**Design of a Cost-Effective, Self-Sustaining Solar-Powered E-Reader Capable of Providing Educational Resource in Deprived Communities Utilising RLCD Technology**

Reuben Marland


## Summary

With the overall purpose of the device being to provide educational recourse, a more revised focus was highlighted during preliminary research: providing medical literature to rural communities without access to health advice. In remote villages, the nearest access for adequate health care advice could be hours away on foot. The device provides a solution to this issue. A Secure Digital card supplies the book data to the device, providing extensive and interchangeable storage. With a dictionary and a keyword search engine built-in, an individual with basic literature knowledge can operate the device and browse for the desired information.

At the end of 2015, the healthcare literacy rate in Sub-Saharan Africa reached only 35.77% [2]. This makes it an ideal first location for initial distribution of the device. Sub-Saharan Africa also represents some of the most irradiated countries such as Ethiopia [6]. A condition that is optimal for solar cell power production.

To construct a device dictated by the product design specification, a wide range of internal and external components must be chosen from. The orientation of the solar cell(s) placement was decided through a convergence matrix comparing pre-visualization renders of the device built in Autodesk Fusion 360. For the other components, a trade-off algorithm was constructed within Matlab to sort through hundreds of each component, removing any non-applicable and those that are too extreme in a category. The primary attribute in component category revolved mainly around cost. The screen changed specification to an electronic paper display after trade-off analysis revealed a cheaper and more well suited component.

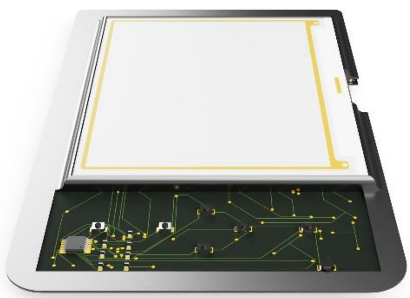
After choosing the components, the base microcontroller was selected: the Raspberry Pi Pico board. The device's printed circuit board had to be designed. The downloaded footprints of each component were assembled and connected to the microcontroller using any reference circuits or pull-up resistors required. The design included a small voltage regulator to ensure the battery's voltage output of 4.2V dropped down to the functioning voltage of all components, 3.3V. A solar controller was introduced to aid maximum power production within the solar panel and protect the battery during charging.

The maximum power point tracking algorithm followed a perturb and observe method. A virtual simulation for this was constructed in Simulink, but the individual components could not be designed, and a simpler model of the controller had to be tested. The basis of creating an operating system, consists of importing the correct libraries, assigning pin locations, and instructing each one to perform a task.

The bill of material calculates the final price of the product, should it be made on a singular basis, to be £103.08, in contrast to £72.34 and £62.55, if it were manufactured in bulk of 100 or 1000 respectively.

Extensive physical testing is still required before distributing the device, as virtual testing will never perfectly emulate the exact internal specification as highlighted during testing the perturb and observe algorithm. Virtual circuit building and simulation follow similar inaccuracies.



Supervised by Mr A. Greener

Department of Mechanical Engineering

University of Bristol

2022/2023

# Declaration

This project report is submitted towards an application for a degree in Mechanical Engineering at the University of Bristol. The report is based upon independent work by the candidate. All contributions from others have been acknowledged and the supervisor is identified on the front page. The views expressed within the report are those of the author and not of the University of Bristol.

I hereby assert my right to be identified as the author of this report. I give permission to the University of Bristol Library to add this report to its stock and to make it available for consultation in the library, and for inter-library lending for use in another library. It may be copied in full or in part for any bona fide library or research worker on the understanding that users are made aware of their obligations under copyright legislation.

I hereby declare that the above statements are true.

{Student signature}



Certification of ownership of the copyright in a dissertation presented as part of and in accordance with the requirements for a degree in Mechanical Engineering at the University of Bristol.

This report is the property of the University of Bristol Library and may only be used with due regard to the author. Bibliographical references may be noted but no part may be copied for use or quotation in any published work without prior permission of the author. In addition, due acknowledgement for any use must be made.

# Contents

# 1 Introduction

## 1.1 Problem definition

In Sub-Saharan Africa (SSA), a general lack of access to literature is observed. In 2012, there was an average of only 1.4 books per pupil, and these books rarely varied in subject [1]. The foundation for societies to progress in education, economic development, and social well-being is provided by literature. Although the issue of textbook-per-pupil will not be solved, access to an extremely wide range of texts can be facilitated.

From 2009 to 2015, the assessment of high health literacy rates, a measure of health knowledge, was conducted in 14 SSA countries through a demographic health survey. A total of 224,751 individuals were assessed, and it was found that only 35.77% were found to be literate in health. In certain countries, a much lower statistic was observed. For example, a health literacy rate of 8.51% was recorded in Niger [2].

One way to solve this issue was the development of a container consisting of six large Liquid Crystal Display (LCD) screens powered by solar panels, which can be transported around by use of a trailer. This container was developed by the United Nations Industrial Development Organization. In Mozambique, the array was utilized for educating communities simultaneously as one teaching class, providing education about the prevention of COVID-19 along with other health issues [3] Instead of being provided as a transportable solution, this Individual Research Project (IRP) outlines the process of creating a smaller device that can be easily distributed and remain within a village, preferably in a central building.

Due to the extensive battery life being a core requirement of an e-reader, combined with the fact that e-readers are only distributed in electricity-rich countries, the need for a solar panel has not been necessary. The implementation of solar panels has only been carried out by individual engineers who worked on their own e-readers at home. For instance, one individual affixed a solar panel to the backside of their first-generation Kobo e-reader [4]. However, scaling up such a solution is not feasible without licensing from e-reader companies themselves, such as Kobo in this case. Although many solar-powered cases have been developed, they face a similar challenge as the core device needs to be available first. A significant challenge also faced is by the current access to literature that relies on electricity. For instance, in rural SSA, only 28.5% of residents have access to electricity [5].

The target areas for a solar-powered device are those characterized by high levels of irradiance, making Ethiopia a favourable candidate [6]. Additionally, SSA faces the challenge of having some of the hottest countries in the world, with Mali being the hottest country in the region [7], experiencing maximum daily temperatures of up to 40°C. To account for temperature considerations, a maximum assumed temperature, with a safety factor of 2, will be set as the threshold that the device can withstand over prolonged periods. A heat sensor will also be incorporated to monitor elevated temperatures. However, it is important to note that these locations may not be the initial distribution targets due to the decrease in solar cell efficiency as temperatures rise [8]. In contrast, SSA also includes countries with high levels of precipitation. For example, Guinea-Congolia experienced an average monthly precipitation of 1225mm in a certain year [9], compared to London's 60mm. The substantial rainfall suggests the need to waterproof the device. However, since this is the initial design phase and specific regions will be targeted first, areas with lower precipitation will be selected for the initial distribution.

## 1.2 Aims

Limited research exists on a device with this specification that has successfully undergone distribution. However, the primary aims for this IRP can be outlined as follows:

- Conducting research on Reflective LCD (RLCD), solar and battery technologies.
- Minimizing power consumption and cost of components within the device.
- Determining required hardware and chassis construction based on layout, weight, size, performance.
- Choosing a Microcontroller (MC) and developing a Printed Circuit Board (PCB).
- Developing an Operating System (OS) and various control techniques for the internal components.

By supplying an e-reader with a large storage capacity, deprived communities can gain access to thousands of books. Considering that a book typically requires approximately 1MB [10], the possibility of extended storage capacity using larger Secure Digital (SD) cards opens the potential for an extensive digital library. The cost of the device is the primary priority which is aided using an RLCD screen. A cheap and durable option which reflects light to display information, instead of using a backlight which would be common for other LCD modules or e-ink displays. The device will implement solar panels, with the secondary priority of power generation to achieve self-sustainability, over general aesthetic, size, or weight.

# 2 Research

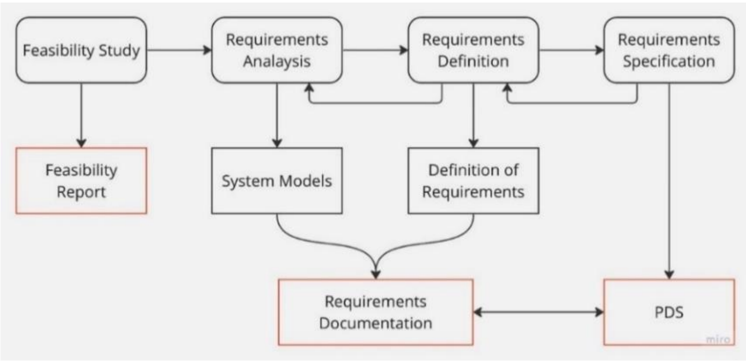



*Figure 1: Research flow [11], created in Miro*

## 2.1 Feasibility report

The feasibility of producing a self-sufficient device utilizing RLCD and solar panel technologies, while accommodating a suitable screen and memory storage, is the focus of this report. The primary factors that may pose limitations in the device production process are power consumption and cost. These factors will play a crucial role in determining the trade-offs among various components.

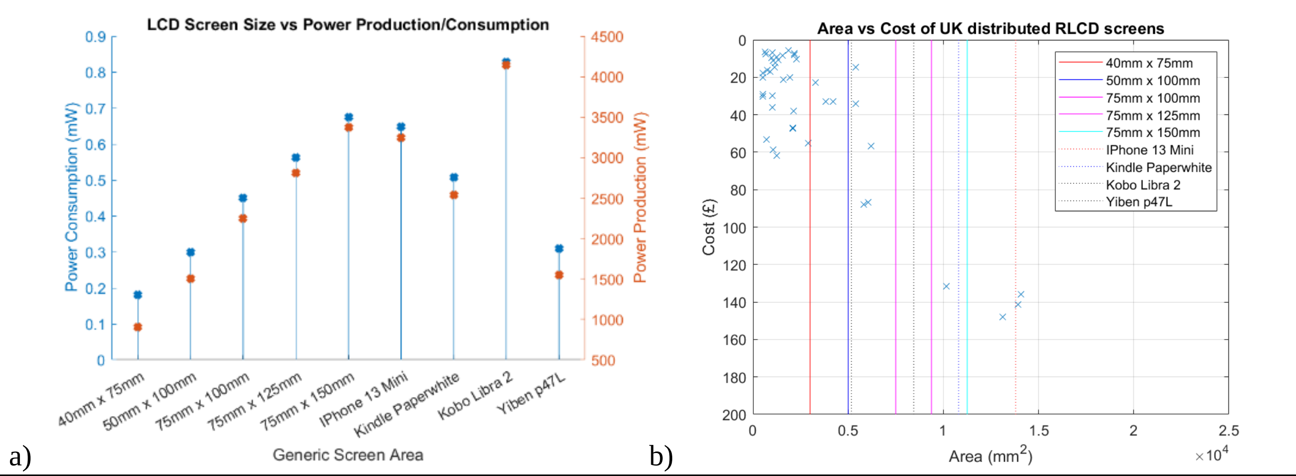



*Figure 2: Feasibility comparison graphs, created using Matlab and data from Digikey [15] and Mouser [16]*

Based on the assumption that RLCD continuously consumes approximately 6µ Watts per cm² [12]. Figure 2a showcases the power consumption of different arbitrary and existing device screen sizes. The figure also includes the solar generation from similar areas, demonstrating that the power generation from a solar cell surpasses the power consumption of screens with the same size. The average power output is derived from a power output of 0.03 Watts per cm²[13].

The Kobo Libra H20 is an e-reader that utilizes an RLCD display. The device consumes less than 1 Watt while active [14]. Based on this information, it can be assumed that a solar cell with a production capacity exceeding 1 watt would be deemed acceptable for the device.

In Figure 2b, the cost of RLCD screen components from Digikey [15] are presented alongside their corresponding areas. The listed areas from Figure 2a serve as a reference. It is important to note that the solar panel and screen are expected to be the most expensive components.

SD cards are available in a range of sizes, starting from 128MB and extending to multiple terabytes. Considering that the average text-based e-book typically occupies 1MB to 2MB of storage, a 16GB SD card would have the capacity to store over 8000 books [10]. When it comes to power consumption, SD cards experience spikes during reading and writing operations. However, the average power consumption is measured during their sleep state. The maximum power consumption of an SD card during sleep is recorded to be 4.95mA [16].

Lithium Polymer (LiPo) batteries are commonly used in e-readers due to their thin profile. Selecting a battery similar to the one found in an Amazon Kindle [17] would serve as a suitable foundation. It is worth noting that the average cost and size of batteries with these specifications do not differ significantly, as confirmed by consulting Mouser [18].

### 2.2 Product Design Specification (PDS)

| No. | Global/ Local | Category | Requirement | Target (x) | Limit | Priority | Test Method |
|---|---|---|---|---|---|---|---|
| 1 | Local | Dimensions | Height of e-reader must be x mm | 150 | 200 | Desirable | Pass/Fail |
| 2 | Local | Dimensions | Width of e-reader must be x mm | 75 | 125 | Desirable | Pass/Fail |
| 3 | Global | Maintenance | The e-reader should have a service interval of at least x hours | 5000 | 3000 | Essential | Physical Testing |
| 4 | Global | Performance | The e-reader should stay powered on for a minimum of x hours | 48 | 10 | Essential | Measure |
| 5 | Global | Performance | The screen shall be made using RLCD technology | Pass | Pass | Essential | Pass/Fail |
| 6 | Local | Performance | The e-reader should have a minimum of x GB storage memory approximately 400*x amounts of 300pg literature | 8 | 4 | Essential | Pass/Fail |
| 7 | Local | Performance | The e-reader should have at least x MB flash memory | 8 | 4 | Desirable | Pass/Fail |
| 8 | Local | Performance | The e-reader must have solar panels capable of providing all necessary power | Pass | Pass | Essential | Measure |
| 9 | Local | Performance | The e-reader must use a battery with a capacity of at least x mAh | 1500 | 1000 | Essential | Pass/Fail |
| 10 | Global | Performance | The e-reader must consume less than x watts | 1 | 1.5 | Desirable | Pass/Fail |
| 11 | Global | Material | The e-reader must be made of a material capable of withstanding exposure from the sun and high temperatures over prolonged periods of time | Pass | Pass | Essential | Pass/Fail |
| 12 | Global | Material | The e-reader must contain no hazardous material | Pass | Pass | Essential | Pass/Fail |
| 13 | Global | Risk | Should the e-reader fail, not harm must come to the user | Pass | Pass | Essential | Pass/Fail |
| 14 | Local | Cost | The screen should not exceed £ x cost | 20 | 30 | Desirable | Pass/Fail |
| 15 | Local | Cost | The solar cell should not exceed £ x cost | 10 | 20 | Desirable | Pass/Fail |
| 16 | Local | Cost | The battery should not exceed £ x cost | 10 | 20 | Desirable | Pass/Fail |
| 17 | Global | Cost | The overall cost of manufacturing the e-reader should not exceed £ x | 60 | 80 | Essential | Sum of costs |
| 18 | Local | Assembly | The e-reader must have buttons | Pass | Pass | Essential | Pass/Fail |
| 19 | Global | Assembly | The e-reader must be sealed during manufacture and must have resistance to environment. | Pass | Pass | Essential | Pass/Fail |

*Table 1: PDS*

### 2.3 Requirements documentation

Due to a limited choice of RLCD screen size, the choice of solar cell may also be limited. To focus on PDS requirements 1, 2, 14, 15, 17, the initial choice of RLCD screen will have to be near £20, as per section 2.1.

To ensure the manufacturing of the device is cost-effective, several factors will be prioritized. One of the key strategies to lower the cost of materials and components is to construct trade-off figures for each component, with price being one of the critical factors to consider, as specified in PDS 14, 15, and 16. By carefully analysing and comparing various components based on price, the aim is to optimize cost without compromising the overall functionality and performance of the device.

Internal storage is an available option, but it comes with the risk of data corruption, which could render the device unusable. To mitigate, incorporating an SD card port provides users with the flexibility to adjust the storage capacity as needed and facilitates easy removal of corrupted data. The design of the SD card port will focus on consuming minimal power, while adhering to the goal of low cost, as specified in PDS 6 and 10.

The objective is to develop a long-lasting battery that can sustain several days of continuous use on a single charge, while also being capable of being charged while in use for potentially unlimited usage, exceeding the requirements outlined in PDS 4. Although, with working towards this goal, the battery selected will exceed the minimum requirements specified in PDS 1 and 2, as capacity increases with size. Ideally, the solar cells will generate more power than what is consumed by the device. However, as a minimum requirement, a battery with a capacity of 1,500mAh will be chosen. To provide a point of reference, Amazon's Kindle, equipped with an 890mAh battery, can power their device for 4 to 10 weeks [17]

To ensure durability and ease of manufacturing, a chassis constructed from a robust material such as polycarbonate or Acrylonitrile Butadiene Styrene (ABS) plastic could provide effective protection. This material can be conveniently manufactured using 3D printing techniques. The device should feature simple and user-friendly controls, including a power button and navigational controllers. To conserve power, the device should avoid using a built-in speaker, although it can include a headphone jack for audio playback. In contrast, the speakers in the current iPhone 14 are rated for a power consumption of 3W [19], which is three times the total power consumption requirement outlined in PDS 10 for this device.

To ensure stable and safe operation, solar cells, which can generate power with varying voltage levels, can be regulated using a solar controller. This controller is utilized to maintain a consistent input voltage, typically around 3.3V, matching the voltage requirement of the device's circuit [20]. By doing so, the risk of exposing the battery to high voltage levels, which could pose potential dangers for the user, is minimized. A Maximum Power Point Tracking (MPPT) algorithm is essential for efficiently drawing power from the solar panel. Solar controllers, such as the Morningstar 30V Solar Charge Controller [21], are components able to facilitate an algorithm, though this particular device is primarily designed for commercial-scale solar panels. In contrast, lower-cost options for solar microcontrollers, such as the Farnell Dfrobot [22] are available. While the possibility of creating a solar controller from scratch will be explored, the option of using a pre-built controller will not be dismissed. Considering the criticality of reliability and user safety, as outlined in PDS 13, it is more ideal to utilize a tested product that has undergone thorough reviews.

## 2.4 Stakeholder analysis

| Stakeholder | Value | Influence | Objectives | Contribution | Impediment Potential | Engagement Strategies |
|---|---|---|---|---|---|---|
| Donors and investors | Medium | High | Reputational return on investment | Initial testing<br>Investment | Withholding capital | Meetings<br>Documentation<br>Ensure return on investment |
| End-users | High | Medium | Device usability and promised capabilities | Raising awareness<br>Utilizing the device | Rejecting its use | Contacting distributors<br>Highlighting usability |
| Government and regulatory bodies | Low | Medium | Ensuring safe distribution | Granting distribution permits | Opposing distribution | Legal support<br>Positive impact |
| Manufacturers and suppliers | Medium | Medium | Enhancing reputation | Supplying components | Supplying faulty components | Capital and reputation returns |
| Content providers | High | High | Awareness and popularity | Offering free licensing | Restricting book use | Reputation<br>Positive impact |
| Not-for-profit organisations | Medium | Medium | Reputational returns and impactful contributions | Providing capital and support | Refusing support | Documentation<br>Functionality<br>Safety<br>Positive impact |

*Table 2: Stakeholder Matrix*

# 3 Design methods

## 3.1 Design plan

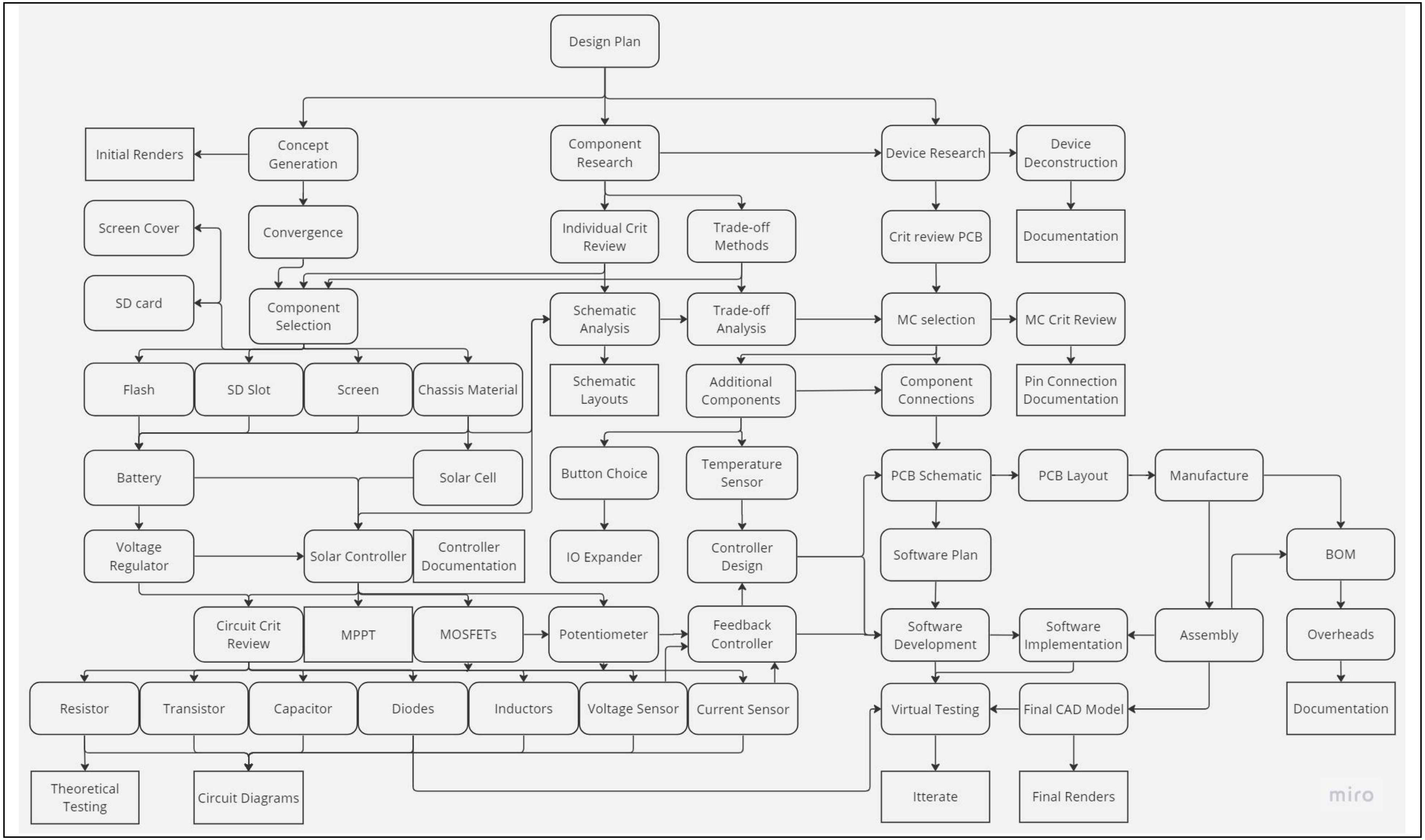



*Figure 3: Design systems diagram, created in Miro*

### 3.2 Concept generation

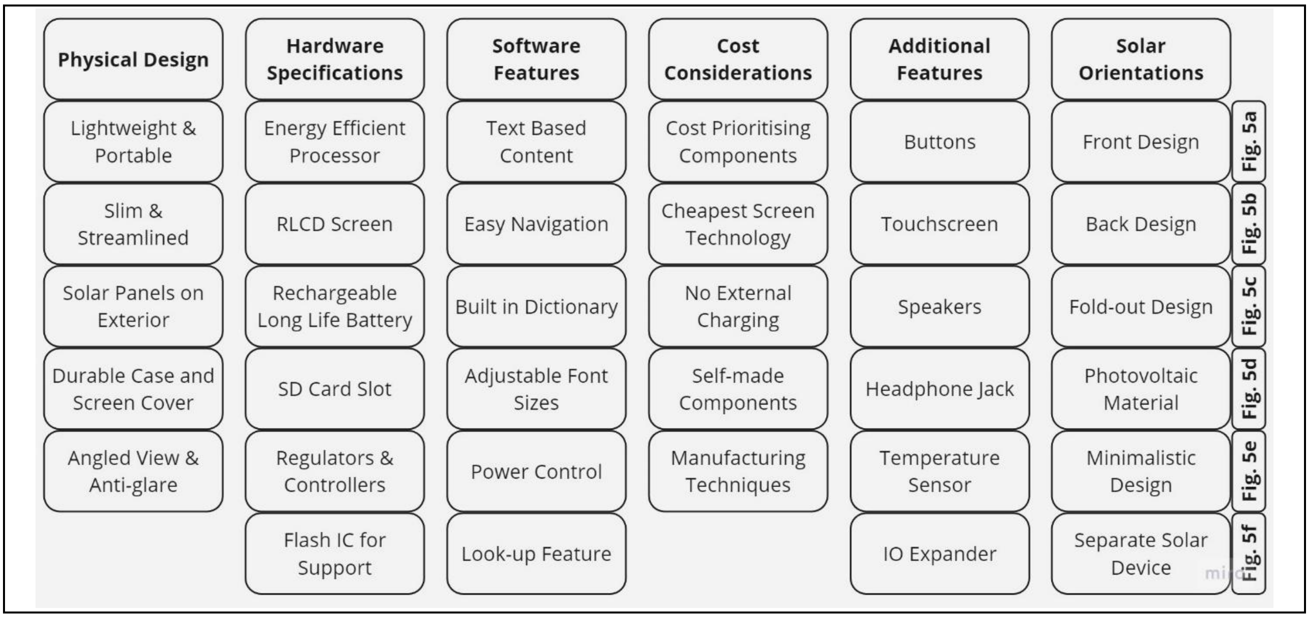



*Figure 4: Concept generation systems diagram, created in Miro*

### 3.3 Concept pre-visualisations

Figure 5 showcases various potential arrangements of the solar cells, contributing to the development of a foundational concept for the e-readers external design. Autodesk Fusion 360 was used.

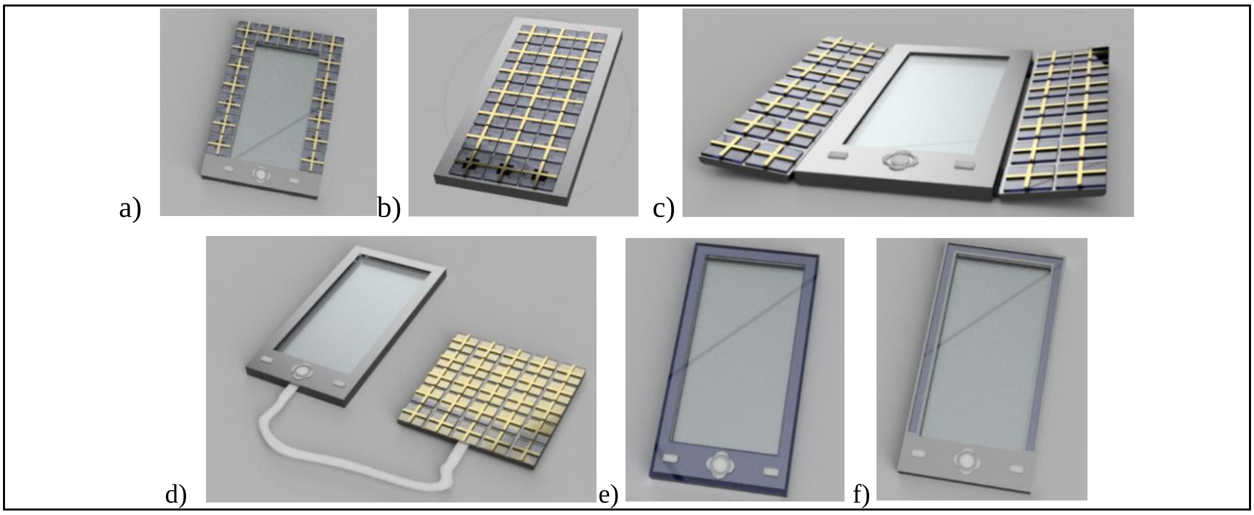



*Figure 5: Pre-visualisation, created in Autodesk Fusion 360*

### 3.4 Solar cell design convergence

| **Concept** | **Figure** | **Aesthetic** | **Assembly** | **Mass** | **Cost** | **Power Production** | **Total** |
|---|---|---|---|---|---|---|---|
| **Weightings** | **-** | **1** | **2** | **1** | **3** | **2** | **-** |
| Front Design | 5a | 3 | 3 | 4 | 4 | 3 | 31 |
| Back Design | 5b | 4 | 4 | 3 | **6** | **6** | **45** |
| Fold-out Design | 5c | 1 | 2 | 2 | 3 | 4 | 24 |
| Minimal Solar | 5d | 5 | 1 | 5 | 2 | 2 | 21 |
| Photoelectric | 5e | **6** | **6** | **6** | 1 | 1 | 29 |
| Separate Solar | 5f | 2 | 5 | 1 | 5 | 5 | 38 |

*Table 3: Solar celll design convergence*

Convergence Table 3 evaluates each concept based on various categories, ranked on a scale of 1 to 6, where 1 represents the worst and 6 represents the best performance. Each category is assigned a specific weight, which is multiplied by the individual concept scores. The scores are then totalled, and the concept with the highest overall score is identified as the optimal choice. Rankings were based on theoretical measurements.

The back design concept results with the highest score, emerging as the preferred choice. This concept not only achieves a high score but also enables the flexibility to accommodate various sizes of solar cells.

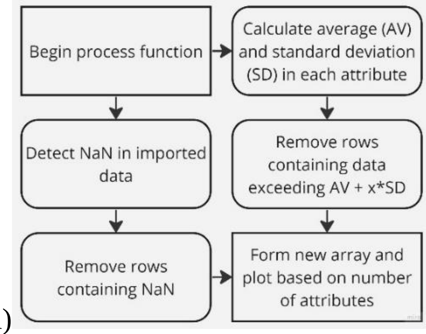
# 4 Component selection

## 4.1 Component selection methods

| | M | N | O | P | Q | R | S |
|---|---|---|---|---|---|---|---|
| 89 | //media.d | Kyocera International, Inc. | 702.25 | NaN | 53.49 | NaN | 26.50 x 26.50 |
| 90 | https://wv | Azumo | 1003.536 | 69690 | 29.81 | 230 x 303 | 36.36 x 27.60 |
| 91 | https://wv | Pervasive Displays | 5393.28 | 120000 | 30.1 | 400 x 300 | 84.80 x 63.60 |
| 92 | https://wv | Pervasive Displays | 45163.008 | 737280 | 210.81 | 960 x 768 | 237.60 x 190.08 |
| 93 | https://wv | Azumo | 1003.536 | 69690 | 36.38 | 230 x 303 | 36.36 x 27.60 |
| 94 | //media.d | Sharp Microelectronics | 6210.72 | NaN | 57.06 | 320 x 240 | 90.80 x 68.40 |
| 95 | https://wv | Azumo | 2904.5469 | 180096 | 55.53 | 336 x 536 | 42.67 x 68.07 |
| 96 | https://wv | Display Visions | NaN | 12384 | 88.38 | 172 x 72 | NaN |
| 97 | //media.d | MikroElektronika | 1151.1205 | 30500 | 14.59 | 122 x 250 | 48.55 x 23.71 |

*Figure 6: Screen section of component database: Columns: Datasheet, Manufacturer, Area, Pixels, Cost, Dimensions*

a)




b)

```
%%~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~SCREEN~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~%%
if screen == on
%Screen size vs resolution vs cost
load('Screen Data.mat')
screen_area_data = table2array(ComponentSelection(1:end,1)); %area
screen_pixels_data = table2array(ComponentSelection(1:end,2)); %pixels
screen_cost_data = table2array(ComponentSelection(1:end,3)); %cost
figure(1)
%data_array = process(data1,data2,...
%   0/data3,0/data4,multiplier,on/off,on/off,on/off,on/off,)
%on/off represents the control of outlier removal, on = upper removal
screen_array = process(screen_area_data,screen_pixels_data,...
    screen_cost_data,0,multiplier,off,off,on,off);
```

*Figure 7: Component selection code, flow created in Miro, code created in Matlab*

Each component of the device is assessed based on 2 to 4 main attributes, which are then compared against each other. This comparison is visualized using 2- or 3-dimensional graphs, with a colour bar utilized for components with 4 variables. These graphical representations aid in weighing and evaluating the attributes of each component in relation to one another.

A comprehensive database was created in Excel for each component, utilizing downloadable databases from Digikey and Mouser. Both sellers offer downloadable comma separated value files, enabling the construction of individual component databases with a minimum of 100 objects. Additionally, these sources consistently provide footprints and 3D models for each device, aiding in the design process. Figure 6 showcases a segment of the screen section within the database, highlighting the collected information. Note, the material selection was facilitated using Polymer Database [23] and Goodfellow [24].

Downloading a wide array of components can lead to issues such as discrepancies in individual product data. In Figure 6, for instance, the Kyocera International. Inc screen model on row 89 lacks a displayed resolution, resulting in the value being shown as Not a Number (NaN). Another challenge is dealing with outliers that could potentially skew the graph. Furthermore, consistency in trade-off processing is essential, regardless of the number of attributes being weighed up. Each component should undergo the same trade-off analysis process to ensure fair and comparable evaluations.

To address these challenges, code was developed to handle the specific issues encountered. For managing multiple attribute trade-off processing, a function called "process" was created. This function follows the flow depicted in Figure 7a. The process code is designed to automatically detect the number of data sets being used and, consequently, the number of attributes involved.

For products with non-applicable inputs, the values are changed automatically to NaN by Matlab when the data is loaded from the excel file. The code detects the row number that the NaN occurs on and deletes the row and carries on, which also pulls the row back every time it removes one to keep up with data.

The code automatically identifies data values that are significantly above or below the average for products within a specific range, which could be considered outliers. This detection can be customized by specifying whether the outliers should be above or below the average. The code provides inputs for this configuration through the 6th to 9th inputs in the process function. Once identified, the code removes the rows of data that contain these outlier values. Figure 7b represents the code that loads the screen data and initialises the process function.

## 4.2 Trade-off figures

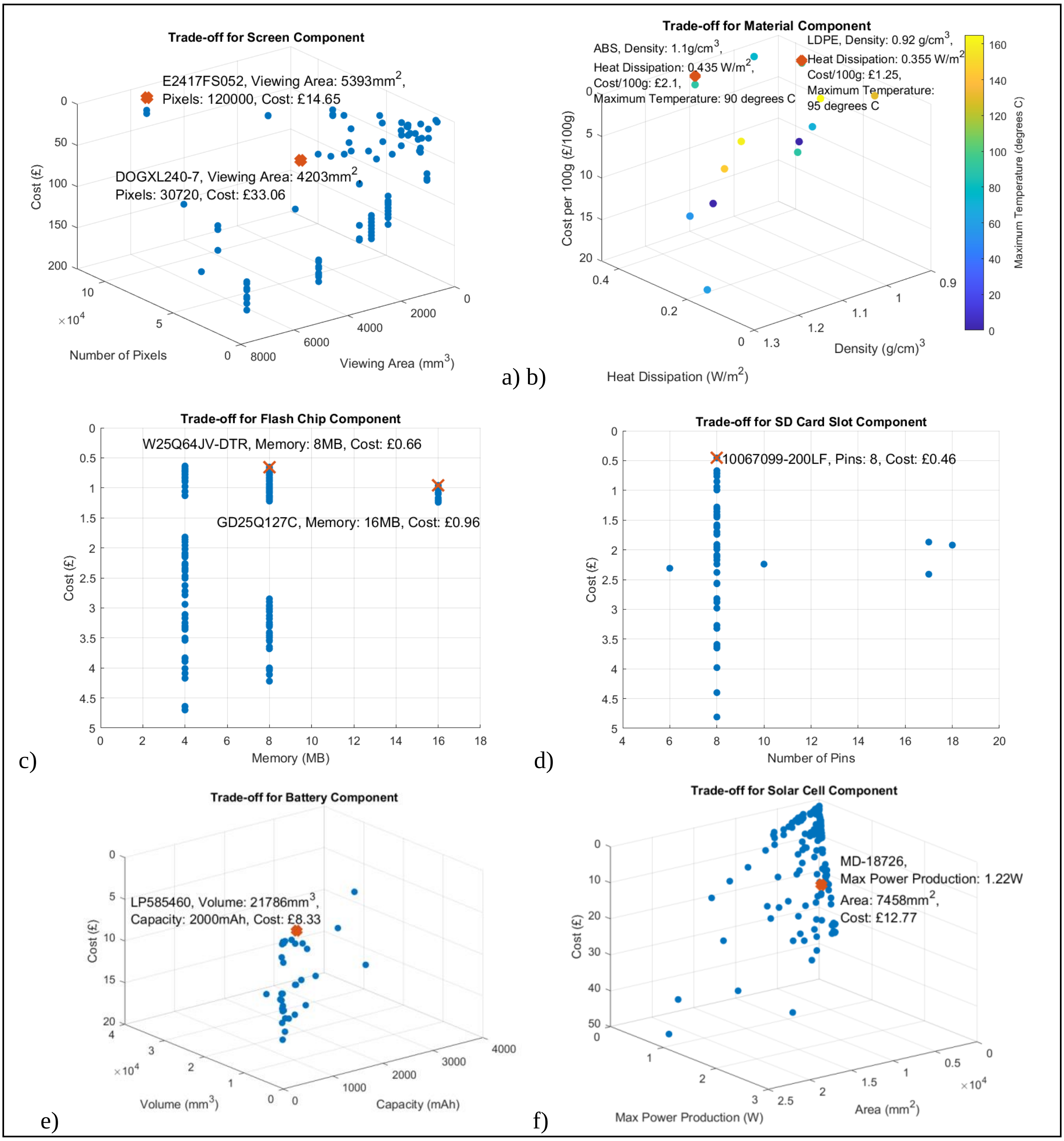



*Figure 8: Trade-off Figures, created using process trade-off code in Matlab*

## 4.3 Component selection

### 4.3.1 Screen

The limited availability of certain components arises when relying exclusively on suppliers such as Mouser and Digikey. There is a scarcity of affordable RLCD displays that offer both a sufficient viewing dimension and a large pixel count, therefore, the inclusion of Electronic Paper Displays (EPDs) were considered. The attributes prioritized for selecting a screen encompassed a large relative viewing area, a significant pixel count, and a low cost. The optimal screen, depicted in Figure 8a and priced at £14.65 from Pervasive Displays (PD), is an EPD display [25]. This product boasts a resolution of 400x300 pixels and operates with a low power consumption of 25mW. Regarding RLCD screens, the best option identified was the EA dogxl240-7 (EAD) [26]. The screen incurs a higher cost of £33.06, as well as featuring a smaller display area and a lower pixel count. The EAD draws a low current of 900uA, resulting in a power consumption of approximately 2.97mA, significantly lower than the PD product. While the power consumption of the PD display is 15 times higher than that of the EAD, opting for the EAD would detrimentally affect the overall user experience due to its limited viewing capability. Additionally, the EAD offers cost advantages compared to the PD display.

#### 4.3.2 Chassis material

To prioritize cost reduction and weight reduction, the focus is placed on minimizing costs and density. Given the prevailing temperatures in SSA and the expected exposure to direct sunlight, it is essential to select a material that efficiently dissipates heat to the surrounding air. Consequently, the attributes of heat dissipation and maximum temperature are maximized during the material selection process.
The outcome of this selection process identifies Low-density Polyethylene (LDPE) as the optimal material, as depicted in Figure 8b. However, it should be noted that LDPE is more commonly used for cable wrapping rather than chassis building [27]. As a contender, ABS exhibits high heat dissipation properties, facilitating even heat distribution for the internal components of the device. ABS is also commonly used in 3D printing, enabling cost reduction and a simplified manufacturing process. With material costs outlined in section 7.2.

#### 4.3.3 Flash IC

The device necessitates the presence of a flash chip to cater to firmware and operating system storage. Power consumption and cost decrease with smaller flash cards, though memory must be maximised. The flash serves the purpose of storing recently accessed books and sections of the OS if the MC memory proves insufficient. In the software stage, the need for increased flash storage arises based on the required number of libraries, though this is improbable. An 8Mb data capacity enables storage of 20,000-160,000 lines of code [28]. Figure 8c exhibits the two most affordable components in the 8Mb and 16Mb range. Both ICs are feasible, yet the smaller option is chosen [29] given that the memory difference should not yield distinction.

#### 4.3.4 SD card slot

For the selection of the SD card slot, the main distinguishing factor among the options is the number of pins (maximised) and cost (minimised). Typically, SD card slots feature 8 pins, although 16 or 18 pins can also be common. Slots with more pins include additional features such as card detection, faster transfer rates, and write protect detection [30]. However, none of these features are required for the SD slot in question, as privacy is not a concern, and the data transfer volume is low due to the limited storage of book pages. The chosen SD card slot is depicted in Figure 8d [31].

#### 4.3.5 Battery

To overcome the limitations on batteries available through Mouser and Digikey, the supply database was expanded to include all batteries [32] and cool components [33]. The crucial attributes for the battery selection are its capacity (maximised), size (minimized), and cost (minimized). Figure 8e showcases the optimal battery choice, which is a 2000mAh 3.7V battery [34].

#### 4.3.6 Solar cell

Wiring multiple solar cells would necessitate either different control systems for each cell or a more complex overall system. Under consideration of the external design choice made in section 3.4, Figure 8f displays the chosen option that combines low cost with higher power production effectively. To accommodate buttons, the front of the device will be approximately 1.5 times the length of the screen. Given that the screen area measures roughly 5390mm² [25], an active area of approximately 7500cm² was selected [35].

# 5 Printed Circuit Board design

## 5.1 Methodology

The use of SamacSys' Component Search Engine by Mouser UK facilitates the provision of PCB symbols, footprints, and 3D models for the components, which are referred to as component assets [36]. These component assets are automatically downloaded into a library within Autodesk Fusion 360 through the utilization of client-side software Library Selector [37].

The software used to create the preliminary designs, Autodesk Fusion 360, acquired Easily Applicable Graphical Layout Editor (EAGLE) CAD in 2016 [38], a specialized software for building electronic circuits and PCB boards. This combination of software in Fusion 360 enables the creation of a final product that includes a generated model of the PCB itself.

## 5.2 Micro-controller choice

The Open-Book, created by Joey Castillo, is a device that places a high priority on affordable manufacturing or construction at home [39]. The design has undergone three iterations, each utilizing different microcontrollers (MCs). The choices for comparison include the Raspberry Pi Pico Board (RPPB) [40], the winner of the ranking, the SAMD51 (Featherwing M4) [42] and the ESP32, which is in the same market.

| MC | Cost | No. of GPIO (General-Purpose Input/Output) | Power Req. | Size | ADC (Analog to Digital) | Memory | Refresh Rate | Additional Features | Score |
|---|---|---|---|---|---|---|---|---|---|
| **Weight** | **5** | **3** | **4** | **1** | **3** | **2** | **1** | **2** | **-** |
| **(a) RPPB** | **£4.0** | 26 | 38 | **2 x 51.3** | 3 | **2** | 60 | Inbuilt board | **46** |
| **(b) SAMD51** | £4.5 | 21 | **12** | 50.8x 22.8 | 6 | 1 | 120 | | 41 |
| **(c) ESP32** | £8 | **34** | 240 | 54.6x 23.4 | **16** | 0.5 | 240 | **In built Wi-Fi + Bluetooth** | 39 |

*Table 4: Microcontroller Comparison Table, data obtained from MC datasheets and Farnell [43]*

## 5.3 Interfacing

The choice of interface for the device will be between Inter-Integrated Circuit (I2C) and Serial Peripheral Interface (SPI). SPI is a 4-wire protocol, while I2C is a 2-wire protocol [44]. Considering that power consumption is the main priority and cost is not a determining factor, the interface with the lowest power consumption will be preferred, although this can be changed as needed. SPI provides faster data transfer rates and lower power consumption due to its dedicated channels for information transfer.

In various protocols, the Command and Data mode (CMD/CD) pins are used to determine the type of communication. Chip Select (CS) pins enable or restrict interaction with the device, ensuring efficient communication management. The Clock Pin (CLK) is responsible for synchronizing data transfer during serial communication, maintaining signal integrity. Data transmission between master and slave devices is facilitated through the Master Out Slave In (MOSI) and Master In Slave Out (MISO) channels. Positive supply voltage (VDD) is utilized to power the device, while the Ground reference voltage (VSS) establishes a common ground, stabilizing the electrical circuit.

In the schematic diagram, Figure 10, several pull-up resistors are connected. These resistors establish a permanent connection to a high level on a specific line. When the MC interacts with the connected pin, it signals the component by transitioning the signal from high to low, indicating communication and eliminating the possibility of floating points. Pull-up resistors are primarily used for CS pins and the switches involved in the circuit. The RPPB datasheet recommends using pull-up resistors with a value of 10kΩ.

## 5.4 PCB Board and Schematic

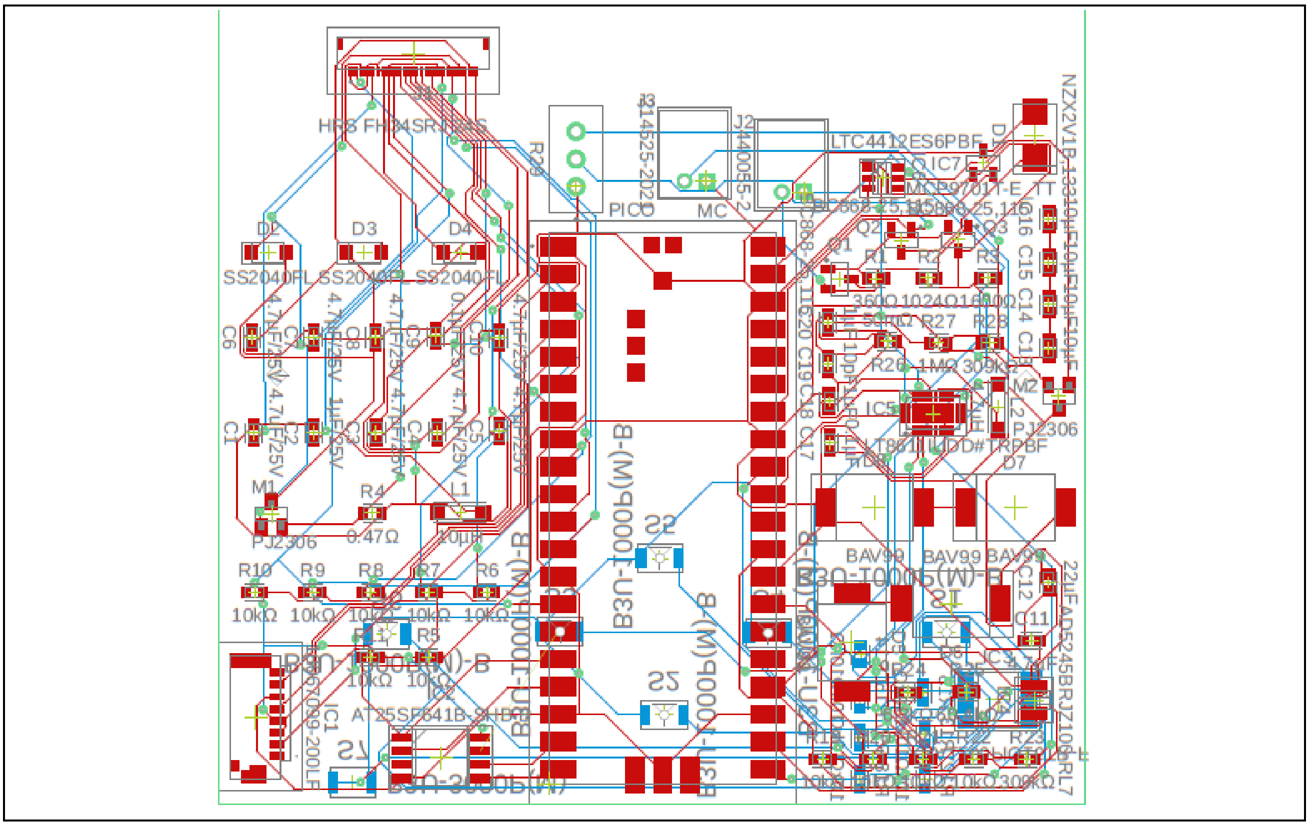



*Figure 9: PCB Layout, created in Autodesk Fusion 360 EAGLE, footprints from Component Search Engine [36]*

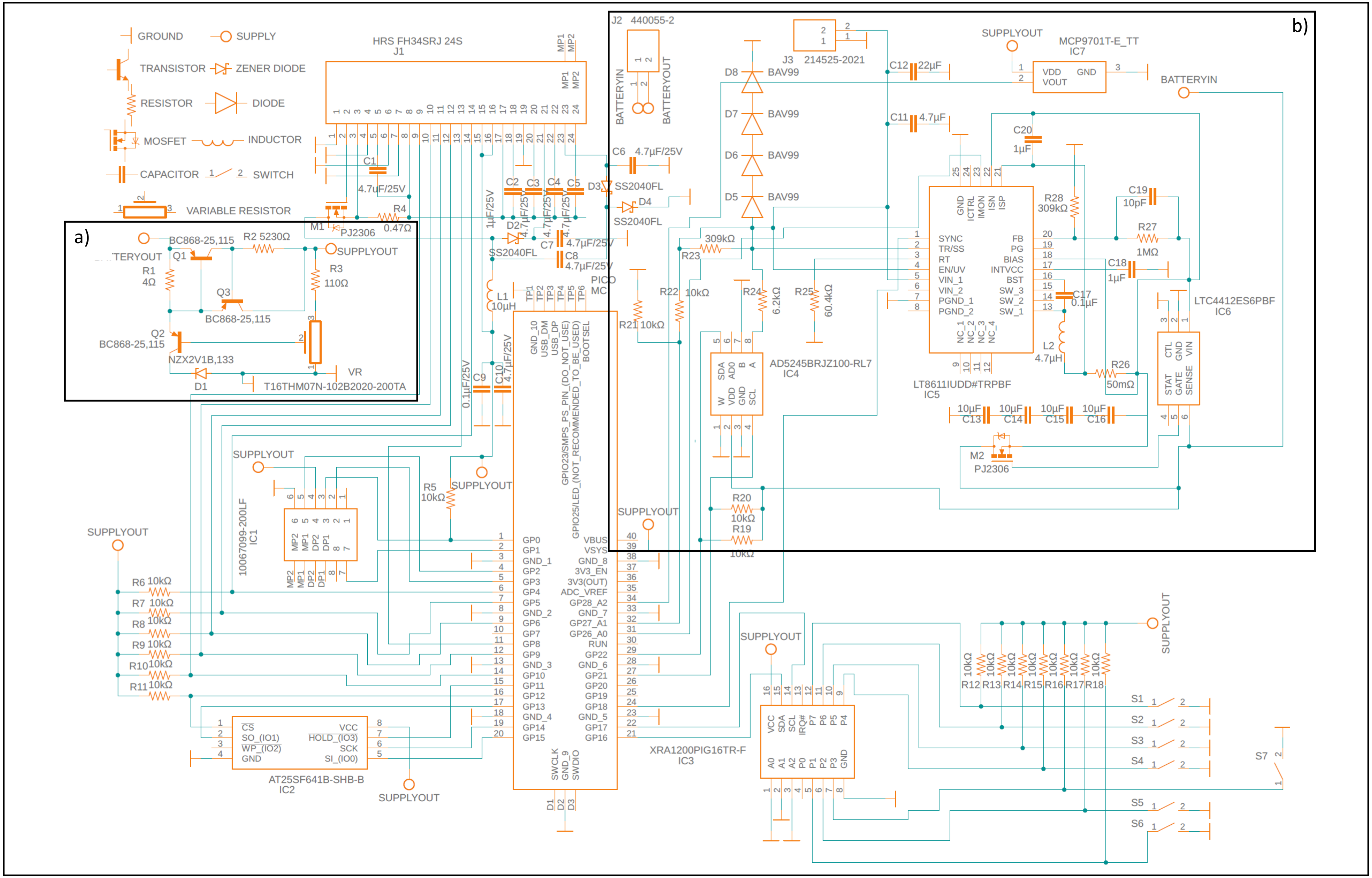


*Figure 10: PCB Schematic, created in Autodesk Fusion 360 EAGLE, footprints from Component Search Engine [36]*

## 5.5 Component Analysis

### 5.5.1 Screen E2417FS052 [25]: Figure 10, J1

The screen of the device features a flexible printed circuit, and the recommended connector is the HRS FH34SRJ 24S [45]. This 24-pin connector is capable of interfacing with the MC and is necessary for high-speed data transmission, as the screen does not have a built-in connector. The recommended circuit configuration, including components such as M1, L1, C1-10, D2-4, and ground connections (GND), is taken from the E2417FS052 datasheet. Multiple pull-up resistors, R6-10, are required for a stable connection.

### 5.5.2 Flash IC W25Q64JV-DTR [29]: Figure 10, IC1

The RPPB will instruct the Flash Integrated Circuit (IC) to hold and transmit information via the MOSI line to store data within the flash chip. A basic dictionary will be coded for, along with a tool to look up key words within the books and the dictionary itself. Due to limitations of flash memory, the onboard dictionary may need to be an edited version of the standard dictionary. With an average word size of 6 bytes [10], a definition can be expected to occupy approximately 100 to 200 bytes if formatted in plain text. Assuming concise definitions, it is estimated that 6MB of data could accommodate around 30,000 definitions. To compare, there are 310,000 definitions listed in the Oxford Dictionary [46]. Preferably a local language would be integrated alongside English to serve as a translator for difficult words or for educational purposes.

### 5.5.3 SD card 10067099-200LF [31]: Figure 10, IC2

An 8-pin micro-SD card will be compatible with the SD card slot. Two separate data lines will be established, with the CD/DAT3 line (pin 2) serving as the MOSI line and the Dat0 line (pin 7) as the MISO line. As the SD card will not be written onto, the CD/DAT3 line can be exclusively dedicated to a CD line.

### 5.5.4 Battery LP585460 [34]: Figure 10, J2

The battery LP585460 is equipped with a built-in Protection Circuit Module (PCM), eliminating the need for an external PCM. It supplies a maximum voltage of 4.2V. However, the other components require a maximum voltage of 3.3V. To achieve this voltage down-step, a voltage regulator is utilized. Further details about this controller can be found in section 5.6. A JST-PHR female connector, 440055-2 [47], is employed to connect the battery to the circuit, with the BATTERYOUT line leading to the voltage regulator and the BATTERYIN line originating from the solar controller.

### 5.5.5 Solar cell MD 18726 [35]: Figure 10, J3

MD 18726 features a simple connection with positive and negative terminal wires. The positive wire should be connected to the input on the solar controller, while the negative wire should be connected to ground. Wires will be soldered to the positive and negative terminals of the solar panel. A 2-way wire housing, specifically the 214525-2021 [48], will be used to connect these wires to the PCB.

### 5.5.6 Push button MHPS2283 [50]: Figure 10, S1-6, Slide button PCM12SMTBR [51]: Figure 10, S7

When the button is pressed or slid, it will either temporarily or permanently complete a circuit. For instance, Switch S1 is connected to pin 7 of the IO expander from pin 1, while pin 2 is connected to ground. Pull-up resistor R12 maintains a constant high output to the IO expander. When the circuit is grounded, indicating that the button is pressed, the output becomes low. This low signal can be detected by the RPPB via GPIO 16, indicating that the button has been momentarily pressed.

### 5.5.7 GPIO expander XRA1200PIG16TR-F [49]: Figure 10, IC3

The GPIO expander is necessary since the available GPIO pins on the RBBP are insufficient to accommodate all the button connections. During pin initialization, each switch will be assigned a dedicated pin within the subdirectory of the expander. The IO expander is connected to the RPPB via a MOSI and SCK line.

### 5.5.8 Temperature sensor MCP9701T-E/TT [52], Figure 10, IC7

An alert will be triggered to the user by the temperature sensor when the device reaches approximately 40 degrees. Exceeding this temperature threshold poses a significant risk of harm to the user. If the temperature continues to rise, the device will automatically shut down, including turning off the solar controller. The sensor is connected to an ADC on the RPPB, which measures voltage changes corresponding to temperature. This voltage is then converted to temperature in the OS.

## 5.6 Voltage regulator, Figure 10a

In the presented circuit design [53], the Zener diode functions as a voltage reference and a switch, grounding the circuit upon reaching its Zener voltage (ZV). Ordinarily, with a simple parallel diode configuration, the ZV would be set to the desired output voltage of 3.3V. However, the incorporation of transistors reduces power dissipation and provides more precise voltage regulation. The peak current draw of the device was calculated to determine the necessary specifications for the voltage regulator. The cumulative current draw of the RPPB [54], screen [25], and SD slot [31] were found to be approximately 94.2mA. With a safety factor of 1.5, the maximum total current demand is estimated to be 150mA. The chosen NPN transistor, BC868-25,115 [55], satisfies these current requirements and possesses a maximum collector-emitter voltage (Vce) that exceeds the input voltage of 4.2V. The transistor's base-emitter voltage (Vbe) is 0.6V, and the current gain(hFE) is 220 at 25 degrees Celsius and 150mA. The potentiometer's (VR) voltage rating was decided based on calculating the maximum voltage across it as shown in equation [1]. The Zener diode's specifications were selected based on the guideline that its current rating should be approximately 10% of the maximum total current [56]. A Zener voltage of 2.1V was determined, accounting for the base-emitter voltage drop across the transistors in equation [2]. The values for resistors R1, R2 were initially calculated using equations [3] and [4] respectively, and then refined with Simulink circuit builder to align with standard resistor values [57]. R3 acted as a resistor that could be fine-tuned and hence was determined in Simulink.

$$VR_{max} = V_{in\ max} - Q2_{base\ emitter} \quad [1]$$

$$V_{zener} = V_{out} - Q1_{base\ emitter} - Q3_{base\ emitter} \quad [2]$$

$$R1 = \frac{V_{base\ emitter}}{I_{limit}} \quad [3]$$

$$R2 = \frac{hFE * (V_{in} - V_{base\ emitter})}{I_{collector}} \quad [4]$$

### 5.7 Solar controller Figure 10b

The controller is based on a reference circuit for developing a microcontroller from Analog Devices [58]. The step-down regulator LT8611 IC5 [59] is utilized, with a maximum input of 42V and a limit of up to 2A. This regulator ensures high efficiency in power conversion with its low quiescent current of 2.5uA. The voltage regulator diode is replaced by the Low Loss PowerPath controller LTC4412 IC6 [60] to minimize power dissipation. The AD5245 IC4 [61], a potentiometer in rheostat configuration, is used for controlling the solar panel through resistive perturbations rather than Pulse Width Modulation (PWM). This simplifies the control algorithm, especially in the Perturb and Observe (PO) algorithm explained in section 6.1.

## 6 Software development

RPPB can be programmed using either MicroPython (MP) or C++. MP is chosen due to personal previous experience in Python. Thonny Python IDE [62] is used to build the code in a virtual environment.

### 6.1 Maximum Power Point Tracking

The process of the PO algorithm is illustrated in Figure 11a. Measurements of the solar cell's output voltage and current are received by the RPPB through ADC pins GPIOA1 and GPIOA0, respectively. The RPPB runs a developed MPPT algorithm to optimize power extraction. Due to limited modelling capabilities, the PO algorithm is tested with a simpler controller. Figure 11b shows the block arrangement in the Simulink design space, and Figure 12 displays a graph of power output over time steps. Variations in power are influenced by changes in irradiance and temperature. The small ripples represent the algorithm perturbing the MOSFET to regulate the circuit's output current by opening and closing the switch. A longer settling time was anticipated, but the solar panel power output maximum not being high explains the observed behaviour.

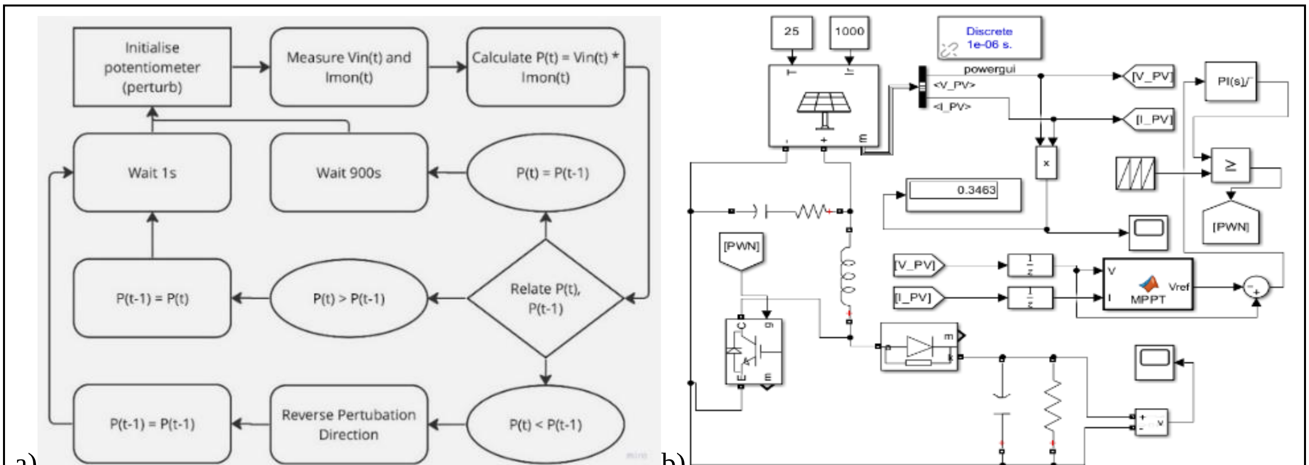



Figure 11: MPPT, flow created in Miro, block diagram created in Simulink

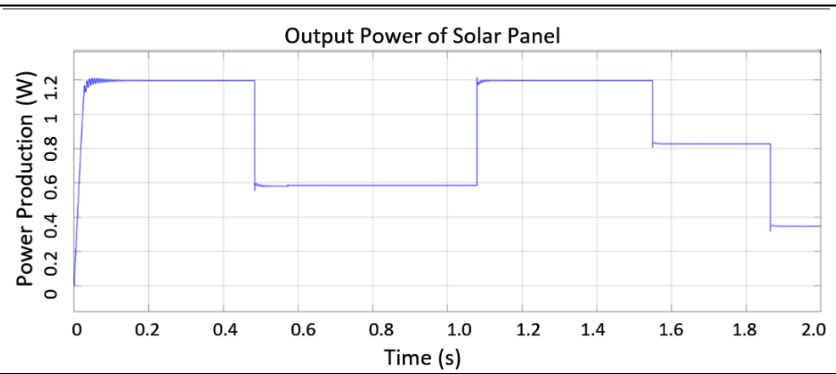



*Figure 12: Effect of Perturb and Observe, made from Simulink block setup*

### 6.2 General software

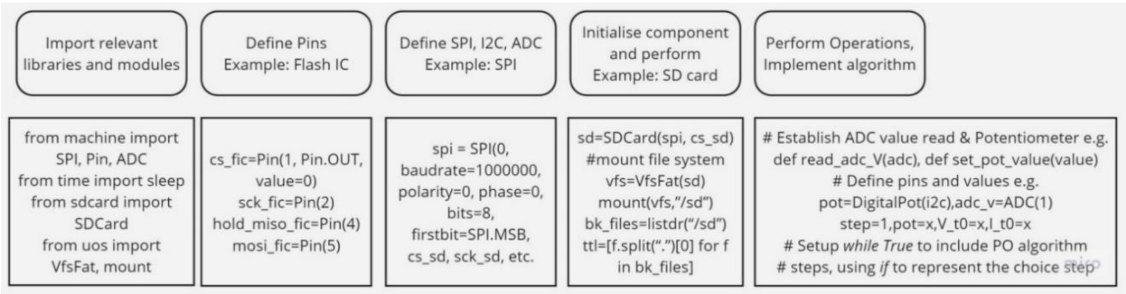



*Figure 13: General Software Flow, created in Miro*

The general flow of the OS code within RPPB is described by Figure 13.

# 7 Manufacture

## 7.1 Manufacture of chassis and PCB

The chassis, including holders for the battery, screen, solar panel, and PCB, will be 3D printed. The estimated mass of ABS required is 250g, as measured in Fusion 360. The PCB design will be submitted to PCBway [63] for evaluation and pricing. The general price quoted for a simple dual-sided standard PCB with 2 layers and specified dimensions is £5.00.

## 7.2 Bill of Materials

| Component | Manufacture Number | Units | Individual Price (£) | Mass Price £/100 | Mass Price £/1000 |
|---|---|---|---|---|---|
| **Screen** | £ | 1 | 14.65 | 14.65 | 14.65 |
| **Flash** | W25Q64JV-DTR | 1 | 0.94 | 0.76 | 0.71 |
| **SD slot** | 10067099-200LF | 1 | 0.70 | 0.49 | 0.39 |
| **SD** | SDSDQEB-008G [64] | 1 | 10.55 | 8.37 | 8.03 |
| **Battery** | LP585460 | 1 | 8.33 | 7.50 | 7.50 |
| **Chassis** | ABS material 250g | 1 | 6.00 | 3.50 | 3.50 |
| **PCB** | COMPANY | 1 | 5.00 | 2.50 | 1.50 |
| **Solar cell** | MD-18726 | 1 | 13.00 | 11.50 | 11.50 |
| **Resistors** | - | 29 | 2.90 | 0.29 | 0.29 |
| **Diodes** | - | 8 | 0.80 | 0.08 | 0.08 |
| **NPN Transistors** | BC868-25,115 | 3 | 1.32 | 0.72 | 0.35 |
| **Capacitors** | - | 20 | 2.00 | 0.20 | 0.20 |
| **Mosfets** | - | 2 | 0.60 | 0.3 | 0.02 |
| **Inductors** | - | 2 | 0.20 | 0.02 | 0.02 |
| **Button push** | TL2285OA | 6 | 5.10 | 3.96 | 3.36 |
| **Button slide** | PCM12SMTBR | 1 | 0.90 | 0.70 | 0.55 |
| **MC** | RPPB | 1 | 4.29 | 4.00 | 4.00 |
| **Temperature Sensor** | MCP9701T-E/TT | 1 | 0.27 | 0.19 | 0.19 |
| **Step Down regulator** | LT8611IUDD#TRPBF | 1 | 10.36 | 7.74 | 6.14 |
| **PMIC** | LTC4412ES6#TRPBF | 1 | 3.79 | 2.78 | 2.02 |
| **potentiometer** | AD5245BRJZ100-RL7 | 1 | 2.12 | 1.53 | 1.04 |
| **IO Expander** | XRA1200PIG16TR-F | 1 | 1.15 | 0.81 | 0.53 |
| **Screen Connector** | HRS FH34SRJ 24S | 1 | 2.38 | 1.91 | 1.22 |
| **Battery Connector** | 440055-2 | 1 | 0.11 | 0.08 | 0.06 |
| **Solar Cell connector** | 214525-2021 | 1 | 0.45 | 0.26 | 0.20 |
| **Total** | - | - | 103.08 | 72.34 | 62.55 |

*Table 5: Bill of Materials, constructed by consulting Digikey and Mouser*

# 8 Device evaluation

## 8.1 Evaluation of project success

The title of this report is not adhered to by the chosen screen, resulting in an adjustment of PDS 5. The issue of RLCD screen size limitation could not be ignored, and a better fit was found in the EPD display, which boasts a higher pixel count and a lower price point. The height of the e-reader meets the target of 138mm, as specified in PDS 1. However, the width is seen to be 88mm, exceeding the target of PDS 2, but remaining within the limit. The width and height of the final device may be considered an improvement on original expectations, as a device with a near 4:3 aspect ratio has been found to be comfortable to hold and view. Due to virtual modelling, the service interval PDS 3 cannot be tested. A maximum power draw of 495.5mW is achieved by the device, fulfilling PDS 10, additionally this could decrease by a factor of 10 under nominal conditions. The battery capacity of 2000mAh, exceeding PDS 9, allows the device to theoretically last 13.3 hours under maximum current load, but potentially up to 130 hours under nominal conditions, adhering to PDS 4. Features such as an SD card, 8MB flash storage, and navigational buttons are included in the device, achieving PDS 6, 7 and 18. ABS was chosen partly due to its environmental exposure protection, theoretically achieving PDS 11, although physical testing would be necessary for true evaluation. No hazardous materials are contained in the chassis, although the internal components may include some alongside the PCB board being manufactured with lead. LiPo batteries, containing hazardous materials, are unavoidable. Since unavoidable, PDS 12 is not met. The major problem with the device might be the failure to achieve PDS 13. Without physical testing, it is impossible to determine if there is absolutely no risk to the user. If a prototype were to be built, this issue would need to be tackled directly, and it would be a priority. The overall price of the device was £103.08, failing PDS 17, primarily due to unexpected parts becoming necessary later in the project and the use of distributors able to provide footprints. The costs of the screen, solar cell, and battery were £14.0065, £13.00, and £8.33, respectively. While the screen and battery costs met the target set in PDS 14 and 16, the solar cell fell within the limits dictated by PDS 15. A thorough investigation into the complete manufacturing process from start to finish has not yet been conducted. However, in the current state of building individual devices and forming prototypes, a perfect seal would not be achieved due to at home assembly techniques. Other environmental factors, such as dust or water, have not been considered in this report, resulting in a failure of PDS 19.

## 8.2 Further work

While attempting to construct a device that adheres to multiple internal specifications not foreseen at the beginning, several areas are left with work to be done. Most of these limitations stem from the exclusive reliance on virtual modelling of the device as well as time constraints. With a physical prototype, multiple factors could be tested, and the product's true viability could be assessed.

If a prototype of the device were built, many technical aspects could be appropriately evaluated. The main assessment point would be the connection between the solar cells and the LiPo battery. If the battery receives excessive voltage, there is a risk of causing harm to the user. To test this, the solar cell should be connected via its solar controller to a higher voltage battery that is not at risk of explosion. A data scope reading the ADC data would read the solar cell output and measure it against varying light levels. The data results would allow for solar controller adjustments. Further improvement in control could be achieved by having a separate report on the proportional plus integral controller built into the feedback algorithm, resulting in a finely tuned transfer function. More thorough validation is generally required. Methods could be through extensively detailed virtual models as well physical testing and consulting various fundamental equations.

A deeper research aspect should have been included in the feasibility report, thoroughly assessing the individual components required for a device of this type. A more accurate cost assessment could have been conducted, along with considerations for other aspects in the report. During research, multiple legal factors were considered, mostly from the International Electronics Commission (IEC). Extensive research would be required for this particular topic, ideally involving a consulting legal guide, leading to the decision to exclude this topic from the report.

Further research into the use of multiple solar cells was not included to avoid overcomplicating the device at this early stage, but investigating the technical requirements would enable a greater range of device designs. The component selection section of the report could have included more figures on various internal components, possibly comparing different solar controllers and selecting individual resistors, transistors, diodes, and capacitors. Producing more trade-off figures would allow for more robust choices.

The PCB would require testing. Each selected component would be sourced, and a prototype of the e-reader would be built. A testing regime of battery testing, general voltage testing of units with a lower chance of short-circuiting, software testing, and temperature testing would be followed. Environmental testing would also be conducted. Multiple prototypes would likely be required for a full product assessment.

The software's functionality with the allowed flash memory set might be limited. The software code would need to be tested in various ways, such as checking if the screen displays correct data, if data can be extracted from the SD card, and using a multi-meter to test if the various controllers within the device operate nominally. Regarding the book data, Electronic Publication (EPUB) would be the chosen format. Further research must be conducted to determine whether there are enough medical texts supporting this format.

The PCB could benefit from fine-tuning, and a full evaluation of each individual component's purpose would provide clarity. The choice of SPI protocol as the interface limited the amount of GPIO access on the RPPB. Opting for I2C would eliminate the need for the GPIO expander, though data transfer rates would decrease.

In terms of manufacturing, using non-UK distributors could further reduce device costs, but the reliability of each component would significantly decrease. Each footprint would also need to be designed from the datasheet itself, consuming a considerable amount of time.

# 9 References


[1] Heather F McClintock, Julia M Alber, Sarah J Schrauben, Carmella M Mazzola, Douglas J Wiebe, 2020, “Constructing a measure of health literacy in Sub-Saharan African countries”, *Health Promotion International*, Volume 35, Issue 5, Pages 907–915, https://pubmed.ncbi.nlm.nih.gov/31504512/ [Accessed: 12/02/2023]

[2] Fredriksen, B., Brar, S., Trucano, M., 2015, “Getting Textbooks to Every Child in Sub-Saharan Africa: Strategies for Addressing the High Cost and Low Availability Problem. Directions in Development--Human Development”, © Washington, DC: World Bank, http://hdl.handle.net/10986/21876 [Accessed: 12/02/2023]

[3] Kisakye, E., Burrel, L., 2020, “How solar-powered tablets are educating rural communities about COVID-19 in Mozambique”, https://www.unido.org/stories/how-solar-powered-tablets-are-educating-rural-communities-about-covid-19-mozambique [Accessed: 19/02/2023]

[4] Flapke, 2011, “Solar Charging E-reader.”, https://www.instructables.com/Solar-charging-ereader/ [Accessed: 19/02/2023]

[5] The World Bank, 2020, “Access to electricity, rural (% of rural population) – Sub Saharan Africa”, https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=ZG [Accessed: 12/02/2023]

[6] The World Bank, 2020, “Solar Photovoltaic Power Potential by Country”, https://www.worldbank.org/en/topic/energy/publication/solar-photovoltaic-power-potential-by-country [Accessed: 12/02/2023]

[7] Oluwole, V., “Top 10 hottest countries in Africa in 2022”, https://africa.businessinsider.com/local/lifestyle/top-10-hottest-countries-in-africa-in-2022/25kpe0y#:~:text=Mali%20is%20the%20hottest%20country,large%20part%20of%20the%20nation, [Accessed: 19/02/2023]

[8] Fox, S., 2017, “How Does Heat Affect Solar Panel Efficiencies”, https://www.greentechrenewables.com/article/how-does-heat-affect-solar-panel-efficiencies [Accessed: 19/02/2023]

[9] WildLife Safari, n.d, “What are the Wettest Areas of Africa”, https://wildlifesafari.info/what-are-the-wettest-areas-of-africa.html#:~:text=Situated%20below%20the%20Guinean%20region,2%2C200%20to%205%2C000%20each%20year. [Accessed: 19/02/2023]

[10] Balsom, P., 2015, “The Surprising Things You Don’t Know About Big Data?“, https://www.adeptia.com/blog/surprising-things-you-dont-know-about-big-data#:~:text=Think%20of%20it%20this%20way,a%20petabyte%20is%201%2C024%20terrabytes. [Accessed: 19/02/2023]

[11] Pati, S., n.d, “Software Engineering – Software Requirement Tasks“, https://www.geeksforgeeks.org/software-engineering-software-requirement-tasks/ [Accessed: 19/02/2023]

[12] Ynvisible, n.d, “Power Consumption: Electrochromic Display vs. E-Paper vs. LCD”, https://www.ynvisible.com/news-inspiration/energy-efficiency-electrochromic-displays-e-paper-reflective-lcd#:~:text=LCD%20continuously%20consumes%20about%206%C2%B5W,often%20the%20content%20is%20changed. [Accessed: 19/02/2023]

[13] Yes Energy Solutions, n.d, “How much energy do solar panels produce for your home?”, https://www.yesenergysolutions.co.uk/advice/how-much-energy-solar-panels-produce-home#:~:text=Sometimes%20called%20'rated%20capacity'%20or,1%20kW%20and%204%20kW [Accessed: 19/02/2023]

[14] Marzocchi, O., “Current consumption of the Kobo Libra H20”, https://www.marzocchi.net/Olafsen/Hardware/CurrentKoboLibraH2O?setview=en [Accessed: 14/05/2023]

[15] Digikey, n.d, “Homepage”, https://www.digikey.co.uk/ [Accessed: 14/05/2023]

[16] Shangsha Industral, 2006, “Micro SD Specification”, https://web.archive.org/web/20130207004550/http:/www.dtt8.com/images/micro-sd%20specification.pdf [Accessed: 19/02/2023]

[17] Device Specifications, n.d, “Amazon Kindle Paperwhite – Battery”, https://www.devicespecifications.com/en/model-battery/92752e19 [Accessed: 19/02/2023]

[18] Mouser, n.d, “Homepage”, https://www.mouser.co.uk/ [Accessed: 14/05/2023]

[19] Starting to DJ, 2023, “How Are Phone Speakers So Loud? How Many Watts?”, https://startingtodj.com/how-are-phone-speakers-so-loud-how-many-watts/ [Accessed: 14/05/2023]

[20] Bagur, J., Chung, T., 2023, “Guide to 3V3 and 5V Power Supplies Differences”, https://docs.arduino.cc/learn/microcontrollers/5v-3v3 [Accessed: 14/05/2023]

[21] Morningstar, 2011, “Datasheet” https://uk.rs-online.com/web/p/solar-charge-controllers/9132412 [Accessed: 19/02/2023]

[22] DFROBOT, n.d, “Datasheet”, https://www.farnell.com/datasheets/3740627.pdf [Accessed: 19/02/2023]
[23] Polymer Database, n.d, “Homepage”, https://www.polymerdatabase.com/ [Accessed: 12/03/2023]
[24] Goodfellow, n.d, “Homepage”, https://www.goodfellow.com/ [Accessed: 12/03/2023]
[25] Pervasive Displays, 2018, “Datasheet” https://www.pervasivedisplays.com/wp-content/uploads/2019/06/1P190-00_01_E2417FS052_20180511.pdf [Accessed: 14/05/2023]
[26] Display Visions, 2022, “Datasheet”, https://www.lcd-module.com/fileadmin/eng/pdf/grafik/dogxl240-7e.pdf [Accessed: 12/03/2023]
[27] Special Chem, n.d, “Comprehensive Guide on Polyethylene” https://omnexus.specialchem.com/selection-guide/polyethylene-plastic#:~:text=LDPE%20uses%20majorly%20revolve%20around,of%20LDPE%20is%20plastic%20bags.L [Accessed: 12/03/2023]
[28] Sayfan, G, 2022, “Undestand How Much Memory Your Python Objects Use”, https://code.tutsplus.com/tutorials/understand-how-much-memory-your-python-objects-use--cms-25609 [Accessed: 14/05/2023]
[29] SPI flash, 2017, “Datasheet”, https://docs.rs-online.com/c64b/0900766b81623048.pdf [Accessed: 14/05/2023]
[30] SD Card, n.d, “SD Standard Overview” https://www.sdcard.org/developers/sd-standard-overview/ [Accessed: 14/05/2023]
[31] Amphenol, 2011, “Datasheet”, https://www.mouser.co.uk/datasheet/2/18/1/10067099-2577377.pdf [Accessed: 14/05/2023]
[32] All Batteries, n.d, “Homepage”, https://www.allbatteries.co.uk/ [Accessed: 14/05/2023]
[33] Cool Components, n.d, “Homepage”, https://coolcomponents.co.uk/ [Accessed: 14/05/2023]
[34] Nova Battery, 2011, “Datasheet”, https://cdn.shopify.com/s/files/1/2311/3697/files/LP585460-1S-2000mAh.pdf?15920493496374739557 [Accessed: 14/05/2023]
[35] Voltaic, 2020, “Datasheet”, https://cdn.sparkfun.com/assets/b/c/7/e/1/MD-18726-1.2_Watt_6_Volt_Small_Solar_Panel_-_ETFE.pdf [Accessed: 14/05/2023]
[36] Component Search Engine, n.d, “Homepage”, https://componentsearchengine.com/ [Accessed: 14/05/2023]
[37] Library Loader, n.d, “Homepage”, https://www.samacsys.com/library-loader/ [Accessed: 14/05/2023]
[38] Sattel, S., 2016, “Autodesk acquires EAGLE: Q&A and a look into future!”, https://www.autodesk.com/products/fusion-360/blog/autodesk-acquires-eagle-qa-look-future/#:~:text=That's%20right%2C%20in%20case%20you,And%20we're%20super%20excited! [Accessed: 19/03/2023]
[39] Castillo, J, 2022, “The Open Book”, https://www.oddlyspecificobjects.com/projects/openbook/ [Accessed: 14/05/2023]
[40] Raspberry PI, 2023, “Datasheet”, https://datasheets.raspberrypi.com/pico/pico-datasheet.pdf [Accessed: 14/05/2023]
[41] SAMD51, 2023, “Datasheet”, https://www.mouser.com/datasheet/2/268/60001507A-1130176.pdf [Accessed: 19/03/2023]
[42] ESP32, 2023, “Datasheet”, https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf [Accessed: 19/03/2023]
[43] Farnell, n.d, “Homepage”, https://uk.farnell.com/ [Accessed: 14/05/2023]
[44] Total Phase, 2021, “The Differences Between I2C and SPI”, https://www.totalphase.com/blog/2021/07/i2c-vs-spi-protocol-analyzers-differences-and-similarities/ [Accessed: 26/03/2023]
[45] Hirose, 2022, “Datasheet”, https://www.mouser.co.uk/datasheet/2/185/FH34SRJ_24S_0_5SH_99__CL0580_1255_6_99_2DDrawing_0-1615044.pdf [Accessed: 14/05/2023]
[46] OED, 2022, “Homepage”, https://www.oed.com/ [Accessed: 14/05/2023]
[47] TE Connectivity, 2020, “Datasheet”, https://www.mouser.co.uk/ProductDetail/TE-Connectivity/440055-2?qs=DE9Qji9blsSmCkgS7fKI6w%3D%3D [Accessed: 14/05/2023]
[48] Molex, 2022, “Datasheet”, https://eu.mouser.com/ProductDetail/Molex/214525-2021?qs=By6Nw2ByBD3TTW3ZUGHeSQ%3D%3D [Accessed: 14/05/2023]
[49] EXAR, 2011, “Datasheet”, https://www.mouser.co.uk/datasheet/2/146/xra1200_100_092011-1856036.pdf [Accessed: 14/05/2023]
[50] E-Switch, 2013, “Datasheet”, https://www.mouser.co.uk/datasheet/2/140/ESCH_S_A0000508628_1-2546473.pdf [Accessed: 14/05/2023]
[51] PCM, 2022, “Datasheet”, https://www.mouser.co.uk/datasheet/2/240/pcm-3051144.pdf [Accessed: 14/05/2023]
[52] Microchip, 2023, “Datasheet”, https://www.mouser.co.uk/datasheet/2/268/MCP9700_Family_Data_Sheet_DS20001942-3132871.pdf [Accessed: 14/05/2023]
[53] Lambert, G., “How to make voltage regulator circuits”, https://www.circuitbasics.com/voltage-regulators/ [Accessed: 16/04/2023]
[54] Peppe8o, 2023, “Raspberry Pi Pico W Power Consumption”, https://peppe8o.com/raspberry-pi-pico-w-power-consumption/ [Accessed: 23/04/2023]
[55] Nexperia, 2011, “Datasheet”, https://www.mouser.co.uk/datasheet/2/916/BCP68_BC868_BC68PA-1578974.pdf [Accessed: 14/05/2023]
[56] Mohankumar, D., 2009, “The Art of Zener Regulation”, https://www.electroschematics.com/the-art-of-zener-regulation/ [Accessed: 23/04/2023]
[57] Engineering ToolBox, 2010, “Resistors – Standard Values”, https://www.engineeringtoolbox.com/resistors-standard-values-d_1659.html [Accessed: 14/05/2023]
[58] Faubert, P., “High Efficiency Solar MPPT Battery Charger Using LT8611 and AD5245”, https://www.analog.com/en/technical-articles/high-efficiency-solar-mppt-battery-charger-using-lt8611-and-ad5245.html [Accessed: 23/04/2023]
[59] Analog Devices, 2022, “Datasheet”, https://www.analog.com/media/en/technical-documentation/data-sheets/lt8611.pdf [Accessed: 14/05/2023]
[60] Analog Devices, 2022, “Datasheet”, https://www.analog.com/media/en/technical-documentation/data-sheets/ltc4412.pdf [Accessed: 14/05/2023]
[61] Analog Devices, 2022, “Datasheet”, https://www.analog.com/media/en/technical-documentation/data-sheets/ad5245.pdf [Accessed: 14/05/2023]
[62] Thonny, n.d, “Homepage”, https://thonny.org/ [Accessed: 30/04/2023]
[63] PCBWay, n.d, “PCB Instant Qoute”, https://www.pcbway.com/orderonline.aspx [Accessed: 30/04/2023]
[64] SanDisk, n.d, “Datasheet”, https://www.mouser.co.uk/datasheet/2/669/SanDisk_10092017_HiEndurance_Connected-Home_Produc-1216974.pdf [Accessed: 14/05/2023]