was important to decide on a chipset that wouldn't limit any potential design routes further in the project. One of the foreseen circumstances would be peer-to-peer (P2P) communication between two antennas such as the passport and a smartphone. Traditional RFID, that which is supported by the RC522 chipset, does not support P2P or communication with a smartphone therefore the decision was made to use PN532 (Nor et al., 2017). The PN532 chipset uses near field communication (NFC) which is a form of RFID and works in a very similar way. The chipset chosen, shown below in Figure 11, will be used alongside MIFARE Classic 1k RFID tags to transfer and store data.

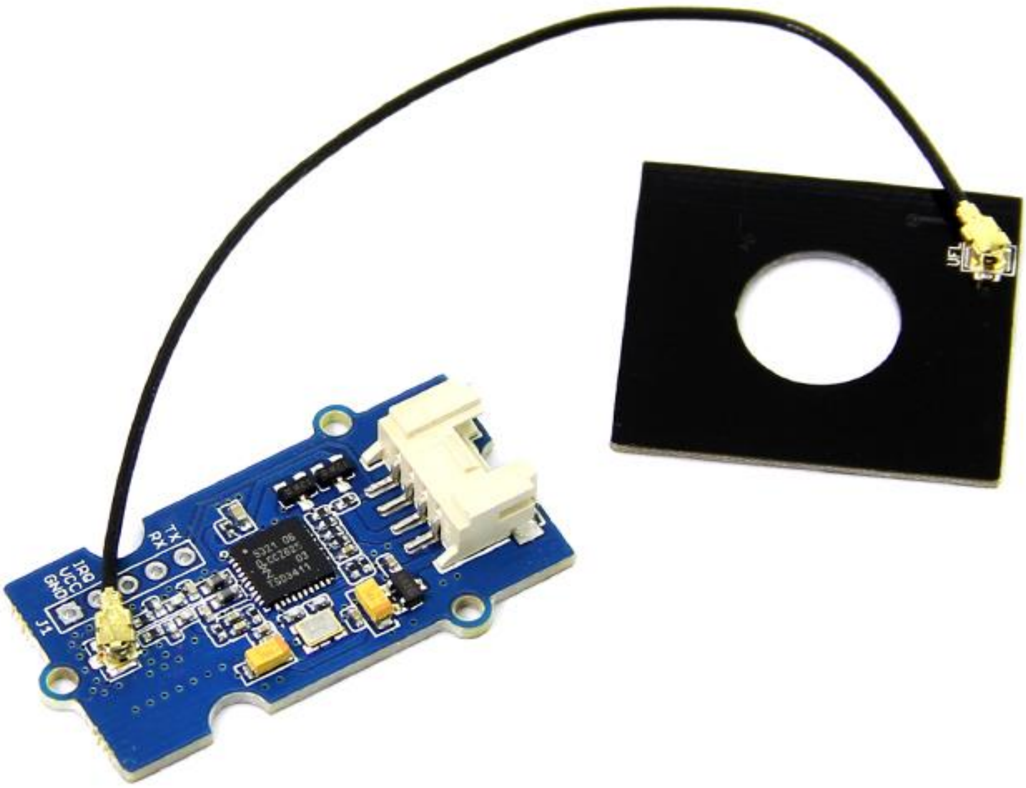


Figure 11: An image of the PN532 chipset used to communicate with RFID tag.

4.2 Choice of Communication Protocol

The PN532 chip chosen can communicate with the NFC antenna using either the Universal Asynchronous Receiver/Transmitter (UART) or Inter Integrated Circuits (I2C) protocols. Both protocols would work fine however there are some key differences that could make one more suitable than the other.

4.2.1 UART

The UART protocol uses a two-wire bus, a transmit line and a receive line, that does not use addressing of devices to identify them, seen in Figure 12. This means that only two devices can be used connected to each other to transfer data. Additionally, as UART is an asynchronous protocol, there is no clock signal and devices rely on their own internal clocks. This makes it simple and efficient but introduces a risk of data corruption (Zibayiwa, 2021).

Figure 12: A diagram depicting the function of the UART communication protocol (HiBit, 2023).

Another point to mention is that UART is one of the most widely used communication protocols, due to it's simplicity, so would allow the passport to be versatile and easily understood by all.

4.2.2 I2C

I2C is a more complex protocol than UART however provides more advanced features. It also uses a two-wire bus which consists of a data line (SDA) and a clock line (SCL), both found in Figure 13. Even though it only uses a two-wire bus it can still communicate with multiple different devices as it makes use of addressing, where each device has a unique address (Zibayiwa, 2021).

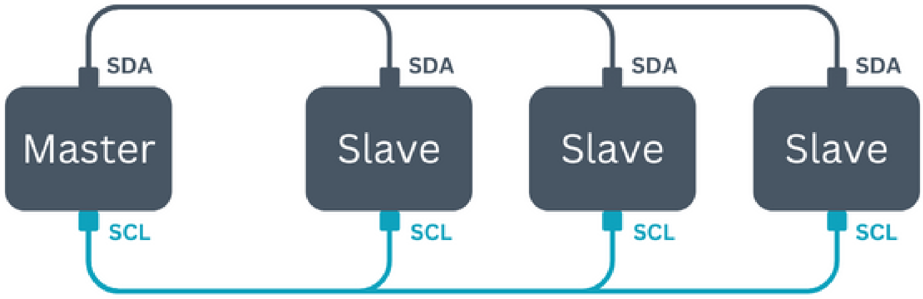


Figure 13: A diagram depicting the function of the I2C communication protocol (HiBit, 2023).

It also has error detection capabilities that would help with troubleshooting if anything went wrong during the prototyping of a passport.

4.2.3 Decision

Overall, due to the simplicity of UART, and the fact that only one passport will be scanned at once, it has been chosen as the protocol to take forwards. While I2C does offer more features such as addressing and error detection they are not a necessity for the project and the simplicity of the communication is more important. Furthermore, there is always the option to transition to using the I2C protocol later in the project if it were to be deemed necessary.

4.3 RFID Programming

4.3.1 Memory Layout

In a MIFARE Classic 1k RFID tag the memory is laid out in blocks and sectors, as shown in Figure 14. Each block contains 16 Bytes and each sector contains 4 blocks. The first sector however contains manufacturer information about the tag and the last block of each sector contains the sector trailer and the authentication key (NXP, 2018).

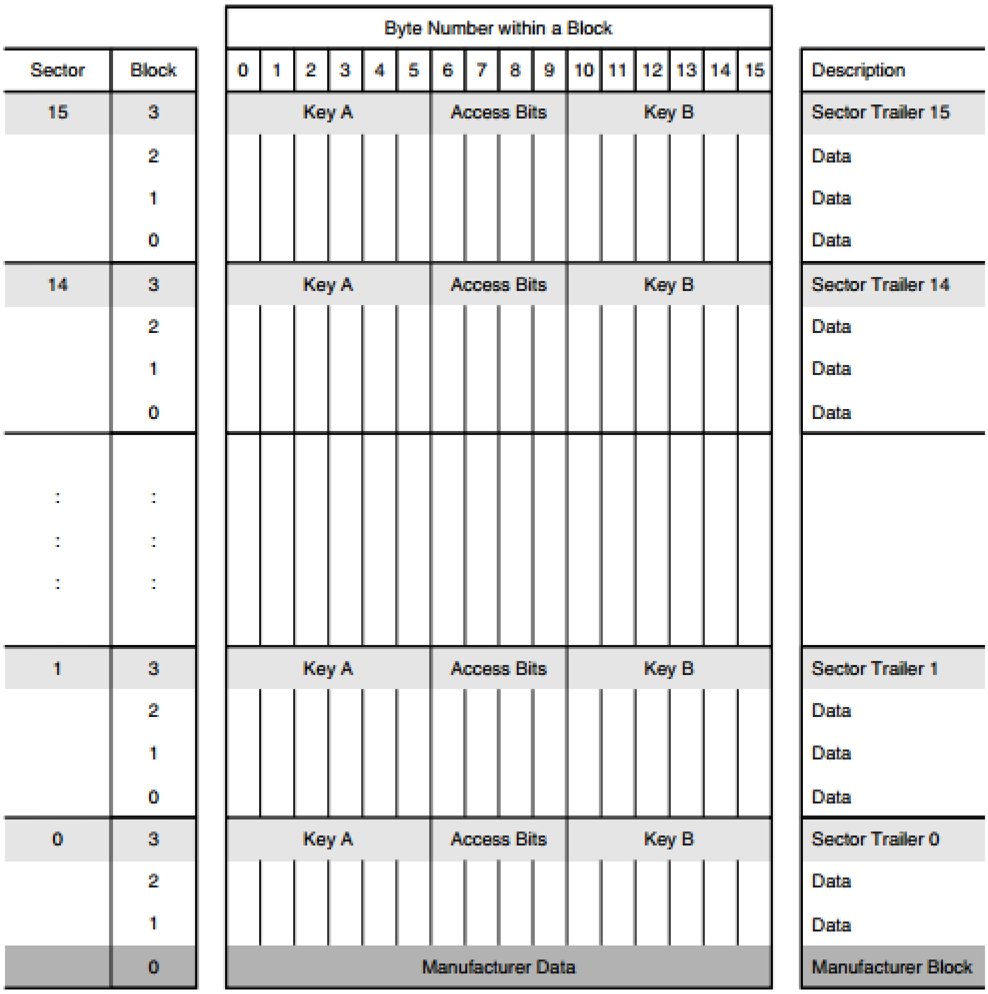


Figure 14: An image describing the layout of memory within the MIFARE classic tags.

The section trailer and authentication key are used when trying to read and write to the tag.

4.3.2 Reading and Writing

In order to create a program that communicates and stores data on the RFID tags there are a few points that need to be considered. The reading and writing of the tag must be done block by block as the chipset can only communicate and target one block at a time. Additionally, the data stored within the tags is in a hexadecimal format so all inputs and outputs needed to be translated between this and the ascii format.

As different operations are needed for reading and writing a decision was made to create two separate programs for each function. That way they could be switched between during testing to ensure that not only was data being written but that it could also be read. There was an introduction of step-by-step updates to ensure that the user understood what the program was doing with the tags. Examples of the programs functions can be found in Figure 15 with the full codes being found in Appendix B.

```
---- Opened the serial port COM4 ----
NDEF Writer
Found chip PN532
Firmware ver. 1.6
Enter the data to write to the NFC tag: (Max 45 characters)
---- Sent hex encoded message: "03" ----

 0x3
Number of blocks needed: 1
Loading...

Place a formatted Mifare Classic NFC tag on the reader.
Loading...

Place a formatted Mifare Classic NFC tag on the reader.
Loading...

Place a formatted Mifare Classic NFC tag on the reader.
Loading...

Place a formatted Mifare Classic NFC tag on the reader.
Found an NFC card!
UID Length: 4 bytes
UID Value:  0xEA 0xD4 0x3C 0x59
4
4
Block 4 authenticated
Block 4 written
5
4
Block 5 authenticated
Block 5 written
```

```
---- Opened the serial port COM4 ----
NDEF Writer
Found chip PN532
Firmware ver. 1.6
Loading...

Place a formatted Mifare Classic NFC tag on the reader.
Loading...

Place a formatted Mifare Classic NFC tag on the reader.
Found an NFC card!
UID Length: 4 bytes
UID Value:  0xEA 0xD4 0x3C 0x59
Trying to authenticate block 4
1
Authentication Successful
Reading Block 4
Data for Block 4
 03 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................

Read failed
Trying to authenticate block 5
1
Authentication Successful
Reading Block 5
Data for Block 5
 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
```

Figure 15: An image containing examples of the reading and writing programs.

5 RFID Interaction User Testing

5.1 Creation of Prototype and Test

5.1.1 Prototype

In order to gain the users opinions on the RFID tags being on electronic devices and their locations it was important to bring a physical element into the user testing. This comprised of a small box that was mocked up to look like a microwave, depicted in Figure 16. The choice of microwave was simply because it is one of the more recognisable electronic devices in the home that resembles a small box in shape.

Figure 16: A picture of the prototype used during user testing 1.

It was also important to consider where the tag would be placed on the box, not only because the users would be asked about their feelings on the position of the tag, but also it would help with accessibility during the test. It was chosen to place the tag on the side of the device as this is easy for the participants to see and access as well as being out of the way from the main controls for the microwave.

5.1.2 Test

The test and following questions were designed and chosen to gain the most from the short periods of time I was asking the participants to engage for. The testing was focused on the writing and reading of data to and from the tag stored within the prototype. Users were asked to enter a string of characters into a laptop and then hold the antenna up to the “Scan Here” symbol. Following this they were asked to perform a similar task holding the antenna up to the tag and reading the output on the laptop which should be the string of characters they input.

The questions that preceded and followed this test were not only related to the test but also tried to clarify from users their feeling on the positioning of tags as well as how they would feel about using the either the chosen final design in Figure 9 or a more Low-Tech option. A final point they were asked about was on how clear the current “Scan Here” instruction was and what might make the process clearer without the need for explanation.

5.2 Outcomes from User Testing

In this section just the main points that came up often will be talked about, a full breakdown of responses can be found in Appendix C.

5.2.1 Opinions on DPPs

Many users felt that, in the current form the DPP is taking, they would be happy for it to be included on their home products. A common point brought up was that they would not want it to be intrusive or contribute to a rise in cost of the product, especially given the current economic climate (ONS, 2024).

5.2.2 Passport Location

When asked about their preferred location for a device like this, many felt that the current position on the side of a product was acceptable. Almost all participants stated that they would not want the passport to be on the front of their products as they do not feel they would use it enough to warrant this and it would “ruin the aesthetics”. Additionally, consistency was a common point raised by participants as it would make the use of passports easy across many devices if they knew exactly where to tap without having to check.

5.2.3 Clarity in Scanning

When asked if they knew what to do with the passport without any input from the researcher many users stated that it was clear that they needed to scan something behind the symbol but to them it was not clear what they needed to scan, how they needed to scan it, and why they were scanning something. This suggests that context on what the DPP is and why it is on the product is important for ensuring users are not afraid to use it and understand it’s function. A secondary point was that some users struggled to place the scanner in the right place to detect the tag leading to them requiring assistance from the researcher. Therefore, a more robust locating solution could be implemented to ensure a solid connection every time.

5.2.4 Feedback

During the writing and reading of data on the passport many users were unsure when the data had been written or read, occasionally they also pulled the scanner away before it could completely read the data. This led to the conclusion that a form of feedback, Visual or Audio, would be very beneficial to inform the user when they should approach the tag and when the transfer of data is complete.

5.2.5 Trust in Data Storage

Other than the feedback, participants were very pleased with the speed and ease they were able to write data to and read data from the tag. Unfortunately however, it became clear during testing that occasionally the data would come back slightly corrupted. As most participants entered sentences it was easy to decipher, but if for example a model number was entered, and this was corrupted it could lead to misinformation for any users of the passport. Therefore, some further testing is required to ensure that the corruption of data is kept to a minimum or avoided altogether.

5.2.6 Interface Implementation

Additionally, when attempting to read the output of the tag, due to the nature of the technology, lots of extra information was displayed. This confused participants and many stated that they would prefer to interact with a more graphical user interface where all the raw data is kept out of sight. “That can be left to the expert” one participant mentioned.

5.2.7 Low-Tech is preferred

Similarly to the reasons for the interface, the majority of users stated that the Low-Tech concept would be their preferred option due to the potentially better eco-credentials it exhibits as well as the fact that screens and electronics are also a bit confusing and “Overkill”. The main concerns of users are that the extra electronics are unlikely to be used often enough for them to see value. One participant mentioned however that for devices that are already heavily electrified, but outside of this project’s scope, a screen might make sense. There was also a concern raised about the reliability of Low-Tech data as, for example, a user might be able to change the data themselves. Multiple participants agreed that if the information were kept in a secure box this problem would be solved.

5.3 Summary

Overall, after compiling the user testing responses, it is clear that the user preference is to go for the Low-Tech prototype. Additionally, a large focus for the next steps of the project should be to focus on the interface and interaction between users and the passport. This will be easier to do for the low-tech prototype as many prototypes can be made rapidly.

6 ECO-AUDIT OF HIGH- AND LOW-TECH CONCEPTS

To ensure that the correct choice is made between concepts an Eco-Audit needs to be completed. This will be used alongside the results from the user testing as the user testing covers the user need aspect whereas the Eco-Audit covers the ecological impact aspect. All the data for materials in the Eco-Audit was collected from Granta.

6.1 DEFINING HIGH AND LOW-TECH CONCEPTS

As part of the Eco-Audit, the components within a product or system need to be identified. With no fixed design for any of the concepts this will have to be general and assumptions about components will need to be made. Below are a few early assumptions that have been made:

- Firstly, RFID tags will be used in both prototypes as these have been chosen as the technology used for data storage and data transfer. The RFID technology analysed for the audit will be a tag without a casing, Figure 17. Essentially a copper coil and small circuit board.

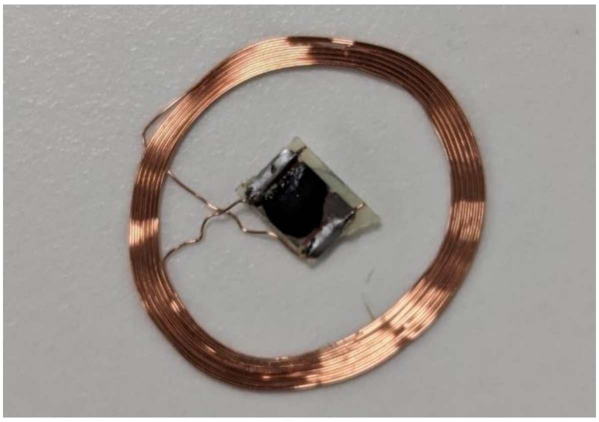


Figure 17: An image revealing the inner workings of an RFID tag.

- Secondly, the “Low-Tech” concept will contain no further electronic elements than the aforementioned RFID tag. It will however be using more physical methods for conveying information so these will need to be considered and included.
- Thirdly, the “High-Tech” concept will however be using further electronics. As this audit is quite general and broad, a simple selection of electronics that would be likely to appear in a final design will be chosen and analysed.

6.2 LOW-TECH ECO-AUDIT

6.2.1 Identify Components

For the Low-Tech concept the components that have been identified as potentially being included are:

- Printed Stickers
- Acrylic Scratch-offs
- RFID Tag
- Box and Insert

The traces of ink that may be used to print text and icons onto the passport have been ignored for this brief analysis due to the minimal effect they will have.

6.2.2 Analysis

The results of this Eco-Audit can be found in Figure 18 and Table 1, with the impacts of these being explored further in the following sections. For a complete breakdown of the Eco-Audit see Appendix D.

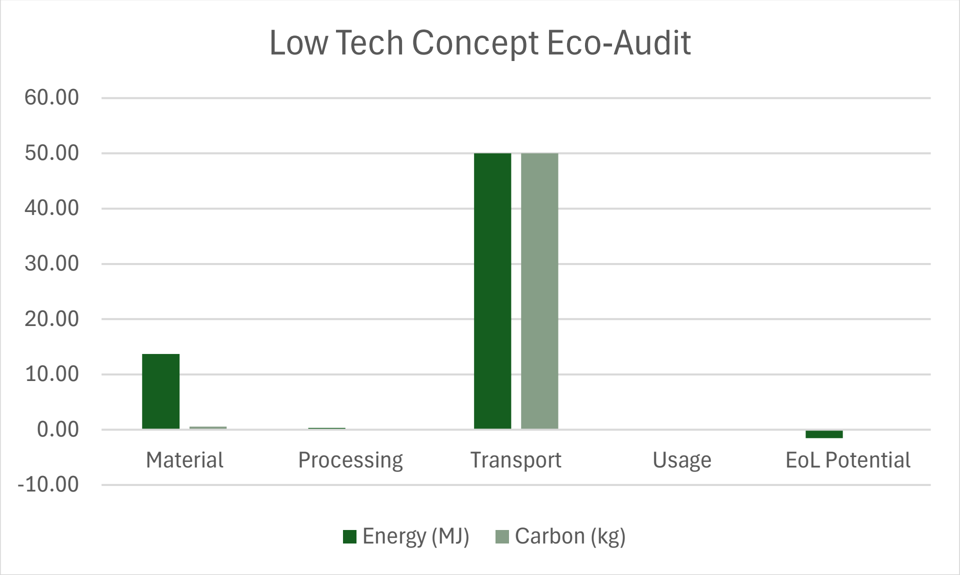


Figure 18: A chart of the Eco-Audit completed for the Low-Tech concept.

Table 1: The embodied energy and carbon emission data relating to the Low-Tech Eco-Audit.

	Energy (MJ)	Carbon (kg)
Material	13.70	0.53
Processing	0.33	0.07
Transport	50i	50i
Usage	0	0
EoL Potential	-1.54	-0.06
Total	12.49	0.54

6.2.2.1 Material Production

The material production is the largest contributor to both the embodied energy and carbon emissions. Additionally, 98% of both the energy and carbon emissions are from the production of Acrylonitrile butadiene styrene (ABS) for the box and insert the passport is likely to be comprised of. ABS was the chosen material for this as it is typically the material used for electrical surrounds like those seen around plug sockets, a similar use case as here.

6.2.2.2 Processing

The processing of materials and production of the concept would result in much less embodied energy and carbon being released than the production of materials. For these calculations Granta was used and the manufacturing processes for each component were approximated to extrusion or moulding. Whilst Granta did not have values for manufacturing methods that would allow creation of the Scratch-offs, moulding was used for this as it was the largest value so could be considered a worst-case scenario.

6.2.2.3 Transportation

In terms of calculating the embodied energy and carbon emissions for the transportation of the concept it was impossible to find a real value. This is due to there being no fixed locations for manufacture or retail. However, this is not a problem as the Eco-Audits are being used to compare concepts rather than calculate exact eco-credentials. As both concepts are likely to be very similar in volume it is only their weight than can be used as a tool for comparing energy and emissions during travel. Therefore, a constant 'i' has been used to represent the per gram energy and emissions during transportation which can be multiplied by the mass. For the Low-Tech concept the total mass has been estimated to approximately 50g.

6.2.2.4 Usage

Similarly, for the usage of each concept, the small power draw from the RFID technology in each concept will be excluded as it is the same for both concepts. The Low-Tech concept therefore does not contribute any embodied energy or carbon emissions as the RFID component is the only one that draws power.

6.2.2.5 End of Life Potential

The energy and carbon that can be saved by recycling has also been included into the eco-audit analysis. While not every passport may be recycled it is worth looking into as hopefully the presence of the passport will encourage recycling further than it currently is already.

Fortunately, for this concept and the components identified, all parts are recyclable meaning that there is a slight reduction in the overall eco-credentials when recycled. ABS, the material chosen for the box casing is highly recyclable and makes up 95% of the recovered energy and emissions.

6.2.3 Summary

Overall, the Low-Tech concept has a fairly small eco-footprint with 12.49MJ of energy needed and 0.54kg of carbon released. As mentioned, this is only a rough approximation of an Eco-Audit so real values may vary from this. The small eco-footprint alongside the user opinion of the Low-Tech concept being preferred creates a good case for taking it forwards. However, an Eco-Audit of the High-Tech concept needs to be completed in order to confirm this.

Additionally, if a full Eco-Audit of this concept is completed in the future it would be important to look into not only the energy and emissions but also the potential toxicity of the scratch-off materials and inks.

6.3 High-Tech Eco-Audit

6.3.1 Identify Components

The High-Tech concept is even harder to define than the Low-Tech version. However, some generalisations and assumptions have been made for the purposes of this Eco-Audit. The potential components that have been identified are:

- LCD 1602 Screen
- RFID Tag, Antenna and Chipset
- Box
- Arduino Nano
- Breadboard
- Wire
- Miscellaneous Sensors and Electronics

For many of the components here the materials and masses have been generalised to the greatest extent as there are so many materials in an Arduino Nano for example, that it would be inefficient to try and estimate the actual embodied energy and carbon emissions associated with it. For electronic components FR-4, the most common material used for printed circuit boards (PCBs), has been selected alongside copper to base the Eco-Audit on.

6.3.2 Analysis

The results of this Eco-Audit can be found in Figure 19 and Table 2, with the impacts of these being explored further in the following sections. For a complete breakdown of the Eco-Audit see Appendix E.

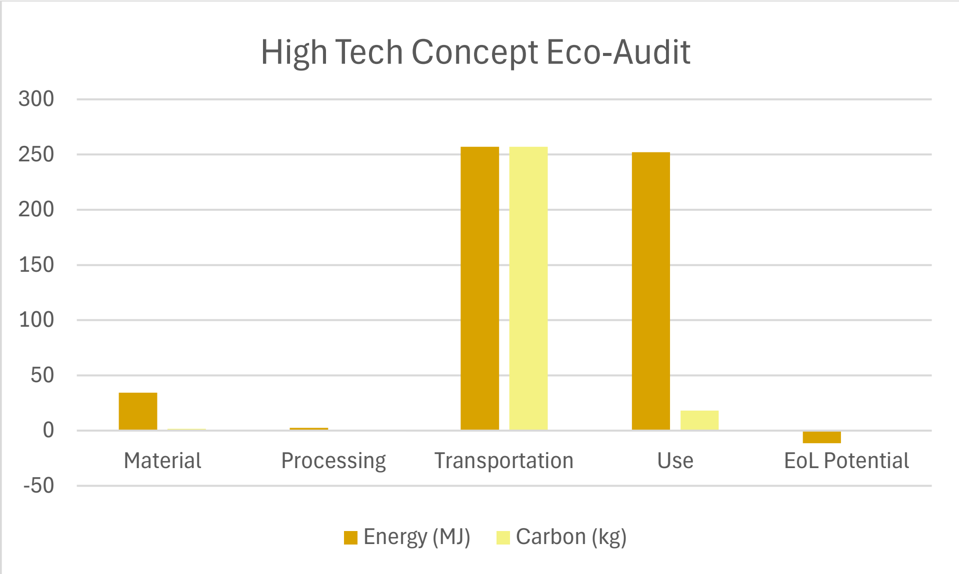


Figure 19: A chart of the Eco-Audit completed for the High-Tech concept.

Table 2: The embodied energy and carbon emission data relating to the High-Tech Eco-Audit.

	Energy (MJ)	Carbon (kg)
Material	34.421	1.5029
Processing	2.466	0.352938
Transport	257i	257i
Usage	252	18.04
EoL Potential	-11.3282	-0.58702
Total	277.5588	19.308818

6.3.2.1 Material Production

The energy and emissions needed to produce the materials for the High-Tech concept are much greater than that for the Low-Tech concept. This is largely due to the presence of PCBs which use complex materials such as the aforementioned FR-4. For example, the liquid-crystal display (LCD) screen alone generates 11.2MJ of energy and 0.46kg of carbon almost matching the entire Low-Tech concept. The box is also larger than the one from the previous Eco-Audit therefore generating more emissions.

6.3.2.2 Processing

Similar methods were used to calculate the manufacturing and processing impacts as in the Low-Tech Eco-Audit. Granta was used to find moulding and extrusion impacts however for PCB components containing FR-4 compression moulding specifically was used as this is the most applicable method. The manufacture and processing of the concept is the least impactful part of the process; however, this does not appear to be enough to recover it to the levels of the Low-Tech concept.

6.3.2.3 Transportation

The same 'i' constant has been used for the Eco-Audit here. Assuming that 'i' is the same for both concepts the emissions and energy required will be approximately 5x greater than the Low-Tech concept. This is due to the added weight of the electronic components especially the LCD Screen and the Breadboard.

6.3.2.4 Usage

As this concept is using electronic components it will need to be plugged in and requires use of energy. The two components that will use external power are the Arduino and the LCD screen with the sensors and other miscellaneous electronics drawing power through the Arduino. Assuming the Arduino draws 58mA and the screen draws 20mA (Soderby, 2024), the usage stage of the passport concept contributes most to the embodied energy and carbon emissions. This is because, while the power draw is quite small, across the estimated service life of 20 years it accumulates in a large total power usage. This high negative contribution to the eco-credentials is likely why most people during user testing felt that the High-Tech concept would be too much.

6.3.2.5 End of Life Potential

Due to the greater number of components and materials there is more potential for recycling in the High-Tech prototype over the Low-Tech prototype. This is deceiving however as the PCB components are unlikely to be recyclable and therefore will contribute further to the E-waste issue that the passport is trying to solve.

6.3.3 Summary

Overall, the High-Tech Eco-Audit has revealed the major downfall of the concept being that it potentially contains a lot of embodied energy and contributes heavily to carbon emissions. This is the opposite of the goal of the DPP and therefore suggests that other options should be considered.

In the future if PCB technologies advance and become easily recyclable, alongside renewable energies becoming more common place, the idea of a High-Tech DPP could be reconsidered.

6.4 Comparison

To conclude, the Eco-Audits highlighted the downfalls of the High-Tech concepts and, alongside the user preferences for the Low-Tech option, this is the concept that should be taken forwards. Therefore, the High-Tech concept at this point was omitted from the project.

As the Low-Tech concept is still not perfectly defined however, it will be important to access user's interactions with potential elements within the concept as well as access the viability of different techniques for conveying information and data without the need for the RFID tag to be scanned.

7 STAKEHOLDER MAPPING

After presenting the chosen concept at a mid-project prototyping review it became clear that the prototype itself did not explain the functionality of DPPs, why they are needed, and why they are so beneficial. Amongst other feedback, one member of the panel suggested that applying the prototype to scenarios that users may be able to relate to would help convey the concept a lot more effectively. Therefore, the interactions between all stakeholders and the DPP need to be analysed to identify key scenarios that will help explain the concept. The first step for this is creating a roadmap, Figure 20, for how a passport is interacted with.

7.1 PRODUCT LIFECYCLE ROADMAP

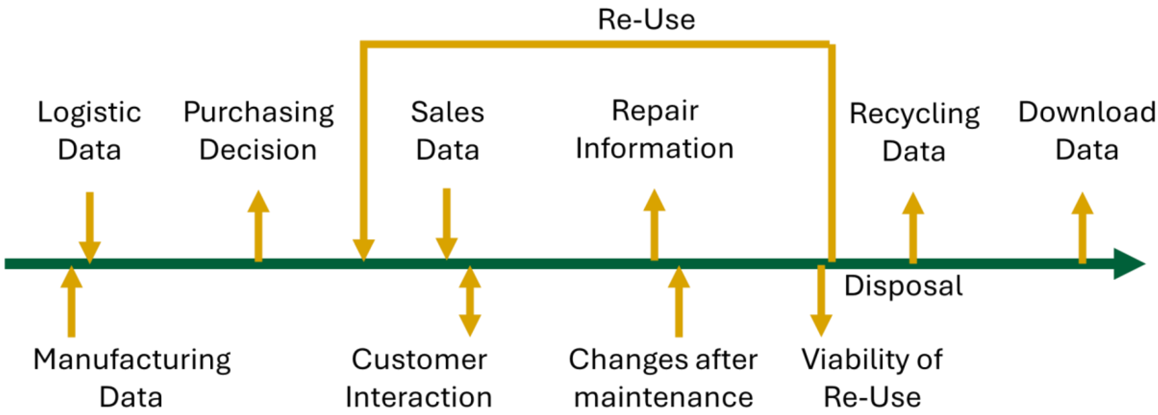


Figure 20: A diagram of the interactions during the lifecycle of a DPP.

7.2 STAKEHOLDERS IN LIFECYCLE

For the selection of key scenarios, the users of the DPP need to be extracted from the roadmap. The users that have been identified are:

- Manufacturer
- Company / Brand
- Prospective Customer
- Retailer
- Consumer
- Technician
- Recycling Contractor
- Waste Contractor
- DPP Agency

7.3 SELECTION OF KEY SCENARIOS

While creating prototypes and examples for each of the interactions identified would be best as all stakeholders would be able to understand their part in the functioning of a DPP, this is not feasible given the scope and timescales of the project. Therefore, key scenarios have been identified that provide a clear overview of the function of a DPP:

- Input of manufacturer data to the RFID tag
- Consumer reading of information
- Technician making changes during scheduled maintenance

- Consumer or Recycling Contractor reading data to determine life left

7.3.1 Input of Manufacturer data

Essentially the first step in the lifecycle of a DPP, the input of data into the passport is one of the most important interactions. This is because this data is likely to be used at almost all the following interactions. Additionally, by demonstrating how data can be input into the tag, the concept of the passport holding information about the product becomes clear.

7.3.2 Consumer reading

As the entire reason for iterating from the original prototype to the current Low-Tech concept was users requiring some form of visual elements on the passport, the interaction of a consumer reading information about their product from the passport has been deemed as another important step to prototype. Additionally, this step will be prototyped initially and subjected to user testing as consumers have the potential to make the DPP effective or not and therefore iterations to this prototype are vital.

7.3.3 Technician Updates

For more complex products that require technicians to service and maintain them, during the visits from the technicians they will be able to update both the physical and digital elements from the passport. This interaction has been chosen to show the power of a DPP in tracking data about a product during its usage which can then be used later in the lifecycle to inform critical decisions.

7.3.4 Determining Remaining Lifetime

In order to convey why the DPP has been introduced, the decision made at the end of a products life to keep it in circulation should also be prototyped. This will inspire the understanding that DPPs can have a great effect in reducing the products being disposed of as well as keeping working components in circulation for longer than they currently are.

8 Consumer Reading User Testing

8.1 Investigation of methods

In order to ensure that the user testing session is as beneficial as possible for the project, current Low-Tech methods of conveyance already in use today will be investigated and adapted. This is because they are likely to have already gone through a development and iteration process meaning their current form is the best way to convey information.

8.1.1 Printed Stickers

The first method that will be accessed are printed stickers. A great example of these used already are the Safety Seal stickers found on German number plates, shown in Figure 21.

Figure 21: An image of Safety Seal stickers found on vehicle license plates in Germany (CustomEuropeanPlates.com, 2024).

The left sticker indicates the region the car is registered to, while the right indicates when the safety inspection and emission test needs to be renewed. The regional sticker, or a sticker like it, is unlikely to be particularly useful in the case of the DPP as it only conveys one static piece of information that would not change through the lifetime. The secondary safety sticker could however be used in the context of a DPP as there is data that takes numerical forms that need updating throughout the life of products. Additionally, to withstand the high level of wear and tear that is likely to be experienced, the stickers are made from a Polyvinyl Chloride (PVC) material which is also resistant to UV-bleaching. As the DPP stickers need to withstand a lesser level of wear and tear, this PVC material should be suitable.

8.1.2 Write-on Stickers

A second method that will be considered are write-on stickers. These are more versatile than the printed stickers as they are not limited by how the stickers have been printed. An example of these are Electrical Safety stickers, Figure 22, often found on electrical devices especially across more public spaces like universities, schools and leisure centres.

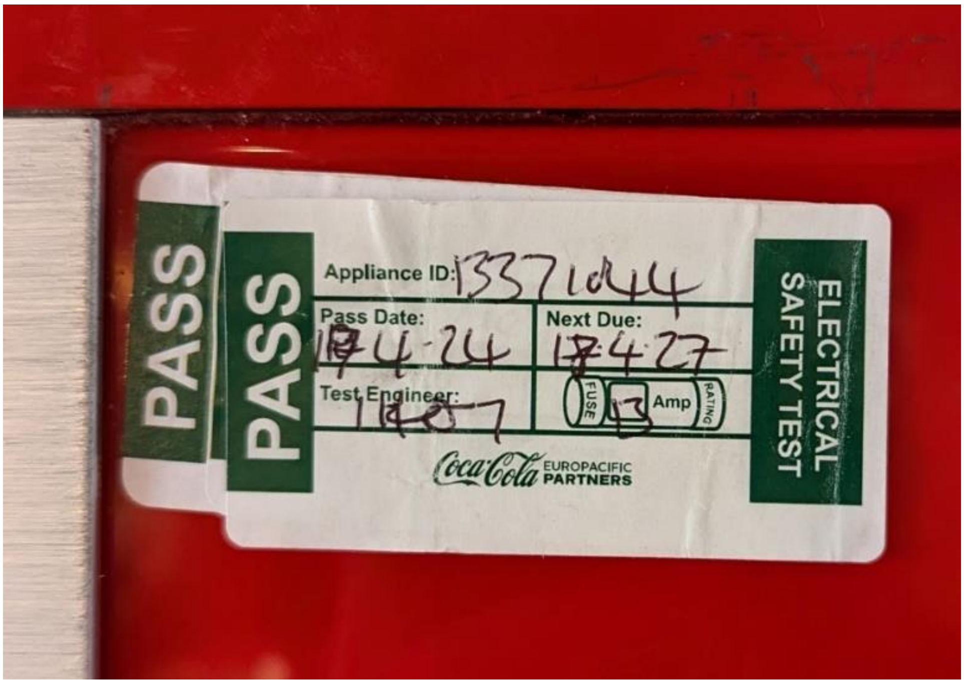


Figure 22: An image of write-on safety seals used for electrical devices in public spaces.

These could be used to convey any forms of data and potentially, depending on material, could be reused by simply wiping off what had already been written. Unfortunately however, the process of writing out data onto the stickers is more time consuming than having one already printed and could be harder to understand if different people update the passport in different ways.

8.1.3 Scratch-Off

The third method of conveying information in a Low-Tech way would be to used scratch off materials on-top of data that has already been printed. This would allow data to be updated by simply scratching off another section. A concept drawing for this is shown below in Figure 23.

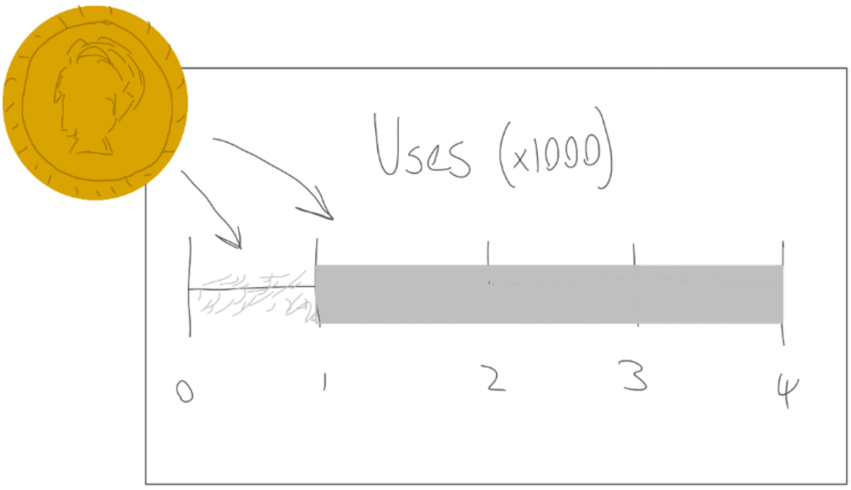


Figure 23: An image suggesting how scratch off technologies could be used in the DPP context.

While this is the easiest method for updating data there are a few downsides compared to the stickers. Firstly, the material that has been scratched off will cause a build-up and block the visibility of other elements of the DPP and secondly the area taken up will be a lot larger as all of the data for the life of the product needs to be there and covered by the scratch offs.

8.1.4 Fading Ink

And finally, in the tattoo world there is currently an ink under development that has the capability to fade over time. This time to fade is affected by the amount of ink used to create the images so this could be used to update data that is affected by time such as the age and length of warranty. A concept drawing for how this could be used in the context of a DPP is shown in Figure 24.

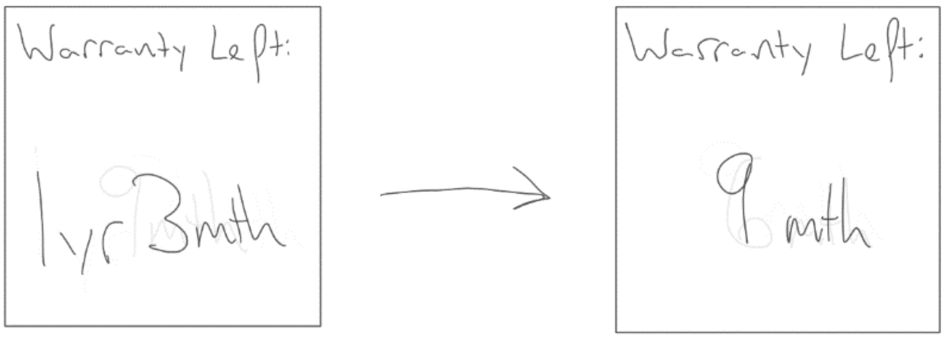


Figure 24: An image suggesting how fading ink could be used in the DPP context.

This however is an emerging technology and currently requires microorganisms that are found within the body to breakdown the ink. If this could be adapted to a DPP scenario it would likely be the most efficient way of conveying time related data.

8.2 Creation of Prototype and Test

8.2.1 Prototype

In order to assess the best methods for conveying the data a prototype needed to be created to show how these visual elements might look within the context they are expected to be in. Instead of creating a physical design for the whole product, only the DPP element was prototyped as shown by Figure 25. By prototyping it this way not only is it clearer how the visual elements will look within a DPP but also the concepts of a security box or pouch and methods to secure each can also be prototyped and tested.

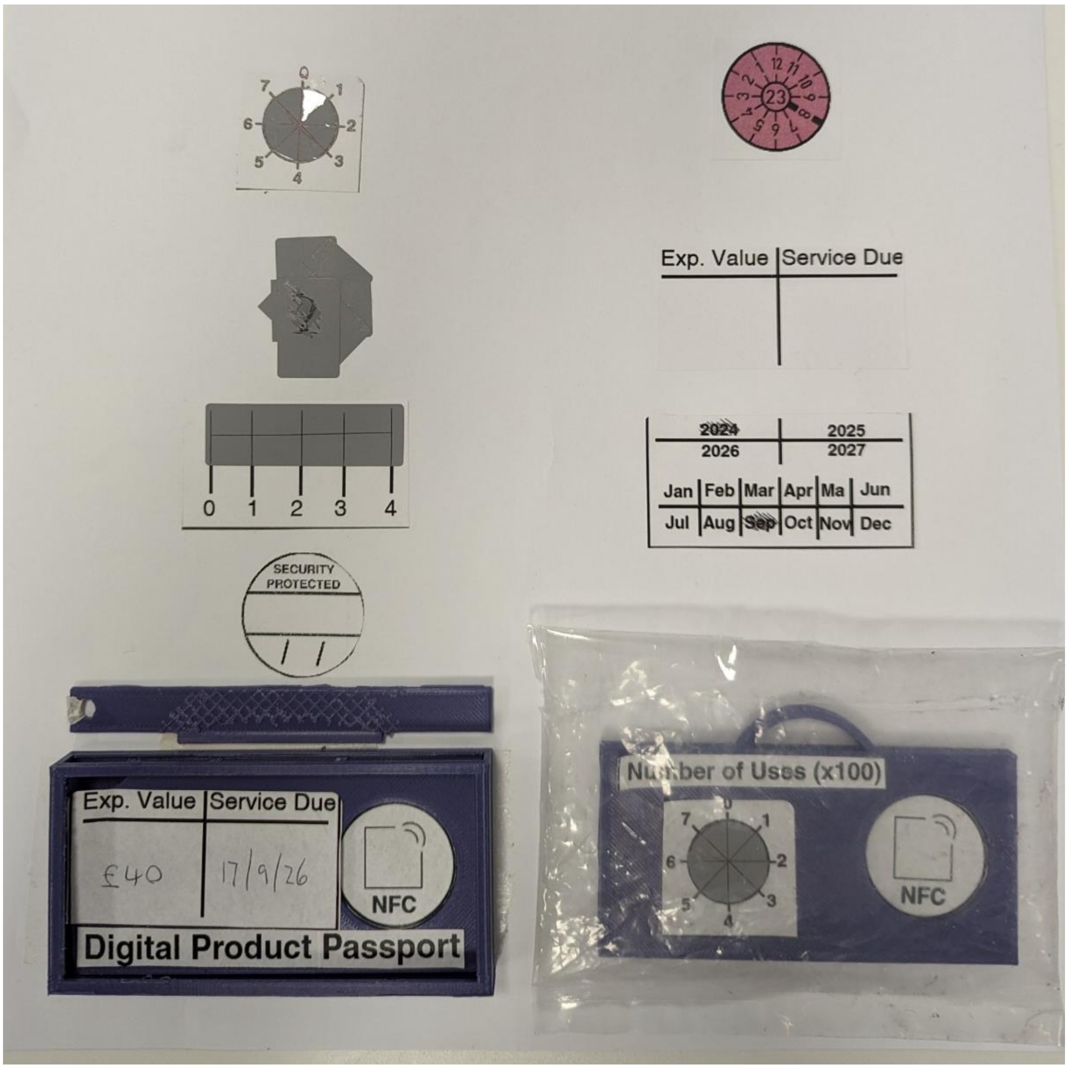


Figure 25: An image of the Low-Tech prototype elements used during the user testing session.

While security of users' data is not being considered, an integral part of the passport is the trust in the data held. Therefore, the security box and pouch are more to protect the data from wear and tear, especially the Low-Tech elements, and to act as an interface between the product and the passport than to keep the data secure.

8.2.2 Test

8.2.2.1 Extending user opinions

It was noted at this point during the project that the sample of participants that participated in the first session of user testing were predominantly comprised of young engineers, as seen in Figure 26. This could cause a bias in the results that were generated from the testing, especially in the case of choosing a concept that should be pursued.

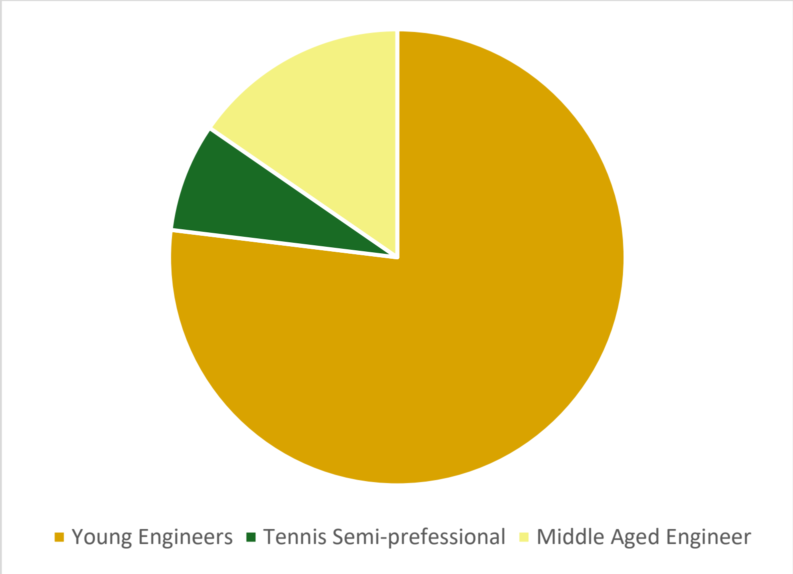


Figure 26: A chart demonstrating the demographic breakdown for the first user testing session.

For this reason, during this round of user testing, the demographic for the sampled participants will be expanded and those that are outside of the young engineer demographic and will be asked questions about the High- and Low-Tech concepts similarly to the end of the previous user testing session.

8.2.2.2 Questions

For this session of user testing, alongside some being asked about preferences regarding High- and Low-Tech concepts, participants will be shown multiple methods of conveying information in a Low-Tech manner as well as be asked to update the information contained on them. Participants will be asked which they felt conveyed information in the most understandable way, and which were the easiest to update. They will then be shown different options for protecting the passport, a box or a pouch, and asked how they feel about each and how they should be protected from tampering, either a key or security sticker.

8.3 Outcomes of User Testing

In this section just the main points that came up often will be talked about, a full breakdown of responses can be found in Appendix F.

8.3.1 Expanded Sampling

After expanding the demographic chosen for user testing and questioning new participants on what concept they preferred, Low- or High-Tech, a very clear conclusion can be drawn. The new participants that were outside of the original ‘young engineer’ demographic suggested in 4 out of 5 cases that they would also see the Low-Tech concept having more value and more usability than the High-Tech concept.

Overall this means that the percentage of participants asked that prefer the Low-Tech concept over the alternatives reaches 64.7%, depicted in Figure 27. This can be considered a significant proportion and therefore with certainty the Low-Tech option is the one that should be pursued.

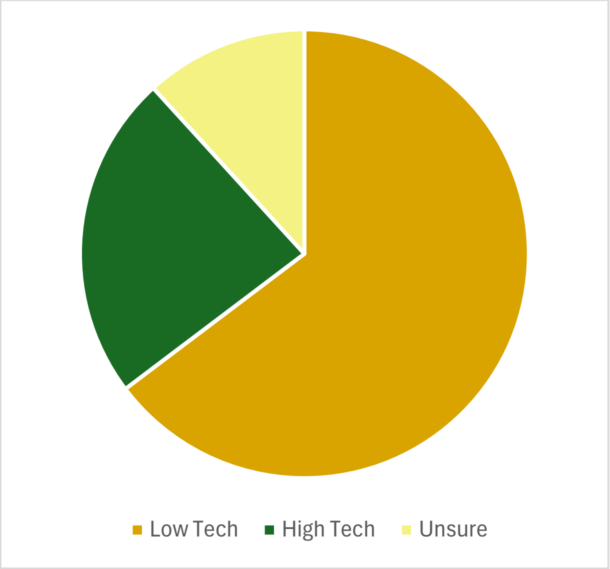


Figure 27: A chart depicting the user preferences for different versions of the DPP.

8.3.2 Method of Conveyance

When it came to the main focus for this user testing session, the conveyance of data in a Low-Tech manner, participants were more divided. There was a majority with 56.3% stating that simply the plain text option, seen in Figure 28, was the easiest to understand, followed by the numerical circle, similar to German safety sticker, which participants described as compact and efficient. There were a few votes for both the timeline and list but these are insignificant in comparison. When participants were asked to update each method and were then asked which was easiest it was applying stickers that came out on top with 50%. The fading ink idea was second and the scratch-off elements came up last.

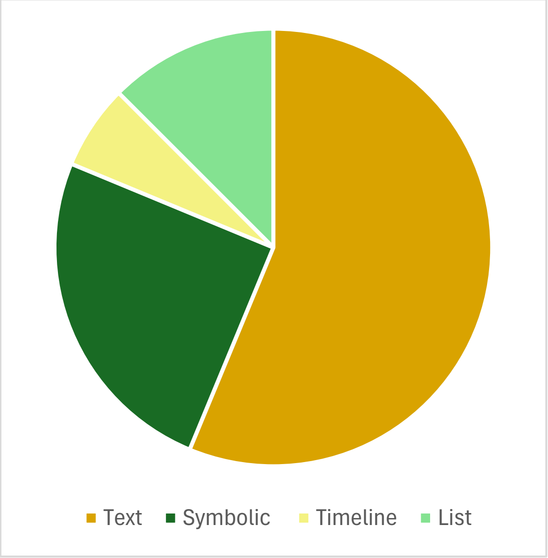


Figure 28: A chart revealing the user preferences for different Low-Tech information methods.

These tests show that simply presenting the data in a familiar way to users and in a way that needs no description is best. Additionally, the popularity of the fading ink is understandable as it is a completely hands-free process, however, the technology is not available yet for printer ink so is something that could be considered in the future were it to become reality.

8.3.3 Protection of Passport

In the next part of the testing participants were given two options in terms of protection of the passport, a box enclosure or a small pouch. 69% of users stated that they'd prefer a box as, not only is it more protective, but it could also be integrated into the design of the product. However, there were complaints about the box being too bulky from not only those that chose the pouch but also some participants that chose the box. The box, Figure 29, will therefore be taken forwards but with a potential iteration with a view to reduce the size and bulkiness.

Figure 29: A render of the box used to protect the passport.

8.3.4 Security of Passport

The final section of the user testing session was to assess how potential DPP users may want to keep the data secure, either by key or sticker. A large majority chose the sticker as not only is the key more effort to use but participants felt that a tamper sticker would be suitable for the purpose. As mentioned already in this report, the actual security of users data is not being considered for this project, therefore this test was to inform the choices that could be made were data security to be considered in the future.

9 Detailed Design

9.1 Design of RFID Interface

9.1.1 Functionality

After asking users to interact with RFID tags in the first user testing session there were points mentioned that generated insights for how the reading and writing to tags could be improved:

- Clearer instructions on what to do and when
- Scale the complexity of interaction with user
- A Graphical User Interface (GUI) would be clearer
- Feedback on what is going on

The entire code for the interface can be found in Appendix G.

9.1.1.1 GUI

The first iteration to be employed was implementing a GUI, seen in Figure 30. This not only made it clearer and easier for the user to navigate the process of reading and writing but also kept all functions in one place. Figure 31 shows how the original program ran and how the GUI improves the reading and writing experience for the user by reducing the number of actions they need to complete.

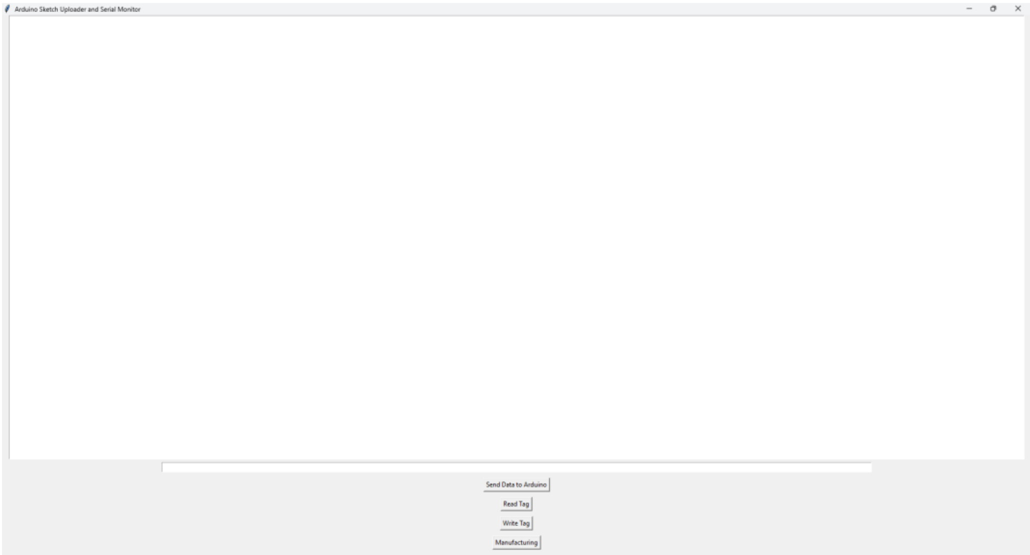


Figure 30: An image of the GUI in a standby state.

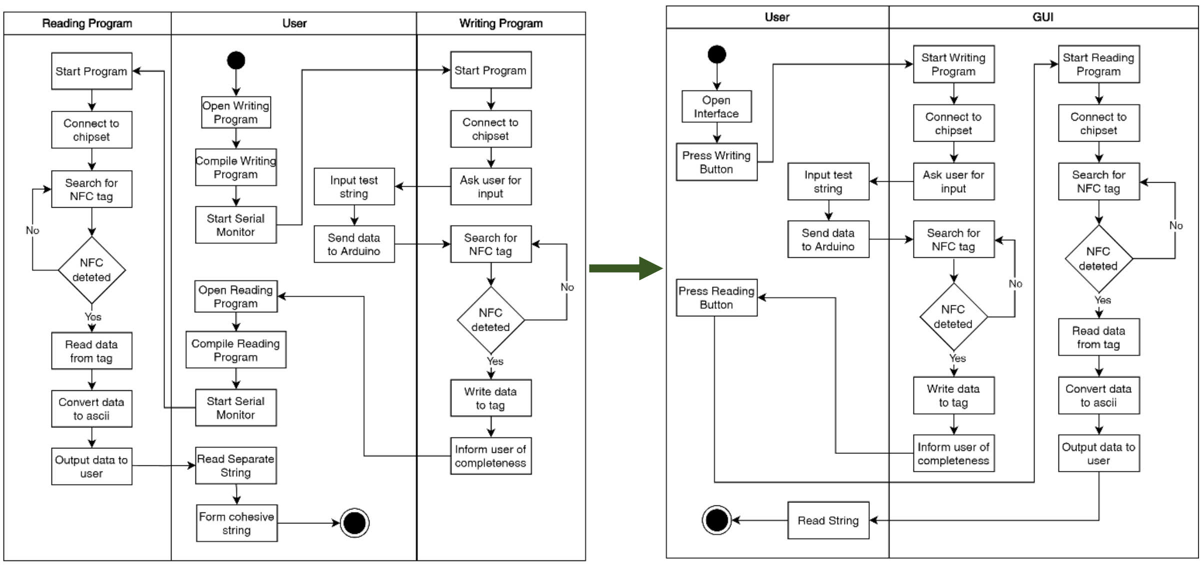


Figure 31: A comparison of swimlane diagrams where the left diagram is before the GUI and the right is after.

The GUI works by uploading an Arduino Sketch to the device and then monitoring the serial output which it then displays in the large text box in the centre. One issue that was overcome during the development of the GUI was that the serial output from the Arduino cannot be monitored alongside sending data to the Arduino along the same serial port. Therefore, the monitoring of the output from the Arduino is paused briefly to allow the data to be sent then is restarted. While this solution works it is not necessarily perfect as outputs from the Arduino could be missed while the monitoring restarts, with the technology on hand this appears to be the best solution.

9.1.1.2 Scaling Complexity to User

Secondly, in order to ensure that the RFID technology will be adequate for all stakeholders in the DPP value chain the individual interactions need to be adapted to the required complexities. A separate program for the upload of manufacturing data was created, its functionality shown in Figure 32. This was done as it is unlikely that the manufacturer will need to or have the time to input custom data or check that the tags are being written. Therefore, the program refreshes faster and can write to more passports is an equivalent length of time.

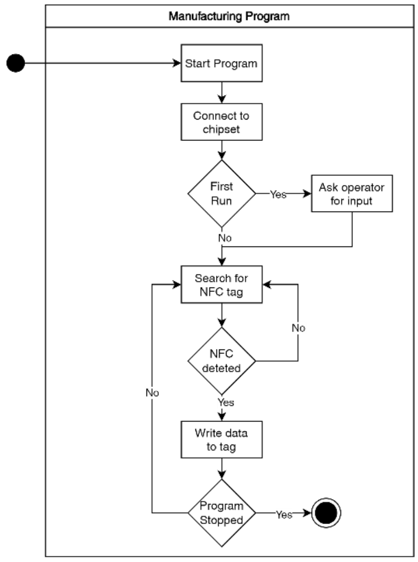


Figure 32: A swimlane diagram explaining the functionality of the manufacturing version of the passport writing program.

Additionally, the needs of a technician or recycling contractor and the consumer of the product are very different. The consumer is likely only interested in certain sections of the data whereas the other stakeholders could be wanting to access any sections of the data as well as the processing of the data. Therefore, the existing program that displays all information regarding the authentication and reading and writing of each block can be used by technicians and a simplified program was designed that only displays to the user the data on the tag and clear instructions.

9.1.1.3 Clearer Instructions and Feedback

On the topic of clear instructions, in the user testing session, many users mentioned that it was hard to tell what was going on and what they should be doing. This cause not only confusion for them but also meant that the reading and writing of data failed in a few instances. In order to rectify this the outputs were simplified so that only the most recent line appeared, or most important lines appeared when the user needed them. Figure 33 shows the difference this can make for the users understanding.

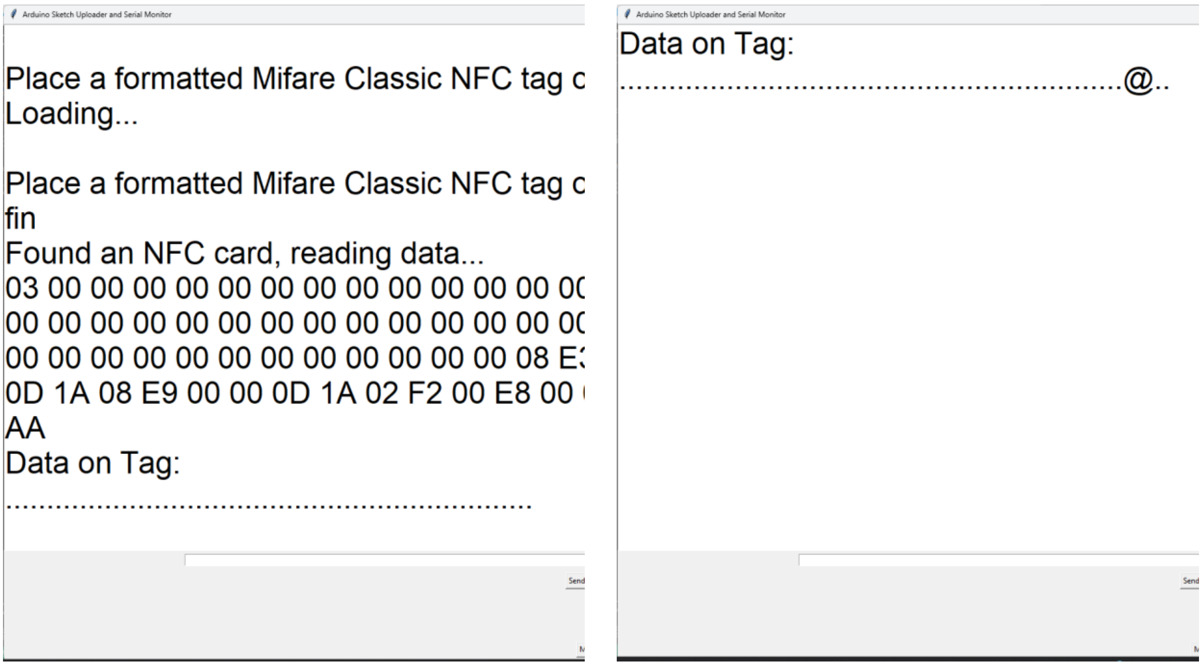


Figure 33: A comparison between showing all the data, left, and showing just important data, right.

9.1.2 Layout

While arguably the functionality of the interface is the most important part, the interface should also be laid out in an easy to navigate and pleasing manner to ensure that users are happy to keep coming back to use it (Diehl et al., 2022).

Firstly, the interface was kept monotone in colour to ensure that users are not distracted by or drawn to certain areas of the interface (Diehl et al., 2022). This is especially important for stakeholders that do not interact with DPPs often as, due to the speed of information transfer, some of the instructions flash up on the screen very quickly then disappear. Secondly, all the buttons were placed close together and are always visible to ensure that it is easy to switch between programs should a user need to write to the tag then read it in quick succession. Finally, for the more simplified, consumer oriented, version of the program the size of the text was increased to allow for easier reading at a glance, this is seen in Figure 34. This was made possible as only a small amount of text is ever displayed in the box.

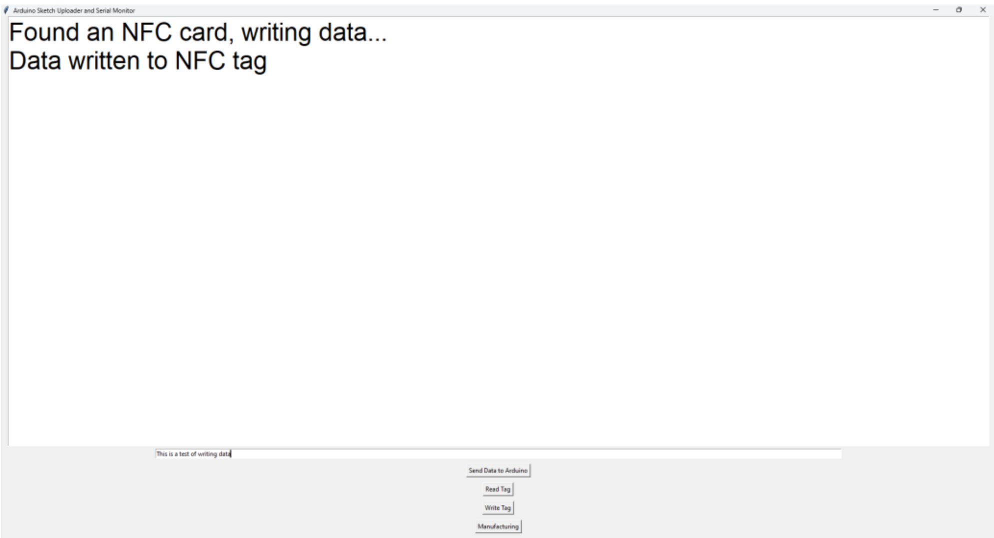


Figure 34: A screenshot of the GUI outputting feedback to the user.

9.2 Design of Final prototype

9.2.1 Design Iteration

9.2.1.1 Box

As stated in the second user testing summary, the box needs to be iterated upon to reduce it's 'bulkiness'. The method for this iteration was using the TRIZ technical contradiction matrix (TRIZ40, 2024). For this example, the strength and durability of the product was kept the same and the volume of the concept was the feature to improve. This gave 4 potential routes for iteration: Preliminary anti-action, Spheroidaility, Another dimension, and Dynamics. Both Sphereoidality and Dynamics can be ruled out instantly as a spherical shape would reduce the flat surface areas for displaying information and sticking to the product, and making the passport dynamic would detract from its Low-Tech goals. Preliminary anti-action is potentially applicable when it comes to the information contained in the passport but is not relevant at this stage leaving only 'another dimension'.

Currently the functionality of the passport can be considered to be operating in two dimensions, both in the representation of data as well as in the access of the insert. These dimensions are represented in Figure 35.

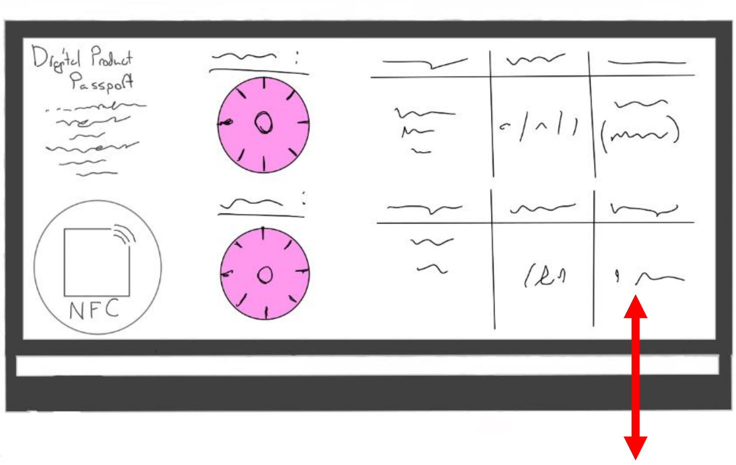


Figure 35: An image depicting how the current insert is inserted and removed.

The dimension that has been chosen to be introduced is a further dimension in the access of the insert, depicted by the green arrow in Figure 36. This has been chosen as the current reason for the concept being so bulky is so that a door and hinges can be placed allowing access and security for the insert.

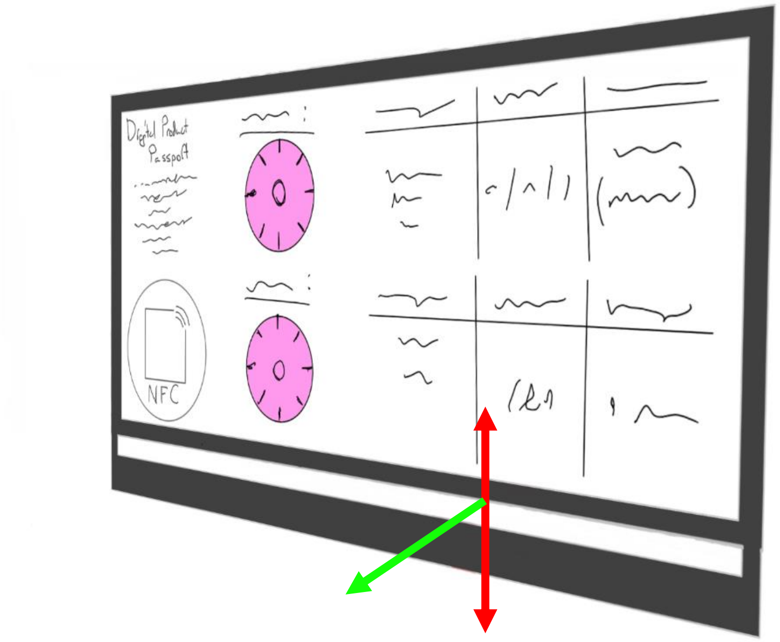


Figure 36: An image depicting how an extra dimension can be introduced to the design.

The way this third dimension has been introduced is by incorporating a slit-style opening that can be pulled out to gain access but returns to a closed position when not experiencing any external forces. This concept, Figure 37, will now be designed in detail with a focus on sticking to the requirements set out by the specification.

Figure 37: A render of the final box design.

9.2.1.2 RFID Tag

Additionally, it was noted during testing of the updated GUI that the RFID tags struggled to be picked up when placed upon a metal surface. This is due to the metal interfering with the electromagnetic signals generated by the RFID antenna and tag. This would mean that the current design would only be able to be placed on a product with a plastic exterior, limiting it's potential consumer base. Therefore, for the final concept an anti-metal RFID tag should be used as these generate stronger signals that the metal surfaces would not affect.

9.2.2 Assumptions

In order to design the passport, there are some assumptions that need to be made about the concept and the concepts it is based upon.

9.2.2.1 Surface Area of Passport

While the volume of the passport was drastically reduced after the TRIZ analysis, the surface area that the passport occupies on the surface of the product it is placed on will remain the same at 155mm x 80mm (l x h). This is to ensure that the right balance is stuck between amount of data displayed on the passport and the space taken up by the passport.

9.2.2.2 Curvature

As the passport should be applied to a variety of products it should be able to withstand being placed on a curved surface of a product. The most extreme example of a curved surface on small electromechanical products has been assumed as the surface of a kettle as typically this is a single circular curved surface. After taking measurements from a selection of kettles it was found that the smallest had a diameter of 155mm. The passport therefore should be able to be placed on a product that has curved surfaces of radius 77.5mm or greater. The full list of measurements can be found in Appendix H.

9.2.2.3 Adhesion to Product

The adhesion of the passport to the product it is related to will be considered outside of the scope of the project and this can be something for the manufacturer to worry about as different adhesives are likely to be needed depending on the material and shape of the surface the passport is being applied to. For the prototype a double-sided tape will be used as this will be suitable for the materials of the prototype components and the radius it is being placed on.

9.2.3 Opening

In order to ensure that a one size fits all approach would be suitable for the insert opening some physical testing needed to take place. An iterative approach was taken to the design of this opening, with the radius of the opening being the variable of change. Testing took place at both flat and curved positions initially, however it was found that, even at the smallest openings, on a flat surface access was easy so only curved testing was necessary, shown in Figure 38. After multiple iterations it was found that an opening with a radius of 500mm was optimal as not only did it allow easy access on both flat and curved surfaces but also held the insert in place and cut back on material usage. This reduction in material usage not only benefits the passport by not sticking out as much but also will reduce the carbon and energy required to create the passport.

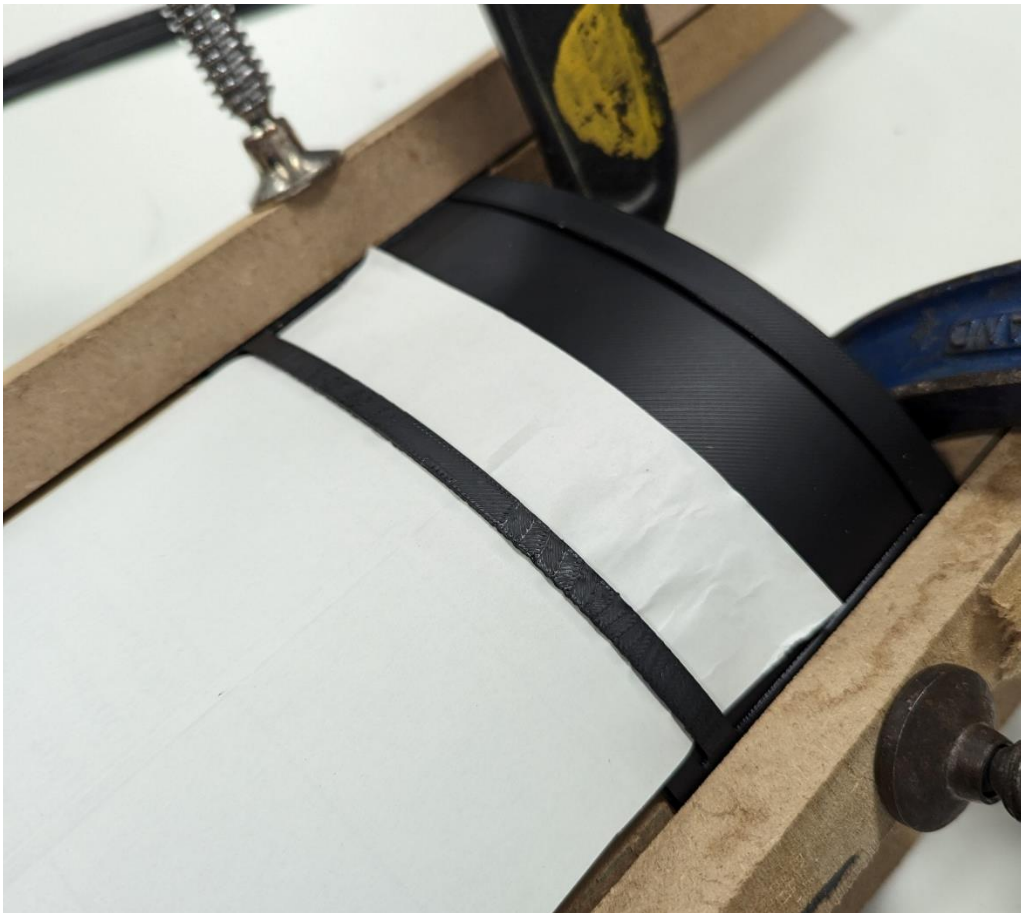


Figure 38: An image of physical testing performed on opening of box.

9.2.4 Finite Element Analysis (FEA)

9.2.4.1 Method

In order to find the maximum bending stress the passport will encounter FEA was used. The setup, as shown in Figure 39, was used where the passport has been fixed in place at the sides and a cylinder with diameter 155mm was placed behind it ready the passport to be bent around it.

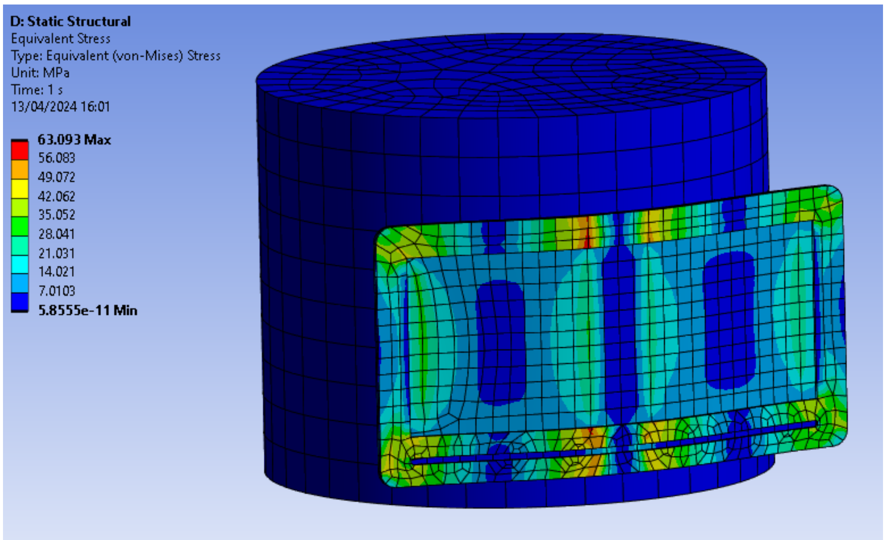


Figure 39: An image of an FEA setup used to calculate stress in the passport.

The sides of the passport can be fixed in place without affecting the output from the analysis as when a cantilever object is in bending, it experiences the greatest moment at the fixed end, depicted in Figure 40 (Gregory et al., 1982). This can be translated to the passport bending around the cylinder as the passport can be treated as two cantilever objects connected at the centre. Therefore, the greatest stresses will be experienced near the centre of the passport allowing the sides to be fixed.

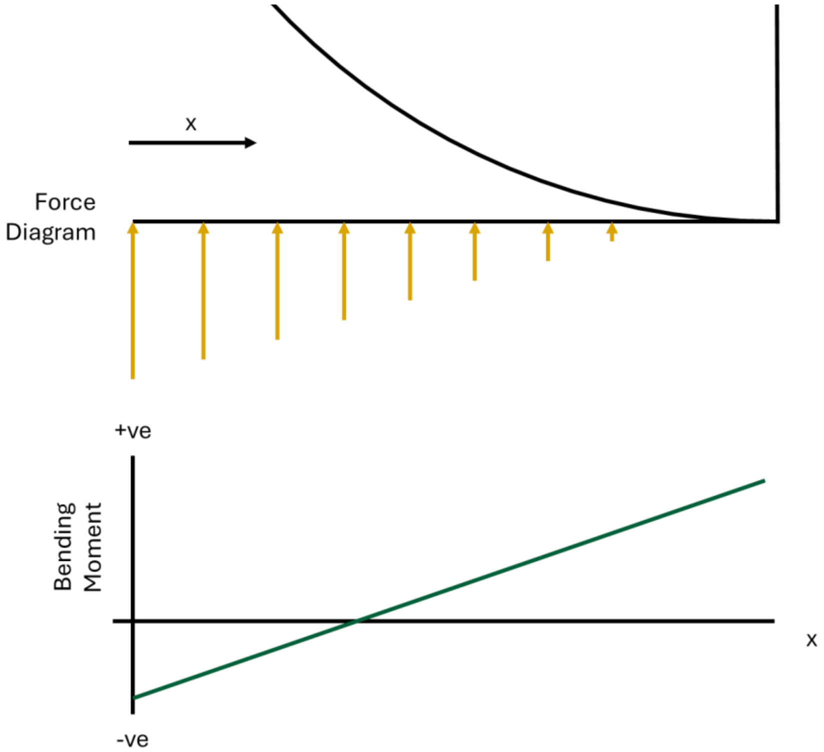


Figure 40: A diagram explaining how bending moment varies along the length of the passport.

9.2.4.2 Analysis

Firstly, the deflection that the cylinder will be pushed into the passport by needs to be calculated. This can be done using the equation of a circle and by calculating the arc angle, Equation 1. The angle of the arc can be calculated by setting the angles against the lengths along the circumference.

$$\frac{\theta}{360} = \frac{77.5}{2\pi r}$$

$$\theta = \frac{77.5*360}{2*\pi*77.5} = 57.3° \quad [1]$$

This angle, along with the equation of a circle can be used to calculate deflection as shown in Figure 41 and Equation 2.

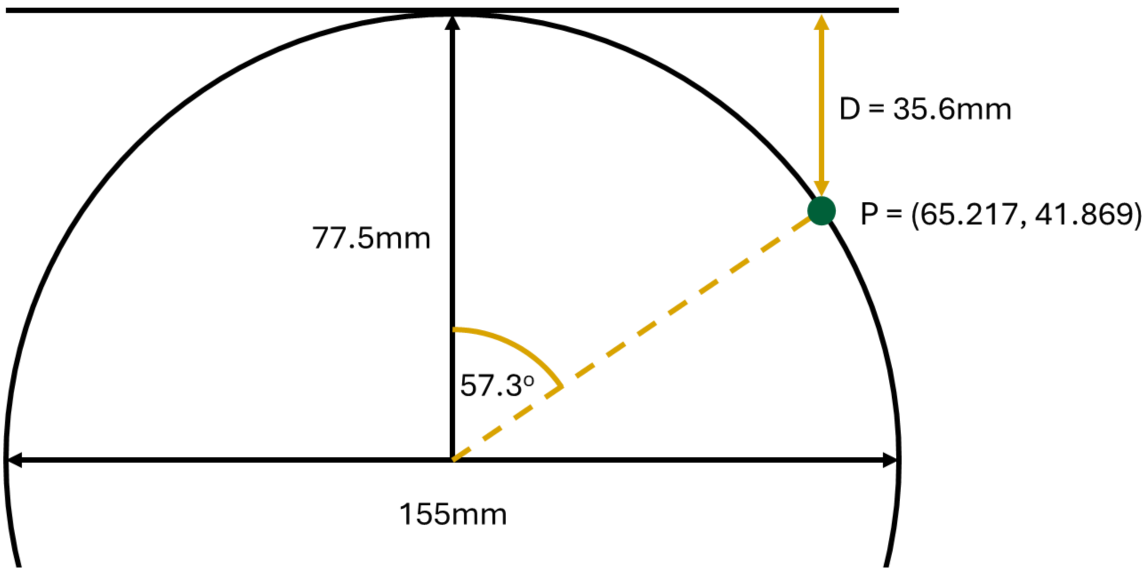


Figure 41: A diagram depicting how the deflection is calculated.

$$P(x_P, y_P) = (r \times \sin\theta\,, r \times \cos\theta)$$

$$P(x_P, y_P) = (65.217, 41.869)$$

$$D = 77.5 - 41.869 = 35.6 \qquad [2]$$

After this was found, the FEA workspace was set up and the mesh element size was initially set automatically to 20mm. This resulted in a mesh that looked like the one in Figure 42. After analysis, like Figure 39, it was found that the deflection experienced was 36.087mm and the stress 86.307MPa. The deflection experienced here is more than expected so a mesh convergence needed to be completed.

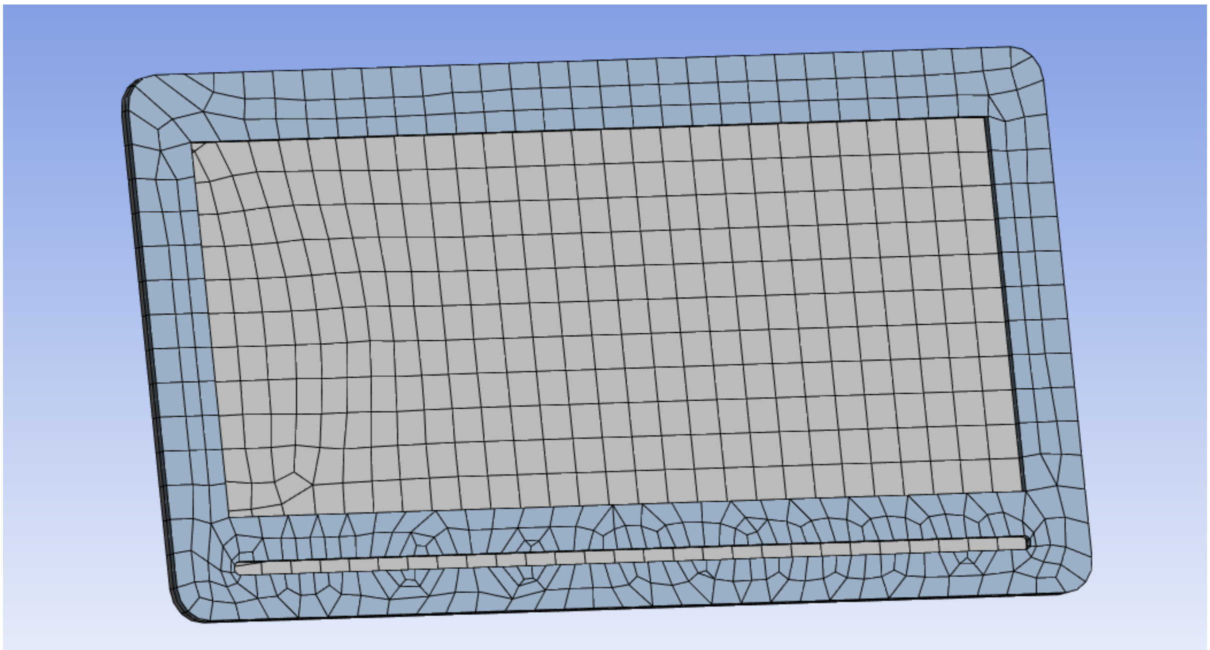


Figure 42: An image of the mesh created for the passport model.

9.2.4.3 Convergence

A mesh convergence optimises the model to give the best possible results. As a mesh size of 20mm resulted in a deflection that was larger by quite a margin, the next analysis was using a mesh size of 10mm. This was then repeated, reducing the mesh size by 1mm each time, until it reached 1mm. After 1mm it was then reduced by 0.1mm each time until it reached 0.5mm. This data can be found in Appendix I and is depicted in Figures 43 and 44, where the X-axis is the number of elements that increases non-linearly with the decreasing mesh size.

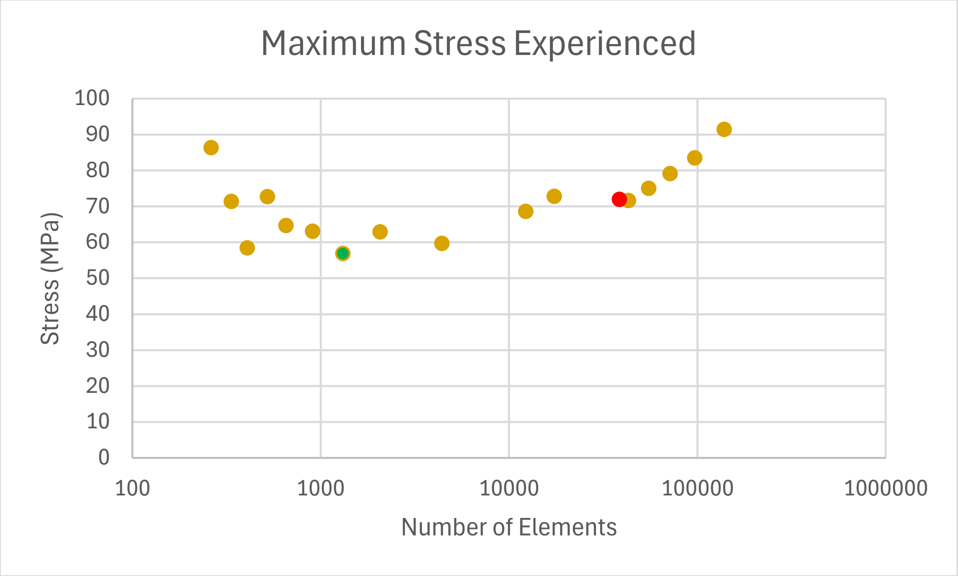


Figure 43: A chart depicting the maximum stress experienced as it varies with mesh size.

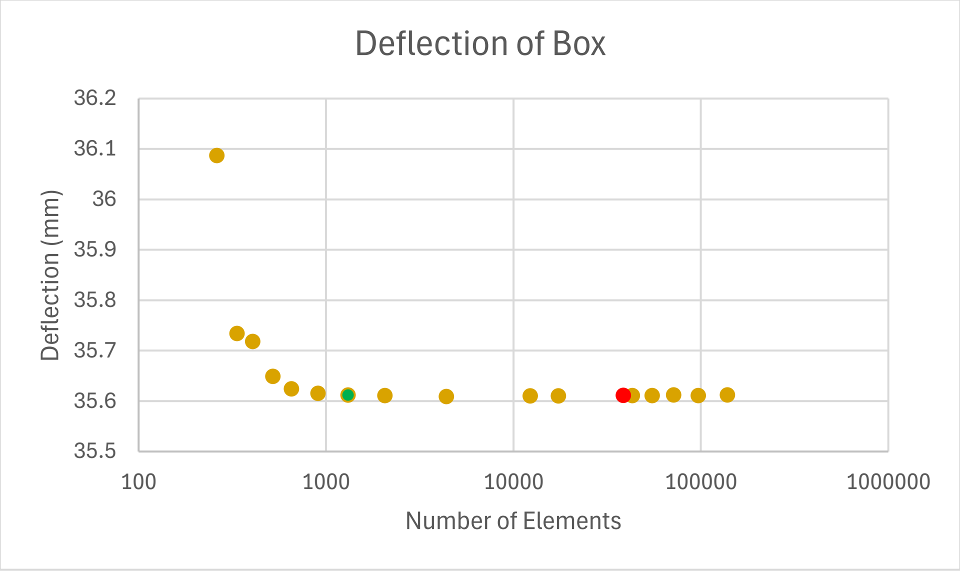


Figure 44: A chart depicting the deflection of the passport as it varies with mesh size.

The deflection chart highlights a convergence as the mesh size was decreased, especially past 5mm, shown by the green point. As the stress chart seems most stable around the mesh sizes of 0.9mm and 1mm, for the final stress analysis seen in Figure 45 and 46, a mesh size of 0.95mm was used. This gave a maximum stress of 71.93MPa and a deflection of 35.61mm, shown with the red point in the charts above.

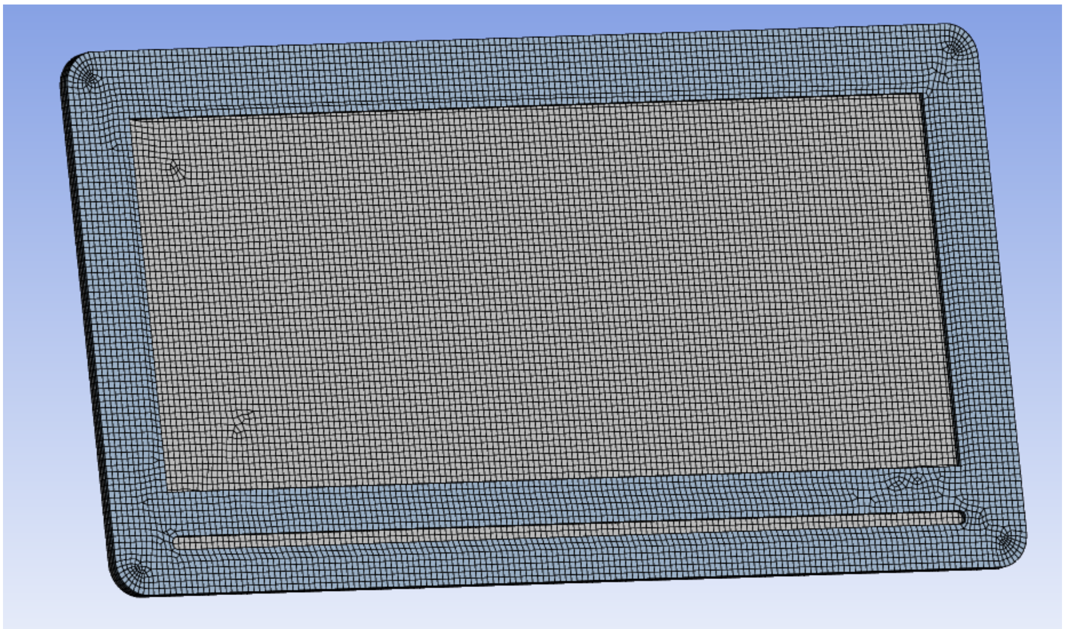


Figure 45: An image of the mesh created for the passport model using a mesh size of 0.95mm.

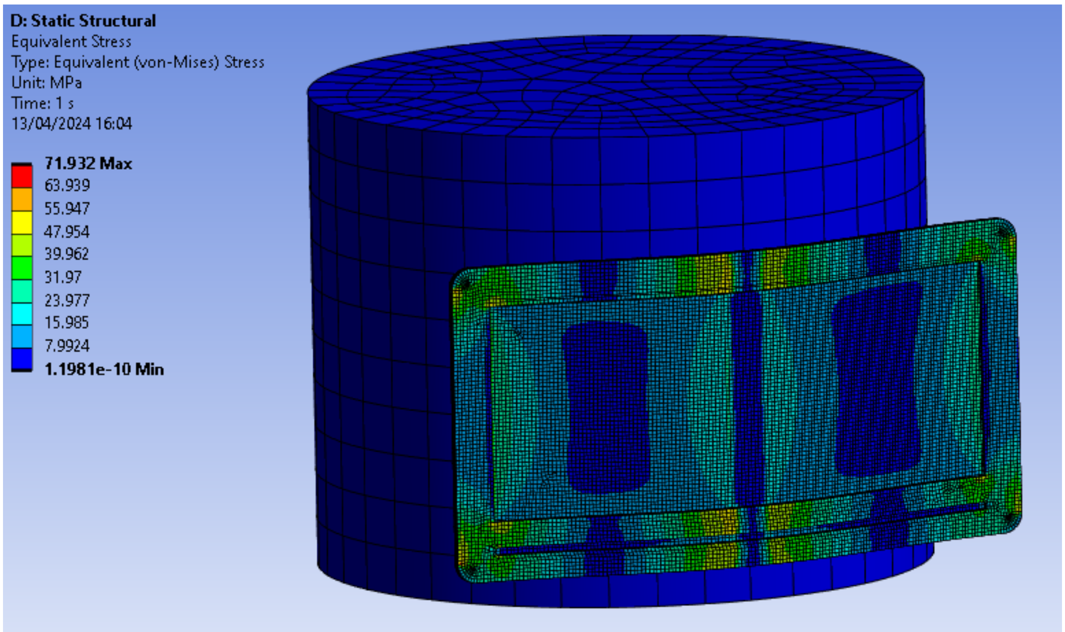


Figure 46: An image of FEA analysis of the passport using a mesh size of 0.95mm.

9.2.5 Materials

To create an accurate Eco-Audit, and ensure the final concept is as complete as possible, the materials for each component need to be decided. There are 3 main components to the updated box design: The casing, the insert, and the clear screen. This excludes the stickers that will be used to display information, however the material for these have already been chosen to be PVC in Section 8.1.1.

Initially, certain material groups were excluded such as chipboard and metal. Chipboard was excluded due to its potential to absorb moisture and deform, with metal being excluded due to added weight and increased cost when compared with alternatives. There is scope for metal being considered if the product is deemed to be premium in build and style.

After this, materials were chosen based on their wide availability and recycling capabilities. The materials that will be considered for each section are shown in Table 3 and will then be narrowed down to select final materials.

Table 3: A table containing materials that could be used for each component.

Case	Insert	Screen
ABS	ABS	Acrylic
Polycarbonate (PC)	Polycarbonate	Polyhydroxyalkanoate (PHA)
Thermoplastic Polyurethane (TPU)	Thermoplastic Polyurethane	High-Density Polyethylene
High-Density Polyethylene (HDPE)	High-Density Polyethylene	Low-Density Polyethylene
Low-Density Polyethylene (LDPE)	Low-Density Polyethylene	

9.2.5.1 Case and Insert

As the case and insert are performing very similar functions and can be manufactured in the same way they can be made from the same material. There were two main constraints when it came to selecting between the options for these components: The maximum bending stress, and the service temperature. The bending stress that the parts are likely to experience was calculated using the FEA to be 71.93MPa. This constraint limits the material choices down to ABS, HDPE and LDPE. By adding the constraint of a service temperature of 95degC, the maximum temperature experienced on the exterior surface of a single walled kettle, HDPE can be selected as the sole material for both the casing and the insert.

9.2.5.2 Screen

While not a screen in the electronic sense, the screen will need to satisfy the same constraints of bending stress and service temperature. The bending stress constraint limits the material choices to clear Acrylics and the same polyethylenes (HDPE and LDPE). The service temperature however does not narrow this list down any more, so a further constraint is required. This constraint was the hardness of the material as the more scratches it can withstand the longer a passport can be considered serviceable and more importantly readable by the consumer. This led to Acrylic being chosen as the material for the screen.

9.2.6 Eco-Audit

With all the materials now chosen, a detailed Eco-Audit of the final concept can be completed. There were a few assumptions that must be made that allowed the required data to be collected and calculated:

- The transportation was not considered due to there being no way to predict where the passports may be manufactured, applied to products, where these products are shipped, and where they end up being used.
- The usage was taken into account and was based on one interaction with the RFID tag per month for a 20 year lifetime.
- The energy and carbon generated from the usage phase will be based upon UK figures for power generation (ESO, 2024).

Figures 47 and 48 depict the Embodied Energy and Carbon Emissions of the a 20 year lifetime for a passport. The relationship between Material, Processing and Recycling is very similar across both charts, however, the in the usage phase the carbon appears to be greater relatively in comparison to the energy. This is likely due to the choice of UK power generation emissions which is still dependent on non-renewable sources but is likely to reduce as the transition to renewables progresses. For a more in-depth breakdown of the Eco-Audit see Appendix J.

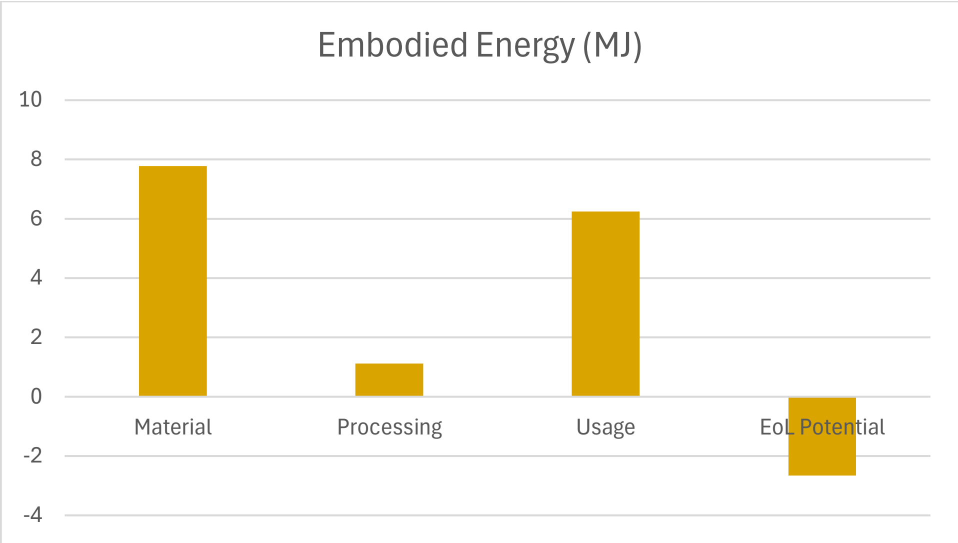


Figure 47: A chart of the Embodied Energy at each stage of life for the final prototype.

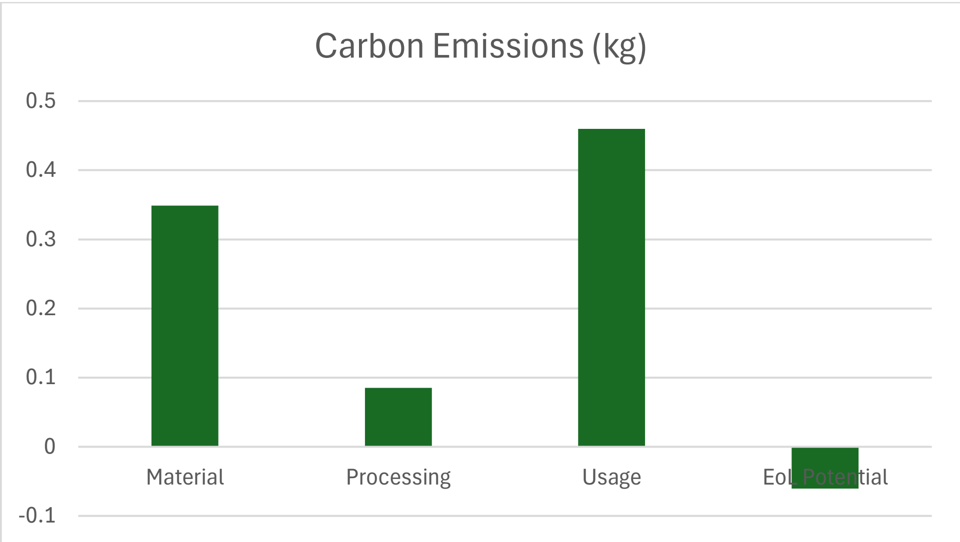


Figure 48: A chart of the Carbon Emissions at each stage of life for the final prototype.

10 Reflection

10.1 Solution Specification

With the final concept completed, it should be validated against the design specification created towards the end of last semester and main goals for the project. However, due to the big changes in design direction there are many points in the design specification that are no longer valid. Therefore, this section acts as a solution specification comparing the final prototype against some of the important requirements that are still valid. Figure 49 visualises some of these.

Cost is a big factor in the implementation of new technologies and procedures and that is why a requirement was set for the passport to cost a maximum of £4. The calculated cost per unit for the final prototype is £0.43, cost breakdown in Appendix K, and therefore satisfies this requirement, even with the added cost of including high-capacity anti-metal NFC tags. There will be added costs in the implementation of equipment on supply lines and elsewhere in the value chain but due to these being relatively in-expensive, possible within the project budget of £250, and the numbers of DPPs they could potentially process, the cost per unit tends to almost zero.

The capacity of data is also an important factor as, depending on the product, there are many factors that can be tracked. For the final prototype a high-capacity tag with 64kB has been specified as this should allow for an increased volume of data to be stored.

The other main goal of the concept is to convey information easily to users. For the requirement set in the specification this ease of understanding was based upon how quickly the stakeholder can complete their interaction. For both reading and writing to the tag the maximum transfer time recorded was 310ms, with the entire writing-to-tag process taking on average 8.7 seconds. Therefore, the final concept adheres to the overarching goal of conveying information easily as well as the requirement of having interactions be less than 10 seconds in length.

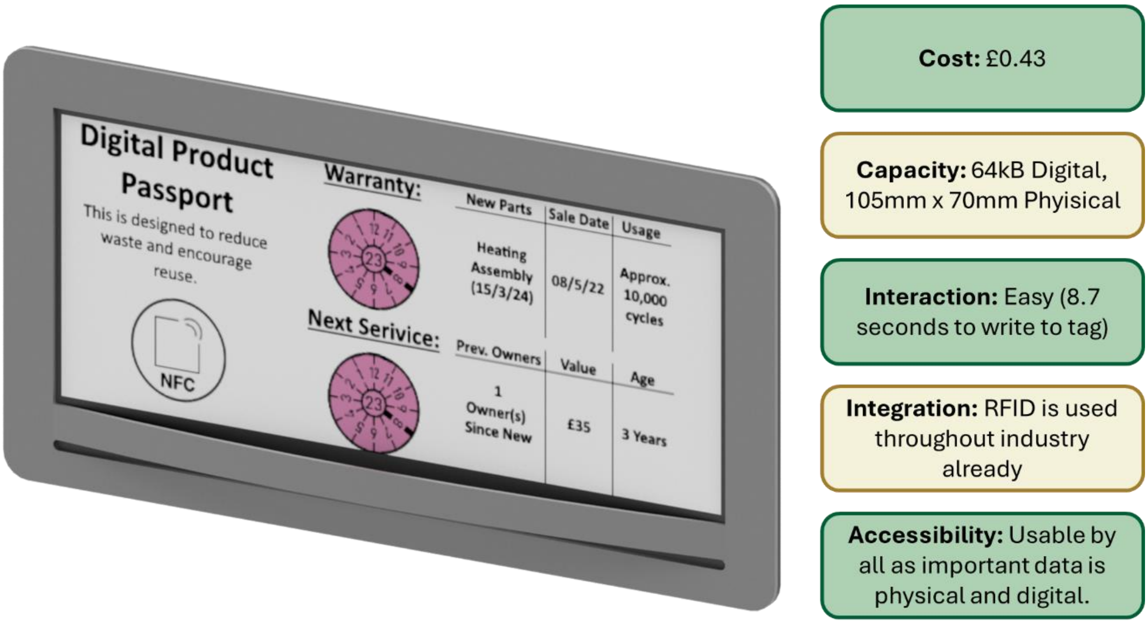


Figure 49: A render of the final passport concept alongside important specification points it meets.

10.2 Evaluation of Viability

As explained in the introduction, DPPs have been introduced as part of a plan to create a more circular economy and therefore should not be contributing further to emissions than it saves. To ensure this is the case, the Eco-Audit completed for the final concept was compared to that of a toaster, the simplest product within the bounds set for small electromechanical devices. Figure 50 represents the Eco-Audit for the final concept and Figure 51 represents one for a simple toaster purchased from Argos (Lo, 2015).

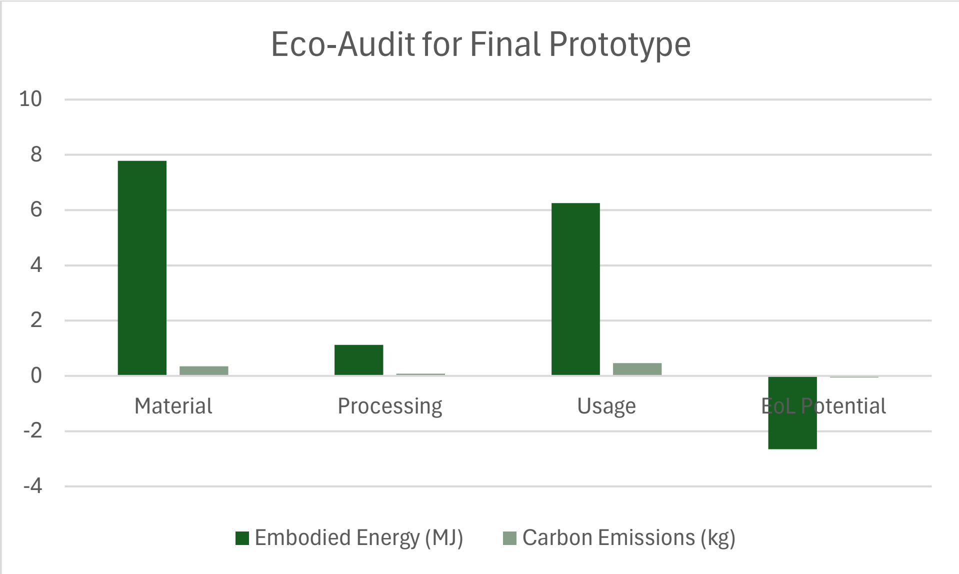


Figure 50: A chart of the Eco-Audit for the final prototype.

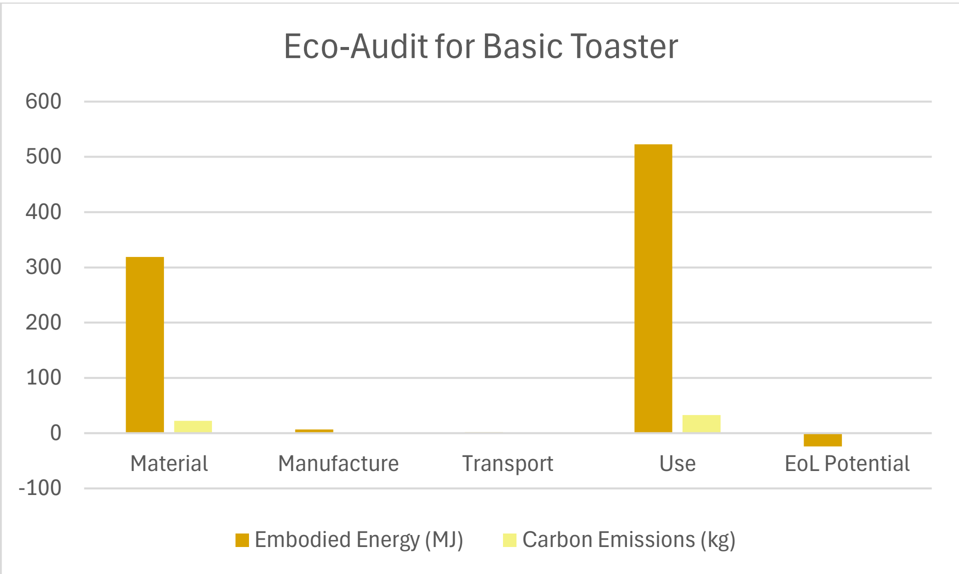


Figure 51: A chart of the Eco-Audit for a Basic Toaster from Argos.

As can be seen the DPPs embodied energy and carbon emissions are less than 1% that of the toaster meaning that its added effect on creating E-waste is negligible. Additionally, the EoL potential for the toaster is 24MJ and 1.08kg of energy and carbon respectively, greater than the energy and carbon of the passport. Therefore, assuming that the passport allows for near to full recyclability of the product, the concept fulfils another of its main goals of reducing waste more than it is contributing.

10.3 Effects on wider value chain

Some of the wider benefits of the DPP across the entire value chain for a product are:

- Assisting in manufacturing – As the DPP helps recycle materials and recover useful components, providing that they are managed correctly, manufacturers should be able to make savings in their production of new products.
- User Care – The passport encourages and helps users to take care of their products more effectively as users will be able to scan the tag and find information on how to keep their product maintained as well as how to properly fix is should a component break or stop working.
- Eco-Thinking – Due to the passport being visibly stuck onto many devices people interact with in the modern world, it is likely that it will encourage more environmental thinking during everyday life.
- Retailers – The ability to find information about product quickly could help second-hand retailers can provide validation relating to the history of the product as well as help first-hand retailers make sales.

10.4 Comparison against eco-conscious solutions

Throughout semester 2 the design direction shifted from creating a High-Tech passport to a more Low-Tech passport. This was a critical decision, so the final prototype needs to be compared against alternatives to ensure the correct choice was made.

While a DPP passport is one method for reducing waste and encouraging environmental thinking there are other methods. One example is using additional technology to reduce the impact of the use phase of a product such as eco-kettles and eco-toasters. These products typically offer eco-credentials like “up to 40% energy savings” and “better for the environment” (Haier, 2024). In order to understand these products better a component decomposition took place of the smart kettle, results in Figure 52.

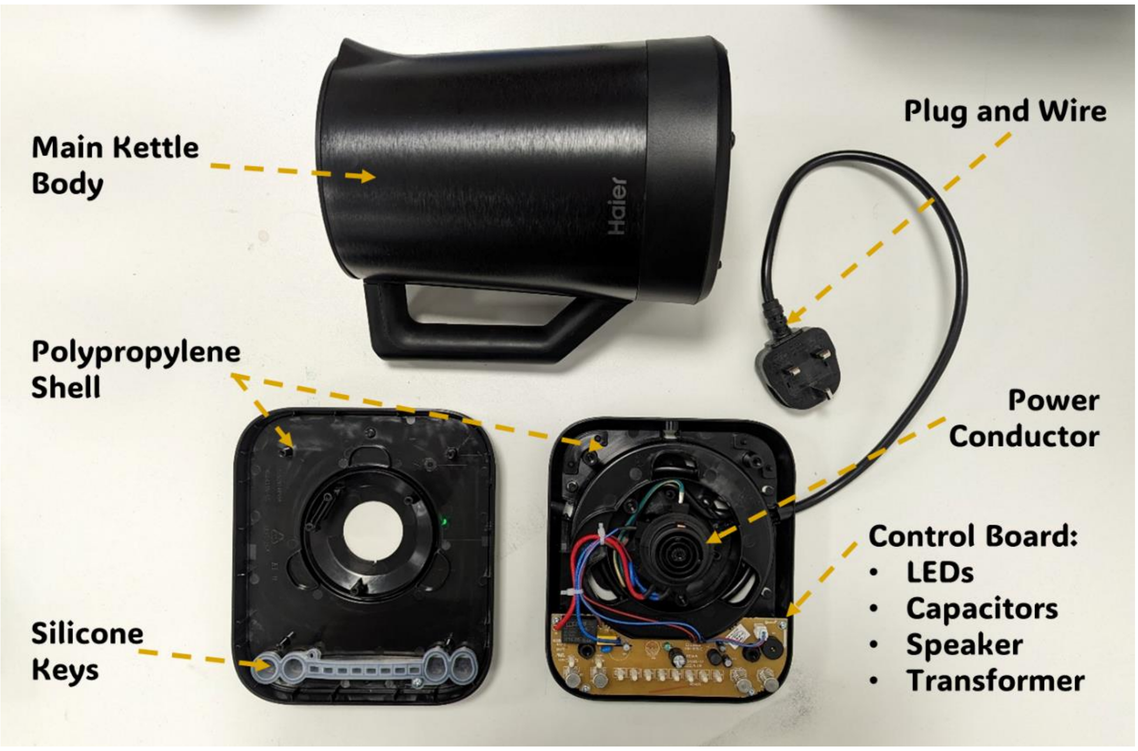


Figure 52: A component decomposition of the smart kettle.

As can be seen, these products are a good representation of what the High-Tech passport might have included, electronics and additional materials. Firstly, in terms of the costs of each, as mentioned already the passport could cost approximately £0.50 (including cost of equipment for manufacturers and technicians) whereas the added cost for incorporating smart and eco features into a kettle or toaster is a minimum of £20. Calculations for this can be found in Appendix L. The passport therefore is a much cheaper option and, with this cost being passed down to customers, it would be the preferred choice (Peachey, 2022).

The functionality of each method is the main differing point as the passport is passive and the eco-features of the appliances are more active and require user engagement. The passport has been designed through an iterative process including user testing at important stages so it is assumed that stakeholders will find it easy to use. On the contrary, a small batch of user testing, Appendix M, was completed of the eco-kettle and toaster in which users stated that “it’s harder to use than the original” and “[they] did not know where to start so would likely use a standard one”. This suggests that the passport, due to its Low-Tech and simplistic nature, is the better option for stakeholder interaction.

As the passport is passive however it makes no contribution to directly reducing the impact of the product it is applied to. The smart kettle and toaster chosen for testing do reduce the impact. The kettle chosen can reduce the temperature it boils water to as well as boil just 250ml of water, whereas the industry standard is 500ml. The toaster can toast one side more than another, saving energy when toasting items like rolls whose inside users may prefer crispier and outside softer. Both products, therefore, are able to reduce the embodied energy and carbon emissions associated with their respective use phases. This reduction comes at a cost of increasing both factors for the manufacture of the product suggesting that eco-friendly products are only better than the passport if their life is long enough to recover the additional energy and carbon that goes into their production.

11 Future Works

The continuation of the project, while not entirely obvious, can be narrowed down to 4 main suggested pieces of work. Firstly, the creation of an easier to navigate and more attractive smartphone app, an example shown in Figure 53, for interaction with the RFID tag would ensure that users are able to read and write to the tag without having to move the product to a scanner.

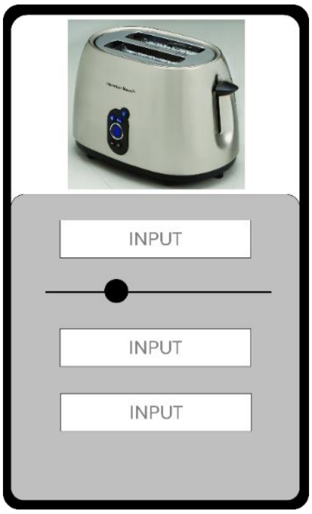


Figure 53: An image depicting how a smartphone app may look for communication with a DPP.

Secondly, restricting the access and permissions for certain users would ensure that important data is kept secure for only users that need it and the interaction is easier for all stakeholders as they only have to read through and look at data relevant to them. The security of data and the sticker mentioned in Section 8.3.4 could also be implemented here.

Thirdly, defining the data that should be input to the tag and recorded using Low-Tech elements for each product type would allow for the capacities of the tags to be tested as well as pushing the interface to its required limits. This would also have the benefit of encouraging manufacturers to adopt DPPs for other products they may have, as it would become clear how they work at this point.

Finally, perhaps the most important future work would be longer-term testing of the passport in homes with consumers. This is because it can be hard to gauge from short 15 minute user testing sessions how consumers may feel about the concept and there may be some elements that are flawed with the concept that will only be revealed after being used contextually for an extended period of time.

12 Conclusion

The Digital Product Passport project initially started with a wide brief that could have been taken in any direction. After reading into the background information, goals were set to create a DPP for small electromechanical devices and to take a user centric approach in the design process. This resulted in multiple rounds of user testing throughout the project that incrementally progressed the project and ensured the design choices being made were focused on improving the ease for all stakeholders.

Initially the user testing was centred around ensuring that users were able to interact with the RFID tags and how this could be improved. As part of the feedback from this user testing session a full GUI was created that massive simplified and sped up the reading and writing process. It then transitioned into testing to ensure that elements of the chosen Low-Tech concept were as easy to understand as they could be.

All of the choices and changes in design direction through the project were validated through either Eco-Audits or comparisons against similar alternatives. This proved that the concept created aligned with the goals and exceeded other options that could be chosen. A final Eco-Audit was created and compared against an Eco-Audit of a typical toaster to ensure that not only did the DPP not contribute further to E-waste, only 1% that of the toaster, but also had the scope to massively reduce the waste generated by the toaster.

This final Eco-Audit was completed on the final prototype which went through multiple iterations as well as different tests to ensure that not only would it be able to fit and function on product of all shapes and sizes but it also allowed HDPE and Acrylic to be selected as materials. One of these tests was an FEA which found a maximum bending stress of 71.93MPa and led to the selection of the above materials.

This project concluded with an assessment of how the passport may have beneficial effects not only for the consumer of the product but also for the wider value chain including manufacturers, retailers and technicians. Future work was also suggested for if this project were to continue as well as alternative routes for exploration were the project to be repeated again from the beginning.

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14 Appendicies

Appendix A – Design Specification

Category	No.	Description	Quantification	Source	Wish / Demand	Weight
Functionality	1	Technology used should be viable	Technology chosen should be capable of holding 1kb of data	Mini Study 1	D	
	2	Passport concept should be easy to learn	Users should be able to understand how to use the product after one example	Mini Study 2	W	M
	3	Passport concept should be easy to use	Users should be able to complete their interaction with the passport within 10 seconds	Mini Study 2	D	
	4	Concept should have visual feedback elements	Passport should contain a digital or analogue output that users can understand	Mini Study 2	W	M
	5	Concept should be able to identify the correct products	Passport should have a way of letting the user know which product is associated with it	Concept Presentation	D	
	6	Passport concept should only allow each stakeholder to access or edit their data	There should be a form of locking or protection for data that only certain users should have access to	Mini Study 2	D	
	7	Concept should make it clear who is in ownership of the passport at any given time		Mini Study 1	W	L
	8	Concept should be able to have data written to it quickly	The transfer of data to or from the passport should take no longer than 1 seconds	Mini Study 2	W	H
	9	Passport Concept should only accept data in the forms it's expecting	Passport should have a blocker that only allows certain forms or pieces of data to be input	Concept Presentation	D	
	10	Passport Concept should prioritise the more polluting and complex components within electronics	Components containing rare and toxic metals and chemicals should be targeted	Concept Presentation	W	M
	11	Passport concept should automatically collect data about critical components	The prioritised components should have their usage and condition tracked every 6 hours or each use	Research	D	
	12	Concept should allow for manual entry where needed		Mini Study 2	W	L

	13	Passport concept should use a technology that allows for flexible data structure	Data within the passport should have the ability to be partitioned and customised through its life	Mini Study 1	D	
	14	Digital Product Passport concept should keep the data in a raw form only processing for the users understanding		Mini Study 2	D	
	15	The passport should be reusable at End of Life	The passport should be able to be retrieved and data wiped			
Geometry	16	Concept should integrate with existing supply lines	The passport itself should not require any special environmental conditions and any external equipment should be made up from standardised components	Mini Study 2	W	H
	17	Passport should be able to fit into all styles of product within the electronics sub-category	Product should be no bigger than 675cm2	Mini Study 2	W	H
	18	Concept should be a consistent size and shape across all products		Mini Study 2	W	M
	19	Concept should be visible or accessible from all angles		Mini Study 1	W	M
	20	Passport should be easy to make	Use nonspecialised materials and manufacturing techniques	Student	D	
Interaction	21	Passport concept should interact the same way for all products	After testing the process on one product a user should be able to apply the same principles to a second product without assistance	Mini Study 2	D	
	22	Concept should be easy to work with on supply chains	The additional annual downtime in production lines caused by the setup and maintenance of integrating passports into products should be no more than 20 hours	Mini Study 2	W	H
	23	Passport concept should be ergonomic for all potential users	The product should be designed to minimise user interaction and where needed should make it easy for any user to interact	Mini Study 2	D	

	24	Passport concept should not affect the existing uses of the product		Mini Study 2	D	
	25	Essential passport concept functions should be simple enough for people with no experience of technology to use		Concept Presentation	D	
	26	The complexity of interaction with the concept should be adjustable	The data and visual feedback elements should have a form of customisation allowing the user to tailor the passport to their ability	Concept Presentation	W	M
	27	The data on the passport should be accessible both online and offline	There should be a full database either online or offline with essential pieces of data accessible by both	Concept Presentation	W	L
	28	The passport should not affect the aesthetics of the product	Manufacturers should be able to paint, cover or place stickers over the passport or use the same materials as the electronic product	Mini Study 2	W	L
Cost	29	Concept should be accessible for small scale production as well as large scale	Integrating a passport into a product should be able to be completed manually and automatically	Mini Study 2	D	
Cost	30	Passport concept should not require expensive retrofitting to supply chains		Mini Study 2	W	H
Cost	31	Cost of passport should be less than or equal to the savings gained by manufacturer	The cost of the passport itself should be less than £4	Concept Presentation	D	
Cost	32	All prototyping must be below budget	The budget for prototyping is £200	Unit Outline	D	
Cost	33	All parts in final design must be priced	All parts should be listed in a Bill of Materials	Student		
Sustainability	34	Passport Concept should not contribute more to the E-waste problem than it's reducing	Passport should be made from environmentally friendly materials where possible and use minimal electronic components	Concept Presentation	D	
Sustainability	35	Concept should be resistant to light wear and tear	The passport should be able to withstand 16 years of typical household use for all products within the subcategory chosen	Mini Study 1	W	M

Legislation	36	Passport concept should adhere to Digital Product Passport and EU Circularity legislation		Research	D	
	37	Passport concept should adhere to general supply chain legislation		Mini Study 2	D	
	38	Passport concept should not affect adherence to other legislations for electronic products	UKCA and CE Legislation	Mini Study 2	D	
Safety	39	The DPP should be designed safely	There should be minimal pinch points and sharp edges	Student	D	
	40	There should be no risk of electrocution	The electronics in the passport should be insulated or inaccessible	Student	D	

Appendix B - Original Program Code

Reading Program

```
// Purpose: Read the data from the Mifare Classic NFC tag

#include <SoftwareSerial.h>
#include <PN532_SWHSU.h>
#include <PN532.h>
SoftwareSerial SWSerial( 3, 2 ); // RX, TX

PN532_SWHSU pn532swhsu( SWSerial );
PN532 nfc( pn532swhsu );
String tagId = "None", dispTag = "None";
byte nuidPICC[4];

void setup() {
    Serial.begin(9600);
    Serial.println("NDEF Writer");
    nfc.begin();
    uint32_t versiondata = nfc.getFirmwareVersion();
    if (! versiondata)
    {
      Serial.print("Didn't Find PN53x Module");
      while (1); // Halt
    }
    // Got valid data, print it out!
    Serial.print("Found chip PN5");
    Serial.println((versiondata >> 24) & 0xFF, HEX);
    Serial.print("Firmware ver. ");
    Serial.print((versiondata >> 16) & 0xFF, DEC);
    Serial.print('.');
    Serial.println((versiondata >> 8) & 0xFF, DEC);
    // Configure board to read RFID tags
    nfc.SAMConfig();
}

void loop() {
    Serial.println("Loading...");
    Serial.println("\nPlace a formatted Mifare Classic NFC tag on the reader.");
    uint8_t success;
    uint8_t uid[] = { 0, 0, 0, 0};  // Buffer to store the returned UID
    uint8_t uidLength;              // Length of the UID (4 or 7 bytes depending on
ISO14443A card type)
    const int block_size = 16;
    const int block_num = 4;
    success = nfc.readPassiveTargetID(PN532_MIFARE_ISO14443A, uid, &uidLength);
    if (success) {
        Serial.println("Found an NFC card!");
```

```
Serial.print("UID Length: ");Serial.print(uidLength, DEC);Serial.println(" bytes");
Serial.print("UID Value: ");
for (uint8_t i=0; i < uidLength; i++)
{
   Serial.print(" 0x");Serial.print(uid[i], HEX);
}
Serial.println("");

uint8_t blockData[block_num][block_size];

for (int i = 0; i < block_num; i++) {
    // Authentication
    Serial.print("Trying to authenticate block ");
    Serial.println(i+4);
    uint8_t keya[6] = { 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF };
    uint8_t j = (i+4)/4;
    Serial.println(j);
    success = nfc.mifareclassic_AuthenticateBlock(uid, uidLength, (j*4), 1, keya);

    if (success) {
        Serial.println("Authentication Successful");


        Serial.print("Reading Block ");
        Serial.println(i+4);
        success = nfc.mifareclassic_ReadDataBlock(i+4, blockData[i]);
        if (success) {
            Serial.print("Data for Block ");
            Serial.println(i+4);
            nfc.PrintHexChar(blockData[i], block_size);
            Serial.println("");
        } else {
            Serial.println("Read failed");
        }
        uint8_t data[16];
        success = nfc.mifareclassic_ReadDataBlock(4, data);
        if (success) {
            Serial.println("Reading Block 4:");
            nfc.PrintHexChar(data, 16);
            Serial.println("");
        } else {
            Serial.println("Read failed");
        }
    } else {
        Serial.println("Authentication failed");
    }
}
delay(500);
```

```
        // Print entire block data in hex
        for (int i = 0; i < block_num; i++) {
            nfc.PrintHexChar(blockData[i], block_size);
        }
    }
    delay(100);
}
```

Writing Program

```
// Purpose: This program writes data to an NFC tag using the PN532 library.

#include <SoftwareSerial.h>
#include <PN532_SWHSU.h>
#include <PN532.h>
SoftwareSerial SWSerial( 3, 2 ); // RX, TX

PN532_SWHSU pn532swhsu( SWSerial );
PN532 nfc( pn532swhsu );
String tagId = "None", dispTag = "None";
byte nuidPICC[4];
String userInput = "None";


// Prepare the data to be written to the NFC tag
uint8_t block_num = 60;
uint8_t block_size = 16;
uint8_t num_blocks_needed;
uint8_t blockData[10][16];

void setup() {
    Serial.begin(9600);
    Serial.println("NDEF Writer");
    nfc.begin();
    uint32_t versiondata = nfc.getFirmwareVersion();
    if (! versiondata)
    {
      Serial.print("Didn't Find PN53x Module");
      while (1); // Halt
    }
    // Got valid data, print it out!
    Serial.print("Found chip PN5");
    Serial.println((versiondata >> 24) & 0xFF, HEX);
    Serial.print("Firmware ver. ");
    Serial.print((versiondata >> 16) & 0xFF, DEC);
    Serial.print('.');
    Serial.println((versiondata >> 8) & 0xFF, DEC);
    // Configure board to read RFID tags
```

```
    nfc.SAMConfig();

    // Create data to be written to the NFC tag
    Serial.println("Enter the data to write to the NFC tag: (Max 45 characters)");
    while (Serial.available() == 0) {
        ;
    }
    userInput = Serial.readString();
    Serial.println(userInput);

    String hexRepresentation[userInput.length()];
    for (int i = 0; i < userInput.length(); i++) {
        hexRepresentation[i] = String(userInput[i], HEX);
    }
    for (int i = 0; i < userInput.length(); i++) {
        Serial.print(" 0x");Serial.print(hexRepresentation[i]);
    }
    Serial.println("");

    // Calculate the number of blocks needed to store the data
    num_blocks_needed = userInput.length() / block_size;
    if (userInput.length() % block_size != 0) {
        num_blocks_needed++;
    }
    Serial.println("Number of blocks needed: " + String(num_blocks_needed));

    // Split the data into blocks
    int j = 0;
    for (int i = 0; i < userInput.length(); i++) {
        blockData[j][i % block_size] = userInput.charAt(i);
        if (i % block_size == block_size - 1) {
            j++;
        }
    }

    // Test blockData output
    //Serial.println(blockData[0][0], HEX);
    //Serial.println(num_blocks_needed/4);
    //Serial.println(blockData[0][1]);
    //Serial.println(blockData[0][2]);
    //Serial.println(blockData[1][0]);
}

void loop() {
    Serial.println("Loading...");
    Serial.println("\nPlace a formatted Mifare Classic NFC tag on the reader.");
    uint8_t success;
    uint8_t uid[] = { 0, 0, 0, 0};  // Buffer to store the returned UID
```

```
    uint8_t uidLength;              // Length of the UID (4 or 7 bytes depending on
ISO14443A card type)
    success = nfc.readPassiveTargetID(PN532_MIFARE_ISO14443A, uid, &uidLength);
    if (success) {
        Serial.println("Found an NFC card!");
        Serial.print("UID Length: ");Serial.print(uidLength, DEC);Serial.println(" bytes");
        Serial.print("UID Value: ");
        for (uint8_t i=0; i < uidLength; i++)
        {
            Serial.print(" 0x");Serial.print(uid[i], HEX);
        }
        Serial.println("");

        for (int i = 4; i <= (num_blocks_needed+4+(num_blocks_needed/4)); i++) {
            if ((i+1) % 4 != 0) {
                uint8_t keya[6] = {0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF};
                uint8_t j = (i/4);
                Serial.println(i);
                Serial.println(j*4);
                success = nfc.mifareclassic_AuthenticateBlock(uid, uidLength, (j*4), 1,
keya);
                if (success) {
                    Serial.println("Block " + String(i) + " authenticated");
                    success = nfc.mifareclassic_WriteDataBlock(i, blockData[i-4]);
                    if (success) {
                        Serial.println("Block " + String(i) + " written");
                    } else {
                        Serial.println("Block " + String(i) + " write failed");
                    }
                } else {
                    Serial.println("Block " + String(i) + " authentication failed");
                }
            }
            else {
                Serial.println("Block " + String(i) + " is a sector trailer");
            }
        }
        delay(2000);
    }
    delay(300);
}
```

Appendix C - Initial User Testing

Participant	1	2	3	4	5	6
Questions						
1 (Location & Appearance)						
Feelings on tags?	Fine as long as it's not too intrusive	No strong feelings	Good, Helps with fixing and getting data on product	Helps when disposing and warranty	Happy as long as not expensive and there is value	Fine, Preferrably not too expensive and complicated
Accessible Location?	Want's it out the way	Out of the way a bit, No clutter on interaction surfaces	Side is fine, would be difficult if in a cabinet	Yes on the side, not in the way	Top corners work well, don't want it on the back	Would prefer it to be obvious but not spoiling the front
Usage understanding?	Self explanatory due to symbol however not clear what to scan with	Easy, but could be dependant on device	Easy to understand (Just Scan), Maybe use NFC logo	Probably struggle if old to understand what to do, what is the point of the tag	It's purpose and what it is would help	Don't know what it's meant to be doing
2 (Writing Data)						
Easy to Upload?	Simple	Very easy	Easy	Writing data easy	Very Easy	Fairly easy
Why / Could be made easier?	Would help if the orientation was clearer / wasn't needed.	Orientation wasn't particularly clear	Using a better antenna for easier transfer	Small learning curve to it, orientation / rotation could be clearer	Clearer orientation	Orientation is annoying
3 (Reading Data)						
Easy to Read?	Simple again	Very Easy	Easy	Easy to scan	Easy	Fairly Easy again
Why / Could be made easier?	Feedback would be useful to know when complete	Indication of completion of transfer	"	Some form of feedback would be better (Haptic / Visual)	Bigger scanning range would help	Would prefer to have feedback on when the process is done, improve the speed of detecting the tag
4 (Interpretation)						
Is the data easy to understand?	Not quite there, Needs perfecting	Extra information and numbers confusing.	Simplify the output to just the user text	Confusing trying to infer / UI would be easier	Easy to read	Yes, UI would be a nice addition
5 (Progression)						
Low-Tech Prototype?	Stickers appear useful initially, however wouldn't be updateable over time	Hesetant to self-update info, lack confidence in the data (Box would help)	Stickers would be too much effort to keep updated	Stickers aren't secure however happy to scan and update himself	Stickers like fire-extinguisher and electronic safety stickers would be good	Low tech is preferred
High-Tech Prototype?	Overenginnered, shouldn't need to be there	Screen and digital data storage provides more data security	Screen is better, automated	-	Screen is overcomplicated and would use lots of power, E-INK?, Already have a screen on phone	Screen isn't that useful due to how often the tag is needed
Extra Points		Bottle Cap Aging				

	8	9	10	11	12
able	Lovely, Personal tracking of usage and helping second hand sales is nice	Unsure, presentation and security would be important	Should be fine, Data security and customisability is important.	Not bothered, cost is a concern	Not a problem, but would be better if passive
Would prefer it out the way as not used often	On bottom might be nice due to low usage, out of the way	Side or Top (Consistent for all products to improve ease of usage)	Dependent on usage frequency	Side / back is fine, as long as aesthetics aren't ruined	Anywhere outside of interaction space
Symbol could make it clear that NFC technology is being used (Looks a bit like wifi)	The scan here isn't necessary as the symbol makes it obvious	How is it relevant / why should I use it?	Indication of how to scan would be nice	Symbol makes it obvious	Not sure what to scan
	Very Easy	Accessible	Very Easy	Easy	Easy
Have alignment arrows / Help with orientation	User intergace would be nice, feedback on what is going on	Would prefer to know what to do, scale safety and security with difficulty	Would be nice for the scanner to be more compact, or in phone	Notification of writing data would be nice	Clearer instructions would be nice
	Very Easy again	Quick Easy	Easy	Very Easy	Easy
	"	-	Quite time consuming	Feedback would be nice	Improved range / Introduction of feedback (Noise or visual)
Numbers are confusing, words on separate lines is annoying	Mispelt words a dealbreaker, would make model numbers impossible	Inconvenient to read for the user, technician or someone in the know will be fine	Blocks and numbers are confusing, GUI would be easier to understand	UI would make understanding easier, not much faith in technology due to errors	Easy to understand
Stickers or others could fall off, however more economical	Stickers and other low-tech options already used, non-customisable	-	Low-tech is better as cost could be a big concern for the DPP	Would like minimal work to be placed on users	Prefers stickers
Screen or other high-tech elements are overkill	High tech would be better however could be too much if not used often	-	Could just use a phone screen	Automatic collection makes it easy	High tech is too much for the average use. Might make more sense of high tech devices

Appendix D - Low-Tech Eco-Audit

Section	Component	Energy (MJ)	Carbon (kg)		Material
Material Production	Stickers	0.1282	0.00578		PVC
	Box + Insert	13.485	0.52		ABS
	Scratch Offs	0.074	0.004		Acrylic
	RFID	0.009	0.00064		Copper
	Total	13.6962	0.53042		
					Process
Processing	Stickers	0.0119	0.00089		Rolling
	Box + Insert	0.305	0.0697		Moulding
	Scratch Offs	0.0118	0.00088		Rolling
	RFID	0.0008	0.00006		Extrusion
	Total	0.3295	0.07153		
	Transportation	50i	50i		Where i is a constant representing the per gram carbon and energy emissions of transportation
	Use	0	0		Excluding RFID in usage as this is the same across both
Recycling	Stickers	0.044	0.00199		
	Box + Insert	1.467	0.0567		
	Scratch Offs	0.0256	0.0014		
	RFID	0.00275	0.000214		
	Total	1.53935	0.060304		

Appendix E - High-Tech Eco-Audit

Section	Component	Energy (MJ)	Carbon (kg)		Material
Material Production	LCD Screen	11.153	0.4632		90% FR-4, 10% Copper
	Arduino	2.36	0.0988		90% FR-4, 10% Copper
	RFID Antenna + Chipset	1.679	0.0699		90% FR-4, 10% Copper
	Breadboard	5.12	0.262		70% ABS, 30% Nickel-Silver
	Wires	1.097	0.044		50% Copper, 50% Rubber
	Misc Elec	2.502	0.155		50% Copper, 25% ABS, 25% Nickel-Silver
	Box	10.51	0.41		100% ABS
	Total	34.421	1.5029		
					Process
Processing	LCD Screen	0.6654	0.05293		Compression Moulding
	Arduino	0.1412	0.011198		Compression Moulding
	RFID Antenna + Chipset	0.0998	0.00794		Compression Moulding
	Breadboard	0.417	0.0675		Injection Moulding
	Wires	0.16	0.0132		Extrusion
	Misc Elec	0.2176	0.02517		Compression Moulding
	Box	0.765	0.175		Injection Moulding
	Total	2.466	0.352938		
	Transportation	257i	257i		Refer to previous sheet
	Use	252	18.04		Assuming 20 years service with only Screen and Arduino needing power
Recycling	LCD Screen	-	-		FR-4 is non recyclable
	Arduino	-	-		FR-4 is non recyclable
	RFID Antenna + Chipset	-	-		FR-4 is non recyclable
	Breadboard	1.658	0.0851		
	Wires	0.1364	0.00992		
	Misc Elec	5.85	0.35		
	Box	3.6838	0.142		
	Total	11.3282	0.58702		

Appendix F - Second User Testing

Participant	1	2	3	4	5	6	7	8	9	10
Questions										
1 (Understanding)										
Easiest to Understand?	Pie Chart / Symbolic	Symbolic	Text	Text	Text or List	Text	Text	Text	Text or Symbolic	Text
Why?	Very Clear and obvious what it means	Very clear and concise	Only tells you useful information	Obvious what it means and format is expected	Text is easiest to see at a glance (Visio spacial trackpad) and could be customisable	Makes sense, titles held to prepare you for information	White space around makes it look less cluttered and clear	It is only giving information that is needed	Text is very obvious what it means, Symbolic is nice and consise	Tells me what I want to know, could be changed
Extra?	List is big and inefficient	Transition between fading ink could be unclear	Hard to get scratch offs perfect, and fading ink could be unclear	Interim of fading ink could be used	Symbolic is very unclear, List is better as names of month indicate category		Timeline and Pie Chart were particularly unclear as it was not obvious to scratch	Timeline is also nice as it is layed out from left to right	Symbolic would only work if users knew how to navigate it	List is nice but could be a bit of a waste of space
2 (Updating)										
Easiest to Update?	Placing a new sticker is easiest	New sticker is easiest	New sticker is easiest	New Sticker or fading ink	New Sticker	Scratching or fading ink	Sticker or Fading ink	Scratching or Fading Ink	New Sticker	Sticker or Fading Ink
Why?	Less effort and work needed	Less effort	No need to worry about scratching within lines	Scratch off was more effort	Very Quick	Scratching is less waste and fun, Ink means that there is not was to forget	The less human input the better	Less interaction is better as there's less opportunity for mistake	Very quick and controllable	Less effort needed
Extra?		It is close however			Pie Chart could be hard to scratch due to tight corners		Scratch off would require me to have a coin or something similar to hand		Sticker is similar process to updating tag (Information comes off and goes on)	Fading ink would be unclear as it would all be overlapping each other
3 (Protection)										
Preferred Option?	Box	Pouch	Box	Box	Box	Box	Box	Box	Box	Pouch
Why?	More Solid and Secure	Box is a bit chunky	Could be included as part of the design	Clearer, Cleaner and more durable	Pouch looks like waste and shipping material	Pouch isn't particularly secure	Robust, Pouch could get pierced	Durable, Gives the appearance of higher quality	Much more protective, Aesthtics of protection aswell	Box is a bit big and could get in the way especially on fitted appliances
4 (Security)										
Preferred Option?	Sticker	Sticker	Pin	Pin	Sticker	Sticker	Sticker	Sticker	Pin	Sticker
Why?	No need to lock it away and sticker already appears on other products		More secure	More Secure	No need for lock	For ease but is less secure, security is unlikely to be needed though	No need for complete security	Locking away in uneccessary and complex, Sticker is more passive	More Secure, Sticker is Subject to Wear and Tear	No need to lock info away

11	12	13
Text or List	Symbolic	Timeline
Easy to see what information I am being told	Doesn't take up much space, could be applied to a variety of information	Makes lots of sense, very familiar to me
Would be nice to have circles rather than crossing out on list	Scratch-offs and list take up uneccessary space	
Fading Ink	Sticker	Scratch-off
No need for me to do anything	Very simple and easy, familiar	Easy to change
	Would be uncomfortable with fading ink as I don't know what it is	There is less waste when compared to replacing stickers each time
Pouch	Pouch	Box
Not much wear and tear happening so pouch is fine	Pouch would fit in better as smaller.	Box is more pretective and could be colour matched with product
Sticker	Pin	Sticker
Less effort needed for stickers	More secure with pin, keeps my data safe	Sticker is easier especially if there are consequences for breaking it

Appendix G - GUI Code

Interface

```
import subprocess
import serial
import threading
import time
import tkinter as tk
from tkinter import font as tkfont  # Import the font module

# Global variable to control serial monitoring
monitoring_paused = False
oneshow = False
ser = None  # Serial object

def upload_sketch(sketch_path, com_port):
    global ser
    try:
        # Close the serial connection if it's open
        if ser and ser.is_open:
            ser.close()
    except serial.SerialException as e:
        print("Error closing serial connection:", e)

    # Compile the sketch
    compile_process = subprocess.Popen(['C:\\Program Files\\Arduino CLI\\arduino-cli.exe',
'compile', '--fqbn', 'arduino:avr:uno', sketch_path])
    compile_process.wait()

    # Upload the compiled sketch to the Arduino
    upload_process = subprocess.Popen(['C:\\Program Files\\Arduino CLI\\arduino-cli.exe',
'upload', '-p', com_port, '--fqbn', 'arduino:avr:uno', sketch_path])
    upload_process.wait()
    print("Sketch uploaded")

def upload_and_monitor(sketch_path, com_port, text_widget):
    global monitoring_paused, ser
    monitoring_paused = True  # Pause serial monitoring
    upload_sketch(sketch_path, com_port)
    time.sleep(3)  # Wait for the Arduino to reset
    monitoring_paused = False  # Resume serial monitoring
    start_monitoring(com_port, text_widget)

def monitor_serial(com_port, text_widget):
    global monitoring_paused, ser, oneshow
    serial_data = []  # List to store serial data
    try:
        ser = serial.Serial(com_port, 9600)  # Adjust baud rate as per your Arduino sketch
```

```
        while not monitoring_paused and ser.is_open:
            if ser.in_waiting > 0:
                if oneshow == False:
                    data = ser.readline().decode().strip()  # Read serial data
                    text_widget.insert(tk.END, data + '\n')  # Display latest data
                    text_widget.see(tk.END)  # Scroll to the end

                    # Store each line in the serial_data list
                    serial_data.append(data)

                    if data == "AA":
                        monitoring_paused = True  # Pause serial monitoring
                        text_widget.delete('1.0', tk.END)  # Clear previous data

                        # Extract final 5 lines of serial data
                        serial_data = serial_data[-5:]

                        # Delete the first 50 characters of each line
                        serial_data = [line[51:] for line in serial_data]

                        # Append each line onto the end of the previous line
                        serial_data = [serial_data[0] + serial_data[1] + serial_data[2] +
serial_data[3] + serial_data[4]]

                        # Display the stored serial data
                        text_widget.insert(tk.END, 'Data on Tag:' + '\n')
                        text_widget.insert(tk.END, serial_data[0] + '\n')
                        text_widget.see(tk.END)

                    if data == "Loading...":
                        oneshow = True

                elif oneshow == True:
                    text_widget.delete('1.0', tk.END)  # Clear previous data
                    data = ser.readline().decode().strip()  # Read serial data
                    text_widget.insert(tk.END, data + '\n')
                    text_widget.see(tk.END)

                    if data == "fin":
                        text_widget.delete('1.0', tk.END)  # Clear previous data
                        oneshow = False
    except serial.SerialException as e:
        print("Serial monitoring error:", e)
    finally:
        if ser and ser.is_open:
            ser.close()

def start_monitoring(com_port, text_widget):
```

```
    serial_thread = threading.Thread(target=monitor_serial, args=(com_port, text_widget))
    serial_thread.daemon = True  # Daemonize thread so it will be automatically killed when 
the main program exits
    serial_thread.start()

def send_data_to_arduino(data, com_port):
    global monitoring_paused, ser
    try:
        # ser = serial.Serial(com_port, 9600)  # Adjust baud rate as per your Arduino 
sketch
        ser.write(data.encode())  # Send data to Arduino
    except serial.SerialException as e:
        print("Error sending data to Arduino:", e)

def convert_hex_to_ascii(hex_string):
    # Convert hexadecimal string to ASCII
    ascii_string = bytearray.fromhex(hex_string).decode()
    return ascii_string

# GUI setup
root = tk.Tk()
root.title("Arduino Sketch Uploader and Serial Monitor")

# Define font styles
bold_font = tkfont.Font(weight="bold")
large_font = tkfont.Font(size=36)  # Adjust size as needed

# Text widget to display serial data
text_area = tk.Text(root, height=15, width=70, font = large_font)
text_area.pack()

# Entry widget to input data to be sent to Arduino
entry = tk.Entry(root, width=220)
entry.pack(pady=5)

# Button to send data to Arduino
def send_data():
    data = entry.get()  # Get data from entry widget

    if data:
        if len(data) > 45:
            text_area.insert(tk.END, 'Data String is more than 45 Characters long.' + '\n')
            text_area.see(tk.END)
            return
        else:
            send_data_to_arduino(data, 'COM4')  # Adjust COM port as per your Arduino setup
    else:
        print("Please enter data to send.")
```

```
btn_send = tk.Button(root, text="Send Data to Arduino", command=send_data)
btn_send.pack(pady=5)

# Button to upload and monitor Sketch 1
def upload_and_monitor_sketch1():
    text_area.delete('1.0', tk.END)  # Clear previous data
    sketch_path = r"C:\Users\miles\OneDrive - University of Bath\Desktop\Seeed 
Libraries\Seeed_Arduino_NFC\examples\WriteTag\ReadTag\ReadTag.ino"
    upload_and_monitor(sketch_path, 'COM4', text_area)

btn_sketch1 = tk.Button(root, text="Read Tag", command=upload_and_monitor_sketch1)
btn_sketch1.pack(pady=5)

# Button to upload and monitor Sketch 2
def upload_and_monitor_sketch2():
    text_area.delete('1.0', tk.END)  # Clear previous data
    sketch_path = r"C:\Users\miles\OneDrive - University of Bath\Desktop\Seeed 
Libraries\Seeed_Arduino_NFC\examples\WriteTag\WritetoTag\WritetoTag.ino"
    upload_and_monitor(sketch_path, 'COM4', text_area)

btn_sketch2 = tk.Button(root, text="Write Tag", command=upload_and_monitor_sketch2)
btn_sketch2.pack(pady=5)

# Button to upload and monitor Sketch 3
def upload_and_monitor_sketch3():
    text_area.delete('1.0', tk.END)  # Clear previous data
    sketch_path = r"C:\Users\miles\OneDrive - University of Bath\Desktop\Seeed 
Libraries\Seeed_Arduino_NFC\examples\WriteTag\Manufacturing\Manufacturing.ino"
    upload_and_monitor(sketch_path, 'COM4', text_area)

btn_sketch3 = tk.Button(root, text="Manufacturing", command=upload_and_monitor_sketch3)
btn_sketch3.pack(pady=5)

root.mainloop()
```

Manufacturing Program

```
// Purpose: This program writes data to an NFC tag using the PN532 library.

#include <SoftwareSerial.h>
#include <PN532_SWHSU.h>
#include <PN532.h>
SoftwareSerial SWSerial( 3, 2 ); // RX, TX

PN532_SWHSU pn532swhsu( SWSerial );
PN532 nfc( pn532swhsu );
String tagId = "None", dispTag = "None";
```

```
byte nuidPICC[4];
String userInput = "None";

// Prepare the data to be written to the NFC tag
uint8_t block_num = 60;
uint8_t block_size = 16;
uint8_t num_blocks_needed;
uint8_t blockData[10][16];

void setup() {
    Serial.begin(9600);
    // Serial.println("NDEF Writer");
    nfc.begin();
    uint32_t versiondata = nfc.getFirmwareVersion();
    if (! versiondata)
    {
      Serial.print("Didn't Find PN53x Module");
      while (1); // Halt
    }
    nfc.SAMConfig();

    userInput = "Part Replaced: Heater, Shell: Aluminium 6016";

    String hexRepresentation[userInput.length()];
    for (int i = 0; i < userInput.length(); i++) {
        hexRepresentation[i] = String(userInput[i], HEX);
    }
    Serial.println("");

    // Calculate the number of blocks needed to store the data
    num_blocks_needed = userInput.length() / block_size;
    if (userInput.length() % block_size != 0) {
        num_blocks_needed++;
    }

    // Split the data into blocks
    int j = 0;
    for (int i = 0; i < userInput.length(); i++) {
        blockData[j][i % block_size] = userInput.charAt(i);
        if (i % block_size == block_size - 1) {
            j++;
        }
    }
}

void loop() {
    Serial.println("Loading...");
    Serial.println("\nPlace a product under scanner");
```

```
    uint8_t success;
    uint8_t uid[] = { 0, 0, 0, 0};  // Buffer to store the returned UID
    uint8_t uidLength;              // Length of the UID (4 or 7 bytes depending on
ISO14443A card type)
    success = nfc.readPassiveTargetID(PN532_MIFARE_ISO14443A, uid, &uidLength);
    if (success) {
        Serial.println("fin");
        Serial.println("Found an NFC card, writing data...");
           for (int i = 4; i <= (num_blocks_needed+4+(num_blocks_needed/4)); i++) {
            if ((i+1) % 4 != 0) {
                uint8_t keya[6] = {0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF};
                uint8_t j = (i/4);
                Serial.println(i);
                Serial.println(j*4);
                success = nfc.mifareclassic_AuthenticateBlock(uid, uidLength, (j*4), 1,
keya);
                if (success) {
                    success = nfc.mifareclassic_WriteDataBlock(i, blockData[i-4]);
                    if (success) {
                        Serial.println("Data written to NFC tag");
                    } else {
                        Serial.println("Data not written to NFC tag");
                    }
                } else {
                    Serial.println("Authentication Failed");
                }
            }
            else {
                // Serial.println("Block " + String(i) + " is a sector trailer");
            }
        }
        delay(1000);
    }
    delay(100);
}
```

Reading Program

```
// Purpose: Read the data from the Mifare Classic NFC tag

#include <SoftwareSerial.h>
#include <PN532_SWHSU.h>
#include <PN532.h>
SoftwareSerial SWSerial( 3, 2 ); // RX, TX

PN532_SWHSU pn532swhsu( SWSerial );
PN532 nfc( pn532swhsu );
String tagId = "None", dispTag = "None";
```

```
byte nuidPICC[4];

unsigned long start_time, end_time, elapsed_time;

void setup() {
    Serial.begin(9600);
    Serial.println("NDEF Writer");
    nfc.begin();
    uint32_t versiondata = nfc.getFirmwareVersion();
    if (! versiondata)
    {
      Serial.print("Didn't Find PN53x Module");
      while (1); // Halt
    }
    // Configure board to read RFID tags
    nfc.SAMConfig();
}

void loop() {
    Serial.println("Loading...");
    Serial.println("\nPlace a formatted Mifare Classic NFC tag on the reader.");
    uint8_t success;
    uint8_t uid[] = { 0, 0, 0, 0};  // Buffer to store the returned UID
    uint8_t uidLength;              // Length of the UID (4 or 7 bytes depending on
ISO14443A card type)
    const int block_size = 16;
    const int block_num = 4;
    success = nfc.readPassiveTargetID(PN532_MIFARE_ISO14443A, uid, &uidLength);
    if (success) {
        start_time = millis();
        Serial.println("fin");
        Serial.println("Found an NFC card, reading data...");
        uint8_t blockData[block_num][block_size];

        for (int i = 0; i < block_num; i++) {
            // Authentication
            uint8_t keya[6] = { 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF };
            uint8_t j = (i+4)/4;
            success = nfc.mifareclassic_AuthenticateBlock(uid, uidLength, (j*4), 1, keya);

            if (success) {
                success = nfc.mifareclassic_ReadDataBlock(i+4, blockData[i]);
                if (success) {
                    nfc.PrintHexChar(blockData[i], block_size);
                } else {
                    Serial.println("Read failed");
                }
            } else {
```

```
                Serial.println("Authentication failed");
            }
        }
        delay(500);

        // Print entire block data in hex
        for (int i = 0; i < block_num; i++) {
            nfc.PrintHexChar(blockData[i], block_size);
        }

        Serial.println("AA");
    }
    delay(100);
}
```

Writing Program

```
// Purpose: This program writes data to an NFC tag using the PN532 library.

#include <SoftwareSerial.h>
#include <PN532_SWHSU.h>
#include <PN532.h>
SoftwareSerial SWSerial( 3, 2 ); // RX, TX

PN532_SWHSU pn532swhsu( SWSerial );
PN532 nfc( pn532swhsu );
String tagId = "None", dispTag = "None";
byte nuidPICC[4];
String userInput = "None";


// Prepare the data to be written to the NFC tag
uint8_t block_num = 60;
uint8_t block_size = 16;
uint8_t num_blocks_needed;
uint8_t blockData[10][16];
unsigned long start_time, end_time, elapsed_time;

void setup() {
    Serial.begin(9600);
    Serial.println("NDEF Writer");
    nfc.begin();
    uint32_t versiondata = nfc.getFirmwareVersion();
    if (! versiondata)
    {
      Serial.print("Didn't Find PN53x Module");
      while (1); // Halt
    }
```

```
    // Got valid data, print it out!
    Serial.print("Found chip PN5");
    Serial.println((versiondata >> 24) & 0xFF, HEX);
    Serial.print("Firmware ver. ");
    Serial.print((versiondata >> 16) & 0xFF, DEC);
    Serial.print('.');
    Serial.println((versiondata >> 8) & 0xFF, DEC);
    // Configure board to read RFID tags
    nfc.SAMConfig();

    // Create data to be written to the NFC tag
    Serial.println("Enter the data to write to the NFC tag: (Max 45 characters)");
    while (Serial.available() == 0) {
        ;
    }
    userInput = Serial.readString();
    Serial.println(userInput);

    String hexRepresentation[userInput.length()];
    for (int i = 0; i < userInput.length(); i++) {
        hexRepresentation[i] = String(userInput[i], HEX);
    }
    Serial.println("");

    // Calculate the number of blocks needed to store the data
    num_blocks_needed = userInput.length() / block_size;
    if (userInput.length() % block_size != 0) {
        num_blocks_needed++;
    }
    Serial.println("Number of blocks needed: " + String(num_blocks_needed));

    // Split the data into blocks
    int j = 0;
    for (int i = 0; i < userInput.length(); i++) {
        blockData[j][i % block_size] = userInput.charAt(i);
        if (i % block_size == block_size - 1) {
            j++;
        }
    }
}

void loop() {
    Serial.println("Loading...");
    Serial.println("\nPlace a formatted Mifare Classic NFC tag on the reader.");
    uint8_t success;
    uint8_t uid[] = { 0, 0, 0, 0};  // Buffer to store the returned UID
    uint8_t uidLength;              // Length of the UID (4 or 7 bytes depending on
ISO14443A card type)
```

```
    success = nfc.readPassiveTargetID(PN532_MIFARE_ISO14443A, uid, &uidLength);
    if (success) {
        start_time = millis();
        Serial.println("fin");
        Serial.println("Found an NFC card, writing data...");
        for (int i = 4; i <= (num_blocks_needed+4+(num_blocks_needed/4)); i++) {
            if ((i+1) % 4 != 0) {
                uint8_t keya[6] = {0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF};
                uint8_t j = (i/4);
                success = nfc.mifareclassic_AuthenticateBlock(uid, uidLength, (j*4), 1, 
keya);
                if (success) {
                    success = nfc.mifareclassic_WriteDataBlock(i, blockData[i-4]);
                    if (success) {
                        Serial.println("Tag Written");
                    } else {
                        Serial.println("Tag Not Written");
                    }
                } else {
                    Serial.println("Authentication Failed");
                }
            }
        }
        Serial.println("Data written to NFC tag");
        delay(2000);
    }
    delay(300);
}
```

Appendix H - Kettle Diameter Calculations

No.	Model	Diameter (mm)
1	Al Cook	150
2	Argos	148
3	Haier	158
4	Russel Hobbs	156
5	-	157
6	-	161
	Avg	155

Appendix I - FEA Convergence Data

Mesh Size	Element Number	Deformation (mm)	Stress (MPa)
20	261	36.087	86.307
10	335	35.734	71.315
9	406	35.718	58.417
8	520	35.649	72.669
7	652	35.624	64.622
6	905	35.615	63.093
5	1313	35.612	56.83
4	2060	35.611	62.889
3	4388	35.609	59.624
2	12264	35.61	68.568
1	17347	35.61	72.802
0.9	43020	35.611	71.574
0.8	54992	35.611	74.996
0.7	71540	35.612	79.061
0.6	96658	35.611	83.49
0.5	138472	35.612	91.366
0.95mm mesh is best			
	38686	35.611	71.932

Appendix J - Final Prototype Eco-Audit

Section	Component	Energy (MJ)	Carbon (kg)		Materials
Material Production	Stickers	3.85	0.1734		PVC
	Casing	1.28	0.03		HDPE
	RFID	0.009	0.00064		Copper
	Screen	1.76	0.0969		ABS
	Insert	0.878	0.048		HDPE
	Total	7.777	0.34894		
					Process
Processing	Stickers	0.357	0.0268		Rolling
	Casing	0.35	0.0262		Rolling / Cut from Sheet
	RFID	0.0008	0.00006		-
	Screen	0.277	0.021		Rolling / Cut from Sheet
	Insert	0.139	0.011		Rolling / Cut from Sheet
	Total	1.1238	0.08506		
	Transportation	0	0		
				1.7358	kWh
	Use	6.25	0.46		
Recycling	Stickers	1.32	0.0597		
	Box + Insert	0.437	0.011		
	RFID	0.00275	0.000214		
	Screen	0.6	0.033		
	Insert	0.3	0.0165		
	Total	2.65975	0.120414		

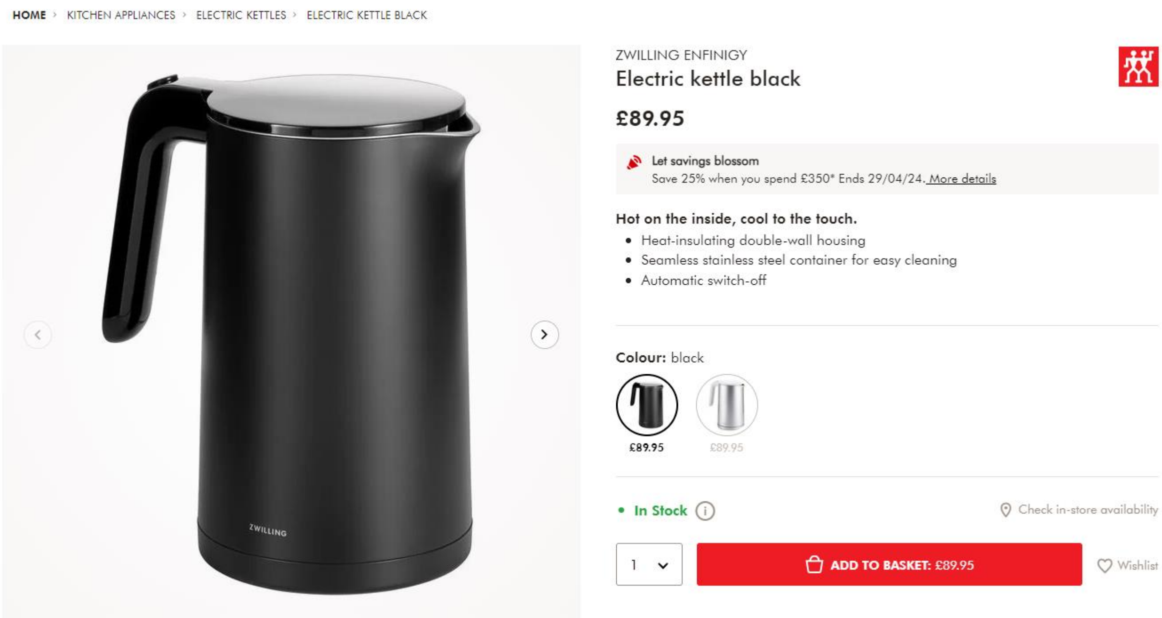
In order to find the use power for the RFID tags the following data was used.

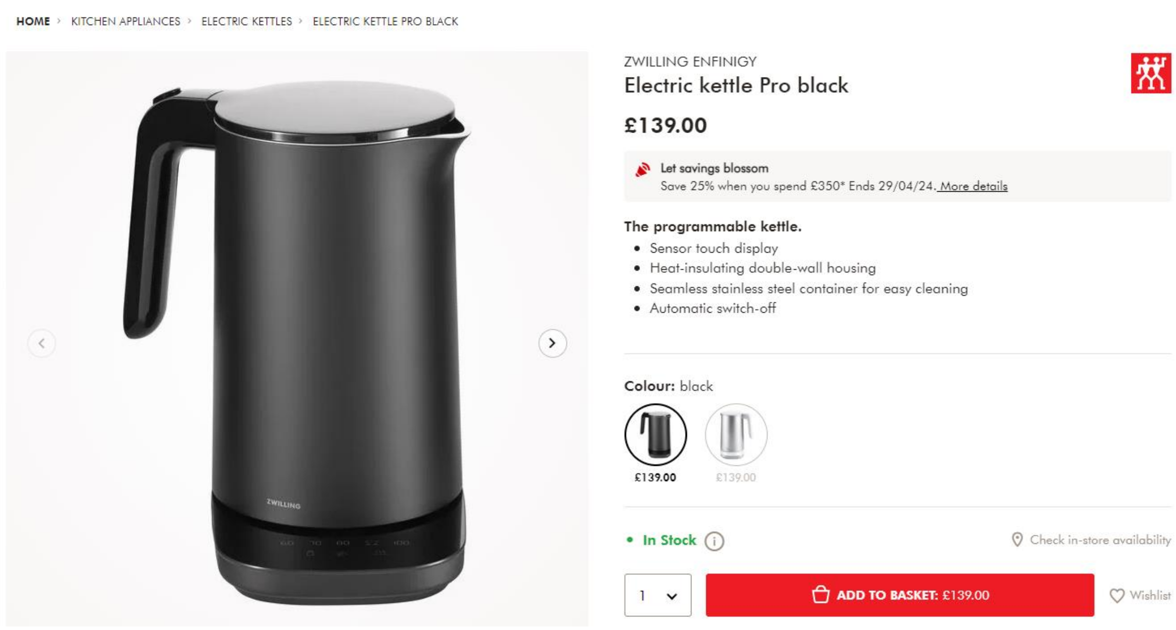
“RFID Tags typically draw 30mA at 1V” (Zhao et al., 2015)

Appendix K - Cost breakdown of final design

Component	Cost	Notes
Anti-metal NFC tag	£0.07	Based of Wholesale cost
Casing	£0.05	Using Granta material cost per kg and approximated moulding costs (FormLabs, n.d.)
Screen	£0.17	Percentage of sheet material area
Insert	£0.03	Using Granta material cost per kg and approximated moulding costs (FormLabs, n.d.)
Stickers	£0.11	Percentage of coloured sheet material
Total	£0.43	

Appendix L - Smart Appliance Costing





Calculate unit cost:

Assuming 30% profit margin as premium product (Elias, 2024)

$$£89.95 \rightarrow £69.19$$

$$£139.00 \rightarrow £106.92$$

Difference in cost:

$$£106.92 - £69.19 = £37.73$$

Rough calculations therefore for other brand, products and designs may be more or less. Likely this design is on the higher end due to extra material needed for base.

Therefore cost of “smart features” on appliances = £20 - £40

Appendix M - Smart Product User Testing

User	1	2	3	4	5
Comments	Prefer old one, new one seems like form over function	Unsure on how it works so if I had the choice I'd use the old one	I like having the extra functions as I never know when I might need them	I think it is harder to use and more steps than the original	I think it is too much although I like the energy saving measures, I don't think I need the smart features