Master Thesis

Prototype Development of a Handheld Speed Camera

for the attainment of the academic degree
Master of Mechanical Engineering
submitted by

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I, Muhammad Haziq bin Mohd Sabtu, student in the Mechanical Engineering program of the Brandenburg University of Applied Sciences, declare in oath that this thesis has been written by myself and has not been written with other than the other than the indicated aids.

It has not yet been presented to an examination committee in this or a similar form.

Muhammad Haziq bin Mohd Sabtu

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3.1 Methodic Product Development

Methodic product development by Pahl and Beitz underscores the necessity of a structured design procedure that not only fosters creativity and inventiveness but also ensures objective evaluation of outcomes. By amalgamating insights from design science, cognitive psychology, and practical experience, Pahl and Beitz's approach to systematic design methodology guides designers in navigating the complexities of technical systems, facilitating the transition from intuitive to purposeful paths and leading to more successful and comprehensible design outcomes. [1]

At the core of the Pahl and Beitz methodology is the understanding that effective product development involves a series of well-defined and interconnected stages [2]. They describe the product development process as a series of stages, each with its own defined objectives and activities. The four main stages are:

Planning and Task Clarification: The process begins with precise planning and task definition, involving collaboration with the marketing or dedicated planning unit. Regardless of origin, whether a product proposal or customer request, a deep understanding of the task is crucial. Detailed insights into prerequisites, constraints, and their significance lead to a comprehensive requirements list—a foundation for subsequent stages.

Conceptual Design: Building on this clarity, the conceptual design phase is pivotal. It seeks a fundamental solution by abstracting functions, identifying working principles, and integrating them into a cohesive structure. This culminates in defining a principle solution, encapsulating the design vision's essence.

Embodiment Design: Transitioning to concrete realization, embodiment design takes the forefront. Guided by technical and economic considerations, designers shape the construction structure. Multiple preliminary layouts assess design strengths and weaknesses, leading to the selection of the most promising variant.

Detail Design: The methodology's apex is the detail design phase, focusing on individual components. Precise arrangements, dimensions, materials, and other aspects are defined. Careful estimation of production possibilities and costs results in comprehensive production documentation, underlining the phase's importance in shaping the overall outcome.

Figure 3.1 illustrates the Pahl and Beitz design process, highlighting the iterative nature of the methodology.

3.2 Fused Deposition Modeling

Fused deposition modeling (FDM) is a widely used technique in additive manufacturing, particularly in 3D printing. It offers several advantages that contribute to its popularity in various industries. One of the main advantages of FDM is its ability to reproduce complex geometries with high precision and accuracy [4].

This makes it suitable for creating intricate and customized designs that may not be achievable with traditional manufacturing methods. Additionally, FDM is a cost-effective process as it reduces material waste by only depositing the necessary amount of material layer by layer [4]. This not only saves costs but also promotes sustainability in manufacturing.

Common plastics used in FDM include acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), and polyethylene terephthalate (PET) [5]. Each of these materials has its own set of advantages and disadvantages that make them suitable for different applications.

To achieve a high quality printing result, there are several parameters that need

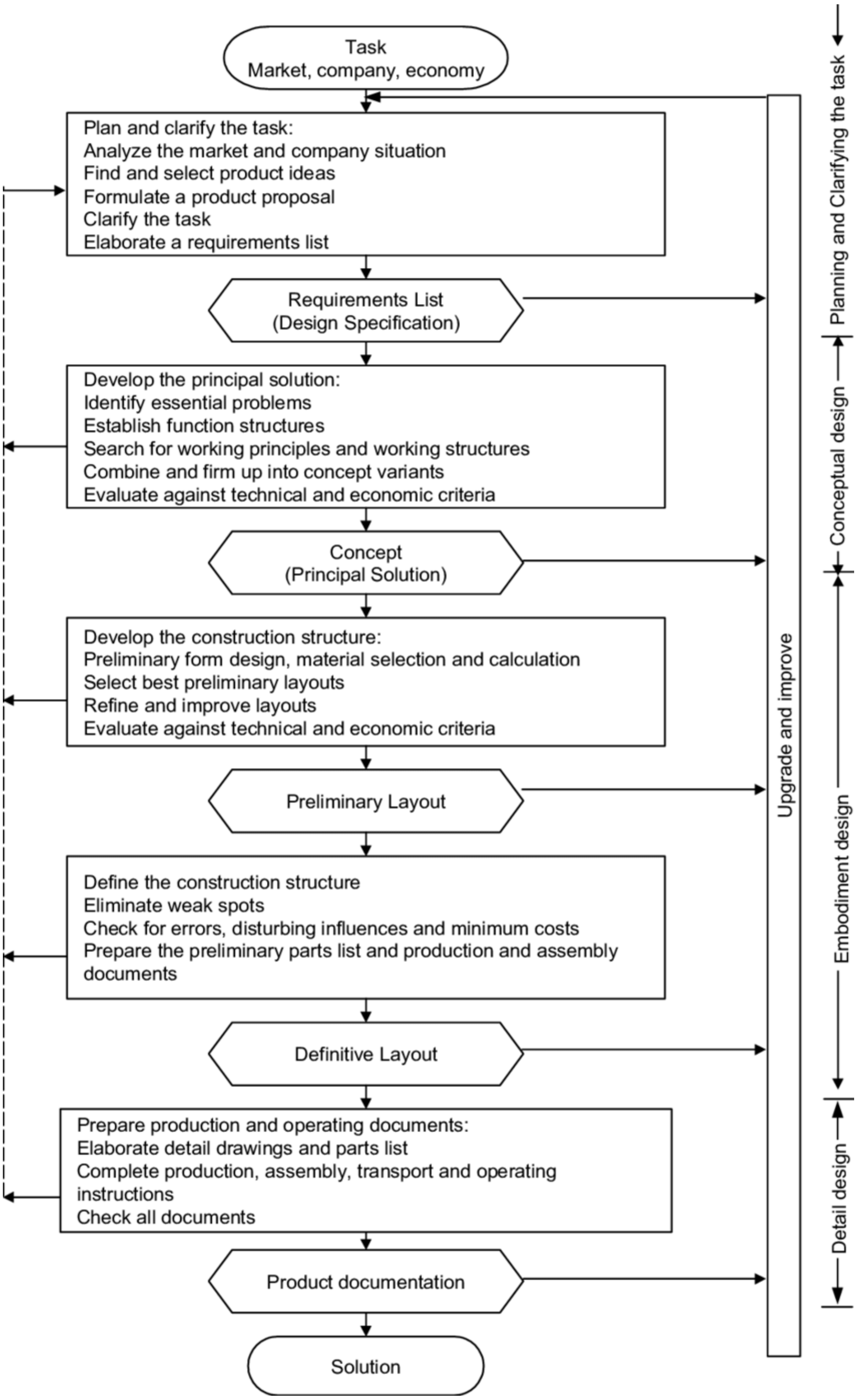


Figure 3.1: Pahl and Beitz's Design Process [3]

to be considered. Takahashi et al. [6] classified these parameters into four categories: (1) operation parameters, (2) machine parameters, (3) machine parameters, and (4) geometry-specified parameters.

3.2.1 Prusa Slicer i3 MK3S+

The Prusa Slicer i3 MK3S+ is an FDM 3D printer designed for desktop use, ideal for tasks like rapid prototyping and small-scale production. With a build volume of 250 x 210 x 200 mm, it can achieve layer heights ranging from 0.05 mm to 0.35 mm [7]. Utilizing Cartesian printing and a single extruder, this printer comes equipped with a heated bed and is compatible with a diverse range of materials such as PLA, ABS, PETG, and nylon [7]. The default nozzle size is 0.4 mm, although alternate sizes can be utilized based on specific printing needs.

This 3D printer is accessible for use by both students and faculty members at the University of Applied Sciences Brandenburg and will play a pivotal role in the prototype development process. Figure 3.2 provides a visual representation of the Prusa Slicer i3 MK3S+, located within the Workshop of the University of Applied Sciences Brandenburg.

3.2.2 PrusaSlicer

PrusaSlicer is a free and open-source slicing software that converts 3D models into G-code, a language that instructs the 3D printer on how to print the object. It is compatible with a wide range of 3D printers and supports a variety of filament materials. PrusaSlicer offers a multitude of features that allow users to customize the printing process to suit their needs.

One of the most important features of PrusaSlicer is the ability to adjust the printing parameters. These parameters include layer height, infill density, and print speed. The layer height refers to the thickness of each layer of the object being printed. The infill density refers to the amount of material used to fill the

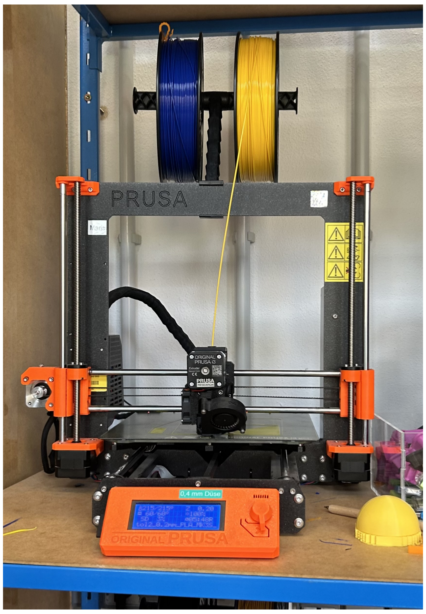


Figure 3.2: Prusa Slicer i3 MK3S+

inside of the object. The print speed refers to the speed at which the printer moves while printing the object. These parameters can be adjusted to achieve the desired quality of the final product.

Another important feature of PrusaSlicer is the ability to add supports. Supports are structures that are printed along with the object to provide additional support during the printing process. They are used to prevent the object from collapsing or deforming during printing. Supports can be added manually or automatically depending on the complexity of the object being printed.

This software is also able to generate a preview of the object being printed. This allows users to visualize how the object will look like once it is printed. Additionally, PrusaSlicer provides an estimate of the amount of filament required for the printing process and also the duration of the printing process. Figure 3.3 shows a screenshot of PrusaSlicer.

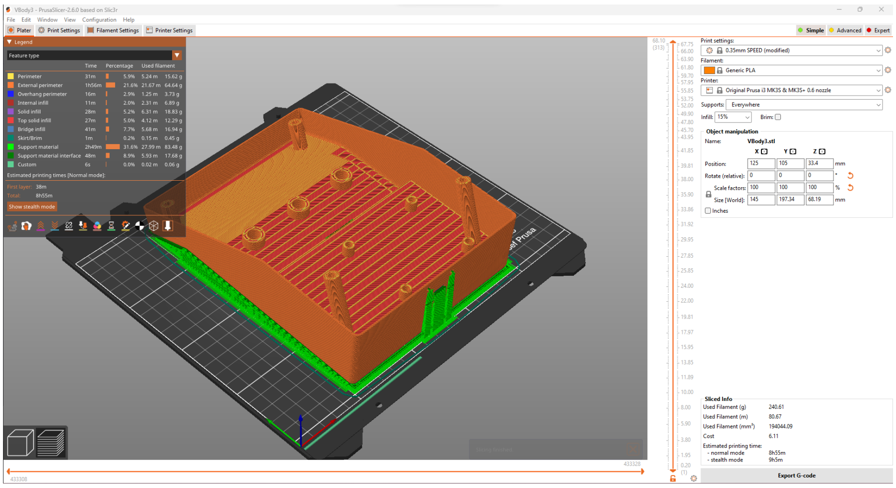


Figure 3.3: Example View of PrusaSlicer

3.2.3 Printing Cost

To perform a cost analysis of the 3D printing process, we will consider the following parameters:

- Material Cost
- Energy Cost

Material cost refers to the cost of the filament used in the printing process. The filament is the material that is deposited layer by layer to create the final product. The cost of the filament is dependent on the type of material used. For this project, we will be using PLA, which costs 29.99 € per kilogram [8].

The amount of filament used in the printing process is dependent on the size of the object being printed. The PrusaSlicer software provides an estimate of the amount of filament required for a given object.

Energy cost refers to the cost of electricity used in the printing process. The amount of electricity used is dependent on the duration of the printing process. The PrusaSlicer software provides an estimate of the duration of the printing process.

Equation 3.1 shows the formula for calculating the cost of 3D printing.

$$C_{print} = m_f \cdot C_f + t_p \cdot C_e \tag{3.1}$$

where C_{print} is the printing cost, m_f is the mass of filament used, C_f is the cost of filament, t_p is the duration of printing process, and C_e is the cost of electricity.

4 Planning and Task Clarification

This chapter delves into the process of planning and clarifying tasks for the prototype, as depicted in Figure 4.1 following Pahl and Beitz's model. As mentioned previously in Chapter 3.1 this step play a critical role in the product development process. They involve precisely defining and understanding the requirements and expectations related to a specific task or project. The aim is to remove any confusion and ensure that everyone involved has a shared understanding of what needs to be achieved.

During this step, the specific goals, limitations, and things that need to be produced for the task are identified [10]. By clarifying and specifying tasks, engineers and designers set a strong foundation for the later stages of product development. This allows them to move forward with a clear sense of direction and focus. To achieve this, Pahl and Beitz formulated a series of questions that must be answered to ensure that the task is well-defined and understood [10]. These questions are:

- What is the objectives of the solution?
- What characteristics should the solution have?
- What characteristics should the solution avoid?

By answering these questions, the requirements for the solution can be identified and spelled out. These requirements will serve as the basis for the subsequent phases of the product development process. The outcome of this step is a list of requirements that outline the needs, expectations, and restrictions tied to the task [10].

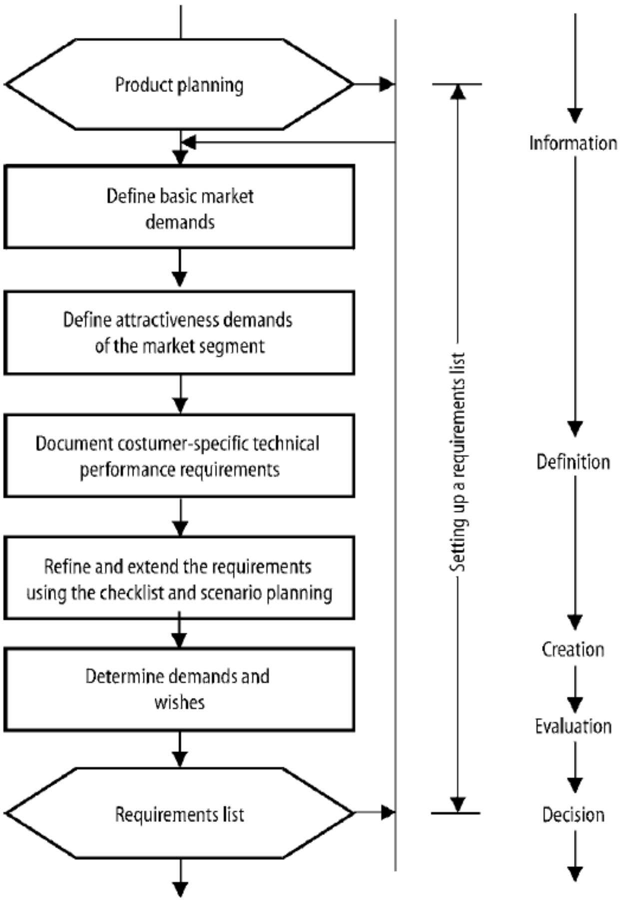


Figure 4.1: Planning and Task Clarification [9]

4.1 Establishing the Prototype's Requirements

To properly establish the requirements for the prototype, it is suggested to propely define the objectives of the prototype and clearly divide them into demands and wishes [11].

Demands, as described by Pahl and Beitz [11], are the essential and non-negotiable requirements that must be fulfilled for the product to be considered successful. They represent the core functionality and characteristics that the product must possess to meet its intended purpose and provide value to the users. Demands are typically based on objective criteria and are crucial for ensuring the product's basic functionality and compliance.

On the other hand, wishes are defined as the desirable but non-essential requirements or features that stakeholders would like to see in the product. Wishes often involve additional functionalities, aesthetics, or user experience enhancements that would provide added value or differentiate the product in the market. While wishes may not be mandatory, they can contribute to customer satisfaction, competitive advantage, and overall product excellence.

In addition, all of the requirements defined is possible must be quantifiable. This means that the requirements must be measurable and testable. This is important for ensuring that the requirements are met and that the product is able to fulfill its intended purpose.

4.2 Identifying the Prototype's Requirements

In this section, the requirements of the prototype will be established. The checklist (see Figure 4.2) will be used as a guideline to ensure that all the requirements are properly identified and defined.

4.2.1 Geometry

When creating a prototype, it's crucial to get its size and shape right so that people can use it effectively. The size determines how big the prototype is and how well it functions. However, we need to be mindful not to make the prototype too large due to manufacturing limitations.

For our prototype, we're utilizing a 3D printing service provided by TH Brandenburg. We're specifically using the Original Prusa i3 MK3S+ 3D printer, which has a maximum printing area of 210 mm by 210 mm by 250 mm [7]. This means we have to work within these size constraints.

To ensure that our prototype fits within these limits, we've decided to slightly reduce its size. We're making it about 10% smaller than the maximum printing

Main headings	Examples
Geometry	Size, height, breadth, length, diameter, space requirement, number, arrangement, connection, extension
Kinematics	Type of motion, direction of motion, velocity, acceleration
Forces	Direction of force, magnitude of force, frequency, weight, load, deformation, stiffness, elasticity, inertia forces, resonance
Energy	Output, efficiency, loss, friction, ventilation, state, pressure, temperature, heating, cooling, supply, storage, capacity, conversion.
Material	Flow and transport of materials. Physical and chemical properties of the initial and final product, auxiliary materials, prescribed materials (food regulations etc)
Signals	Inputs and outputs, form, display, control equipment.
Safety	Direct safety systems, operational and environmental safety.
Ergonomics	Man-machine relationship, type of operation, operating height, clarity of layout, sitting comfort, lighting, shape compatibility.
Production	Factory limitations, maximum possible dimensions, preferred production methods, means of production, achievable quality and tolerances, wastage.
Quality control	Possibilities of testing and measuring, application of special regulations and standards.
Assembly	Special regulations, installation, siting, foundations.
Transport	Limitations due to lifting gear, clearance, means of transport (height and weight), nature and conditions of despatch.
Operation	Quietness, wear, special uses, marketing area, destination (for example, sulphurous atmosphere, tropical conditions).
Maintenance	Servicing intervals (if any), inspection, exchange and repair, painting, cleaning.
Recycling	Reuse, reprocessing, waste disposal, storage
Costs	Maximum permissible manufacturing costs, cost of tooling, investment and depreciation.
Schedules	End date of development, project planning and control, delivery date

Figure 4.2: Checklist for Establishing the Prototype's Requirements [12]

area. This adjustment ensures that our prototype can be comfortably accommodated on the 3D printer at TH Brandenburg. Given these considerations, the largest dimensions we've chosen for the prototype are 190 mm by 190 mm by 220 mm.

4.2.2 Energy

The energy needed for the prototype is really important because it affects how useful and convenient it is. Weve made a requirement that the prototype should be able to work on its own for at least 1 hour using the provided power supply. This rule is in place to make sure the prototype can work by itself and give users a smooth experience.

By being able to work for at least 1 hour, the prototype shows that it can keep running for a reasonable amount of time without needing to be charged often or relying on outside power. This enables users to operate the device without concern for an extended period, offering more opportunities to explore its functionality and capabilities. It also provides users with the freedom to engage with the prototype in real-life scenarios, offering valuable insights into its performance and effectiveness.

4.2.3 Forces

The force requirement for the prototype has two main aspects: ensuring it can handle the weight of its components while also adhering to a maximum weight limit.

Firstly, it's crucial to verify that the prototype can effectively support the weight of its components without compromising its overall structure or functionality. This ensures the prototype's durability and ability to withstand the forces exerted by its components. Additionally, it guarantees that the prototype can be manipulated and operated without the risk of damage or malfunction.

Furthermore, there is a specific constraint that the total weight of the prototype must not surpass 2 kg. This encompasses the collective weight of all internal components, including both the predefined components and any additional materials integrated during the design process. Adhering to this weight limit ensures the prototype remains lightweight and manageable, while still meeting the intended performance criteria.

4.2.4 Materials

When crafting the prototype, it's crucial to carefully consider the specific materials and components that will be used. In this project, there are certain components that have already been chosen, and they must be included to meet the requirements. These components include the Raspberry Pi 4B, a 7-inch touch screen, the Raspberry Pi Camera V2, and the Veektomx 10000mAh power bank.

These chosen components act as essential building blocks for the prototype's function and performance. The Raspberry Pi 4B, a versatile single-board computer, supplies computing power and functions as the core control unit for the prototype. The 7-inch touch screen enhances user interaction by providing a responsive and user-friendly interface for input and output.

The Raspberry Pi Camera V2 enables the capture of images and videos, allowing for a range of applications within the prototype. Lastly, the Veektomx 10000mAh power bank provides a dependable power source, ensuring continuous operation of the prototype.

4.2.5 Ergonomics

When it comes to ergonomics, the prototype has specific demands concerning its dimensions, mass, and how users hold it. First and foremost, the prototype needs to be compact and lightweight. This guarantees that it's easy to carry around, making it simple to handle and move. By minimizing the prototype's size and weight, it enhances user comfort and convenience during use.

Furthermore, a vital aspect of the ergonomics requirement is that users should be able to hold the prototype comfortably. This involves thinking about the prototype's shape, grip, and balance to ensure it's easy and secure to hold. The design should fit naturally into the contours of the user's hand, ensuring a stable and ergonomic grip. By optimizing the prototype's shape and considering user ergonomics, it can deliver a smooth and user-friendly experience.

4.2.6 Production

The production requirement for the prototype focuses on the manufacturing process and the materials used. The prototype must be designed to be manufactured using 3D printing technology. This ensures that the prototype can be produced using the available resources and capabilities. In addition, the prototype must be designed to be manufactured using PLA filament. This material is readily available and offers a good balance of strength and flexibility, making it suitable for the prototype's requirements.

4.2.7 Operation

The operation requirement for the prototype encompasses two key aspects: the ability to be used freehand and the capability to integrate with a tripod for improved stability.

Firstly, the prototype must be designed to facilitate freehand operation. This means that users should be able to interact with and operate the prototype comfortably and conveniently without the need for additional support or mounting. The design should consider ergonomic factors such as grip, button placement, and user-friendly controls, ensuring that users can manipulate the prototype easily and intuitively.

Secondly, the prototype should be capable of integrating with a tripod for enhanced stability when necessary. This feature allows users to attach the prototype securely to a tripod, providing a stable and stationary setup. By integrating tripod compatibility, the prototype can cater to scenarios where steady and controlled operation or positioning is required, such as capturing images or conducting experiments that demand minimal movement.

4.2.8 Assembly

The assembly requirement for the prototype emphasizes the importance of considering the ease of assembly and disassembly of its components. This design consideration enables users to access the inner components easily, facilitating maintenance and repair tasks.

By designing the prototype with ease of assembly in mind, it becomes simpler for users to put the components together without requiring complex tools or specialized knowledge. This promotes user-friendliness and reduces the time and effort required for initial assembly or subsequent modifications. Similarly, easy disassembly allows users to access the internal components when needed, simplifying troubleshooting, repairs, or component replacements.

Additionally, if feasible, the parts of the prototype should be designed with swappable properties. This means that individual components or modules can be easily removed and replaced, without the need to disassemble the entire prototype. Swappable parts enhance modularity, flexibility, and cost-effectiveness, as users can upgrade or replace specific components as needed, rather than replacing the entire prototype.

4.2.9 Costs

The cost requirement for the prototype focuses on the total cost of production. The prototype must be designed to be manufactured within a budget of 100 euros excluding the cost of the predefined components. This budget encompasses the cost of all materials and components used in the production process. By adhering to this cost limitation, the prototype can be produced within the available resources and capabilities.

4.2.10 Schedules

The schedule requirement for the prototype focuses on the time required for production. The prototype must be designed to be manufactured within a time frame of 2 weeks. This time frame encompasses the entire production process, from design to assembly. By adhering to this schedule, the prototype can be produced within the available resources and capabilities.

4.2.11 Durability

The durability requirement for the prototype includes considerations for resistance to dust and water, if feasible. While it may not always be possible to achieve complete resistance, efforts should be made to enhance the prototype's durability in these aspects.

Regarding dust resistance, the prototype should be designed to minimize the ingress of dust particles into its internal components and sensitive areas. This involves employing appropriate seals, filters, or protective enclosures to prevent dust from adversely affecting the prototype's performance or functionality. By reducing the risk of dust accumulation, the prototype can maintain its optimal operation and extend its lifespan.

In terms of water resistance, if feasible and relevant to the intended use, the prototype should exhibit a level of protection against water ingress. This can involve incorporating waterproof or water-resistant materials, seals, or coatings to shield the internal components from moisture. Ensuring water resistance enhances the prototype's durability and enables usage in environments where exposure to water or humidity is likely.

4.3 Requirement List

Table 1 and Table 2 on the following pages show the requirements list which included the requirements described in this chapter.

5 Conceptual Design

Following the clarification of the task is the conceptual design, where in this section of the product development process, designers engage in creative exploration and evaluation of various design ideas and concepts.

Pahl and Beitz describe conceptual design as the phase of the design process where the essential problems are identified through abstraction, function structures are established, appropriate working principles are sought, and these elements are combined to form a working structure. This process lays down the foundation for the solution path by elaborating on a solution principle, ultimately specifying the principle solution. [13]

Figure 5.1 shows the steps involved in the conceptual design phase.

5.1 Abstraction

Traditional solution principles or designs may not provide optimal answers in the presence of new technologies, procedures, materials, and scientific discoveries. Preconceptions, conventions, and risk aversion often hinder unconventional but better and more cost-effective solutions. To overcome fixation on conventional ideas, designers utilize abstraction, focusing on the general and essential aspects rather than particular details. By formulating the task appropriately, the overall function and essential constraints become clear, enabling objective solution selection. [15]

To help in identification of the essential problems, following abstraction techniques are used [16]:

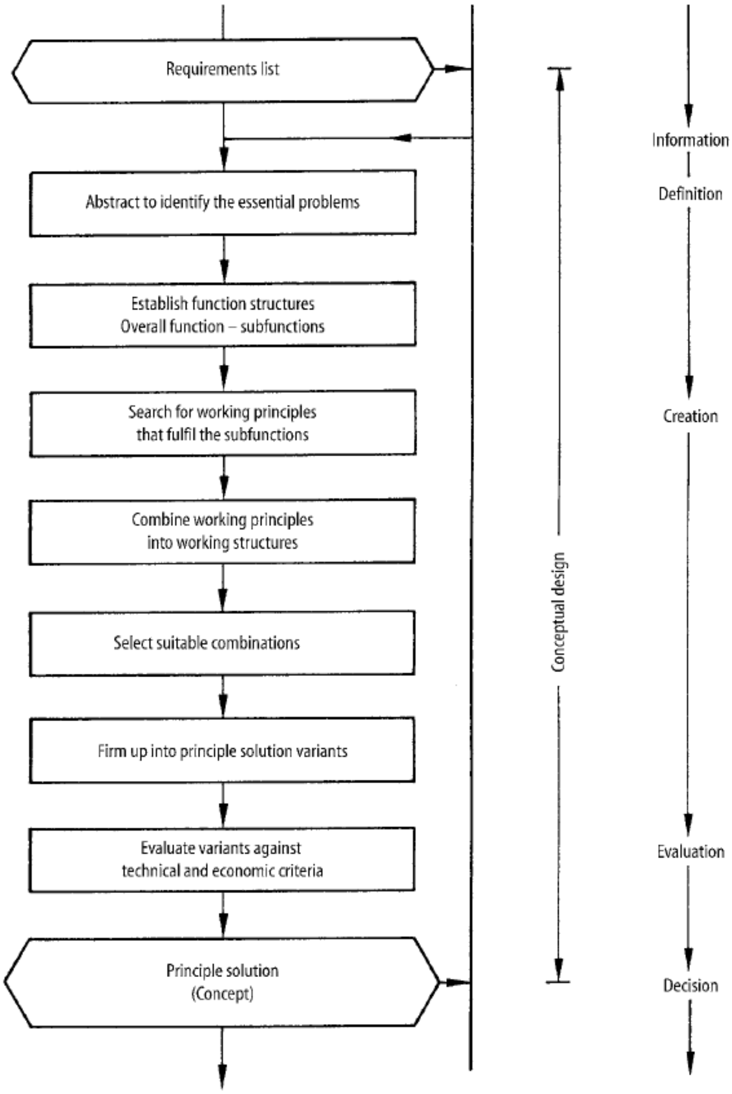


Figure 5.1: Steps in Conceptual Design [14]

- **Step 1:** Eliminate personal preferences.
- **Step 2:** Omit requirements that have no direct bearing on the function and the essential constraints.
- **Step 3:** Transform quantitative into qualitative data and reduce them to essential statements.

- **Step 4:** Generalise the results of the previous step.
- **Step 5:** Formulate the problem in solution-neutral terms.

Figure 5.2 shows the result of the abstraction process.

Result of Step 1 and Step 2

- Ergonomic: Comfortable to hold, Easy to use, Weight distributed evenly
- Portable: Lightweight, Small
- Size (MAX):
- Length: 19 cm
- Width: 19 cm
- Height: 22 cm
- Weight (MAX): 2 kg
- Design: Components are packed in a chassis
- Camera: Camera must be presented in the prototype
- Power: Battery powered, Rechargeable battery, Duration min. 1 hour
- Control: Control via touch screen
- Optional Requirements:
- Durability: Water resistance, Dust resistance
- Modular: Easy to assemble and disassemble, Swappable parts
- Features: Mountable on a tripod
- Production: 3D printed parts

Result of Step 3 and Step 4

- Comfortable to hold, easy to use, and have evenly distributed weight.
- Lightweight and small.
- Not exceed 19 cm in length, 19 cm in width, and 22 cm in height.
- Weigh less than 2 kg.
- Power that lasts a minimum of 1 hour.
- Produced with 3D Printer

Optional Requirements:

- Durable against water and dust.
- Modular

Result of Step 5 (Problem Formulation)

Design a portable device that prioritizes user comfort, ease of use, and ergonomic design while utilizing 3D printing production.

Figure 5.2: Result of Abstraction Process

5.2 Function Structures

Pahl and Beitz [17] define function structures as a graphical representation of the functions of a system and their interrelationships. It is a hierarchical representation of the functions of a system, starting with the overall function and breaking it down into sub-functions. The function structure is a useful tool for identifying the essential functions of a system and for identifying the relationships between the functions.

Figure 5.3 shows the representation of the function structure and the process of breaking down the overall function into sub-functions.

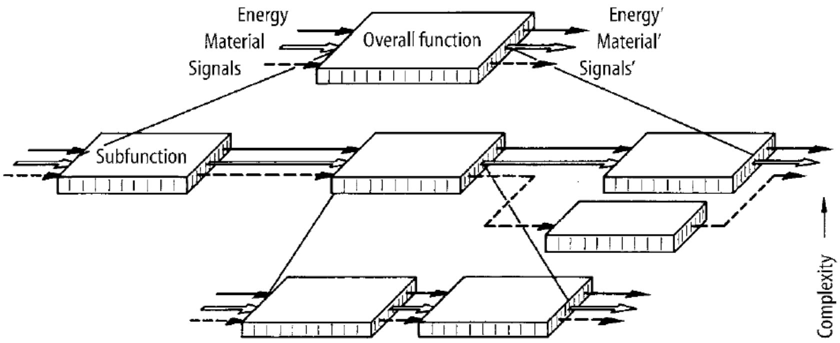


Figure 5.3: Breaking down the overall function into sub-functions [18]

5.2.1 Overall Function

Based on the result of abstraction, the overall function of the system can be represented and visualized using a function structure diagram. This diagram, as shown in Figure 5.4, shows the overall function.

In this overall function, the components of the prototype are defined as an input, while the prototype itself is defined as the output. The overall function will then be further decomposed into sub-functions on the next section.

Figure 5.4: Overall Function of the System

5.2.2 Sub-Functions

The decomposition of the overall function into sub-functions is a crucial step in the conceptual design process. As described by Pahl and Beitz [19] the purpose of this decomposition is to reduce the complexity of the overall system

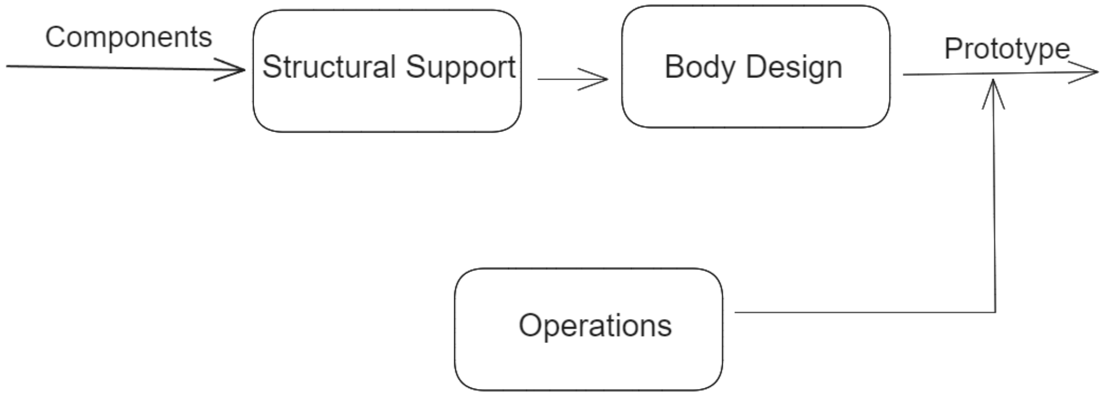


Figure 5.5: Sub-Functions of the System

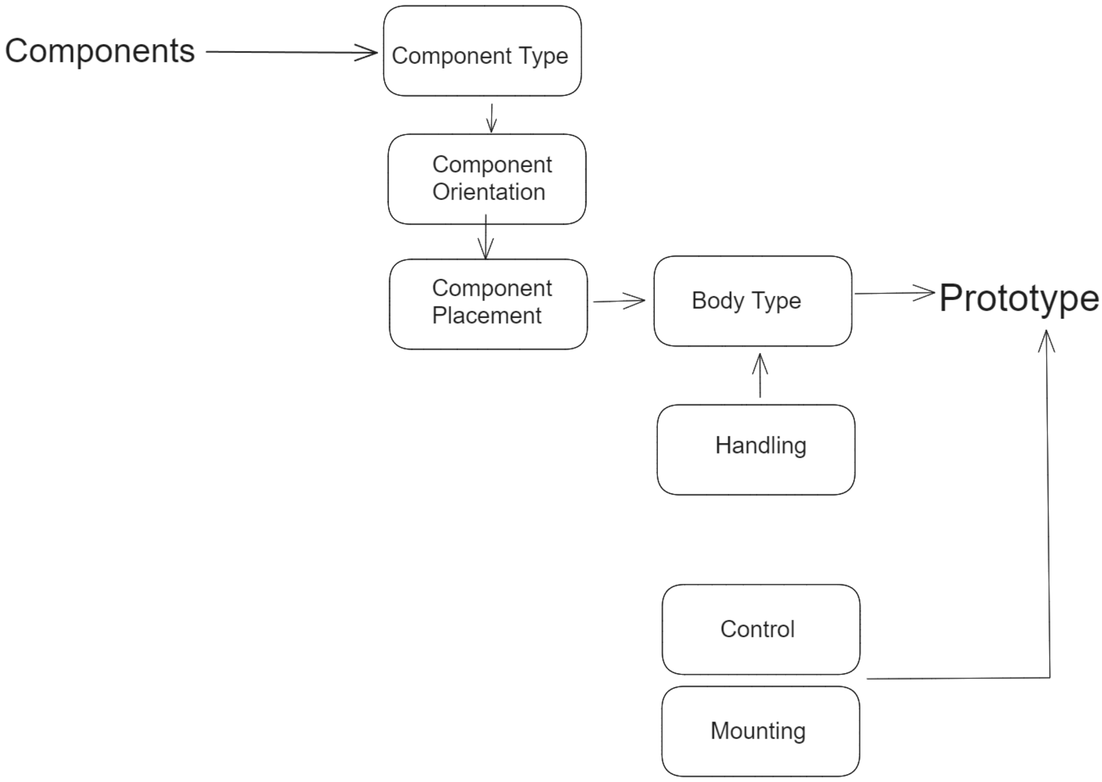


Figure 5.6: Sub-Functions of the System (Final)

and facilitate the identification of suitable solution principles that can fulfill the required functions.

From the overarching function outlined in the preceding section, we establish the constituent subfunctions. Figure 5.5 illustrates the subsystems of the setup. Deriving from the main function, labeled as *Prototype Design*, it breaks down into three subfunctions, specifically *Structural Support*, *Body Design*, and *Operation*.

Structural Support delineates the subsidiary functions associated with providing structural stability to the prototype. This encompasses the manner in which internal components receive support and are fastened within the prototype. Consequently, this subsidiary function is further deconstructed into *Component Placement*, which explicates the arrangement of internal components, and *Component Orientation*, which describes the alignment of internal components, along with *Component Type*, which characterizes the nature of internal components.

Body Design elucidates the subordinate functions concerning the shaping of the prototype's physical structure. This encompasses the design of the prototype's framework, defining its physical configuration. Thus, this subsidiary function is additionally disintegrated into *Body Type*, which defines the outline of the structure, and *Handling*, which details the method by which the prototype is maneuvered.

Operation outlines the subsidiary functions associated with the functioning of the prototype. This incorporates the operation of the prototype's constituents and details the approach to operating the prototype. Hence, this subsidiary function is subsequently subdivided into *Control Mechanism*, which delineates the means by which the prototype is managed, and *Integration with External Mounting*, which explains the process of affixing the prototype to an external tripod stand.

5.3 Developing Working Principles

In the process of developing working structures, one crucial step is to search for working principles. Working principles refer to the physical effects and characteristics that fulfill specific functions of the structure being designed. These principles are combined to create the working structure, and they encompass both the physical processes and the form design features.

The search for working principles aims to generate several potential solution variants, creating what is known as a solution field. This can be achieved by varying the physical effects and form design features. Often, multiple physical effects are involved in fulfilling a single subfunction or even multiple function carriers. [20]

In developing working principles, there are multiple available methods in idea generation. These methods are categorized into three groups:

- Conventional methods
- Intuitive methods
- Discursive methods

Pahl and Beitz [21] describe the *Conventional Methods* as a systematic and data-driven approach. Designers gather information from various sources, such as literature, trade publications, and competitor catalogs, to stay informed about advancements and best practices. They analyze natural systems and existing technical systems to draw inspiration and identify opportunities for improvement. Analogies are used to substitute analogous problems or systems, leading to fresh perspectives. Additionally, empirical studies, such as measurements and model tests, provide tangible data for validating designs and predicting real-world performance.

On the other hand, the *Intuitive Methods*, as described by them [22], tap into creativity and associative thinking. *Brainstorming* fosters a collaborative environment where diverse perspectives generate a wide range of ideas without judgment. *Method 635* adds structure to brainstorming, allowing for systematic idea development within a group. The *Gallery Method* combines individual work with group discussions, using sketches or drawings to explore solution proposals visually. *Synectics* involves combining apparently unrelated concepts to trigger new and fruitful ideas.

Additionally, Pahl and Beitz [23] introduce *Discursive methods*, which amalgamate systematic, step-by-step procedures with elements of intuition and creativity. They involve deliberate analysis of physical processes, leading to multiple solution variants derived from the relationships between variables. This approach fosters a deeper understanding of the problem space, encouraging the discovery of novel solutions while maintaining a level of systematic rigor, making them effective for communication and collaboration among design teams.

5.3.1 Searching for Working Principles

In the process of searching for working principles, a combination of methods are used, namely the *Brainstorming* and *Analysis of Existing Technical Systems*. The brainstorming method is used to generate ideas and concepts, while the analysis of existing technical systems is used to analyze and evaluate the ideas and concepts generated.

Table 5.1 shows the result of idea generation. For a more detailed sketches of the working principles, please refer to Appendix A.1.

		Working Principles			
		1	2	3	4
Function	Components Arrangement	Tablet-like	Point-of-Service-like	Handheld-PC-like	Camcorder-like
	Screen Orientation	Landscape	Portrait		
	Battery Type	Battery Pack	Power Bank	AAA Batteries with Battery Holder	
	Body Type	Bowl	Skeleton	Sandwich	
	Handling	Body Grip	Bump Grip	Pistol Grip	
	External Mounting	Detachable Plate	Built-in Mounting Plate		
	Control Mechanism	Button	Touch Screen	Trigger	Touch and Button

Table 5.1: Classification Scheme for Working Principles

5.4 Combination of Working Structures

In this step, we will connect the working principles assigned to the sub-functions to create potential functional structures. To achieve this, the identified working principles need to be linked in accordance with the functional structure to fulfill the overall function.

The method we will employ for systematic combination is known as Zwicky's morphological box or morphological chart, which is particularly suitable for this purpose. In this approach, the potential principles are represented in a table for better clarity and connected to form functional structures using connecting lines. It is crucial to ensure that only compatible elements are combined.

Figure 5.7 shows the morphological chart with the generated solution variants. The solution variants are labeled as S1 to S9. with each color representing a different solution variant.

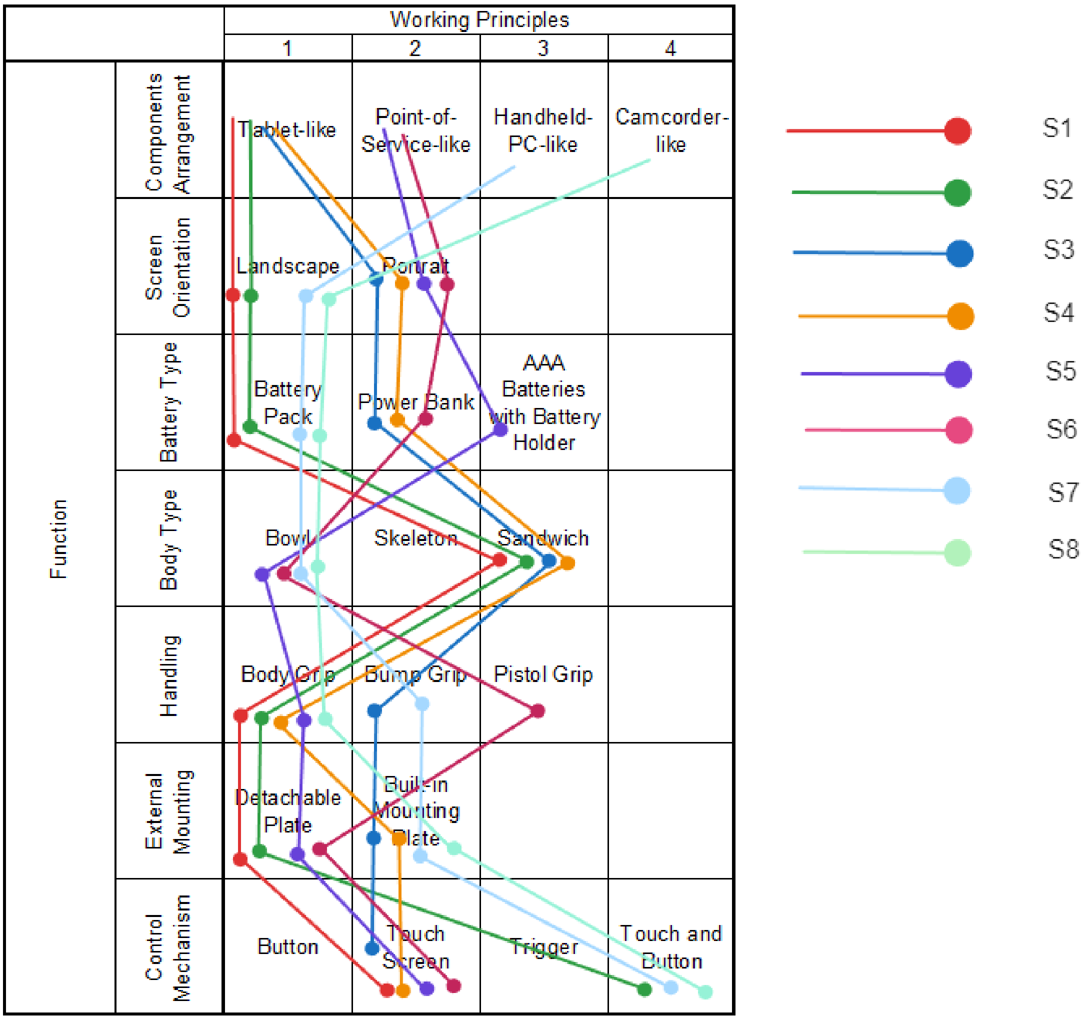


Figure 5.7: Morphological Chart with Solution Variants

5.5 Firming Up into Principle Solution Variants

In this section, we take the functional structures we've identified and transform them into tangible solution options, which are then illustrated in scaled hand-drawn sketches. The text that accompanies these sketches offers a concise description of how they work, including their potential pros and cons. This information forms the foundation for the upcoming decision-making process.

5.5.1 Solution Variant 1

In Solution Variant 1, we encounter a tablet-like design that closely resembles a typical tablet device. The key components, including the Raspberry Pi, Battery, Camera, and Screen, are arranged in a manner reminiscent of a tablet. Notably, the screen orientation is in landscape mode, offering a broader display view for enhanced visual clarity. This orientation is particularly beneficial when the device is used for tasks that require a wider viewing area.

The design is thoughtfully optimized for handheld use, featuring a body grip that ensures comfortable handling. The internal battery integration contributes to a seamless and integrated appearance. To provide robust protection for the internal components, a sandwich-type chassis structure is employed, comprising a top cover, main body, and bottom cover.

For mounting purposes, Solution Variant 1 utilizes a detachable plate tripod system, offering the convenience of easy attachment and removal from a tripod stand. The primary control mechanism for this variant is a touch screen, allowing for intuitive and user-friendly interactions with the device's functionalities.

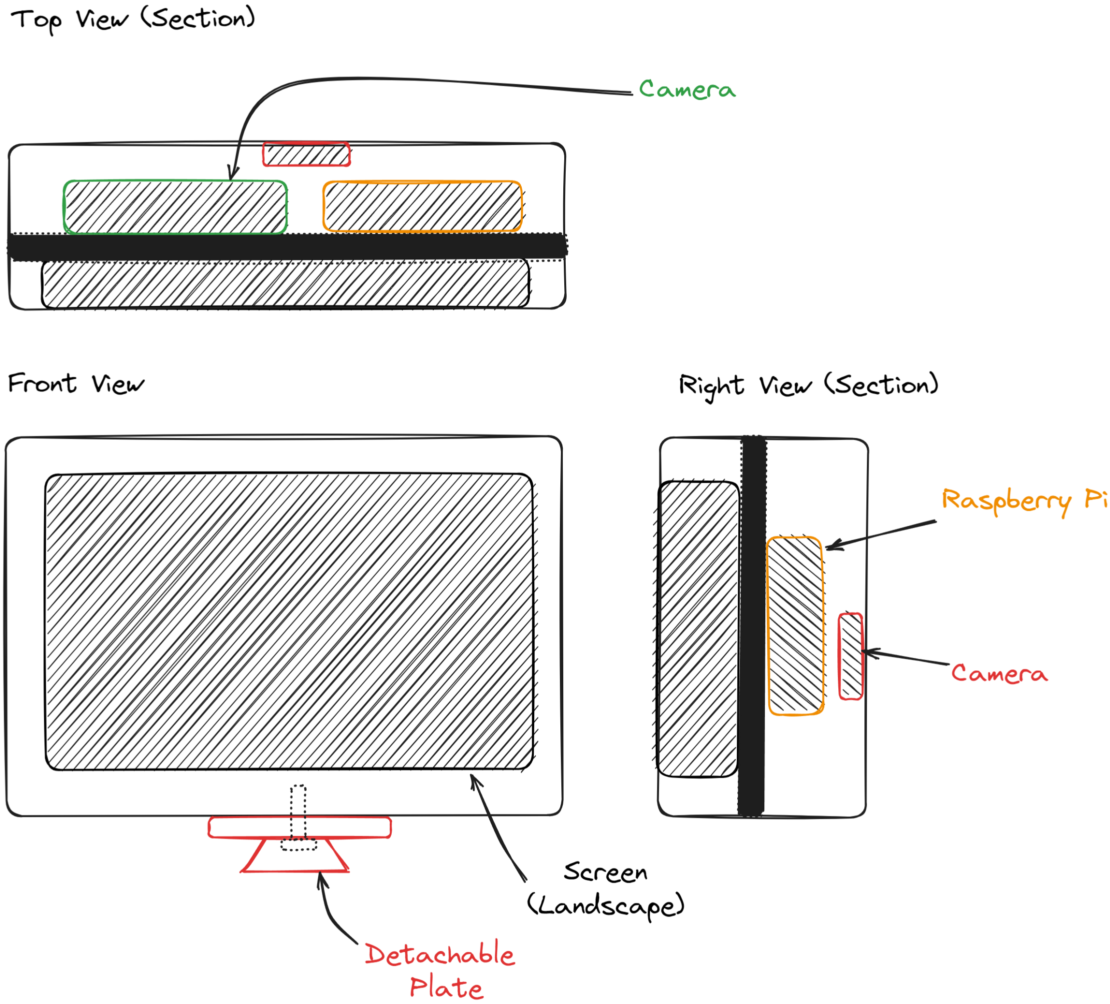


Figure 5.8: Sketch of Solution Variant 1

5.5.2 Solution Variant 2

Much like its predecessor, Solution Variant 2 maintains a tablet-like design, with components arranged akin to a tablet device. It, too, adheres to a landscape screen orientation for an expansive display view. The device is designed to be comfortably held with a body grip.

One significant difference lies in the battery arrangement. Instead of being integrated, Solution Variant 2 opts for a battery pack, potentially offering the advantages of easier replacement and extended usage periods. Like Solution Variant 1, it employs a sandwich-type chassis structure for sturdy protection of internal components.

In terms of mounting, the detachable plate tripod system is retained, ensuring compatibility with tripod stands. What sets Solution Variant 2 apart is the inclusion of physical buttons alongside the touch screen as the primary control mechanism. This addition enhances versatility and usability in various scenarios, as users can choose between touch-based and tactile input.

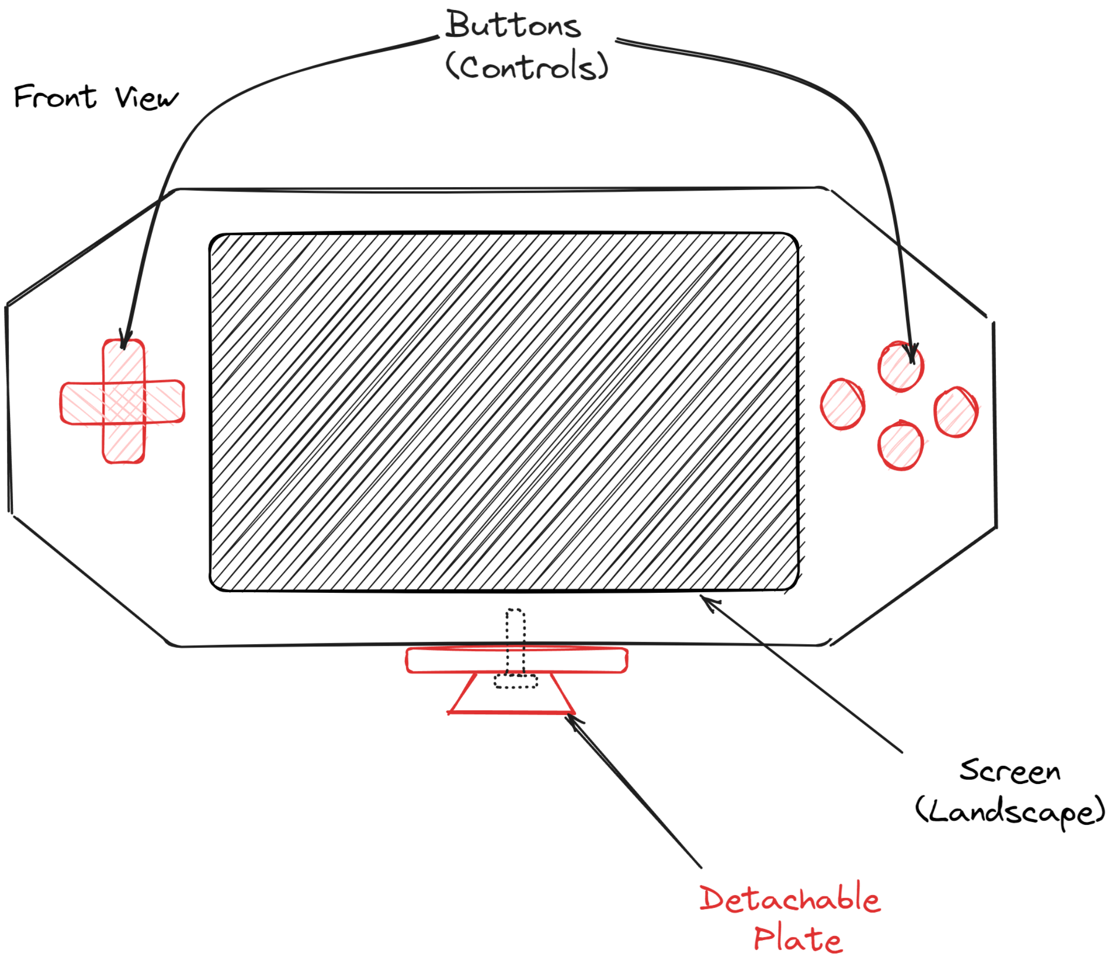


Figure 5.9: Sketch of Solution Variant 2

5.5.3 Solution Variant 3

While Solution Variant 3 maintains the tablet-like component placement found in the previous variants, it introduces a significant departure by adopting a portrait screen orientation. This shift opens up new possibilities for the device's usage, particularly in scenarios where vertical screen space is more advantageous.

The design includes a bump grip for secure and comfortable handling in a vertical position. Notably, the battery is positioned externally in this variant, offering the potential advantage of easier access and replacement. The chassis structure remains a sandwich-type, providing robust protection for the internal components.

For mounting, the detachable plate tripod system is still utilized, ensuring compatibility with tripod stands. Similar to the earlier variants, Solution Variant 3 relies on a touch screen as the primary control mechanism, facilitating intuitive and user-friendly interactions.

One notable advantage of the portrait screen orientation is the improved stability of the device, as the center of gravity is aligned with the device's center. This alignment enhances balance and control when using the device in various orientations, thus enhancing overall usability and versatility.

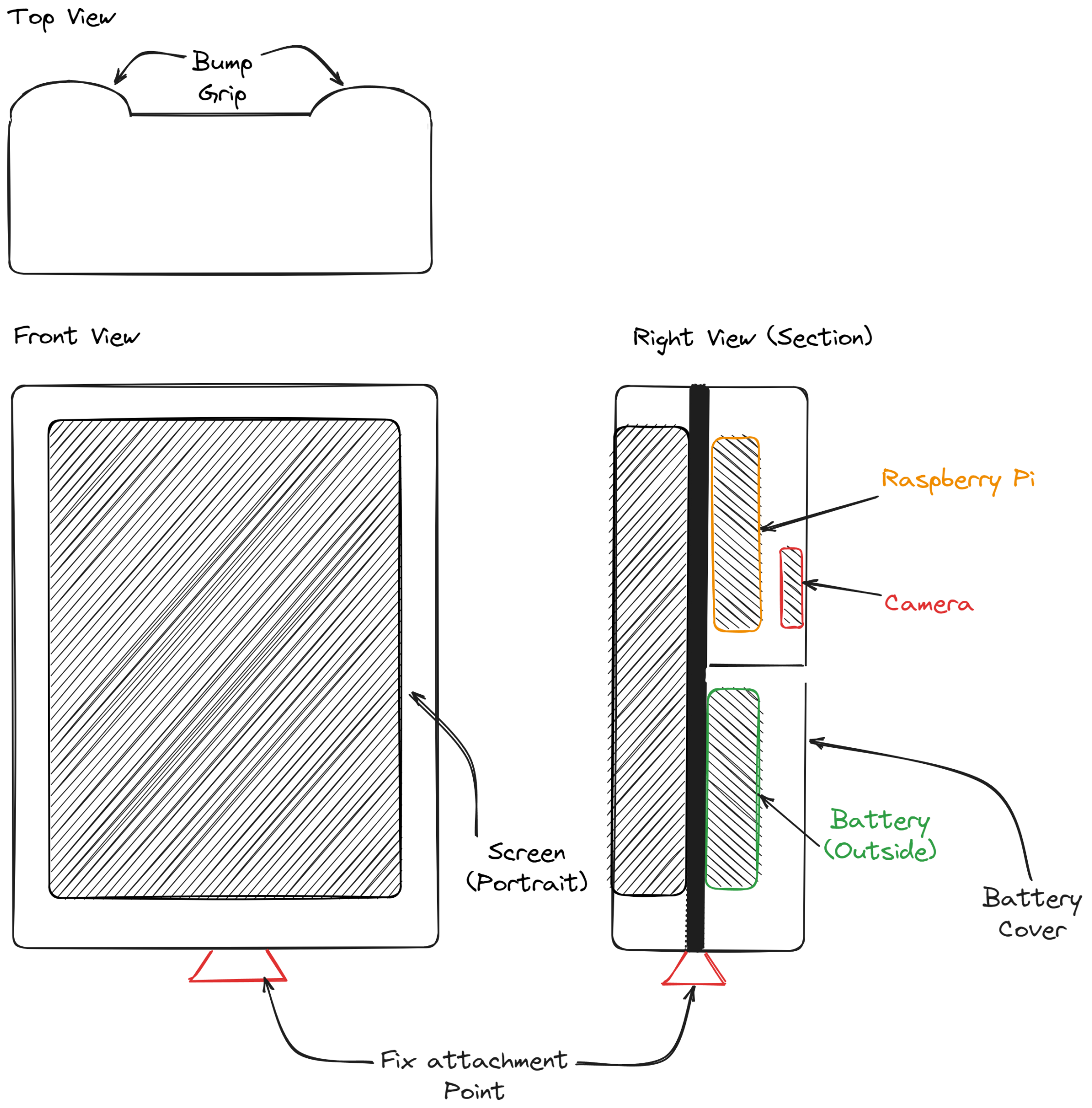


Figure 5.10: Sketch of Solution Variant 3

5.5.4 Solution Variant 4

In Solution Variant 4, we encounter yet another tablet-like design with a portrait screen orientation. Like Solution Variant 3, this orientation offers advantages in certain use cases where a vertical display is preferred.

For handling, the bump grip is employed, providing a secure and ergonomic hold. In terms of battery placement, Solution Variant 4 distinguishes itself by utilizing an external power bank as the power source. This design decision allows for convenient battery replacement or charging when needed.

Unlike the previous variants with sandwich-type chassis structures, Solution Variant 4 opts for a more minimalistic skeleton design. This choice results in a lightweight yet adequately supportive chassis for the internal components. For mounting, a fixed mounting plate is employed, ensuring a stable attachment to a tripod stand.

As with its predecessors, the primary control mechanism remains the touch screen, providing an intuitive and user-friendly interface for operating the device.

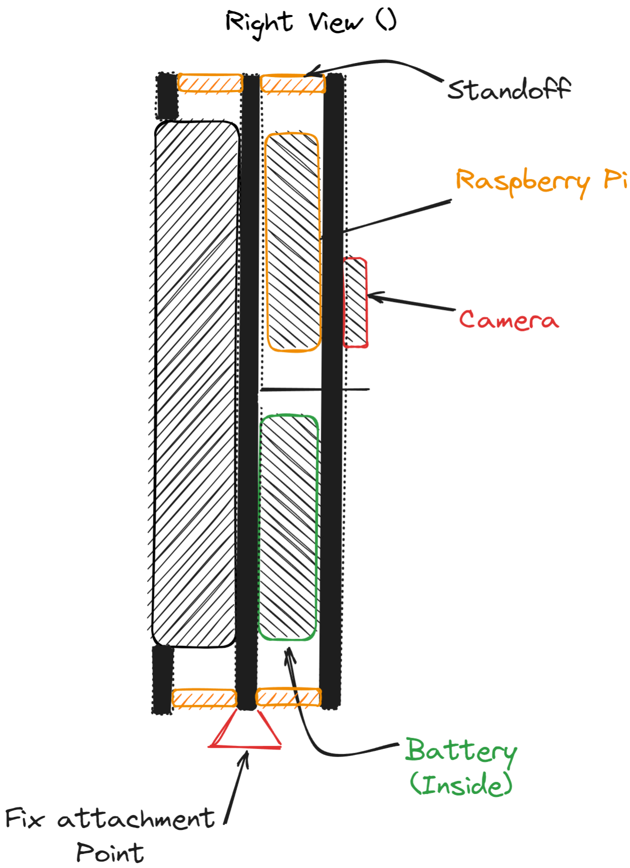


Figure 5.11: Sketch of Solution Variant 4

5.5.5 Solution Variant 5

Solution Variant 5 introduces a unique design approach, deviating from the tablet-like structure seen in previous solutions. Instead, it adopts a Point of Service-like component placement, where the Raspberry Pi, Battery, Camera, and Screen are configured in a distinctive layout. The screen is positioned at an angle, differentiating it from the previous variants.

In terms of screen orientation, Solution Variant 5 retains a portrait mode, which can be advantageous in scenarios requiring vertical displays. The device is designed for body grip handling, offering a secure way to hold and interact with the device.

A notable difference is the external AAA battery setup, which enhances convenience by offering easy battery replacement and compatibility with standard batteries. The chassis structure follows the familiar sandwich-type design, providing robust protection for the internal components.

For mounting purposes, Solution Variant 5 utilizes the detachable tripod system, enabling seamless attachment and detachment from a tripod stand. Like its predecessors, it relies on a touch screen as the primary control mechanism, ensuring intuitive user interactions.

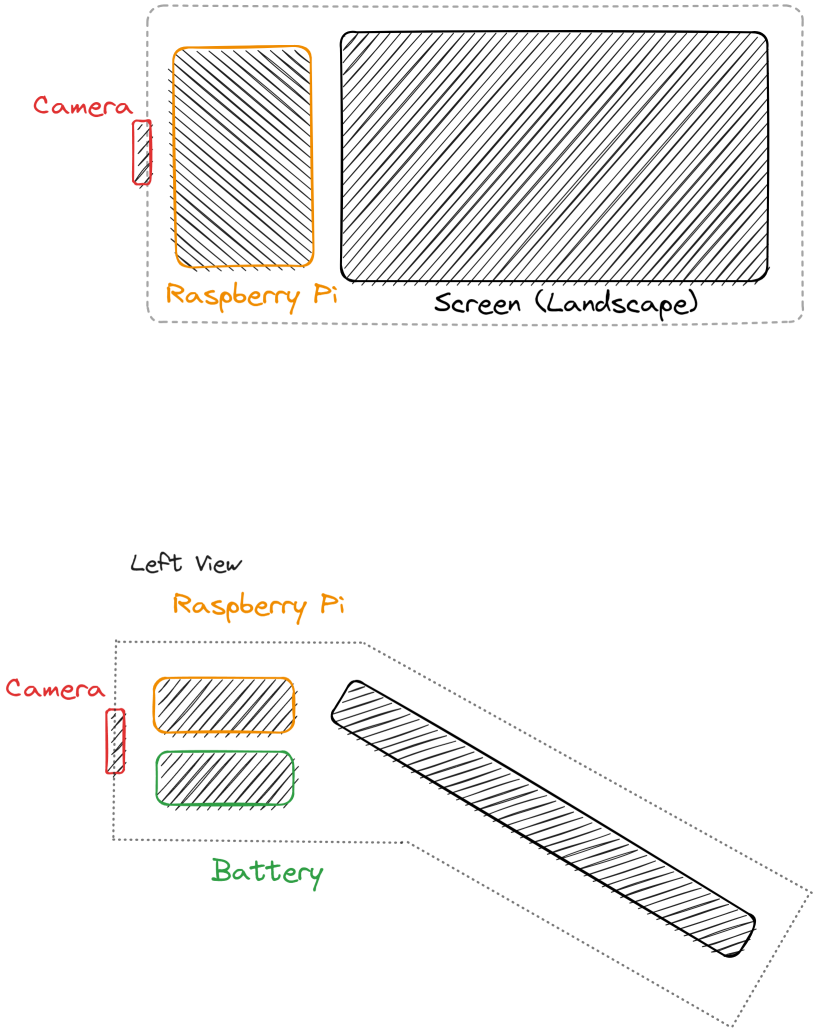


Figure 5.12: Sketch of Solution Variant 5

5.5.6 Solution Variant 6

Solution Variant 6 closely mirrors Solution Variant 5 in terms of component placement and screen orientation. This variant, too, adopts the Point of Service-like layout with a portrait screen orientation. However, it introduces a pistol handle for handling, providing a firm and ergonomic grip for users.

The battery is positioned externally and takes the form of a power bank, offering the same benefits of easy battery replacement and extended usage periods.

In terms of chassis design, Solution Variant 6 employs a bowl-like structure, where all components are attached to the main body. This design choice provides protection and enclosure while reducing overall weight.

For mounting, the detachable tripod system is employed, ensuring compatibility with tripod stands. As with previous variants, the control mechanism relies on the touch screen for user interactions.

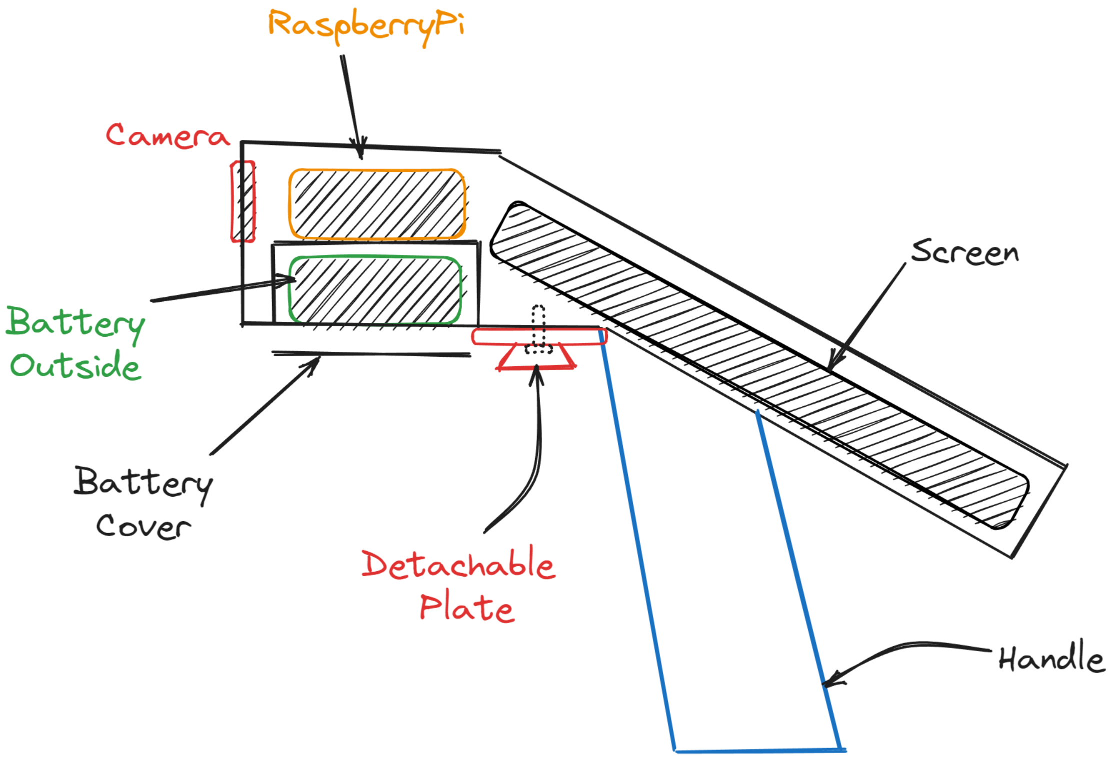


Figure 5.13: Sketch of Solution Variant 6

5.5.7 Solution Variant 7

In Solution Variant 7, we see a distinct design approach with a Handheld PC-like component placement. This configuration aligns the screen and battery, positioning the Raspberry Pi behind the screen.

The screen orientation is set in landscape mode, offering a wider horizontal display view. The device is designed with a bump grip for secure and comfortable handling. Notably, the battery is placed internally and utilizes a battery pack, contributing to an integrated and seamless appearance.

The chassis structure adopts a bowl-like design, ensuring secure enclosure and protection for all components. For mounting, the device incorporates a built in tripod system, providing a stable attachment to a tripod stand.

Solution Variant 7 stands out by combining both a touch screen and physical buttons as the control mechanism. This dual-input approach provides users with multiple options for interacting with the device's functionalities, enhancing versatility and usability in various scenarios.

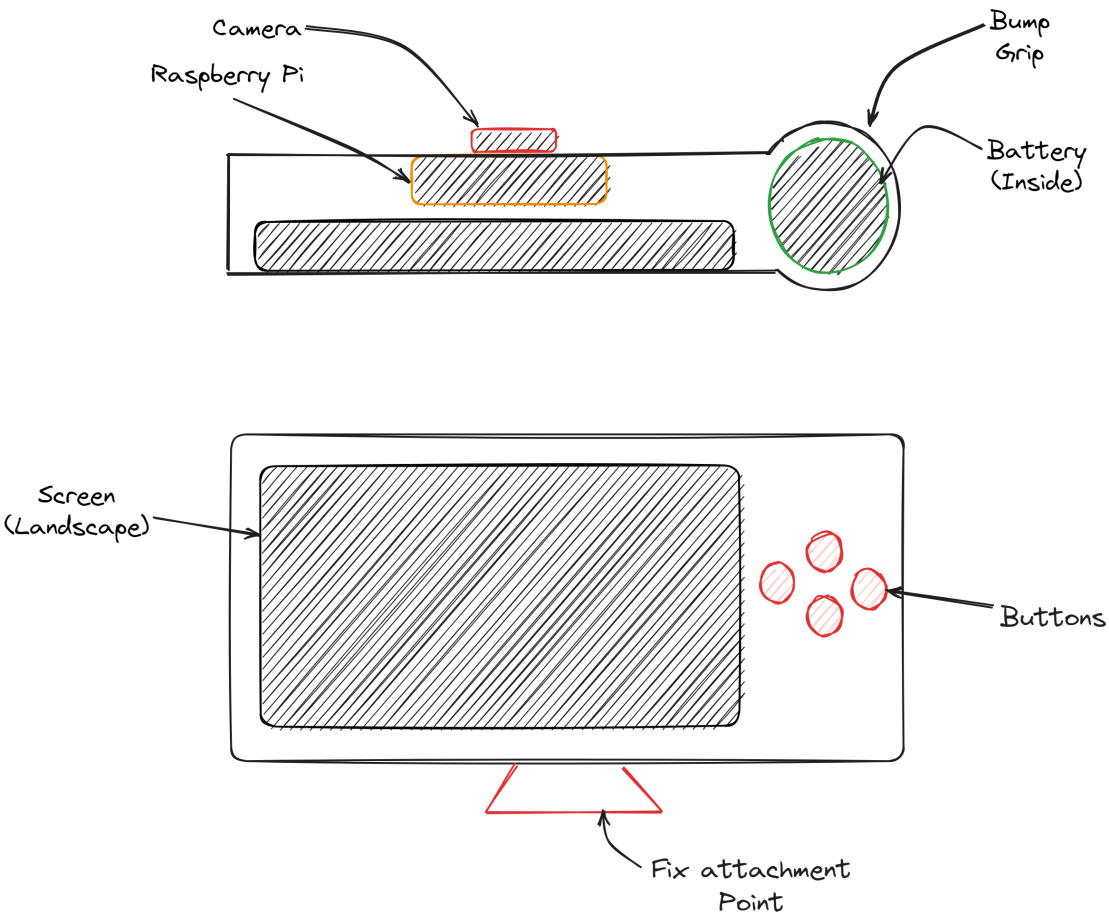


Figure 5.14: Sketch of Solution Variant 7

5.5.8 Solution Variant 8

Lastly, Solution Variant 8 features a Camcorder-like component placement. The Raspberry Pi, Battery, Camera, and Screen are arranged similarly to a camcorder, with the screen positioned at a hinge, allowing it to change angles for flexible viewing.

The screen orientation remains in landscape mode, providing a wide horizontal display view. The device is designed with a body grip for secure and comfortable handling. The battery is placed internally, and a power bank is used to provide a reliable power source for the device.

The chassis structure follows a bowl-like design, offering protection and sturdiness for the internal components. For mounting purposes, a fixed mount tripod system is employed, providing stability and ease of use when attaching the device to a tripod stand.

As with some of the previous variants, Solution Variant 8 combines both a touch screen and physical buttons as the control mechanism, offering users the flexibility to interact

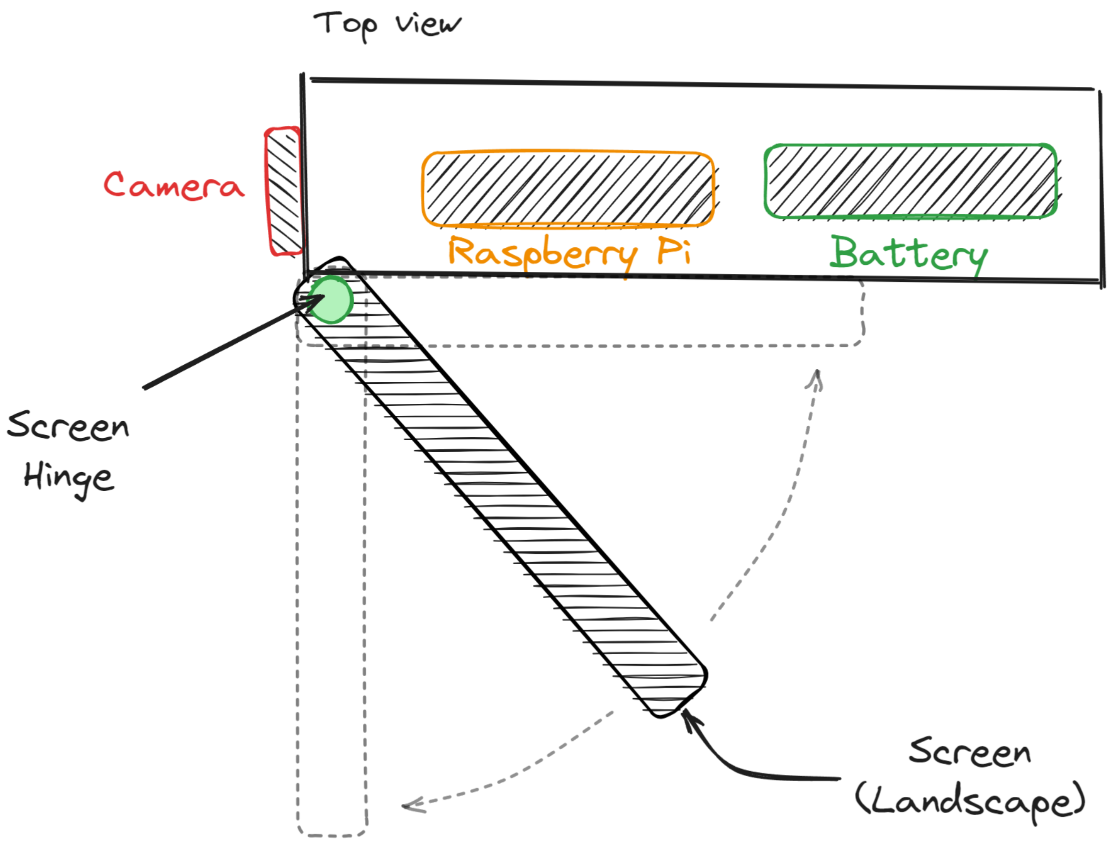


Figure 5.15: Sketch of Solution Variant 8

5.6 Filtering of Solution Variants

As can be seen in Figure 5.7, multiple solution variants were generated. However, not all of these solutions are feasible and practical. As mentioned by Pahl and Beitz [24], it is necessary to reduce the vast number of theoretically possible but practically unachievable solutions as early as possible. However, caution should be exercised not to discard valuable working principles, as they often play a crucial role in forming a favorable and effective working structure when combined with others.

Additionally, Pahl and Beitz [24] suggest a method which can be used to filter the solution variants. This method is known as the selection chart, which consists of two steps: elimination and preference. Initially, all clearly unsuitable proposals are removed. If a substantial number of solutions still remain, preference is given to those that stand out as markedly superior. Only these preferred solutions are evaluated during the final stages of the conceptual design phase.

Pahl and Beitz suggest the following criteria for eliminating unsuitable solutions:

- **Criteria A:** Compatible with the overall task
- **Criteria B:** Fulfill demands of requirement list
- **Criteria C:** Realisable in principle
- **Criteria D:** Within permissible cost

These criteria are applied step by step to examine each solution. If any of the exclusion criteria are not met, the solution is rejected, and further criteria are not assessed. Additionally to the exclusion criteria, the following preference criteria are used to prioritize the remaining solutions:

- **Criteria E:** Incorporates direct safety measures
- **Criteria F:** Preferred by the designer

Criteria E and F are then used to prioritize solutions if there are still too many options after the initial screening. The remarks column provides explanations for excluding or favoring each solution. The final assessment of the functional principles is recorded in the rightmost column of the selection list.

The result of the selection chart, as shown in Figure 5.16, indicates that solutions S1, S4, S5, and S8 have been eliminated and will not be considered for the next stage of the design process.

Page 1	Selection Chart								
		Evaluate solution variants according to selection criteria						Decision	
		Compatible with the overall task	ulfill demands of requirement list	Realisible in principle	Within permissible costs	Incorporates direct safety measures	Preferred by the designer	Remarks: (+) Pursue Solution (-) Eliminate Solution (?) More Information Required (!) Check Specification	
SolutionsVariant	No.	A	B	C	D	E	F		
S1	1	+	+	+	+	?	+	Might have problem with ergonomic	-
S2	2	+	+	+	+	?	?		+
S3	3	+	+	+	+	?	+		+
S4	4	-	+	+	+	+	+	Have almost no protection of inner components	-
S5	5	+	+	+	+	?	+	Less ergonomics due to wide body	-
S6	6	+	+	+	+	?	?		+
S7	7	+	+	+	+	+	+		+
S9	8	+	+	-	?	?	-	Too complex	-

Figure 5.16: Selection Chart for Solution Variants

6 Embodiment Design

The next phase in the design methodology is embodiment design. This phase, as defined by Pahl and Beitz [25], involves starting with the fundamental solution or concept for a technical product and then advancing the design in alignment with technical and economic criteria, taking into account further information. The ultimate objective is to reach a stage where the subsequent detailed design can smoothly progress into the production phase. Figure 6.1 shows the steps involved in this phase.

6.1 Basic Rules of Embodiment Design

When it comes to product design, there are some basic rules that must be followed. As defined by Pahl and Beitz [27], they include clarity, simplicity, and safety. Neglecting these rules can potentially result in issues and accidents. Subsequent sections will provide a comprehensive exploration of these guidelines.

6.1.1 Clarity

Clarity, as described by Pahl and Beitz [28], entails establishing clear and unambiguous connections within a design. This involves ensuring straightforward relationships between subfunctions, inputs, and outputs to prevent any confusion or misinterpretation. It also extends to the selection of a working principle, where designers should choose principles that clarify cause-and-effect dynamics, align with the product's purpose, and optimize its layout by eliminating unnecessary complexity.

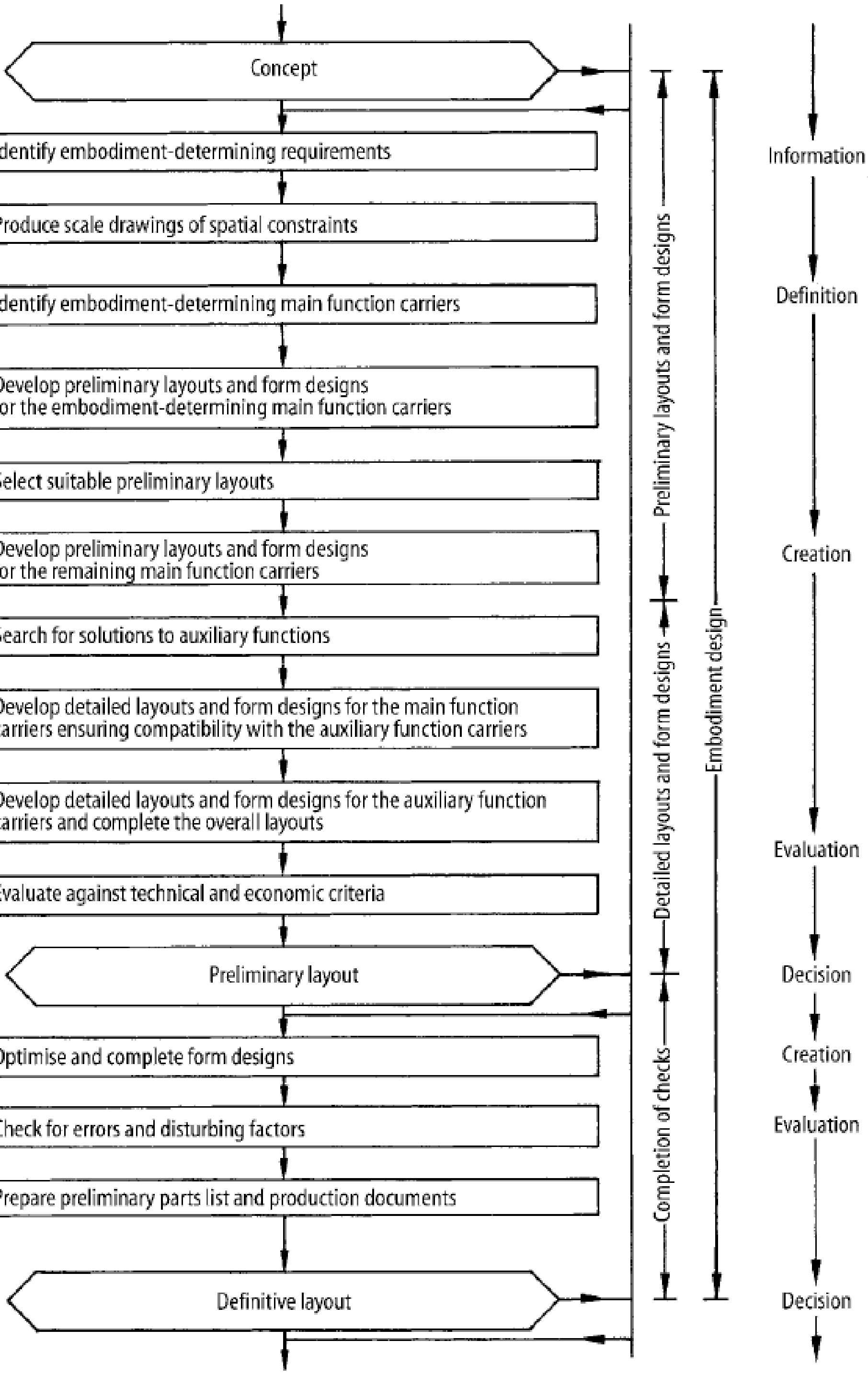


Figure 6.1: Steps in Embodiment Design [26]

Additionally, clarity applies to the broader design structure, whether it involves multiple working principles or component combinations. It mandates that the design facilitates the orderly flow of energy, materials, and signals, preventing adverse effects like excessive forces or wear. This commitment to clarity ultimately enhances the product's reliability and durability.

6.1.2 Simplicity

Simplicity [29] in design is epitomized by an uncomplicated and easily comprehensible approach, often achievable by using fewer components. Such simplicity can lead to cost savings, reduced wear and tear, and minimized maintenance requirements. Nonetheless, it's crucial to strike a balance, as certain functions inherently demand a minimum number of components.

Designers should, therefore, strive for a minimalist approach by employing the fewest components possible while maintaining straightforward shapes, as this promotes efficiency and practicality in the design process. The choice between numerous components with simple shapes, albeit potentially increasing production effort, and a single, more affordable cast component should be made while considering the specific problem and constraints.

6.1.3 Safety

Safety [30] considerations are crucial in ensuring both the effective performance of technical functions and the protection of people and the environment. Designers rely on a safety methodology outlined in the German industry standard DIN 31 000, which encompasses three levels: direct safety, indirect safety, and warnings. In general, designers should prioritize direct safety measures, seeking solutions that inherently eliminate potential dangers. Only when this is not feasible should they resort to indirect safety measures, involving the construction of specialized protective systems.

Warnings, which serve to highlight dangers and hazard zones, are best utilized in conjunction with direct and indirect safety measures, clarifying specific risks. As designers address technical challenges, they encounter various constraints, not all of which can be simultaneously overcome. However, their objective remains to develop solutions that come as close as possible to meeting all requirements. It's important to note that exceptionally high safety demands can complicate design, potentially diminishing clarity and economic viability, and even leading to project abandonment in some cases.

6.2 Guideline of Embodiment Design

In addition the the basic rules of embodiment design, Pahl and Beitz [31] also stress the importance of following a set of design guidelines to help designers meet the specific requirements and constraints. For this project, the following design guidelines are considered:

- Design for production
- Design for ergonomics

6.2.1 Design for Production

Design for production [32] is a design guideline that emphasizes the importance of considering the production process during the design phase. This approach enables designers to optimize the production cost and times while ensuring the product's functionality and quality. By following the basic rules of clarity and simplicity, designers are already on the right track to achieving this goal.

Appropriate Overall Layout Design

Overall layout design, derived from the function structure, influences product division into assemblies and components, including sourcing decisions (in-house, bought-out, standard parts), production procedures, dimensions, batch sizes, joining methods, and quality control.

The layout can lead to differential, integral, composite, or building-block construction methods. Differential Construction involves breaking down components into easily produced parts, facilitating adaptability, increased component batch sizes, and easier quality assurance. However, it demands greater machining and assembly costs and may have functional limitations due to joints.

Integral Construction combines multiple parts into a single component, reducing costs due to integration but can be complex and sensitive to market conditions. Composite Construction involves connecting different parts requiring further work, applying multiple joining methods or using various materials for optimal property utilization.

Building Block Construction results from splitting components so that the parts or assemblies can be used in other products or variants, offering flexibility and cost savings. These construction methods offer specific advantages and disadvantages, depending on the context and design requirements.

Appropriate Form Design of Components

During component form design, designers significantly impact production costs, times, and product quality by choosing shapes, dimensions, surface finishes, tolerances, and fits. These choices influence production procedures, machine types, in-house vs. bought-out components, materials, and quality control procedures.

Conversely, production facilities influence design features, which may include dimension limitations necessitating component division or the acquisition of bought-out components. Many guidelines exist for appropriate component form design, and tolerances are crucial. Figure 6.2 shows the design guidelines for designing components specifically for 3D printing.

6.2.2 Design for Ergonomics

Ergonomics [34] is vital in designing technical products, aiming to align them with human characteristics, needs, and interfaces. It covers a broad range of

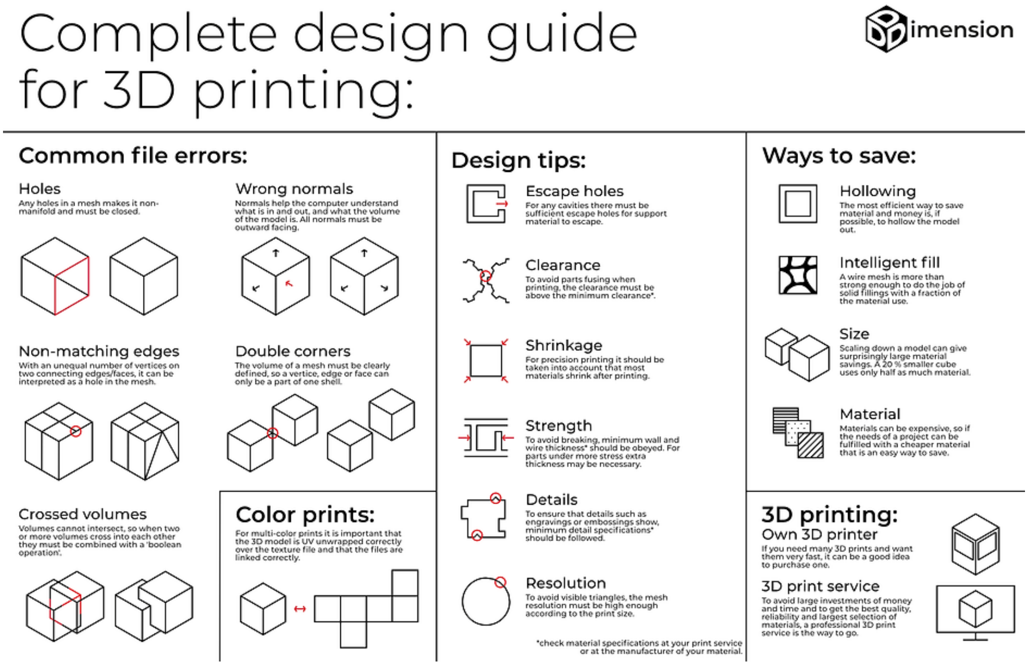


Figure 6.2: Design guidelines for 3D printing [33]

items, including everyday household products and human-machine interfaces. Recent focus has shifted to user-friendly interfaces and ergonomic workplace assessment tools.

Ergonomic design considers various factors, starting with biomechanics, which addresses how body postures and movements interact with product design. Physiological aspects, such as muscle action, circulation, and temperature regulation, are crucial. Sensory factors like light and noise must also be taken into account. Psychological aspects guide design to minimize cognitive load and enhance user-friendliness.

Ergonomics extends to active and passive user involvement. Active involvement necessitates careful planning, assessing if human interaction is necessary and effective. Passive involvement addresses how users are affected by products, considering factors like energy flows, vibrations, light, climate, and noise.

Identifying ergonomic requirements can follow two approaches. The object-based approach is used when designing predefined systems or products, employing checklists tailored to specific items. The effect-based approach applies to new situations, analyzing the effects of energy, material, and signal flows, ensuring they meet ergonomic requirements. Both aim to prioritize user comfort, safety, and efficiency while minimizing discomfort and errors.

6.3 Preliminary Design

In this section, we will explore multiple designs for the device. These designs are detailed 3D models of the device that we will use to evaluate their respective designs and assess their feasibility. Each of these preliminary designs will be based on the selected solution from the previous phase. Alongside the models, we will also present the production costs for each of these designs. For a more detailed breakdown of the production costs, please refer to Appendix **??**.

6.3.1 Preliminary Design Variant 2

In this section, we present a comprehensive design overview of Solution Variant 2. Figure 6.3 showcases the 3D model of Variant 2, while Figure 6.4 provides various perspectives and body measurements of the device. The key emphasis of this design is its ergonomic shape and user-friendly attributes. With a thickness of 49.2 mm (Figure 6.4b), it successfully strikes a balance between being slim and accommodating essential components for optimal performance.

The physical design of Solution Variant 2 adheres to a sandwich-like structure comprising a main body, top cover, and back cover (Figure 6.5). This design choice not only ensures the protection of internal components, but also simplifies assembly and maintenance. The main body of the device functions as the central hub, accommodating the internal components and features, whereas the top and back covers act as protective shields, safeguarding the internal parts from any damage that may result from external factors.

A crucial aspect of the design involves the arrangement of internal components within the device. Following a tablet-like configuration, the main LCD is po-

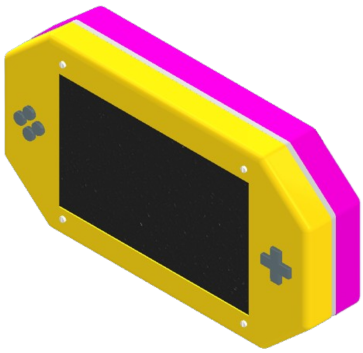
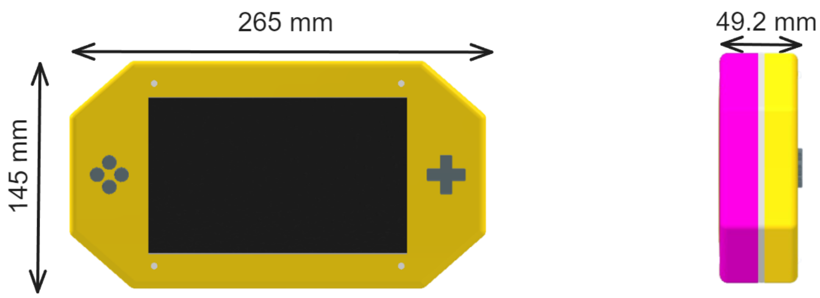


Figure 6.3: Preliminary Design Variant 2



(a) Front View

(b) Right View

Figure 6.4: Views of Preliminary Design Variant 2

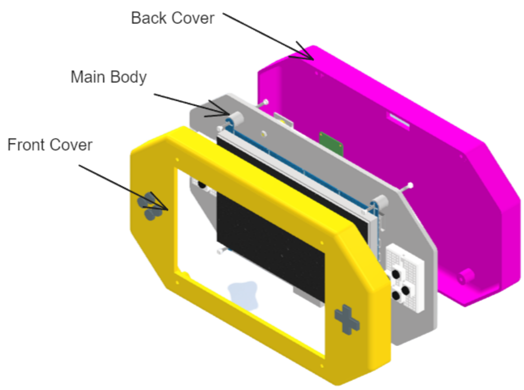
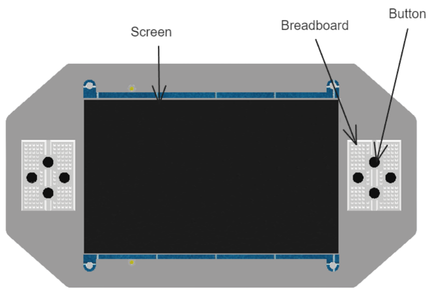
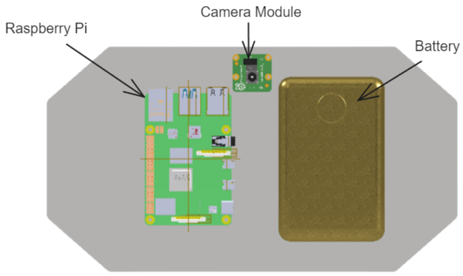


Figure 6.5: Body Components of Preliminary Design Variant 2

sitioned on the front side of the main body, providing users with a clear and interactive interface (Figure 6.6a). Simultaneously, the camera, Raspberry Pi, and battery were strategically placed on the back side of the body (Figure 6.6b)



(a) Front View



(b) Back View

Figure 6.6: Placement of inner components for Variant 2

to optimize the weight distribution and ensure a well-balanced user experience. This arrangement enhances the overall usability and convenience of the device, making it suitable for a wide range of applications.

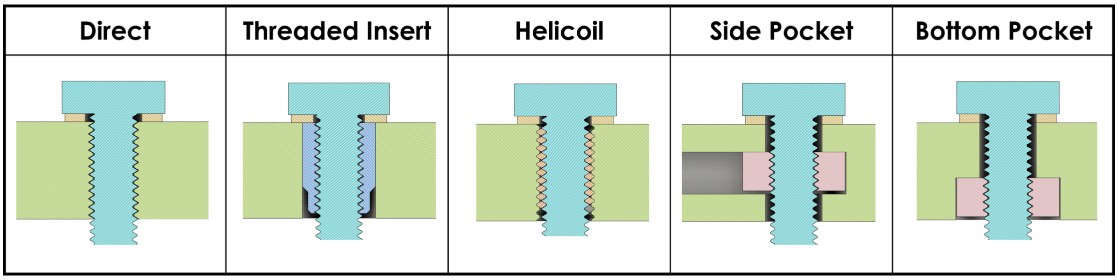


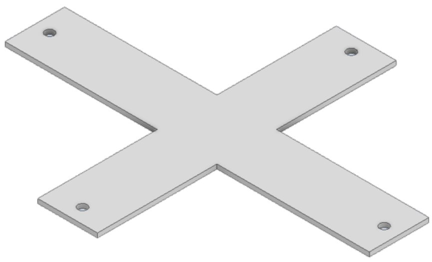
Figure 6.7: Methods to secure components [35]

Ensuring the secure attachment of internal components to the main body is of primary importance in the design process. Various methods of component fastening have been considered, including direct attachment, threaded inserts, helicoils, side pockets, and bottom pockets, as shown in Figure 6.7.

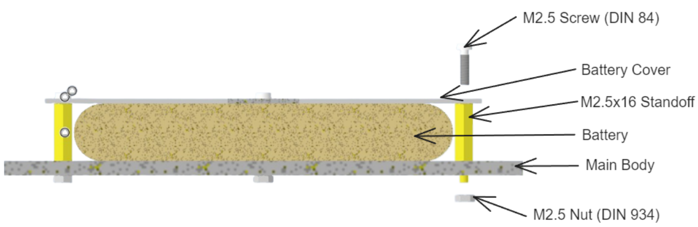
The simplest approach is direct attachment, in which threads are designed into a 3D printed part to allow components to be screwed in. For more robust connections, threaded inserts can be used by designing holes in the 3D printed part and installing inserts appropriately.

Helicoils offer durable threaded holes by inserting coil-shaped inserts into the holes. Side pockets and bottom pockets involve creating cavities or slots in the 3D printed part to hold components securely. Each method has its own advantages and challenges. After careful evaluation, the variant opts for the use of threaded inserts due to its simplicity and robustness.

The battery, which is a critical component of the device, requires special attention to prevent any undesirable movement or instability. To address this concern, an effective method for firmly securing the battery in place is implemented by utilizing a battery cover. Figure 6.8a illustrates the design of the battery cover. The battery cover is then securely attached using screws and standoffs, ensuring that the battery remains in its designated position, even during vigorous handling or movement. Figure 6.8b shows the method used to secure the battery to the main body.



(a) Battery Cover



(b) Placement of components

Figure 6.8: Methods to secure the battery

Solution Variant 2 employs a hybrid input method that combines both touch screen and physical buttons. The touch screen is oriented in landscape mode, while the buttons are positioned on either side of the screen (Figure 6.4a). To enable the integration of the touch screen, HDMI and USB connections were established between the touch screen and Raspberry Pi. Additionally, to facilitate the functionality of the physical buttons, they are connected to Raspberry Pi using general-purpose input/output (GPIO) pins.

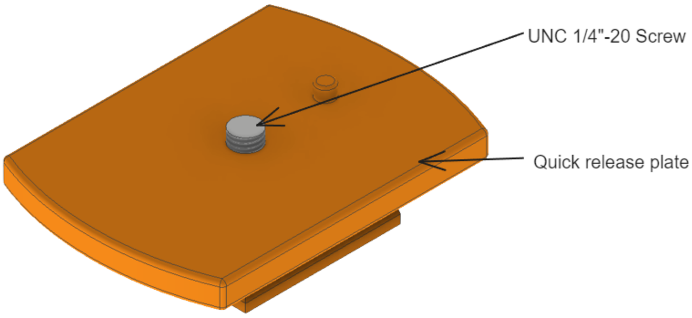


Figure 6.9: Quick release plate

In Figure 6.9, we observe a quick release plate designed to be affixed to the tripod stand. To enhance stability during usage, Solution Variant 2 can utilize a quick release plate, which can be conveniently mounted on a tripod stand.

Cost Calculation

In this section, we will perform a cost analysis for producing Solution Variant 2. It is essential to emphasize that the cost calculation for the 3D printed parts solely considers the material cost and the estimated energy consumption during the printing process. Other expenses, such as the cost of the 3D printer itself, labor, and maintenance, are not factored into the calculation. Additionally, for better comparability with other variants, the costs of the Raspberry Pi, camera module, touch screen, and battery will not be included in the calculation. The formula used to calculate the cost of the 3D printed parts is as follows:

...

6.3.2 Preliminary Design Variant 3

Variant 3 maintains a similar component arrangement to variant 2, with the screen at the front and the camera, Raspberry Pi, and battery at the rear, as shown in Figure 6.11. However, Variant 3 introduced significant changes, such as a portrait-oriented screen and battery type.

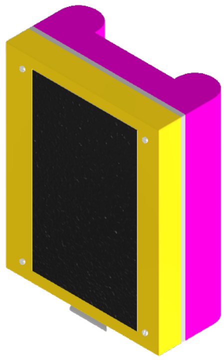
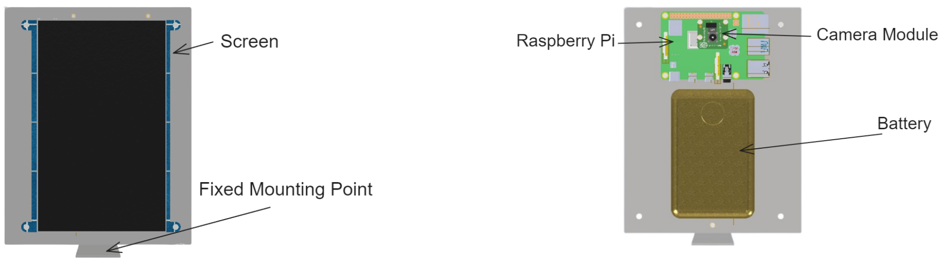


Figure 6.10: Preliminary Design Variant 3



(a) Front View **(b)** Back View

Figure 6.11: Placement of inner components for Variant 3

The chassis structure, similar to variant 2, comprises a main body, top cover, and back cover. The main body accommodates essential electronics and functional elements, while the top and back covers protect the internal components from external forces.

A noteworthy alteration is the inclusion of bumps on the back cover to enhance the ergonomics (Figure 6.12). This adjustment aims to provide a more comfortable grip, improve user engagement, and extend the usability. In addition, the tactile bump serves as a subtle yet impactful refinement, ensuring that the device fits snugly in the user's hand, further enhancing the overall user experience. This thoughtful design element contributes to seamless and enjoyable interaction with the device.

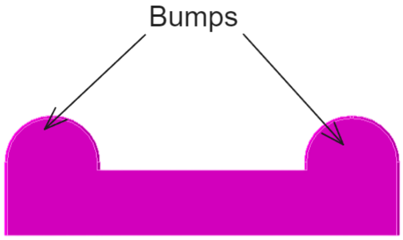


Figure 6.12: Bumps on the back cover

Variant 3 diverted from the standard battery position seen in variant 2, with a more noticeable difference in battery placement. Figure 6.13 illustrates a designated slot within the back cover, strategically designed to house a power bank outside the chassis. This configuration not only enhances the operational stability but also simplifies the process of battery replacement.

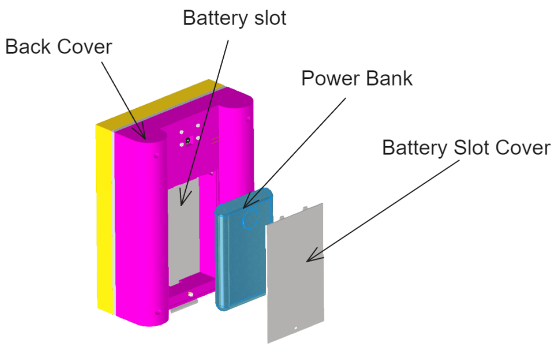


Figure 6.13: Battery Placement

The input methodology was streamlined using a touch screen as the sole interface. This approach simplifies the user experience by eliminating the need for physical buttons and by seamlessly integrating screen interactions. Additional information regarding the integration of the touchscreen with the Raspberry Pi is provided in the previous section.

Figure 6.11a also shows the integration of the mounting point of the tripod directly with the main body in Variant 3. This strategic design allows the mounting point to serve as a sturdy anchor for the device when used in a tripod stand. This direct union ensures secure and stable attachment, enhancing the versatility of the device across various usage scenarios.

Cost Calculation

6.3.3 Preliminary Design Variant 6

Figure 6.14 provides a detailed and comprehensive overview of the initial design concept of Variant 6. This version stands out by organizing its internal components into a configuration resembling a point-of-service (POS) system. This change from previous iterations purposefully positions the screen at an inclined angle, enhancing user interaction and optimizing the screen visibility (Figure 6.15).

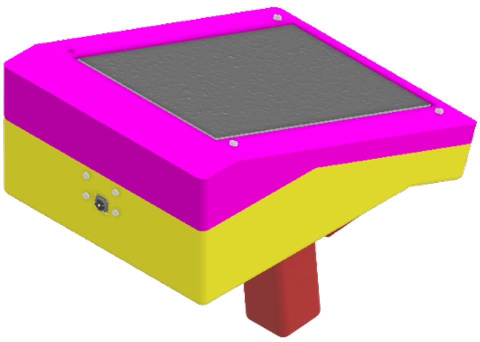


Figure 6.14: Preliminary Design Variant 6

Figure 6.16 demonstrates the design of the handle grip, while Figure 6.17a illustrates its placement on the main body. This ergonomic addition ensures a secure and comfortable hold during operation. Additionally, the handling of the device can be easily switched between the quick-change plate and the handle grip, providing users with flexible options for different scenarios (see Figure 6.17b).

This variant boasts the same input method and battery placement as Variant 3.

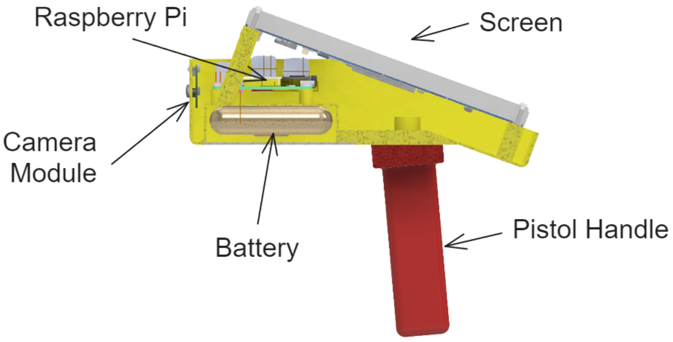


Figure 6.15: Placement of inner components for Variant 3

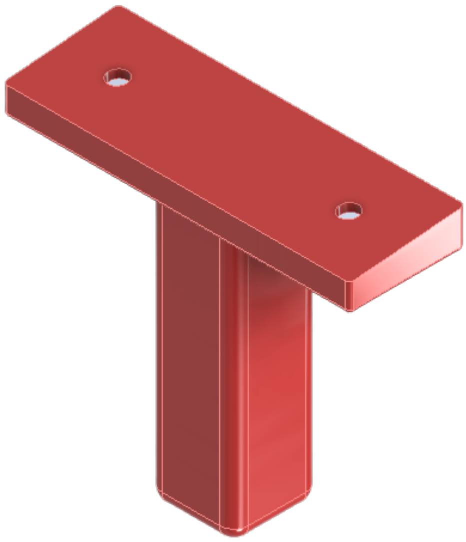


Figure 6.16: Handle Grip

For a comprehensive explanation regarding these aspects, please refer to Section 6.3.2. Touch screens serve as the primary input modality, providing an intuitive and seamless interaction experience. Furthermore, the battery is tucked away in a slot on the back cover and is secured by screws and threaded inserts.

(a) Handle Grip with Main Body **(b)** Quick Release Plate with Main Body

Figure 6.17: Placement of handle grip and quick release plate

Cost Calculation

6.3.4 Preliminary Design Variant 7

Figure 6.18 shows the intriguing concept of variant 7, which is influenced by the handheld PC approach. Here, Raspberry Pi cleverly integrates with the back of the screen, forming a compact and unified structure. Simultaneously, the battery aligned gracefully beside the screen, creating a harmonious arrangement.

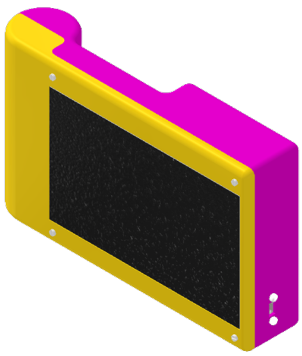


Figure 6.18: Preliminary Design Variant 7

The device features a strategically placed bump on the side, which improves ergonomics and serves as a secure enclosure for the battery (Figure 6.19). The control methods in this variant were similar to those in variant 2, utilizing only touch interfaces.

Similar to variants 2 and 6, this variant also utilized the quick release plate to

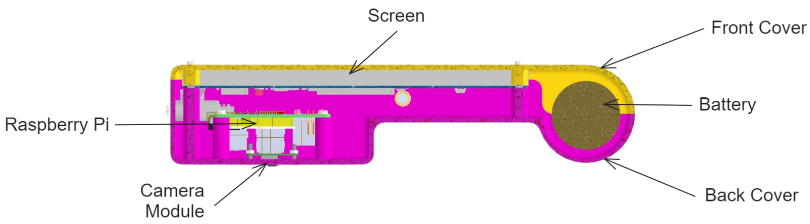


Figure 6.19: Placement of inner components for Variant 7

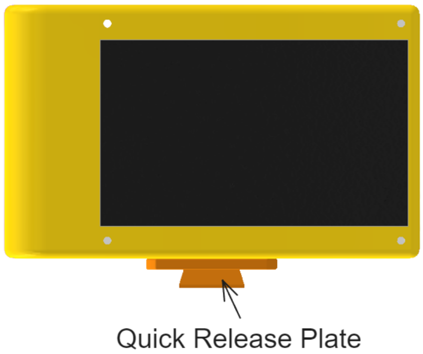


Figure 6.20: Placement of quick release plate

enable integration with a tripod stand. The placement of the plate can be seen in Figure 6.20.

Cost Calculation

6.4 Evaluation with VDI 2225

In this section, we will evaluate the preliminary design variants by utiliting the guideline VDI 2225 [36]. This guideline is a comprehensive framework for evaluating technical solutions based on a balanced consideration of various aspects.

To achieve this, the guideline advocates for methods that provide a holistic evaluation, covering both task-specific requirements and general constraints. These methods aim to not only quantify but also qualitatively assess the properties of different variants, even in the early conceptual phase where information is limited.

The evaluation process, as discussed by Pahl and Beitz [36], outlined in the guideline involves several key steps:

Identifying Evaluation Criteria

This initial step involves defining a set of objectives from which specific evaluation criteria can be derived. These objectives should comprehensively cover decision-relevant requirements and general constraints, ensuring that no crucial criteria are overlooked. The objectives should also be as independent of each other as possible, and expressed in either quantitative or qualitative terms.

Followings are the evaluation criteria for the preliminary design variants:

Weight Distribution: The weight distribution is evaluated based on the weight distribution of the variants and the weight distribution of the individual components. The value for weight distribution is retrieved from Computer-Aided Design (CAD) models through detailed analysis of the device's structural layout and component placement.

Device Weight: Device weight evaluates the overall heaviness of the equipment. A lighter device is generally easier to handle and transport, reducing user fatigue and enabling greater mobility while maintaining performance and durability. The value for device weight is calculated from Computer-Aided Design (CAD) models by summing the individual weights of all components, materials, and structural elements that constitute the device.

Device Size: The size criterion considers the physical dimensions of the device, assessing its compactness and portability. An optimal device size allows for convenient storage, transportation, and operation in various environments without compromising functionality. The evaluation of device size involves measuring key dimensions such as length, width, height, and any protrusions or extensions.

Ease of Assembly: This criterion evaluates the ease of assembling and disassembling the device. Quick and easy assembly and disassembly saves time and increases user convenience, reducing the risk of errors. Evaluation is done by counting the components used in assembly and disassembly. Fewer components often mean a simpler and more user-friendly design. The type and number of fasteners, such as screws or connectors, needed for assembly are also considered.

Swappable Parts: Swappable components refer to the ease with which parts can be interchanged or substituted. This design enhances flexibility, maintenance, and adaptability. The presence of swappable parts encourages component modularity, enabling streamlined repairs and upgrades. Assessment of swappable parts is based on the quantity of interchangeable components and their compatibility. A higher number of swappable parts signifies a design that supports versatility and minimizes downtime for maintenance or repairs.

Weighting Evaluation Criteria

After establishing the evaluation criteria, their relative importance is assessed through weighting factors, w. This step is crucial in eliminating less significant criteria before the actual evaluation. Weightings should reflect the relative importance of each evaluation criterion.

Guideline VDI 2225 aims to avoid weightings and instead relies on criteria of roughly equal importance. However, weightings (like 2x or 3x) are used when there are significant differences between criteria. Table 6.1 shows the weighting factors for the evaluation criteria.

Criteria	Weighting Factor, w
Weight Distribution	2x
Device Weight	3x
Device Size	1x
Ease of Assembly	1x
Swappable Parts	1x

Table 6.1: Weighting Factors for Evaluation Criteria

Assessing Values

This step involves assigning values, v_{ij}, to the variants based on the relative scale of the determined parameters. Guideline VDI 2225 suggests using a range from 0 to 4 for this purpose. Table 6.2 shows the scale used for the evaluation of the preliminary design variants. Tables 6.3 to 6.7 show the value scales for the individual evaluation criteria. Equation 6.1 shows the formula used to calculate the weighted value, wv_{ij}, for each variant.

Points, v_{ij}	Meaning
0	unsatisfactory
1	just tolerable
2	adequate
3	good
4	very good (ideal)

Table 6.2: Value Scale for Evaluation [37]

Weight Distribution	
Range, mm	**Point, v_{ij}**
0-10	4
10-50	3
50-100	2
100-150	1
$\geq$ 150	0

Table 6.3: Value Scale for Weight Distribution

Device Weight	
Range, g	**Point, v_{ij}**
0-500	4
500-1000	3
1000-1500	2
1500-2000	1
$\geq$ 2000	0

Table 6.4: Value Scale for Device Weight

Device Size	
Range, mm	**Point, v_{ij}**
0-100	4
100-200	3
200-300	2
300-400	1
≥ 400	0

Table 6.5: Value Scale for Device Size

Ease of Assembly	
Range	**Point, v_{ij}**
0-25	4
25-50	3
50-75	2
75-100	1
≥ 100	0

Table 6.6: Value Scale for Ease of Assembly

Swappable Parts	
Range	**Point, v_{ij}**
≥ 4	4
3	3
2	2
1	1
0	0

Table 6.7: Value Scale for Swappable Parts

$$wv_{ij} = w_i \cdot v_{ij} \tag{6.1}$$

Determining the Overall Value

The overall value of each variant, OWV_j, is calculated by summing the weighted values, wv_{ij}, of all evaluation criteria (see Equation 6.2).

$$OWV_j = \sum_{i=1}^{n} wv_{ij} \tag{6.2}$$

Comparing Concept Variants

With the overall values, OWV_j, of the concept variants, the variants can be compared and evaluated based on thier rating, R, which is calculated using Equation 6.3. The technical rating, R_t, is calculated using Equation 6.4, where v_{max} is the maximum value of the value scale, and n is the number of evaluation criteria.

The economic rating, R_e, is calculated using Equation 6.5, where C_o is the comparative cost, and $C_{variant}$ is the cost of the variant. For this project, the comparative cost, C_o, is set to be 60% of the cost of the least expensive variant (see Equation 6.6).

The best variant is determined by comparing the total rating, R, of each variant. The variant with the highest total rating is considered the best variant.

$$R = \frac{R_t + R_e}{2} \tag{6.3}$$

$$R_t = \frac{OWV_j}{v_{max} \cdot \sum_{i=1}^{n} w_i} \tag{6.4}$$

$$R_e = \frac{C_o}{C_{variant}} \tag{6.5}$$

$$C_o = 0.6 \cdot C_{minimum} \tag{6.6}$$

6.4.1 Evaluation of Preliminary Design Variant

In this section, the result of the evaluation of the preliminary design variants will be presented. Table 6.10 shows the technical evaluation of the preliminary design variants, while Table 6.8 shows the economic evaluation of the variants. The total rating of the variants is shown in Table 6.9. Based on the total rating, Variant 6 is the best variant, followed by Variant 7, Variant 3, and Variant 2.

For a more detailed calculation, please refer to Appendix **??**.

Production Cost		
Variant	**Cost, $C_{variant}$(€)**	**Economic Rating, R_e**
Variant 2	74.95	0.33
Variant 3	47.97	0.52
Variant 6	44.14	0.56
Variant 7	41.25	0.60

Table 6.8: Economic Evaluation of Preliminary Design Variants

Variant	**Technical Rating, R_t**	**Economic Rating, R_e**	**Total Rating, R**
Variant 2	0.65	0.33	0.4901
Variant 3	0.60	0.52	0.5580
Variant 6	0.70	0.56	0.6304
Variant 7	0.65	0.60	0.6250

Table 6.9: Total Rating of Preliminary Design Variants

Evaluation criteria					Variant 2			Variant 3			Variant 6			Variant 7		
No.	Criteria	Weight	Description	Units	Value	Point	Weighted Weight	Value	Point	Weighted Weight	Value	Point	Weighted Weight	Value	Point	Weighted Weight
1	Weight Distribution	2	Distance of center of gravity	mm	2.49	4	8	54.84	2	4	28.09	3	6	92.18	2	4
2	Device Weight	3	Weight of device	g	1190.60	2	6	1103.30	2	6	1112.60	2	6	889.20	3	9
3	Device Size	1	Length of device	mm	265.00	2	2	185.00	3	3	194.94	3	3	222.50	2	2
		1	Width of device	mm	145.00	3	3	145.00	3	3	145.00	3	3	135.50	3	3
		1	Thickness of device	mm	52.20	4	4	69.20	4	4	80.30	4	4	47.70	4	4
4	Ease of Assembly	1	Number of parts required to be assemble	-	58	2	2	42	3	3	49	3	3	35	3	3
5	Swappable parts	1	Number of swappable parts available	-	1	1	1	1	1	1	3	3	3	1	1	1
	Total	**10**					**26**			**24**			**28**			**26**
	Technical Rating, Rt						**0.65**			**0.6**			**0.7**			**0.65**

Table 6.10: Technical Evaluation of Preliminary Design Variants

6.5 Detail Design

The result of the evaluation of the preliminary design variants shows that Variant 6 is the best variant. Hence, this variant will be used as the basis for the detail design. Any improvements will be added in the design, while any weaknesses will be addressed. The result of this process is the final design of the device.

Power Switch

This component plays a critical role in controlling the Raspberry Pi's power supply. It is imperative to have a reliable method for powering up and shutting down the Raspberry Pi to ensure smooth operation and prevent potential data corruption.

One available method utilizes the GPIO (General Purpose Input/Output) pins to initiate a shutdown sequence for the Raspberry Pi [38]. While effective in bringing the device to a hibernation state, it's important to note that this method doesn't completely cut off power. As a result, the Raspberry Pi still draws a minimal amount of power even in this low-power state [39].

To achieve more efficient power management, a more straightforward approach is recommended. This involves the implementation of a simple physical switch (refer to Figure **??**). This switch functions by directly connecting and disconnecting the power supply to the Raspberry Pi. As a result, when the switch is in the "off" position, it completely severs the power supply, ensuring that the Raspberry Pi consumes no power whatsoever. This approach has been chosen as the preferred method for controlling the power supply in this project due to its effectiveness and simplicity in implementation.

Camera Protection

In the context of the device's design considerations, particular attention has been directed towards safeguarding the camera component. As illustrated in Figure 6.21, the current design accommodates the camera within the body of the device, with the lens extending slightly beyond its confines.

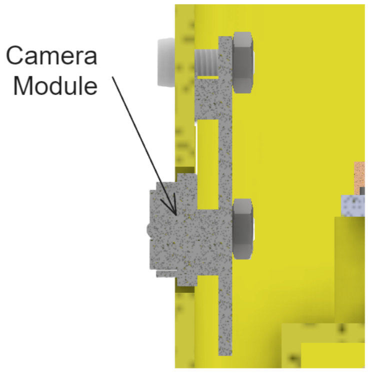


Figure 6.21: Position of the camera component

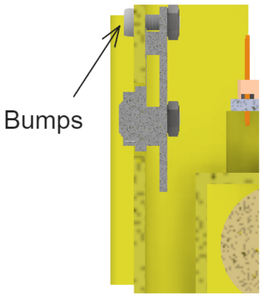
While this configuration is essential for optimal functionality, it does pose a potential vulnerability. Specifically, there exists a risk of inadvertent damage to the camera lens if the device is mistakenly positioned with the lens side facing a surface. Such damage, if incurred, could have severe repercussions on the device's usability.

To address this concern, a purposeful addition has been made in the form of a 3 mm high protective bump (see Figure 6.22). Strategically placed, this bump serves as a safeguard, effectively elevating the camera lens above surfaces and thus averting direct contact.

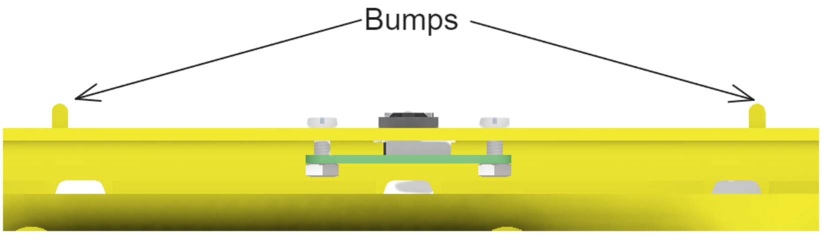
Screen Protection

In parallel to the considerations for camera protection, an analogous concern extends to safeguarding the device's screen. The design, as depicted in Figure, accommodates a screen that sits flush with the device's surface, rendering it susceptible to potential damage if placed on abrasive or uneven surfaces.

Similar to the implementation for camera protection, a parallel measure has been applied to address concerns regarding screen protection. As depicted in Figure 6.23, the design integrates a protective bump around the screen perimeter, mirroring the approach taken for the camera.

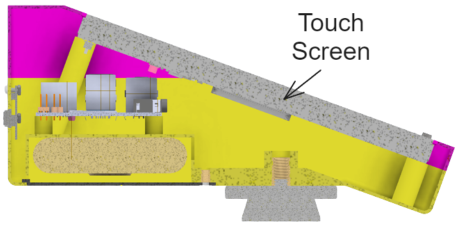


(a) Left View

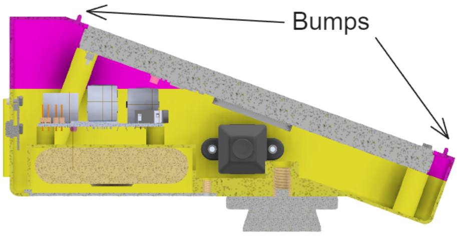


(b) Top View

Figure 6.22: Protective bump for camera



(a) Before



(b) After

Figure 6.23: Protective bump for screen

Column for Threaded Inserts

In accordance with the design specifications detailed in section **??**, threaded inserts have been employed as a critical element for securely fastening components within the body of the device.

It is imperative to note that threaded inserts of varying sizes necessitate distinct minimum wall thicknesses for the columns, as well as specific hole depths to ensure proper engagement and stability. To address this requirement, a comprehensive sizing guide based on Ruthex threaded inserts has been compiled and is presented in Table 6.11.

Thread Size	Hole size (mm)	Min. thickness (mm)	Min. height (mm)
M2.5	4	1.6	6.7
1/4"	8	3.3	13.7

Table 6.11: Sizing guide for threaded inserts [40][41]

LAN Port

The inclusion of a LAN (Local Area Network) port in the device design serves as a crucial convenience feature for users seeking to perform maintenance on the Raspberry Pi without the need for disassembly. This strategic integration allows for seamless connectivity, enabling direct access to the Raspberry Pi's functionalities and resources over a local network. Figure 6.24 shows the LAN port.

Positioned on the side of the device body (see Figure 6.25), the LAN port offers a user-friendly interface, ensuring easy accessibility for maintenance tasks. This thoughtful placement not only enhances the overall user experience but also demonstrates a commitment to user-centric design, allowing for swift and efficient maintenance procedures while minimizing any potential disruption to the device's internal components.

Figure 6.24: The LAN port

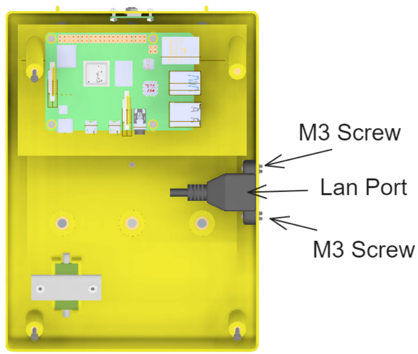


Figure 6.25: Position of the LAN port

Color Scheme

The color scheme plays a crucial role in enhancing the product's appeal. Considering the target market is the police force, we drew inspiration from the Germany police logo, as can be seen in Figure 6.26. Blue, the dominant color in the logo, is used as the primary color for the device. Other color that is presented in the logo is yellow, which is used as the device's handle grip color and the color white, which is used as the color for the devices top cover.

The result of the color scheme can be seen in Figure 6.27.

Figure 6.26: Germany Police Logo [42]

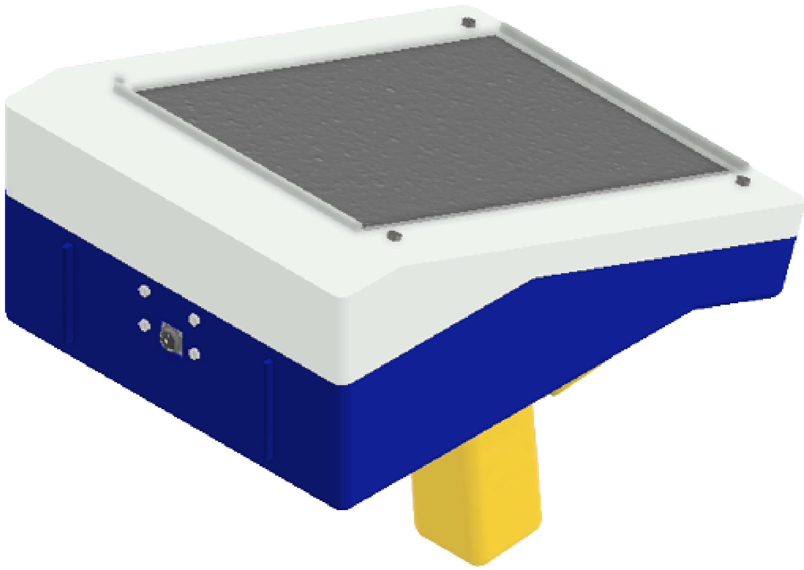


Figure 6.27: Result of recolor

7 Printing and Assembly

In this chapter, the process of printing and assembling the prototype is described.

7.1 Printing

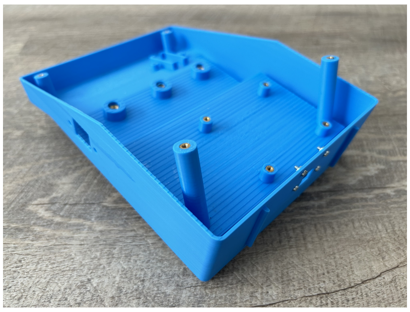
In this section, the process of printing the prototype is described. The prototype was printed using the Prusa Slicer i3 MK3S+ 3D printer. The printing process was performed in the Workshop of the University of Applied Sciences Brandenburg. The printing process was performed using the following parameters:

- Layer Height: 0.2 mm
- Infill Density: 15%
- Print Speed: 60 mm/s
- Supports: Yes
- Filament: PLA

The printing process was performed using the PrusaSlicer software. The PrusaSlicer software was used to generate the G-code for the printing process. Table 7.1 shows the printing time and the amount of filament used for the printing process. The printed parts with its support materials removed are shown in Figure 7.1.

Part Name	Mass of PLA used (g)	Printing Time (h)
Top Cover	57.71	2.00
Main Body	245.05	9.23
Battery Cover	22.21	0.67
Switch Cover	1.31	0.05
Handle Pistol	64.63	1.98
Total	390.91	13.93

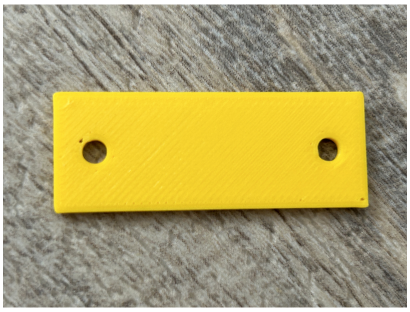
Table 7.1: Printing Time and Filament Used



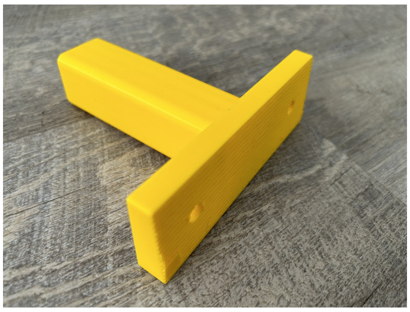
(a) Main Body

(b) Top Cover

(c) Battery Cover



(d) Switch Cover



(e) Handle Pistol

Figure 7.1: Printed Parts

7.2 Assembly

The assembly process is done by following the steps below:

Step 1: Installation of Threaded Inserts

The brass threaded inserts is installed into the main body by using soldering iron [43]. To begin, the chosen threaded insert is positioned onto the target material, aligning it with the desired hole. The soldering iron is then heated to an appropriate temperature, typically within the range of 225 to 245 $^{\circ}C$ for PLA material.

As the soldering iron reaches the optimal temperature, it is gently pressed against the top of the threaded insert, transmitting controlled heat directly into the material. This causes the insert to soften and adhere to the surrounding surface, creating a snug fit. Figure **??** shows an example of the threaded insert installed into the main body.

Step 2: Installation of Switch

Installing a switch to the main body is a straightforward process that requires a few basic materials: the switch itself, a switch cover, two M2.5 nuts, and M2.5 screws. To begin, position the switch inside the designated switch holder (see Figure 7.2), ensuring that the button faces outward for easy access.

Next, the switch cover is placed on top of the switch, aligning it with the switch and the corresponding holes in the main body. Once aligned, the M2.5 screws and nuts are used to secure the switch and the switch cover to the main body. Figure 7.3 shows the completed installation of the switch.

Step 3: Installation of LAN Port

This steps begin by locating the slot of the LAN port on the main body, which is located at the right side of the main body (see Figure 7.4). The LAN port is then inserted into the slot and secured by using the M3 screws Figure 7.5 shows the completed installation of the LAN port.

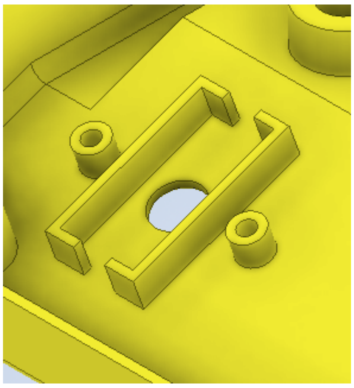


Figure 7.2: The Switch Holder

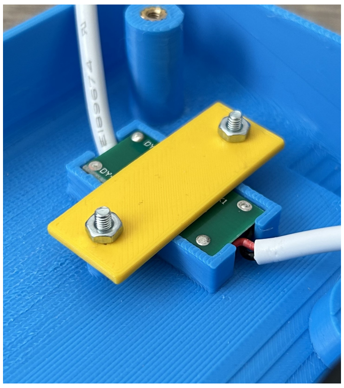


Figure 7.3: The installed switch

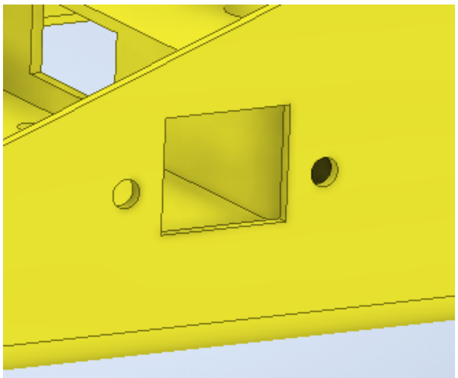


Figure 7.4: The LAN Port Slot

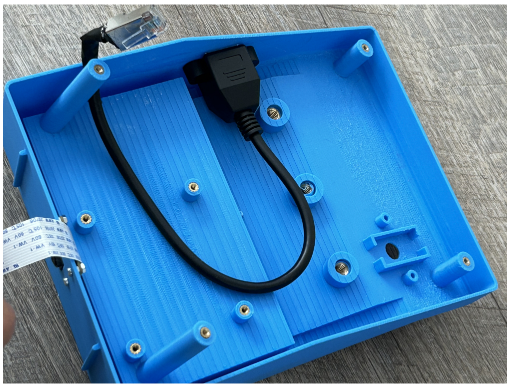


Figure 7.5: The installed LAN port

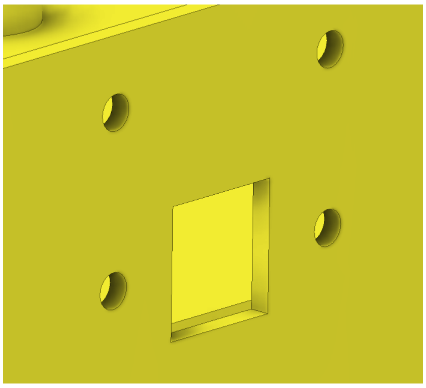


Figure 7.6: The Camera Module Slot

Step 4: Installation of Camera Module

The camera module is installed to the main body by using the M2 screws. The camera module is placed on the designated slot on the main body (see Figure 7.6). The M2 screws are then used to secure the camera module to the main body. Figure 7.7 shows the completed installation of the camera module.

Step 5: Installation of Battery

This process begin by placing the battery into the battery holder (see Figure 7.8). Next, the battery is connected the switch via a 90 degree USB-A to USB-C connector.

To secure the battery to the main body, the battery cover is placed on top of the battery and the main body. The M2.5 screws are then used to secure the

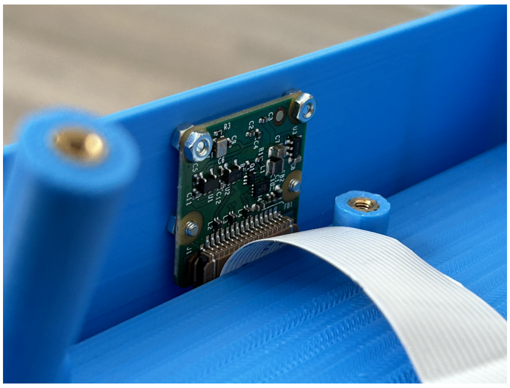


Figure 7.7: The installed camera module

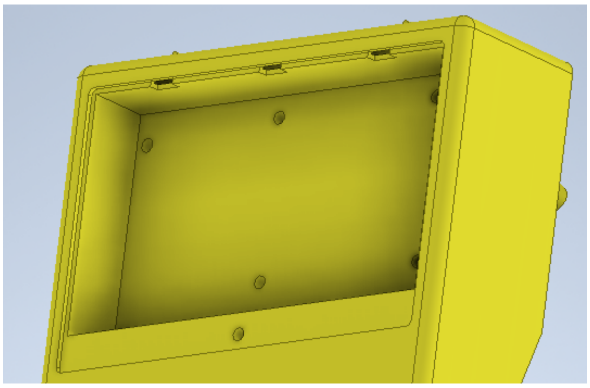


Figure 7.8: The Battery Holder

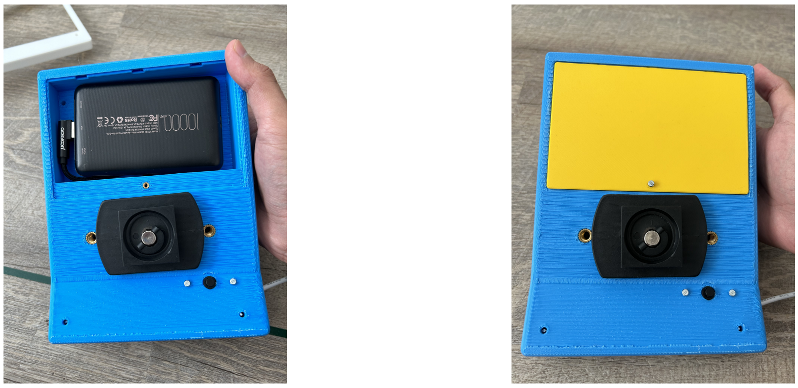
battery cover to the main body. Figure 7.9 shows the completed installation of the battery.

Step 6: Installation of Raspberry Pi

The Raspberry Pi is installed to the main body by using the M2.5 screws. The Raspberry Pi is placed on the designated slot on the main body (see Figure 7.10). The M2.5 screws are then used to secure the Raspberry Pi to the main body.

Next, following connections are made to the Raspberry Pi:

- The LAN port is connected to the Raspberry Pi via a LAN cable.
- The camera module is connected to the Raspberry Pi via a ribbon cable.



(a) Without Battery Cover　　**(b)** With Battery Cover

Figure 7.9: The installed battery

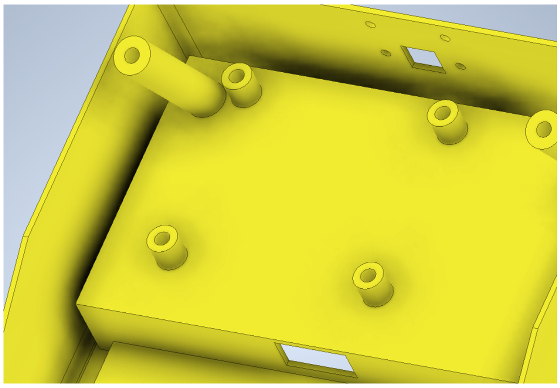


Figure 7.10: The Raspberry Pi Slot

- The switch is connected to the Raspberry Pi via USB-C cable.

Figure **??** shows the completed installation of the Raspberry Pi.

Step 7: Installation of Screen and Top Cover

The final step is to install the screen and the top cover. Begin by placing the screen into the designated slot on the main body (see Figure 7.11) and allign the hole on the screen with the hole on the main body. Next, the top cover is placed on top of the main body. The M2.5 screws are then used to secure the top cover to the main body. Figure **??** shows the completed installation of the screen and the top cover.

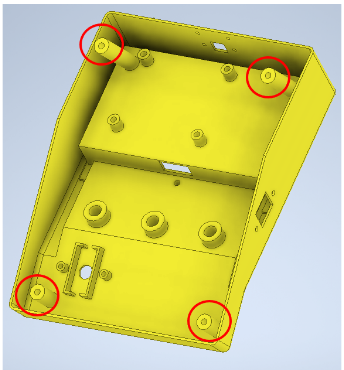


Figure 7.11: The Screen Slot

7.3 Final Product

Figure **??** shows the final product. The total cost of building the product including the cost of printing and all of the materials is shown in Table **??**.

7.4 Conclusion

Part II

GUI Development

1 Methodology

1.1 MVC Pattern

- What is MVC?
- What are the distinct responsibilities and roles of the Model, View, and Controller components in the MVC pattern?
- What are the benefits of using MVC?

The Model-View-Controller (MVC) pattern is a software architectural pattern that separates an application into three interconnected components: the model, the view, and the controller. The model represents the data and logic of the application, the view displays the data to the user, and the controller handles user input and updates the model and view accordingly. This pattern promotes separation of concerns, modularity, and code reusability in software development. [?]

1.2 Design Patterns - Thread Pool

- What is a thread pool?
- What are the benefits of using a thread pool?
- What are the drawbacks of using a thread pool?

A thread pool is a software design pattern that manages a pool of worker threads to efficiently execute tasks. Instead of creating a new thread for each task, a thread pool reuses existing threads, minimizing the overhead of thread creation. It improves performance and resource utilization by limiting the number of concurrent threads and providing a queue to handle incoming tasks.[?]

2 Requirements and Design

2.1 Requirements

Must have:

- Usability - Easy to use
- Performance - Fast processing by utilising multiple threads
- Responsiveness - Responsive GUI, avoid methods that block the GUI thread
- Error Handling - Handle errors gracefully, avoid crashing the application
- Scalability - For future development
- Documentation - user guides, Tooltips, comments
- Design - Clean and simple design

2.2 Wireframe

Program flow and GUI design will be presented in a wireframe.

* Flow of the program is not finalized, will be updated in the future

- All panels involved in the program will be presented here
- Flow of the program will be presented here.

- The arrangement of panels, both preceding and following another panel, will be showcased here.
- What happens when the user clicks on a button will be presented here

2.3 GUI Design

Design of the GUI will be presented here. Panels, Buttons, Textfields, etc.

- Layout of the GUI will be defined here
- What panels will be used will be defined here

3 Solutions and Implementations

In this chapter, the solutions and implementations of the project will be presented.

3.1 Model

Implementation of the Model

- What is the Model?
- What are the key responsibilities of the Model?
- What is the primary purpose and responsibility of the Model component in the application's architecture?

3.2 View

Implementation of the View

- What is the View?
- What are the key responsibilities of the View?
- How does the View handle the presentation and visualization of data to the user?
- How does the View respond to user input and events, and how are these interactions managed?

- What are the mechanisms for updating the View based on changes in the Model or instructions from the Controller?

3.3 Controller

Implementation of the Controller

- What is the Controller?
- What are the key responsibilities of the Controller?
- How does the Controller handle user input and events?
- How does the Controller update the Model and View?

4 Testing

4.1 Unit Testing

Unit testing is a software testing approach that involves testing individual components or units of code in isolation to ensure they function correctly. It verifies the behavior of small, independent units of code, such as functions or methods, to validate their expected functionality and catch any defects early in the development process. [?]

5 Conclusion

Conclusion of the project

Part III

Indexes and Appendix

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A Appendix

A.1 Sketches of Working Principles

A.1.1 Screen Orientation

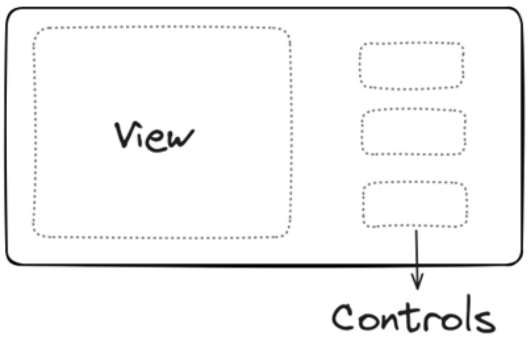
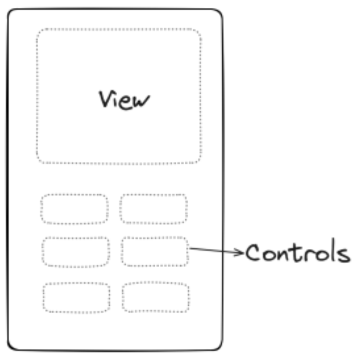
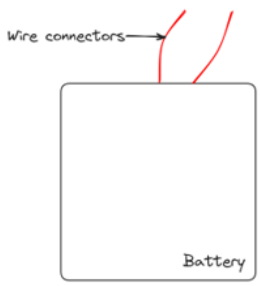
2.1 Landscape	2.2 Portrait
	

Table A.1: Screen Orientation

A.1.2 Battery Type

<table>
<tr><th>3.1 Battery Pack</th><th>3.2 Power Bank</th><th>3.3 AAA Batteries with Battery Holder</th></tr>
<tr>
<td>
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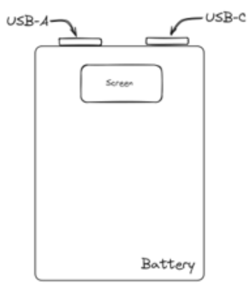
<td>
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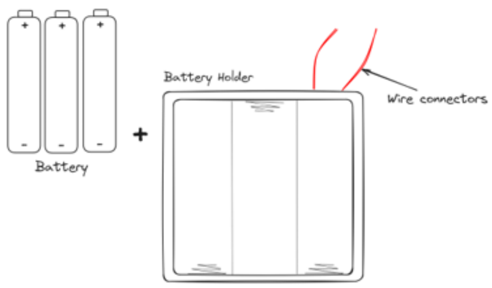
<td>
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Table A.2: Battery Type

A.1.3 Components Placement

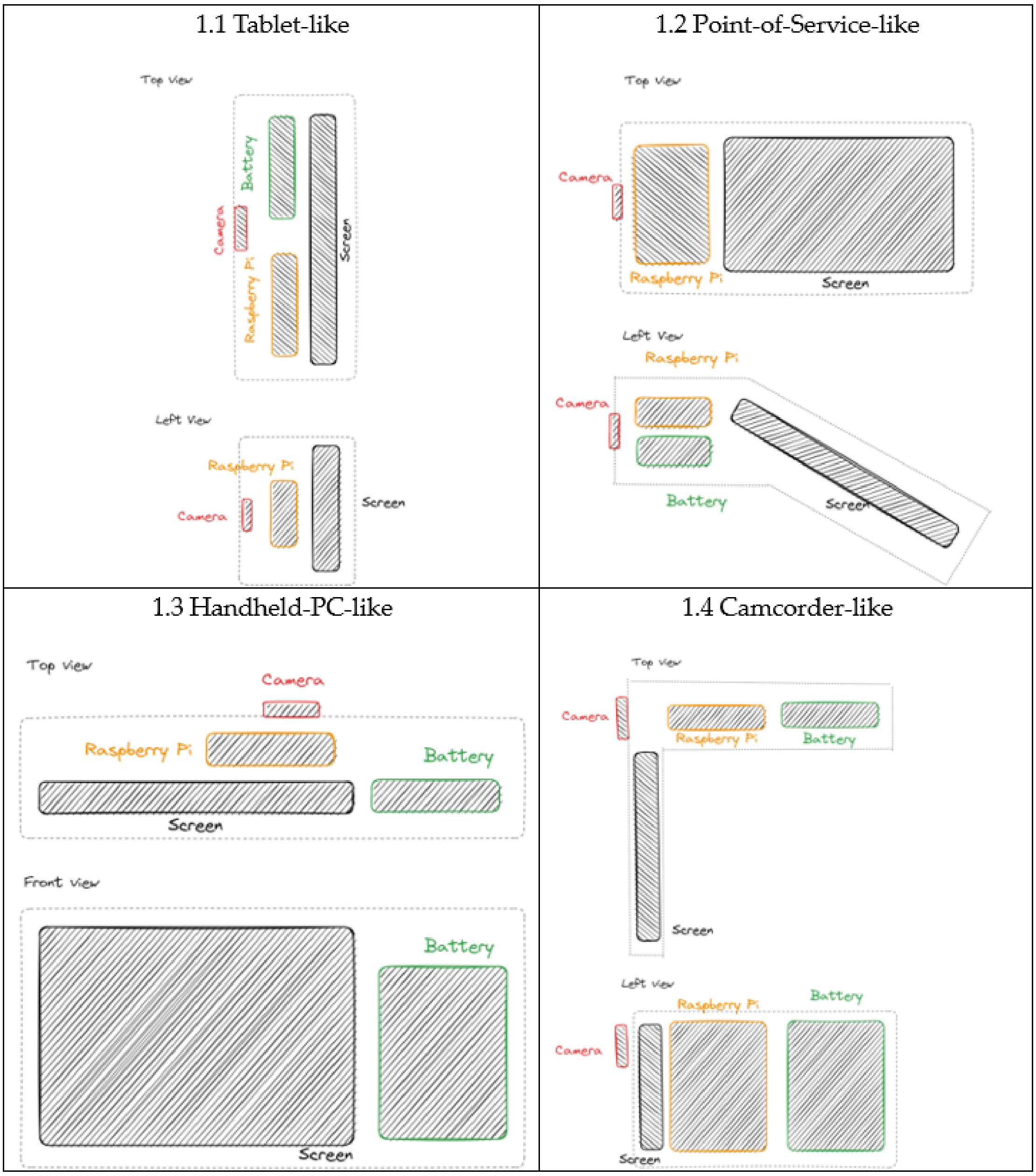

Table A.3: Components Placement

A.1.4 Body Type

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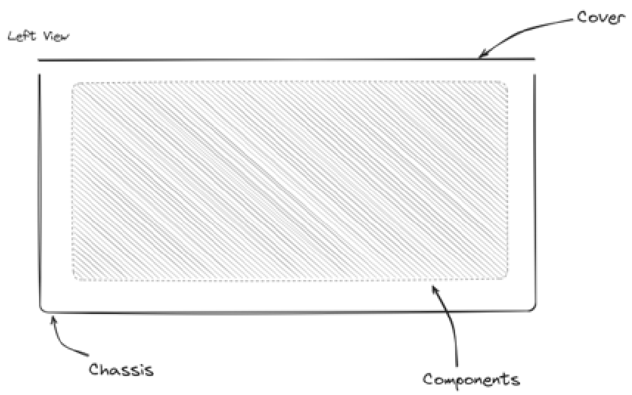
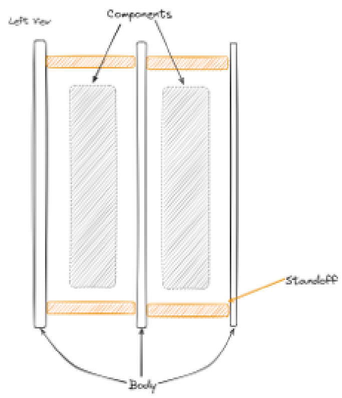

</td><td>4.2 Skeleton

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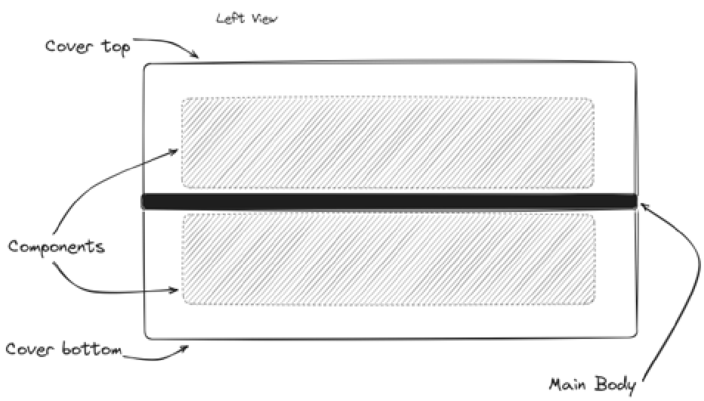

</td><td></td></tr>
</table>

Table A.4: Body Type

A.1.5 Handling

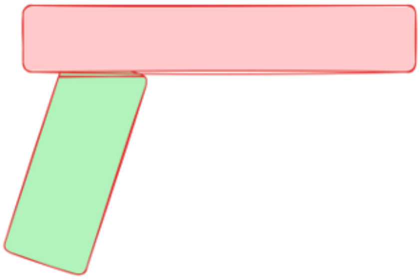
5.1 Body Grip	5.2 Bump Grip	5.3 Pistol Grip
		

Table A.5: Handling

A.1.6 External Mounting

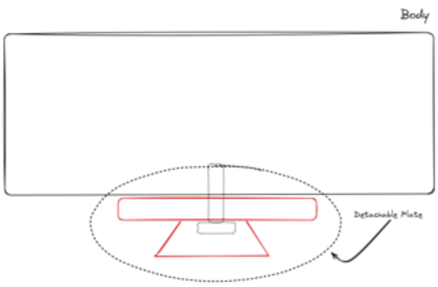
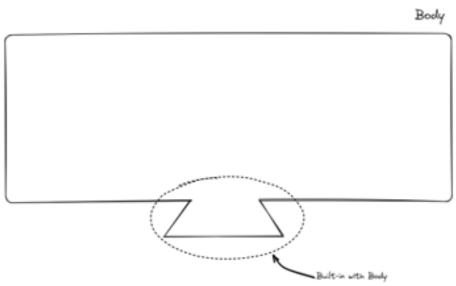
6.1 Detachable Plate	6.2 Built-in Mounting Plate
	

Table A.6: External Mounting

A.1.7 Control Mechanism

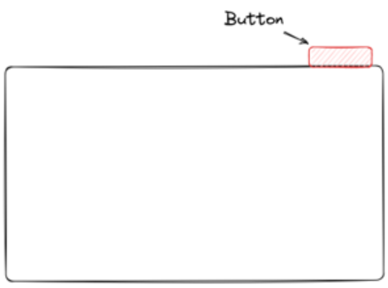
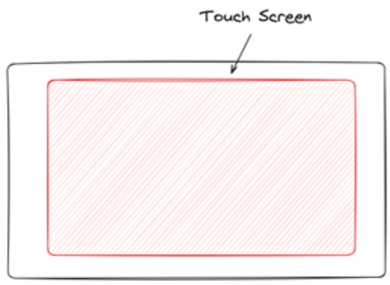
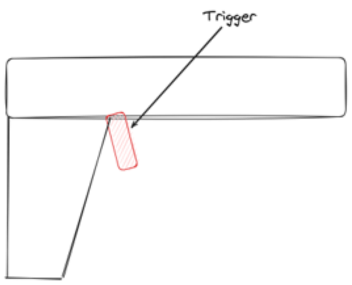
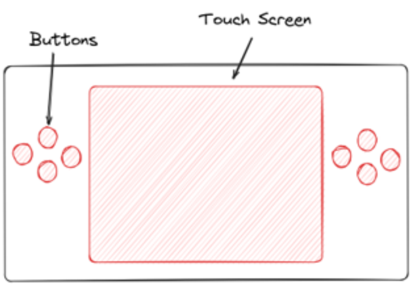
7.1 Button	7.2 Touch Screen
	
7.3 Trigger	7.4 Touch and Button
	

Table A.7: Control Mechanism

A.2 Documentation

- Docs
- Repository

A.3 CAD Drawings

A.4 Bill of Materials

A.5 Code snippets

A.6 Additional information, pictures, handout, etc.

prusa slicer data sheet rpi data sheet pi cam data sheet brass insert data sheet