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.

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Abstract

Abstract

Keywords: Keywords1, Keywords2, Keywords3

Abstract

Kurzfassung

Schlüsselwörter: Schlüsselwörter1, Schlüsselwörter2, Schlüsselwörter3

Contents

1 Introduction

1.1 Motivation

Excessive speeding poses a significant threat to the safety of people on our roads. It impacts those directly involved in accidents, their families, and their communities. Over four years, from 2019 to 2022, Germany experienced an average of nearly 38,000 accidents annually due to speeding [1]. These accidents can have long-lasting consequences, inflicting physical and emotional harm. Countless individuals are injured or tragically losing their lives, profoundly impacting their loved ones. It is crucial to address this issue, and the goal of this thesis is to develop an innovative speed gun system to aid in the reduction of excessive speeding.

1.2 Problem Statement

Law enforcement agencies and road safety organizations often find the current speed gun technologies available in the market too expensive for widespread adoption. These technologies can cost around 2000 €, which creates a financial barrier preventing effective speed monitoring in many regions. This thesis aims to explore alternative speed gun systems that use computer vision to address this challenge. By using this technology, they aim to create a more affordable and robust solution for speed monitoring, which will address the financial constraints of traditional speed guns and open up new possibilities for innovation and customization in speed monitoring technology. Ultimately, this will enhance road safety and reduce accidents caused by excessive speed.

1.3 Previous Work

Previous research has delved into various computer vision methods to tackle the complex challenge of speed monitoring. One remarkable innovation is the image alignment algorithm, which employs feature detection techniques to rectify any inadvertent movement during video recording. This algorithm enhances the stability of recorded footage and ensures accurate speed assessment.

Another technique, object detection coupled with optical flow analysis, tracks pixel movements within consecutive frames and enables the reliable identification of moving objects. This approach is computationally efficient, making it a practical and cost-effective solution for real-time speed monitoring.

Moreover, a method that leveraged the pinhole camera model to measure the distance of objects from the camera's vantage point, enabling accurate distance measurements without the need for complex and costly equipment. Integrating this model into speed monitoring provides a streamlined and economically viable method for assessing speeds with high precision.

1.4 Research Objectives

Our research aims to develop a new type of speed gun that utilizes computer vision technology. The project will consist of two parts. In the first part, we will design the physical structure of the prototype using the VDI 2221 methodology. The second part will focus on software development, creating an easy-to-use interface that leverages computer vision for real-time speed assessment and data analysis. The goal is to create a state-of-the-art speed gun that addresses speeding concerns and sets a new road safety technology standard.

2 State of the Art - Speed Pistol

Law enforcement agencies worldwide utilize speed guns, also known as radar guns or speed pistols, as crucial tools to combat speeding. These devices play a pivotal role in maintaining road safety by accurately measuring the velocity of vehicles on the road [2].

The current implementation of speed pistol usually utilize either the LIDAR (Light Detection and Ranging) or RADAR (Radio Detection and Ranging) technology [3] [4] [5] [6]. These technologies serve as the cornerstone of modern speed measurement devices, allowing law enforcement officers to gauge the speed of vehicles in real-time accurately.

LIDAR technology operates on emitting laser pulses towards a target vehicle and measuring the time it takes for the light to bounce back [4]. The LIDAR device can precisely calculate the vehicle's speed by analyzing the returned signals.

On the other hand, RADAR technology has been a reliable tool in speed enforcement for decades. Radar guns emit radio waves as a focused beam, which bounce off the target vehicle and return to the device. By analyzing the frequency shift of the returned signal, the device can determine the vehicle's speed [7].

However, both of these technologies have their limitations. For instance, LIDAR can be affected by adverse weather conditions like rain or fog, potentially reducing its effectiveness [8]. Conversely, RADAR signals may be susceptible to interference from nearby objects, which can complicate speed measurements in densely populated areas [9].

Both LIDAR and RADAR technologies, while highly effective in speed measurement, come with a notable price tag. A LIDAR device can range from several thousand to tens of thousands of euros [10]. In comparison, RADAR guns, though generally less expensive than LIDAR, can still cost around 2000 € for a high-quality unit [11].

These costs present a significant consideration for law enforcement agencies, especially those operating with limited budgets or in smaller jurisdictions. This limitation highlights the need for exploring more cost-effective alternatives without compromising accuracy and efficiency in speed enforcement.

Part I

Prototype Development

3 Literature Review

3.1 Methodic Product Development

Methodic product development, as mentioned by Pahl and Beitz [12], underscores the necessity of a structured design procedure that fosters creativity and inventiveness and ensures objective evaluation of outcomes. Their method combines knowledge from design science, psychology, and practical know-how. This systematic approach helps designers handle complex technical systems, shifting from instinctive to deliberate decision-making, resulting in more effective and understandable designs.

At the core of the Pahl and Beitz methodology is the understanding that effective product development involves well-defined and interconnected stages [13]. They describe the product development process as a series of stages, each with defined objectives and activities. The four main stages are:

Planning and Task Definition: The process starts with careful planning and defining tasks, often in collaboration with the marketing or dedicated planning team. It is essential to thoroughly understand the task, whether from a product proposal or a customer request. This step involves gaining detailed insights into requirements, constraints, and their importance, forming a solid foundation for the next steps.

Conceptual Design: Once the project goals are crystal clear, the conceptual design phase takes center stage. This phase entails pinpointing the necessary functions, establishing operational principles, and integrating them into a unified structure. Ultimately, this leads to creating a fundamental solution that embodies the core of the design vision.

Embodiment Design: Moving towards tangible realization, the embodiment design phase becomes pivotal. Guided by technical and economic considerations, designers mold the physical structure. Various initial layouts are assessed to identify design strengths and weaknesses, ultimately leading to selecting the most promising version.

Detail Design: The pinnacle of the methodology lies in the detail design phase, which focuses on individual components. Precise arrangements, dimensions, materials, and other aspects are meticulously defined. Thoroughly assessing production capabilities and costs results in comprehensive production documentation, highlighting the phase's critical role in shaping the overall outcome.

Figure 3.1 shows the stages involved in Pahl and Beitz's design process.

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 [15].

This method 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 [15], which 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) [16]. These materials have different mechanical properties, advantages, and disadvantages, making them suitable for different applications.

Takahashi et al. [17] mentioned that achieving a high-quality printing result necessitates considering various parameters. They classified these factors into

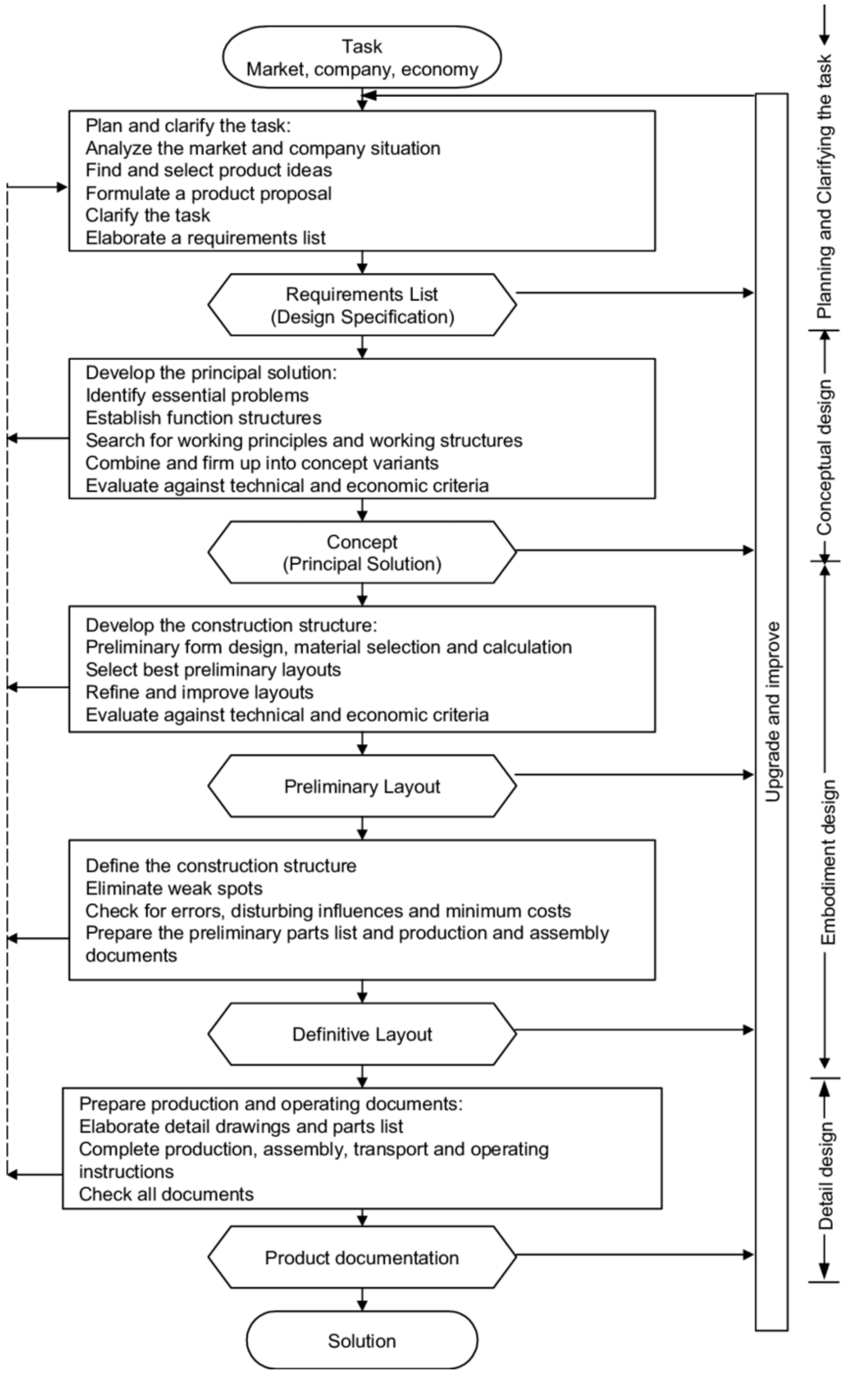


Figure 3.1: Pahl and Beitz's Design Process [14]

four groups: (1) operation parameters, (2) machine parameters, (3) machine

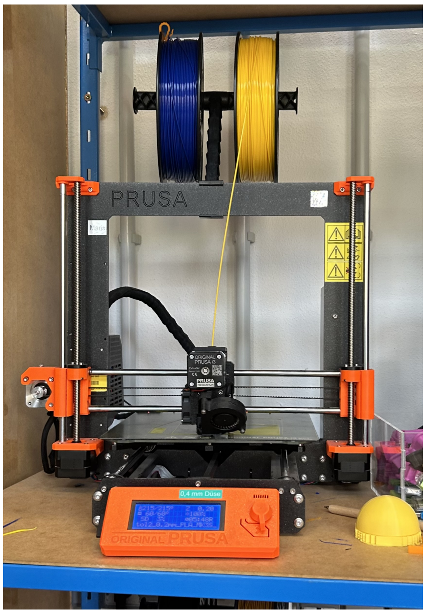


Figure 3.2: Original Prusa i3 MK3S+

parameters, and (4) geometry-specified parameters.

3.2.1 Original Prusa i3 MK3S+

The Original Prusa 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 [18]. This printer has a heated bed and is compatible with various materials such as PLA, ABS, PETG, and nylon [18]. The default nozzle size is 0.4 mm, although alternate sizes can be utilized based on specific printing needs.

This 3D printer is accessible to students and faculty at the University of Applied Sciences Brandenburg and will play a pivotal role in the prototype development process. Figure 3.2 visually represents the Original Prusa i3 MK3S+, located within the University of Applied Sciences Brandenburg Workshop.

3.2.2 PrusaSlicer

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

One of the most essential 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 printed object. The infill density refers to the amount of material used to fill the 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.

PrusaSlicer offers an essential function of adding support to the 3D prints. Supports are structures that print alongside the object to provide extra stability during printing. They prevent any potential collapse or deformation of the object while printing. Supports can be added manually or automatically depending on the complexity of the printed object.

This software can also generate a preview of the printed object, which lets users visualize the result. Additionally, PrusaSlicer provides an estimate of the amount of filament required for the printing process and the duration of the printing process. Figure 3.3 shows a screenshot 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 (C_m)
- Energy Cost (C_e)

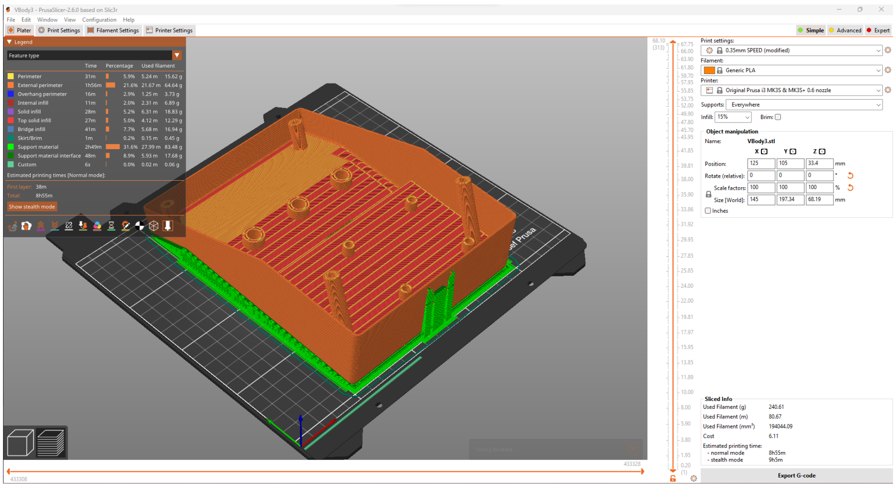


Figure 3.3: Example View of PrusaSlicer

Equation 3.1 shows the formula used to calculate the material cost. This formula involves multiplying the mass of filament used (m_{fil}) by the cost of filament per kilogram(C_{fil}). The cost of the filament is dependent on the type of material used. We will use PLA for this project, which costs 29.99 €/kg [19].

Energy cost refers to the electricity cost of the printing process and is calculated using Equation 3.2. The printing duration (t_p) is estimated directly from the PrusaSlicer software, while the power consumption (P) of the printer is estimated to be about 0.08 kW [18]. By observing the average price of electricity in Germany for the year 2022 [20], the electricity price (C_{el}) is estimated at 0.235 €/kWh.

Equation 3.3 shows the formula for calculating the cost of 3D printing.

$$C_m = m_{fil} \cdot C_{fil} \tag{3.1}$$

$$C_e = t_p \cdot C_{el} \cdot P \tag{3.2}$$

$$C_{print} = C_m + C_e \tag{3.3}$$

4 Planning and Task Clarification

This chapter delves into 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 plays 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 goal is to eliminate confusion and ensure comprehension among all involved parties.

During this step, the task's specific goals, limitations, and required deliverables are identified [22]. By clarifying and specifying tasks, engineers and designers set a strong foundation for the later stages of product development, which allows the designers 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 [22]. These questions are:

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

The requirements for the solution can be identified and spelled out by answering these questions. 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 [22].

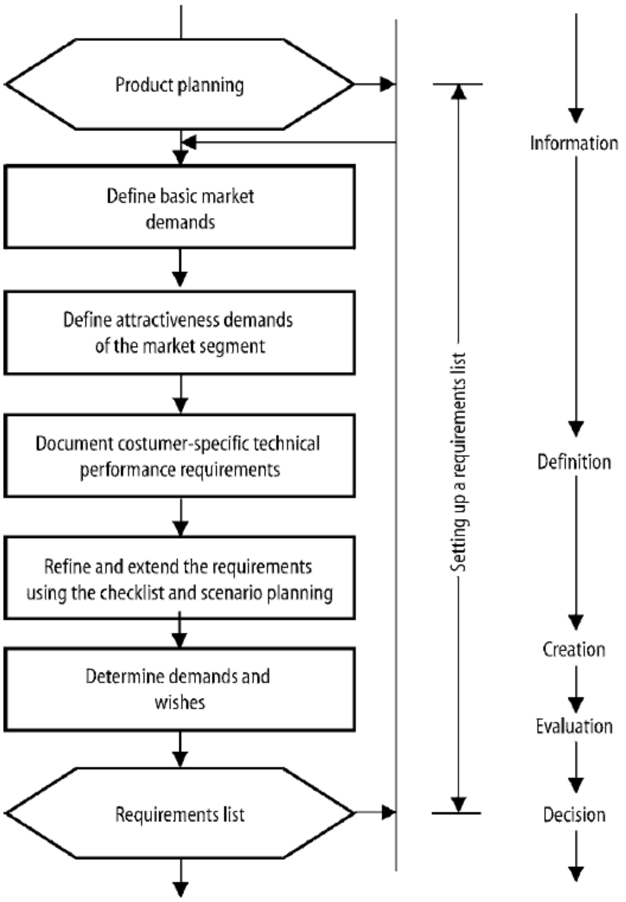


Figure 4.1: Planning and Task Clarification [21]

4.1 Establishing the Prototype's Requirements

To properly establish the requirements for the prototype, it is suggested to properly define the objectives of the prototype and classify them into demands and wishes [23].

Demands, as described by Pahl and Beitz [23], 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 functionality and compliance.

On the other hand, wishes, as defined by them, are desirable but non-essential requirements or features that clients or 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, if possible, all of the requirements defined must be quantifiable, which means that the requirements must be measurable and testable [23]. This specification is essential for ensuring that the requirements are met and that the product can 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 correctly identified and defined.

Geometry

When creating a prototype, adhering to specific size parameters is essential to ensure its functionality and usability for end-users or customers. The prototype must conform to a general size limit of 300 mm x 300 mm x 300 mm (length x width x height).

Additionally, we must consider the limitations of the 3D printer's size capacity. We have opted to employ the printer mentioned previously in Section 3.2.1. This particular printer has a maximum printing area of 210 mm x 210 mm x 250 mm [18].

Ideally, each printed component should fall within the specified printing size range. However, should a component exceed these dimensions, it will be nec-

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 [24]

essary to divide it into two or more parts to facilitate printing. This approach guarantees that each part can be accommodated within the printer's size constraints.

Energy

The energy required for the prototype is crucial because it determines its usefulness and convenience. We have set a requirement that the prototype should function independently for at least an hour using the provided power supply. This guideline is in place to ensure that the prototype can function autonomously and provide users with a seamless experience.

By meeting this requirement, the prototype demonstrates that it can operate reasonably without frequent charging or relying on external power sources. This feature enables users to use the device without any concerns for an extended period, giving them more opportunities to explore its functionality and capabilities.

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 is crucial to verify that the prototype can effectively support the weight of its components without compromising its overall structure or functionality, which 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 requirement encompasses the collective weight of all internal components, including predefined components and any additional materials integrated during the design process. Adhering to this weight limit ensures the prototype remains lightweight and manageable while meeting the intended performance criteria.

Materials

When developing the prototype, it is of utmost importance to thoughtfully consider the specific materials and elements that will be utilized. The client has already preselected specific components for this project, which are mandatory to meet the requirements. These components include the Raspberry Pi 4B, a 7-inch touch screen, and the Raspberry Pi Camera V2.

These elements are fundamental building blocks for the prototype's operation. The Raspberry Pi 4B, functioning as a versatile single-board computer, furnishes computational power and acts as the central control unit for the prototype. The 7-inch touchscreen enhances user interaction by providing a responsive and user-friendly interface for both input and output. The Raspberry Pi Camera V2 facilitates the capturing of images and videos.

Ergonomics

The prototype has specific ergonomics requirements regarding dimensions, weight, and handling. The main goal is to produce a compact and lightweight prototype, making it easy to carry and maneuver, which makes it more comfortable and convenient for users to handle.

Another crucial aspect of the ergonomics requirement is ensuring that users can comfortably hold the prototype. This requirement involves considering the prototype's shape, grip, and balance to ensure it is easy and secure. The design should fit naturally into the user's hand, providing a stable and ergonomic grip.

Production

The client has specified the fabrication of the prototype components to utilize the 3D Printing technology. Furthermore, the design of the prototype must accommodate the use of PLA filament. This material, known for its widespread availability and well-rounded combination of strength and flexibility, aligns with the requirements of the prototype.

Operation

The prototype must fulfill two essential requirements: easy to use freehand without additional support and compatible with a tripod to ensure stability.

The prototype design should allow freehand operation to achieve the first requirement. The design should be ergonomic, with a comfortable grip and easy-to-use controls, making it intuitive for users to use the prototype.

The second requirement is that the prototype should be able to integrate with a tripod to offer better stability when needed. This feature lets users securely attach the prototype to a tripod, ensuring a stationary and stable setup. With tripod compatibility, the prototype can cater to scenarios where steady and controlled operation or positioning is necessary.

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 requirement 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.

The prototype's design should have swappable properties so individual components or modules can be easily removed and replaced without disassembling the entire prototype. Swappable parts enhance modularity, flexibility, and cost-effectiveness, as users can upgrade or replace specific components as needed rather than replace the entire prototype.

Costs

The cost requirement for the prototype focuses on the total cost of production. The manufacturing of the prototype must be within a budget of 300 €, excluding the cost of the predefined components. This budget encompasses the cost of all materials and components used in the production process.

Schedules

The schedule requirement for the prototype focuses on the time required for the design and production phase. The prototype's design must allow for manufacturing within a 2-month window, covering the entire production process, from design to assembly.

Durability

The durability standard for the prototype encompasses considerations for its ability to withstand dust and water, if possible. While achieving complete resistance may only sometimes be attainable, efforts should be directed toward enhancing the prototype's durability in these aspects.

Concerning dust resistance, the prototype's design should minimize the entry of dust particles into its internal components and sensitive areas. This requirement entails using appropriate seals, filters, or protective enclosures to prevent dust from negatively impacting the prototype's performance or functionality.

In terms of water resistance, if relevant to the intended use, the prototype should demonstrate a level of protection against water penetration. This specification may incorporate waterproof or water-resistant materials, seals, or coatings to shield the internal components from moisture.

4.3 Requirement List

Table 4.1 and Table 4.2 shows the list of requirements for the prototype, including the demands and wishes. The demands are marked with a D, while the wishes are marked with a W.

TH Brandenburg		Requirement List Speed Camera	Issued on Page:	1/7/2023 1
Changes	**D/W**	**Requirements**		
		Geometry		
	D	1. Length < 300 mm		
	D	2. Width < 300 mm		
	D	3. Height < 300 mm		
	W	Parts size: 210 mm x 210 mm x 250 mm or less		
		Energy		
	D	Minimal operation time: 1 hour		
		Forces		
5/7/2023		Total prototype weight < 2 kg		
		Materials		
	D	Use all predefined components		
		Ergonomics		
	W	Leightweight		
	W	Comfortable handling		
	W	Compact		
		Production		
	D	3D Printed		
	D	Use PLA filament		
		Operation		
	D	Able to be use in freehand		
	D	Able to integrate with tripod stand		
		Assembly		
	W	Simple assembly or component used		
21/8/2023	D	Swappable Parts		

Table 4.1: Requirement List (1/2)

TH Brandenburg		Requirement List Speed Camera	Issued on Page:	1/7/2023 2
Changes	D/W	Requirements		
		Costs		
13/7/2023	D	Manufacturing costs < 300 €		
		Schedules		
	D	Finished by: October 2023		
		Durability		
	W	Resistant against water		
	W	Resistant against dust		

Table 4.2: Requirement List (2/2)

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.

According to Pahl and Beitz, conceptual design is the stage of the design process where important issues are pinpointed through abstraction [25]. The process involves establishing function structures, searching for suitable working principles, and ultimately combining these elements to create a working structure.

Figure 5.1 shows the steps involved in this phase.

5.1 Abstraction

Due to new technologies, procedures, materials, and scientific discoveries, traditional solution principles or designs may not be able to provide optimal answers, and to overcome fixation on conventional ideas, designers utilize abstraction, focusing on the general and essential aspects rather than particular details [27].

To help in identification of the essential problems, following abstraction techniques are used [28]:

- **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

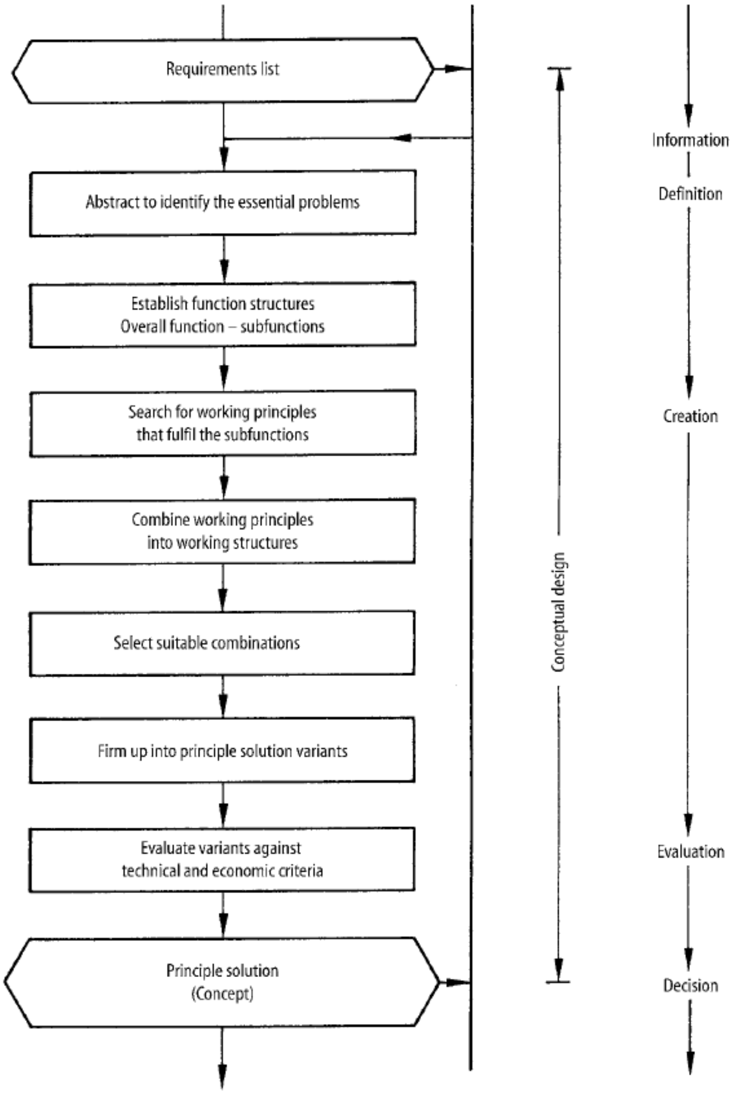


Figure 5.1: Steps in Conceptual Design [26]

essential statements.

- **Step 4:** Generalise the previous step's results.
- **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: 300 mm
- Width: 300 mm
- Height: 300 mm
- 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 300 mm in dimension.
- 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.

Figure 5.2: Result of Abstraction Process

5.2 Function Structures

Pahl and Beitz [29] 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 helpful tool for identifying a system's essential functions and 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.

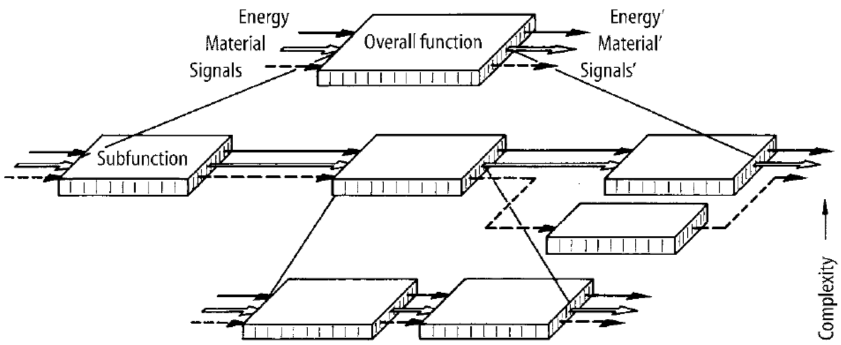


Figure 5.3: Breaking down the overall function into sub-functions [30]

5.2.1 Overall Function

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

In this overall function, the prototype's components are defined as an input, while the prototype itself is defined as the output. The overall function is decomposed into sub-functions in the next section.

Figure 5.4: Overall Function of the System

5.2.2 Sub-Functions

Decomposing the overall function into sub-functions is crucial in the conceptual design process, and as described by Pahl and Beitz [31], the purpose of this decomposition is to reduce the complexity of the overall system and facili-

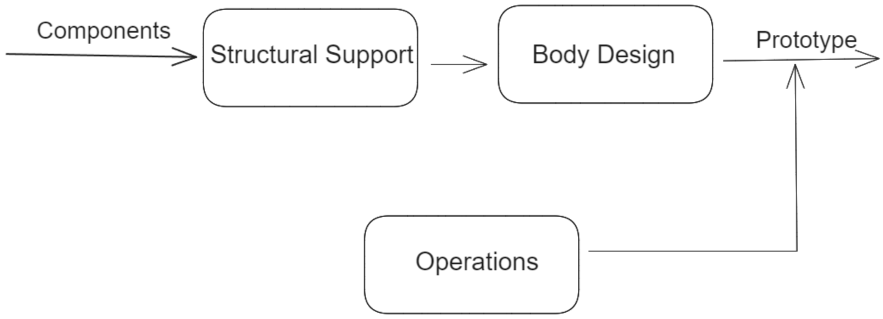


Figure 5.5: Sub-Functions of the System

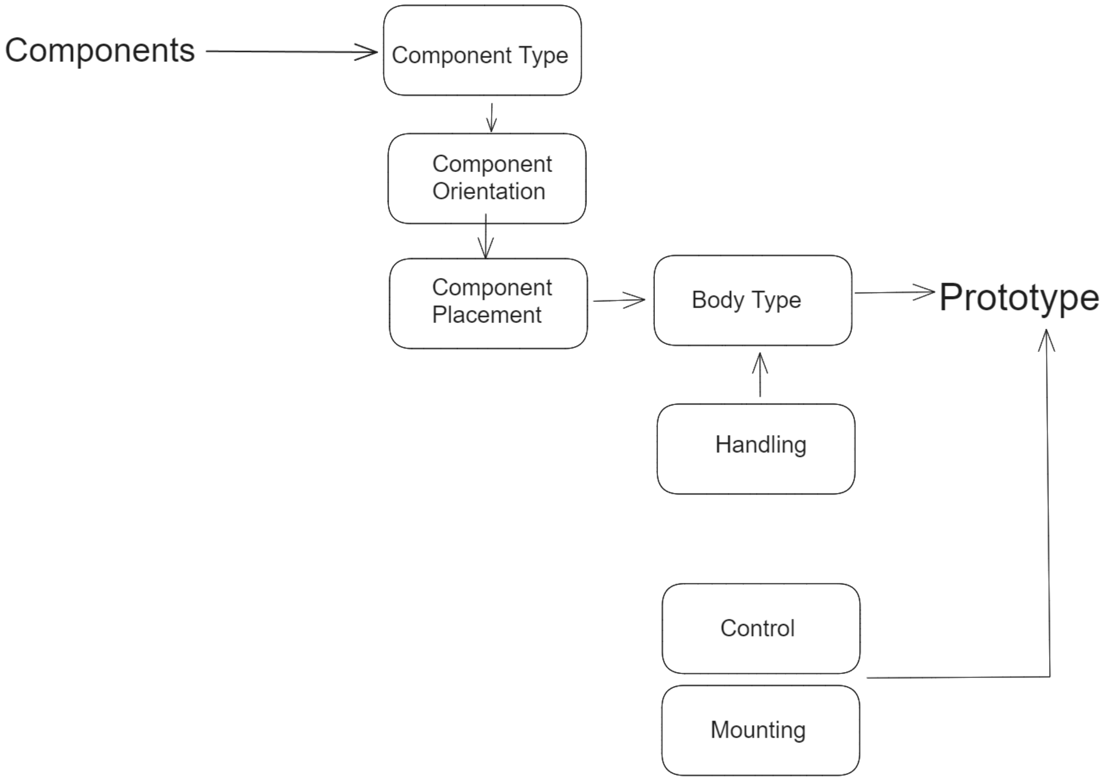


Figure 5.6: Sub-Functions of the System (Final)

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

Figure 5.5 illustrates the sub-functions of the prototype. Deriving from the overall function, labeled as *Prototype Design*, it breaks down into three subfunctions, specifically *Structural Support*, *Body Design*, and *Operation*. The function is then further decomposed into more detailed sub-functions in Figure 5.6.

The term *Structural Support* refers to the measures taken to ensure the structural integrity of the prototype. This sub-function encompasses activities such as securing and stabilizing the internal components within the prototype. To simplify the function, it decomposed into three sub-functions: *Component Placement*, which specifies the positioning of internal components; *Component Orientation*, which details the alignment of internal components; and *Component Type*, which is the type of component itself.

Body Design describe the sub-functions involving the prototype's physical structure. To further simplify the task, this sub-function is decomposed into *Body Type*, which defines the outline of the structure, and *Handling*, which describes the handling of the prototype.

Operation deals with how the prototype works. It describes the device's usage and the components involved during operation. This function is then divided into *Control Mechanism*, which describes the component involved during operation, and *Integration with External Mounting*, which refers to the integration of the prototype with the tripod stand.

5.3 Developing Working Principles

In developing working structures, one crucial step is to search for working principles. As defined by Pahl and Beitz, working principles refer to the physical effects and characteristics that fulfill specific functions of the designed structure [32]. These principles are combined to create the working structure, encompassing physical processes and the form design features. Several potential working structures can be generated by varying the physical effects and form design features, known as the solution field.

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 [33] 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 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 [34], 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.

Additionally, Pahl and Beitz [35] introduce *Discursive methods*, which combines 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.

5.3.1 Searching for Working Principles

We utilize multiple techniques, including *Brainstorming* and *Analysis of Existing Technical Systems*, to establish working principles for this project. Brainstorming helps to generate ideas and concepts, while Analysis of Existing Technical Systems enables us to scrutinize and assess the ideas and concepts generated.

Table 5.1 shows the result of idea generation. For 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 combine the working principles assigned to the sub-functions to create potential working structures. To achieve this, the identified working principles must be linked following the functional structure to fulfill the overall function.

The method we will employ for systematic combination is Zwicky's morphological box [36]. In this approach, the potential principles are represented in a table for better clarity and connected to form functional structures using connecting lines.

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

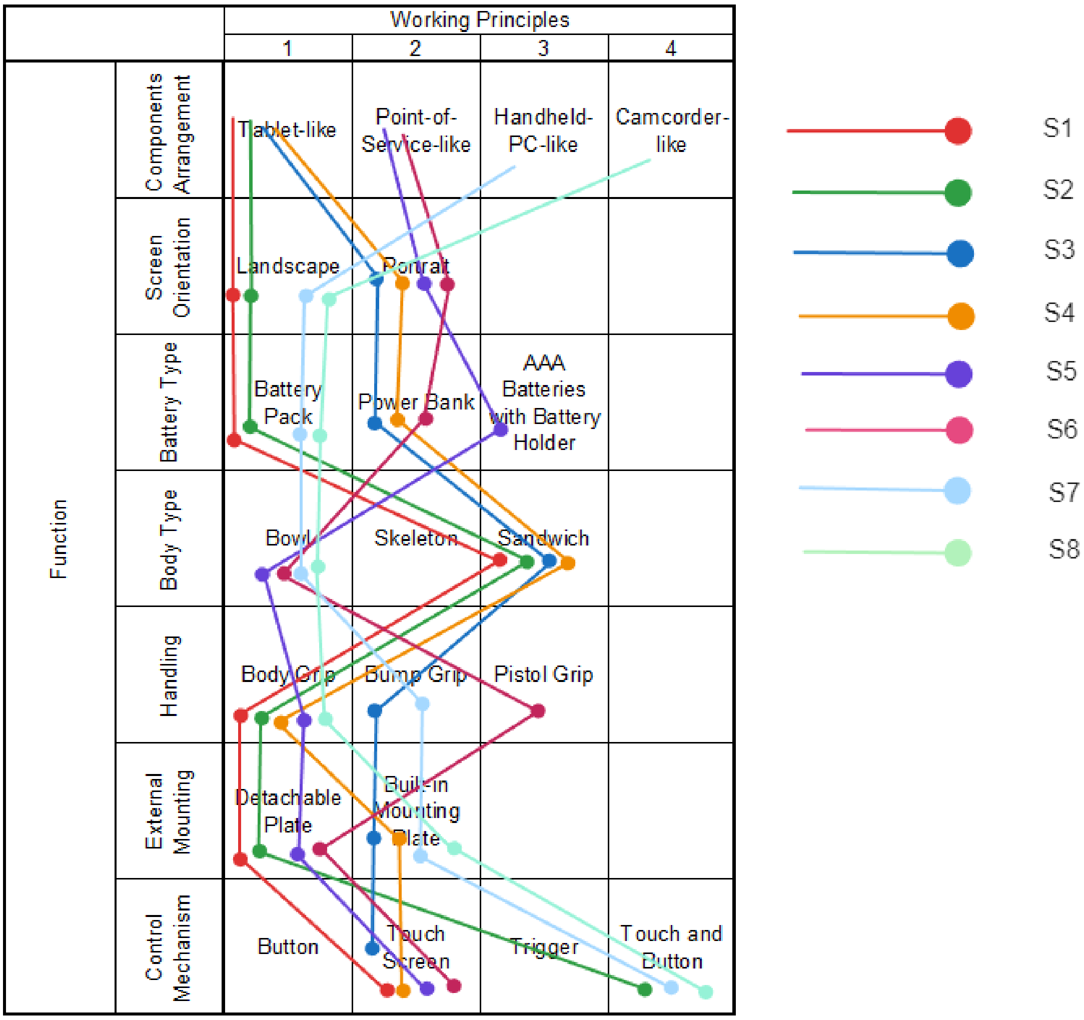


Figure 5.7: Morphological Chart with Solution Variants

5.5 Firming Up into Principle Solution Variants

In this section, we showcase hand-drawn sketches of identified functional structures that have been transformed into practical solution alternatives. Each sketch is accompanied by a brief description of its operations, highlighting its potential strengths and weaknesses.

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. 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. A sandwich-type body provides robust protection for the internal components, 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.

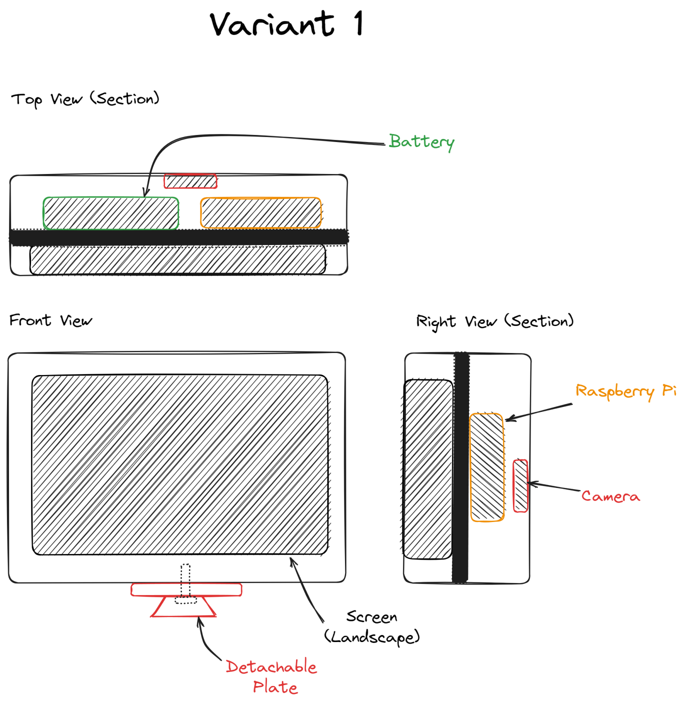


Figure 5.8: Sketch of Solution Variant 1

5.5.2 Solution Variant 2

Like its predecessor, Solution Variant 2 maintains a tablet-like design, with components arranged like 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 body structure for sturdy protection of internal components.

The detachable plate tripod system is retained in terms of mounting, 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.

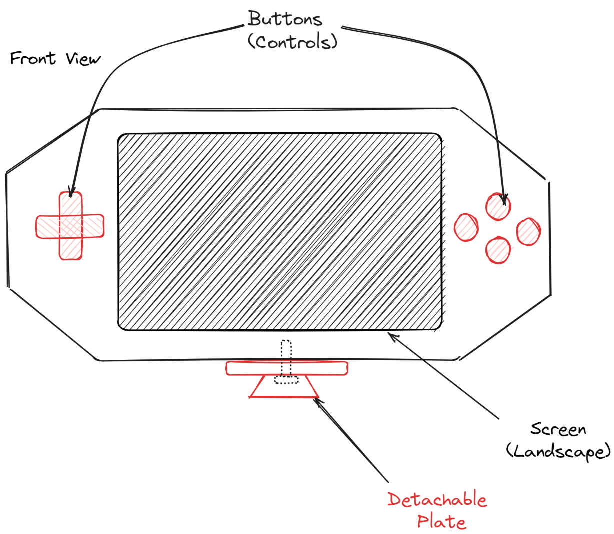


Figure 5.9: Sketch of Solution Variant 2

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 change 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 than horizontal layout.

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 body structure remains a sandwich-type, providing robust protection for the internal components.

A fixed mounting plate is employed, ensuring a stable attachment to a tripod stand. 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.

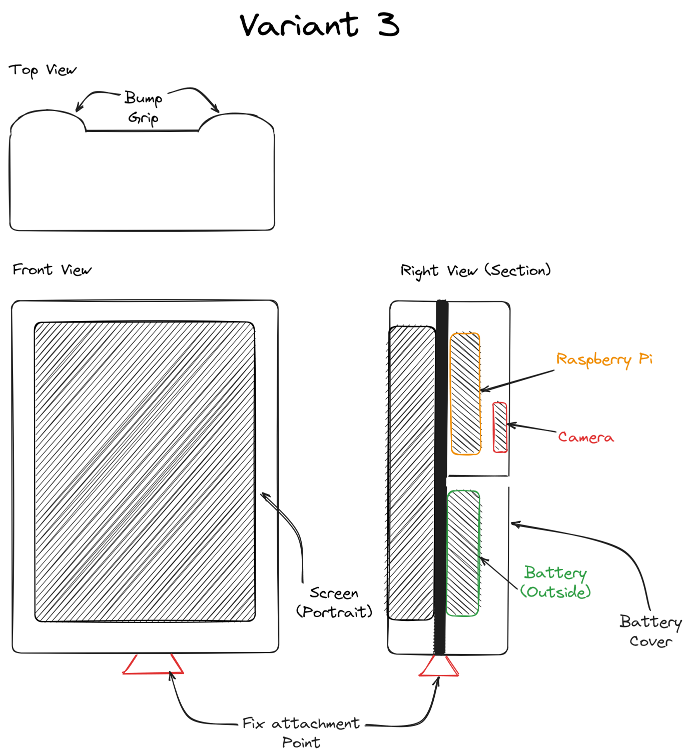


Figure 5.10: Sketch of Solution Variant 3

5.5.4 Solution Variant 4

Solution Variant 4 copies many features from Solution Variant 3, but with one significant change in the body type. Solution Variant 4 opts for a more minimalistic skeleton design, which results in a lightweight yet adequately supportive body for the internal components.

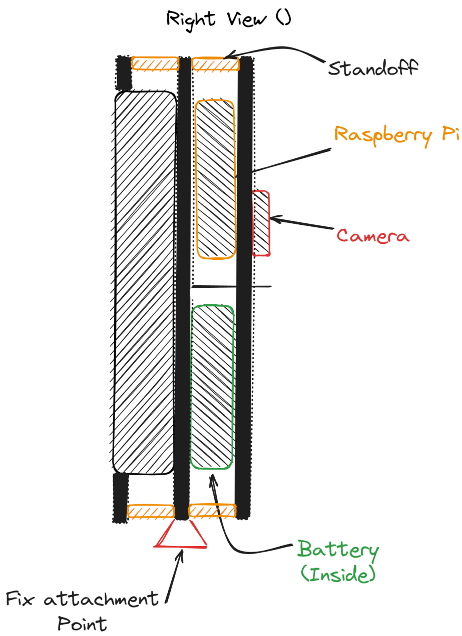


Figure 5.11: Sketch of Solution Variant 4

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.

Regarding 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 body 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.

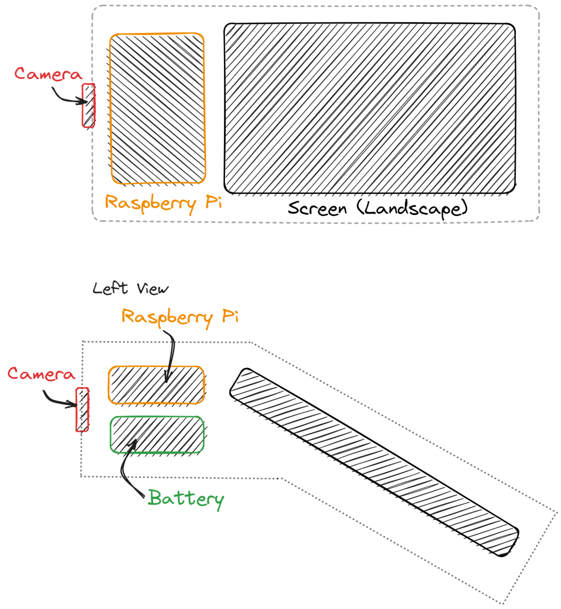


Figure 5.12: Sketch of Solution Variant 5

5.5.6 Solution Variant 6

Solution Variant 6 closely mirrors Solution Variant 5 regarding 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, offering the same benefits of easy battery replacement and extended usage periods. Regarding body design, Solution Variant 6 employs a bowl-like structure with all components attached to the main body. This design choice provides protection and enclosure while reducing overall weight.

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

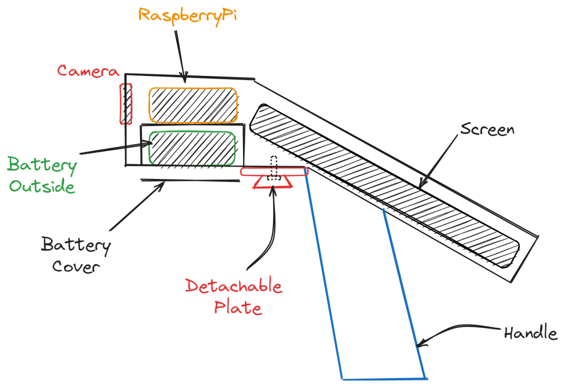


Figure 5.13: Sketch of Solution Variant 6

5.5.7 Solution Variant 7

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

The screen orientation is in landscape mode, offering a broader 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. The device incorporates a built-in tripod system for mounting, providing a stable attachment to a tripod stand.

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

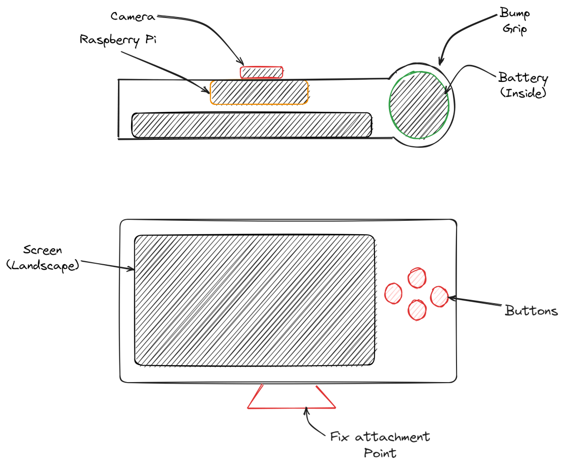


Figure 5.14: Sketch of Solution Variant 7

5.5.8 Solution Variant 8

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 landscape, providing a broad 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.

The chassis structure follows a bowl-like design, offering protection and sturdiness for the internal components. A fixed-mount tripod system is employed for mounting purposes, 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.

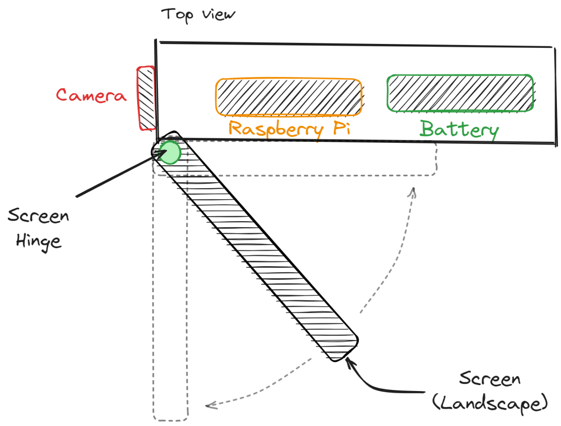


Figure 5.15: Sketch of Solution Variant 8

5.6 Filtering of Solution Variants

As shown in Figure 5.7, multiple solution variants were generated. However, not all of these solutions are feasible and practical. As advised by Pahl and Beitz [37], 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 [37] suggest a method that 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 remain, preference is given to those who 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.

Page 1	Selection Chart								
		Evaluate solution variants according to selection criteria						Decision	
								Remarks: (+) Pursue Solution (-) Eliminate Solution (?) More Information Required (!) Check Specification	
Solutions Variant	No.	Compatible with the overall task	ulfill demands of requirement list	Realisable in principle	Within permissible costs	Incorporates direct safety measures	Preferred by the designer		
		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	+	+	+	+	+	+		+
S8	8	+	+	-	?	?	-	Too complex	-

Figure 5.16: Selection Chart for Solution Variants

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.

6 Embodiment Design

The next phase in the design methodology is embodiment design. This phase, as defined by Pahl and Beitz [38], 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

Regarding product design, some basic rules must be followed. As defined by Pahl and Beitz [40], 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 [41], entails establishing clear and unambiguous connections within a design, ensuring straightforward relationships between subfunctions, inputs, and outputs to prevent confusion or misinterpretation. It also extends to selecting 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.

They also mention that clarity applies to the broader design structure, whether

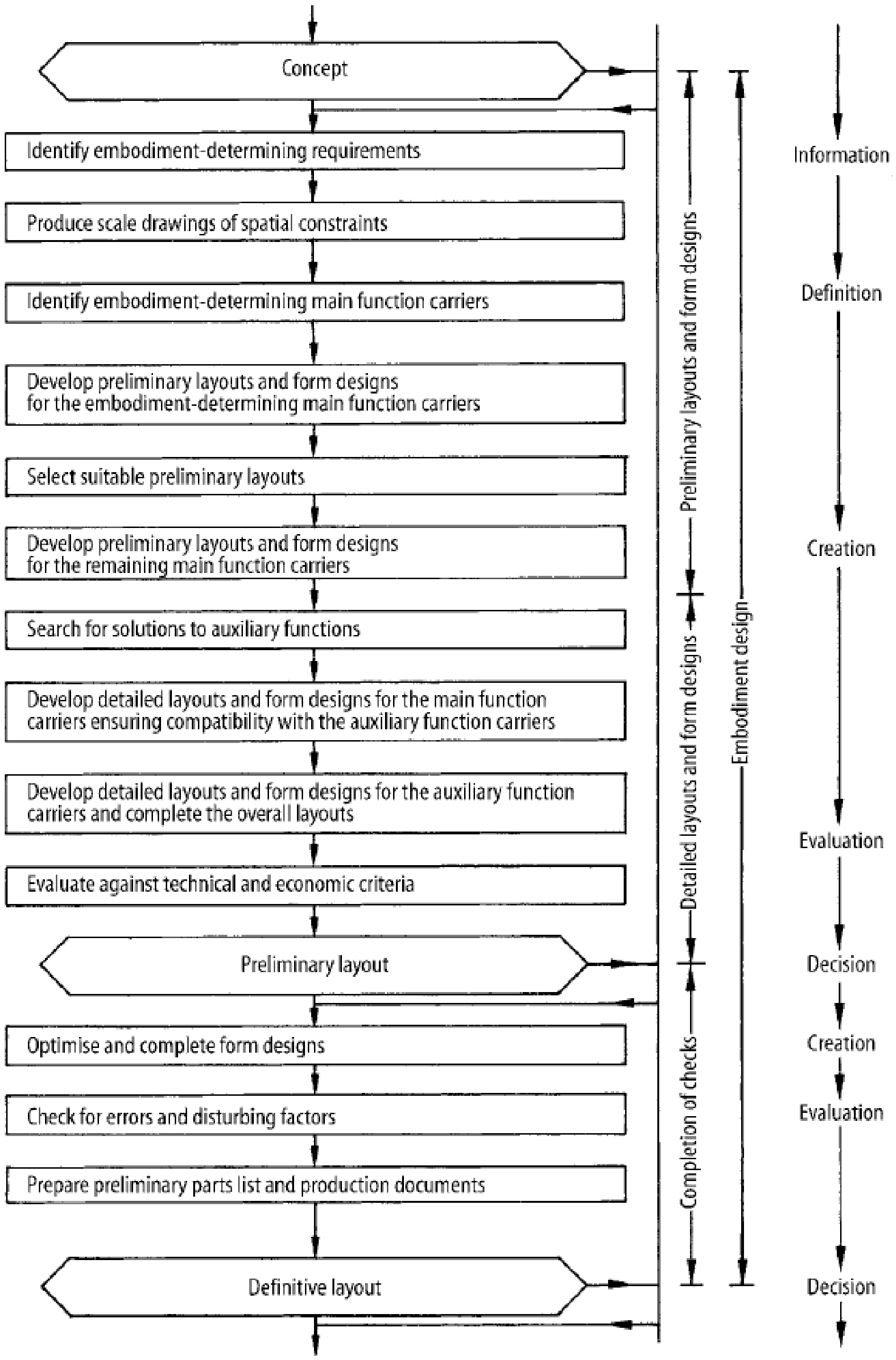


Figure 6.1: Steps in Embodiment Design [39]

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

As defined by Pahl and Beitz [42], simplicity in design is characterized by an uncomplicated and easily understandable approach, often achievable by using fewer components. Such simplicity can save costs, reduce wear and tear, and minimize maintenance requirements. Nonetheless, striking a balance is crucial, as certain functions inherently demand a minimum number of components.

As they advised, designers should strive for a minimalist approach by employing the fewest components possible while maintaining straightforward shapes, promoting 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

According to Pahl and Beitz [43], safety considerations are crucial in ensuring both the adequate 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, encompassing three levels: direct safety, indirect safety, and warnings. 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 highlighting 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 is important to note that exceptionally high safety demands can complicate design, potentially diminishing clarity and economic viability and possibly leading to project abandonment.

6.2 Guideline of Embodiment Design

In addition to the basic rules of embodiment design, Pahl and Beitz [44] also stress the importance of following a set of design guidelines to help designers meet 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

The concept of *Design for Production* outlined by Pahl and Beitz [45] underscores the significance of factoring in the production process during the design stage. This methodology empowers designers to fine-tune production costs and timelines while maintaining the product's functionality and quality. They highlight that adhering to fundamental principles of clarity and simplicity sets designers on the correct path towards realizing this objective.

Appropriate Overall Layout Design

Pahl and Beitz [46] mentioned that the 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 quickly produced parts, facilitating adaptability, increased component batch sizes, and more accessible quality assurance. However, it demands more outstanding 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

As mentioned by Pahl and Beitz [47], numerous factors influence the cost, time, and production quality. These include parameters like shapes, dimensions, surface finishes, tolerances, and fits. These choices are essential in determining production procedures, machine types, materials, in-house vs. bought-out components, and quality control measures.

Furthermore, production facilities can impact the design of features, such as dimension limitations that necessitate component division or the procurement of bought-out components. Many guidelines are available for designing appropriate component forms. The design guideline for 3D printed components is shown in Figure 6.2.

Appropriate Use of Standard and Bought-Out Components

Designers should use readily available standard or bought-out components rather than specially produced ones to ensure favorable supply and storage

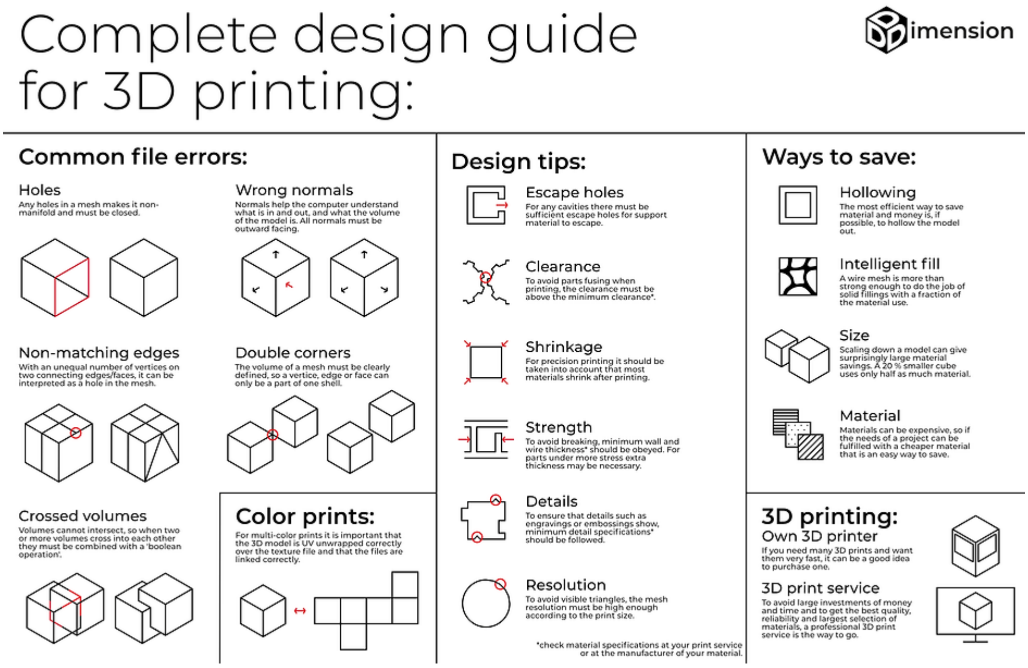


Figure 6.2: Design guidelines for 3D printing [48]

conditions. Bought-out parts are often more cost-effective than in-house production. The decision between in-house or bought-out components depends on factors like production volume, market demand, costs, and available facilities. These factors may change over time, requiring periodic re-evaluation, especially for unique or batch products in heavy engineering.

6.2.2 Design for Ergonomics

Ergonomics is vital in designing technical products, aiming to align them with human characteristics, needs, and interfaces. It covers various items, including everyday household products and human-machine interfaces. Recent focus has shifted to user-friendly interfaces and ergonomic workplace assessment tools.

Pahl and Beitz [49] define ergonomic design as a multifaceted approach considering various factors. Along with biomechanics, it considers how the human body interacts with product design through postures and movements. Physiological concerns such as muscle activity, circulation, and temperature regulation are also crucial considerations. Sensory factors like light and noise must also be considered, along with psychological aspects that aim to enhance user-friendliness and reduce cognitive load.

Ergonomics also involves both active and passive user involvement. Active involvement requires careful planning to assess if human interaction is necessary and practical. Passive involvement considers how products affect users, 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 A.8.

6.3.1 Preliminary Design 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 52.2 mm (Figure 6.4b), it successfully balances being slim and accommodating essential components for optimal performance.

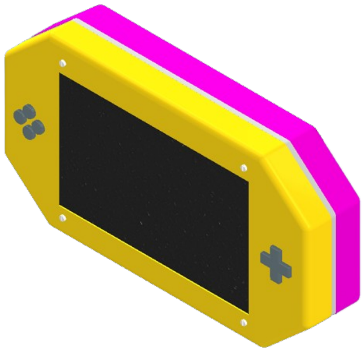
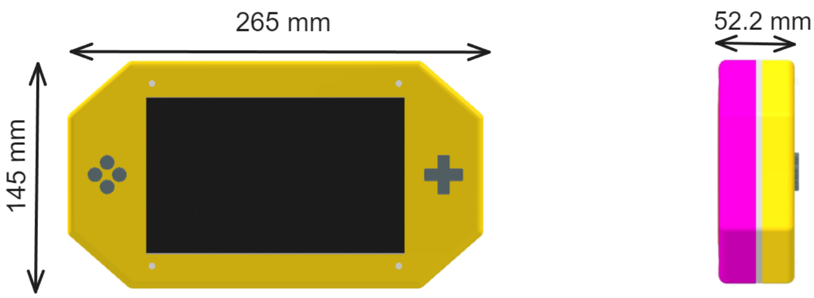


Figure 6.3: Preliminary Design Variant 2



(a) Front View **(b)** Right View

Figure 6.4: Views of Preliminary Design Variant 2

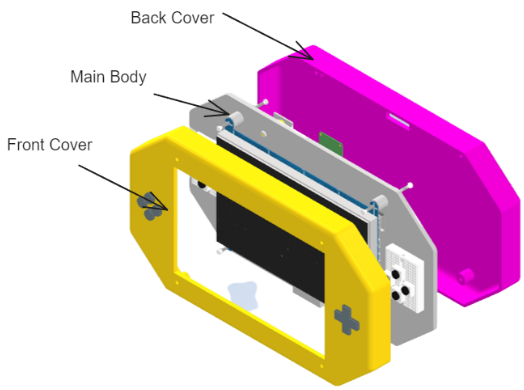
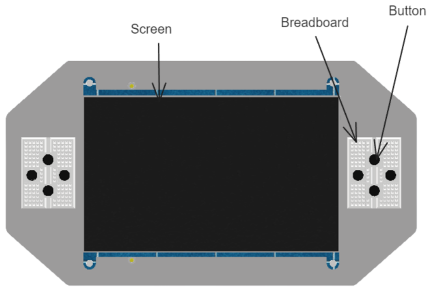
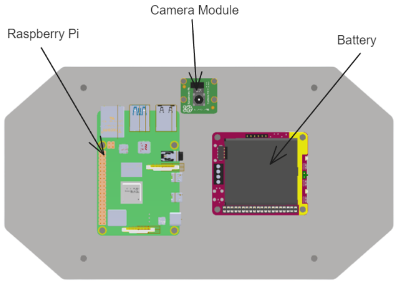


Figure 6.5: Body Components of Preliminary Design Variant 2

The physical design of Solution Variant 2 adheres to a sandwich-like structure comprising a main body, top cover, and back cover (see Figure 6.5). This design choice ensures the protection of internal components and simplifies assembly



(a) Front View



(b) Back View

Figure 6.6: Placement of inner components for Variant 2

and maintenance. The main body of the device functions as the central hub, accommodating the internal components and features. In contrast, the top and back covers act as protective shields, safeguarding the internal parts from any damage from external factors.

A crucial aspect of the design involves arranging internal components within the device. Following a tablet-like configuration, the main LCD is positioned on the front side of the main body, providing users with a straightforward and interactive interface (see Figure 6.6a). Simultaneously, the camera, Raspberry Pi, and battery were strategically placed on the back side of the body (Figure 6.6b) 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.

Ensuring the secure attachment of internal components to the main body is vital in the design process. Various methods of component fastening have been considered, including direct attachment, threaded inserts, helicoils, side pockets,

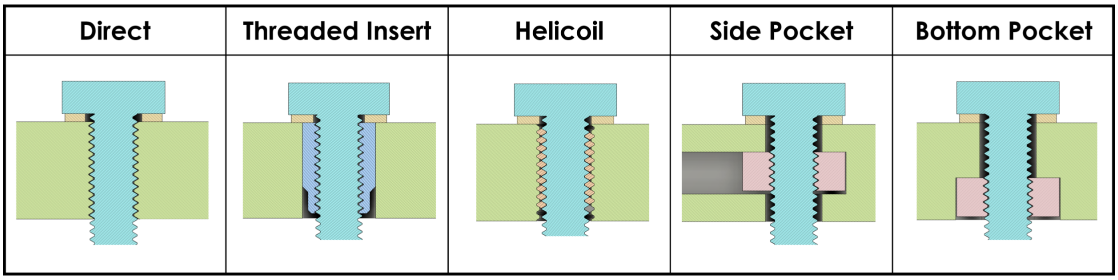


Figure 6.7: Methods to secure 3D-printed components [50]

and bottom pockets, as shown in Figure 6.7.

The most straightforward 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 and bottom pockets create cavities or slots in the 3D-printed part to securely hold components. Each method has its advantages and challenges. After careful evaluation, the variant opts for threaded inserts due to its simplicity and robustness.

Solution Variant 2 employs a hybrid input method combining a 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). HDMI and USB connections were established between the touch screen and Raspberry Pi to enable the integration of the touch screen. Additionally, to facilitate the functionality of the physical buttons, they are connected to Raspberry Pi using general-purpose input/output (GPIO) pins.

In Figure 6.8, 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.

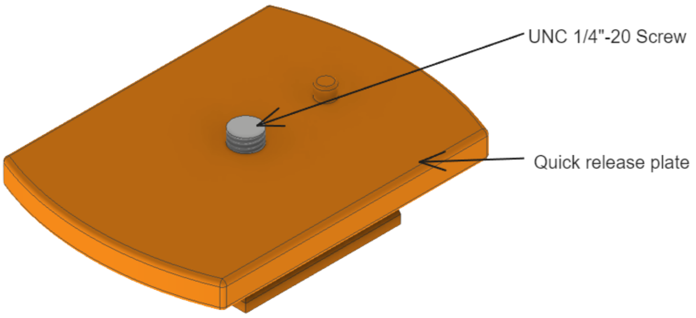


Figure 6.8: Quick release plate

Cost Calculation

Table 6.1 shows the printing cost for each component of this variant, while the total manufacturing cost is shown in Table 6.2. In this calculation, the cost for screen, camera, and Raspberry Pi are not included, as they are used by all variants. The exclusion of these components allows for a more accurate comparison of the manufacturing costs between the variants.

Part Name	Weight of PLA used (g)	Printing Time (h)	Material Cost	Energy Cost	Total Cost
Base	175.07	5.13	5.25 €	0.10 €	5.35 €
Top Cover	105.85	3.32	3.17 €	0.06 €	3.24 €
Back Cover 1	86.73	2.57	2.60 €	0.05 €	2.65 €
Back Cover 2	86.60	2.53	2.60 €	0.05 €	2.64 €
Total	**454.25**	**13.55**	**13.62 €**	**0.26 €**	**13.88 €**

Table 6.1: Printing cost for Variant 2

Parts Name	Amount	Price	Remarks	Total Price
Printing Cost	1	EUR 13.88	Calculated	EUR 13.88
Zylinderschraube M2x10mm (DIN 84)	4	EUR 0.05	Wuerth	EUR 0.20
Zylinderschraube M2.5x10mm (DIN 84)	8	EUR 0.05	Wuerth	EUR 0.40
Zylinderschraube M2.5x18mm (DIN 84)	8	EUR 0.11	Wuerth	EUR 0.88
Zylinderschraube M3x10mm (DIN 84)	2	EUR 0.05	Wuerth	EUR 0.10
Sechskantmutter M2 (DIN 934)	4	EUR 0.04	Wuerth	EUR 0.15
Standoff M2	4	EUR 0.17	Amazon	EUR 0.67
Threaded Inserts M2.5	16	EUR 0.50	Ruthex	EUR 7.99
Threaded Inserts 1/4"	1	EUR 0.00	Ruthex	EUR 0.00
Breadboard	2	EUR 0.04	Amazon	EUR 0.08
Tactile Button	8	EUR 0.00	Amazon	EUR 0.00
Female MicroUsb	1	EUR 4.95	Adafruit	EUR 4.95
PiJuice	1	EUR 45.49	Rasppishop	EUR 45.49
Total				EUR 74.77

Table 6.2: Manufacturing cost for Variant 2

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 6.10. However, Variant 3 introduced significant changes with different screen orientations and battery types.

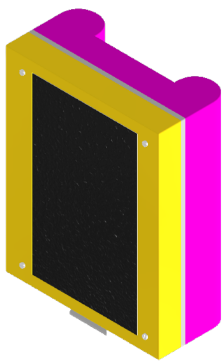
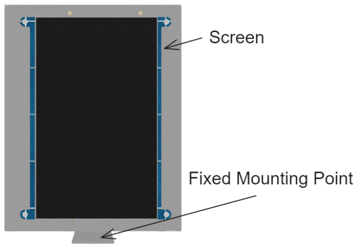
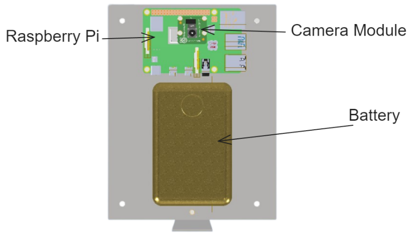


Figure 6.9: Preliminary Design Variant 3

A noteworthy alteration is the inclusion of bumps on the back cover to enhance the ergonomics (Figure 6.11). This adjustment aims to provide a more comfortable grip, improve user engagement, and extend usability. In addition, the tactile bump serves as a subtle yet impactful refinement, ensuring that the device



(a) Front View



(b) Back View

Figure 6.10: Placement of inner components for Variant 3

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.

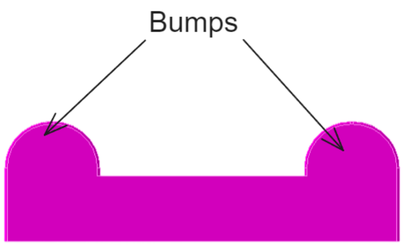


Figure 6.11: Bumps on the back cover

Variant 3 shifted from the standard battery position in variant 2, with a more noticeable difference in battery placement. Figure 6.12 illustrates a designated slot within the back cover, strategically designed to house a power bank outside the body. This configuration enhances the operational stability and simplifies the battery replacement process.

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 seamlessly integrating screen interactions. Additional information regarding integrating the touchscreen with the Raspberry Pi is provided in Section 6.3.1.

Figure 6.10a shows the position of the mounting point of on the main body in

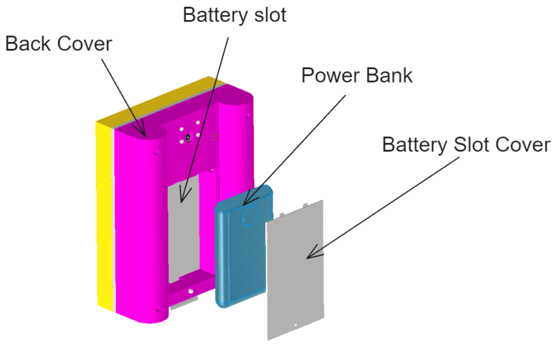


Figure 6.12: Battery Placement

Variant 3. This strategic design allows the mounting point to serve as a sturdy anchor for the device when used in a tripod stand.

Cost Calculation

Table 6.3 shows the printing cost for each component of this variant, while the total manufacturing cost is shown in Table 6.4.

Part Name	Weight of PLA used (g)	Printing Time (h)	Material Cost	Energy Cost	Total Cost
Base	222.96	6.67	6.69 €	0.13 €	6.81 €
Top Cover	71.02	2.08	2.13 €	0.04 €	2.17 €
Back Cover	303.02	9.37	9.09 €	0.18 €	9.26 €
Battery Cover	17.43	0.53	0.52 €	0.01 €	0.53 €
Total	**614.43**	**18.65**	**18.43 €**	**0.35 €**	**18.78 €**

Table 6.3: Printing cost for Variant 3

Parts Name	Amount	Price	Remarks	Total Price
Printing Cost	1	18.78 €	Calculated	18.78 €
Zylinderschraube M2x10mm (DIN 84)	4	0.05 €	Wuerth	0.20 €
Zylinderschraube M2.5x10mm (DIN 84)	4	0.05 €	Wuerth	0.20 €
Zylinderschraube M2.5x18mm (DIN 84)	8	0.11 €	Wuerth	0.88 €
Sechskantmutter M2 (DIN 934)	4	0.04 €	Wuerth	0.15 €
Threaded Inserts M2.5	12	0.13 €	Ruthex	1.54 €
Veektomx	1	25.99 €	Amazon	25.99 €
Total				**48.08 €**

Table 6.4: Manufacturing cost for Variant 3

6.3.3 Preliminary Design Variant 6

Figure 6.13 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 6.14).

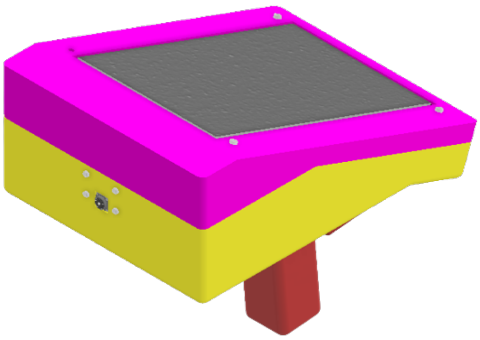


Figure 6.13: Preliminary Design Variant 6

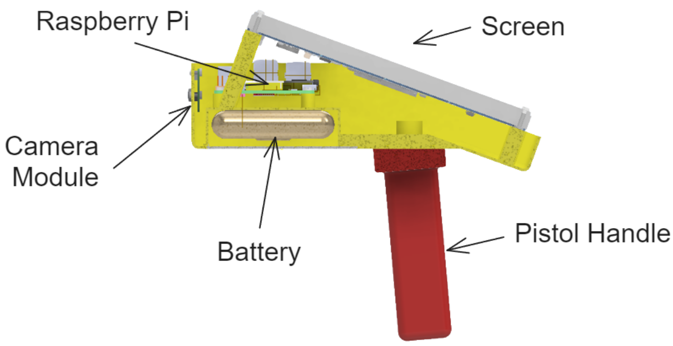


Figure 6.14: Placement of inner components for Variant 3

Figure 6.15 demonstrates the handle grip design, while Figure 6.16a 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 6.16b).

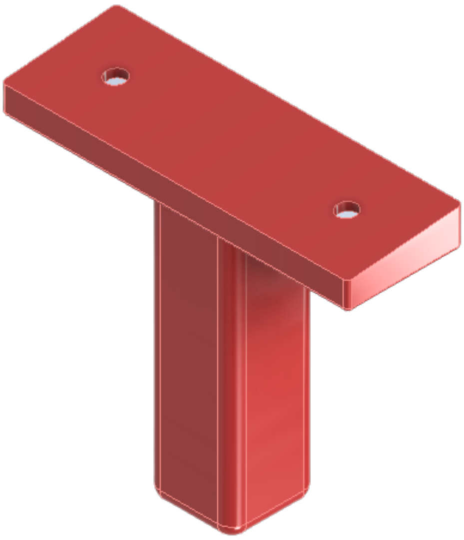
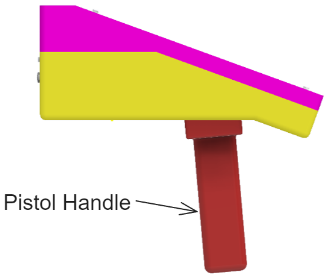
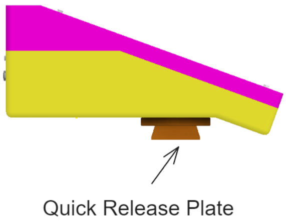


Figure 6.15: Handle Grip



(a) Handle Grip with Main Body



(b) Quick Release Plate with Main Body

Figure 6.16: Placement of handle grip and quick release plate

This variant boasts the same input method and battery placement as Variant 3. Please refer to Section 6.3.2 for a comprehensive explanation.

Cost Calculation

Table 6.5 shows the printing cost for each component of this variant, while the total manufacturing cost is shown in Table 6.6.

Part Name	Weight of PLA used (g)	Printing Time (h)	Material Cost	Energy Cost	Total Cost
Top Cover	55.35	1.87	1.66 €	0.04 €	1.70 €
Main Body	240.25	8.88	7.21 €	0.17 €	7.37 €
Battery Cover	22.21	0.67	0.67 €	0.01 €	0.68 €
Handle Pistol	57.30	1.73	1.72 €	0.03 €	1.75 €
Total	**375.11**	**13.15**	**11.25 €**	**0.25 €**	**11.50 €**

Table 6.5: Printing cost for Variant 6

Parts Name	Amount	Price	Remarks	Total Price
Printing Cost	1	11.50 €	Calculated	11.50 €
Zylinderschraube M2x10mm (DIN 84)	4	0.05 €	Wuerth	0.20 €
Zylinderschraube M2.5x10mm (DIN 84)	5	0.05 €	Wuerth	0.25 €
Zylinderschraube M2.5x18mm (DIN 84)	4	0.11 €	Wuerth	0.44 €
Sechskantmutter M2 (DIN 934)	4	0.04 €	Wuerth	0.15 €
Threaded Inserts M2.5	8	0.13 €	Ruthex	1.03 €
Threaded Inserts 1/4"	3	0.50 €	Ruthex	1.50 €
1/4" Schraube (Kamera)	2	1.40 €	Amazon	2.80 €
Veektomx	1	25.99 €	Amazon	25.99 €
Total				**43.84 €**

Table 6.6: Manufacturing cost for Variant 6

6.3.4 Preliminary Design Variant 7

In Figure 6.17, we can observe a 3D model for variant 7, which draws inspiration from handheld PCs. The design showcases the integration of Raspberry Pi at the back of the screen, creating a compact and unified structure, while the battery is positioned next to the screen.

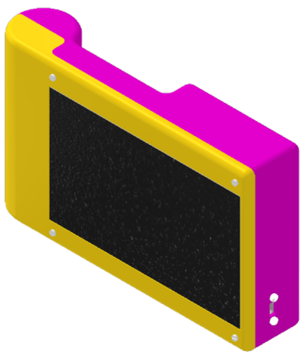


Figure 6.17: Preliminary Design Variant 7

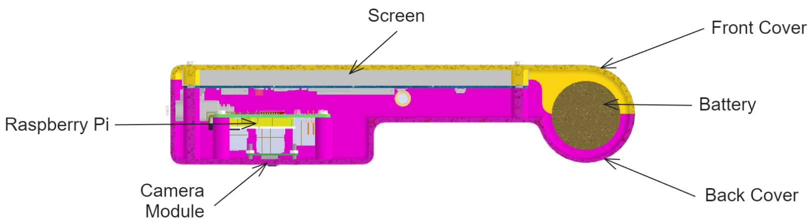


Figure 6.18: Placement of inner components for Variant 7

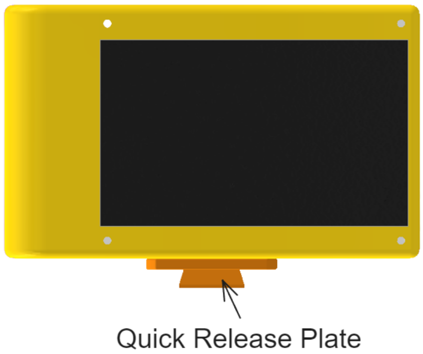


Figure 6.19: Placement of quick release plate

This design includes a bump on the side, enhancing ergonomics as shown in Figure 6.18. As with variants 2 and 6, this variant employs a quick-release plate, facilitating integration with a tripod stand. The placement of the plate can be observed in Figure 6.19.

Cost Calculation

Table 6.7 shows the printing cost for each component of this variant, while the total manufacturing cost is shown in Table 6.8.

Part Name	Weight of PLA used (g)	Printing Time (h)	Material Cost	Energy Cost	Total Cost
Top Cover	61.50	2.08	1.84 €	0.04 €	1.88 €
Back Cover	380.70	11.82	11.42 €	0.22 €	11.64 €
Total	**442.20**	**13.90**	**13.26 €**	**0.26 €**	**13.52 €**

Table 6.7: Printing cost for Variant 7

Parts Name	Amount	Price	Remarks	Total Price
Printing Cost	1	13.52 €	Calculated	13.52 €
Zylinderschraube M2x10mm (DIN 84)	4	0.05 €	Wuerth	0.20 €
Zylinderschraube M2.5x10mm (DIN 84)	4	0.05 €	Wuerth	0.20 €
Zylinderschraube M2.5x18mm (DIN 84)	4	0.11 €	Wuerth	0.44 €
Zylinderschraube M3x10mm (DIN 84)	2	0.05 €	Wuerth	0.10 €
Sechskantmutter M2 (DIN 934)	4	0.04 €	Wuerth	0.15 €
Threaded Inserts M2.5	8	0.13 €	Ruthex	1.03 €
Threaded Inserts 1/4"	1	0.50 €	Ruthex	0.50 €
Cylinder Power Bank	1	19.99 €	Amazon	19.99 €
Female MicroUsb	1	4.95 €	Adafruit	4.95 €
Total				**EUR 41.07**

Table 6.8: Manufacturing cost for Variant 7

6.4 Evaluation with VDI 2225

This section will evaluate the preliminary design variants using the guideline VDI 2225 [51]. This guideline is a comprehensive framework for evaluating technical solutions based on a balanced consideration of various aspects.

The guideline advocates for comprehensive evaluation methods covering task-specific requirements and general constraints. These methods aim to quantify and 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 [51], 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 no crucial criteria are overlooked. The objectives should also be as independent as possible and expressed in quantitative or qualitative terms.

The following 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 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 device's physical dimensions, 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 more straightforward 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. Swappable parts are assessed 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 6.9 shows the weighting factors for the evaluation criteria.

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

Table 6.9: 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. Table 6.10 shows the scale used to evaluate the preliminary design variants. Tables 6.11 to 6.15 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 6.10: Value Scale for Evaluation [52]

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

Table 6.11: 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 6.12: Value Scale for Device Weight

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

Table 6.13: Value Scale for Device Size

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

Table 6.14: Value Scale for Ease of Assembly

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

Table 6.15: 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 their 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, 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 each variant's total rating (R). 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

The result of the evaluation of the preliminary design variants will be presented in this section. Table 6.16 and Table 6.17 shows the technical evaluation of the preliminary design variants, while Table 6.18 shows the economic evaluation of the variants. The total rating of the variants is shown in Table 6.19. Based on the total rating, Variant 6 is the best variant, followed by Variant 7, Variant 3, and Variant 2.

Evaluation criteria					Variant 2			Variant 3		
No.	Criteria	Weight	Description	Units	Value	Point	Weighted Weight	Value	Point	Weighted Weight
1	Weight Distribution	3	Distance of center of gravity	mm	2.49	4	12	54.84	2	6
2	Device Weight	2	Weight of device	g	1190.60	2	4	1103.30	2	4
3	Device Size	1	Length of device	mm	265.00	2	2	185.00	3	3
		1	Width of device	mm	145.00	3	3	145.00	3	3
		1	Thickness of device	mm	52.20	4	4	69.20	4	4
4	Ease of Assembly	1	Number of parts required to be assemble	-	58	2	2	42	3	3
5	Swappable parts	2	Number of swappable parts available	-	1	1	2	1	1	2
	Total	**11**					**29**			**25**
	Technical Rating, Rt						**0.659**			**0.568**

Table 6.16: Technical Evaluation of Preliminary Design Variants (1/2)

Evaluation criteria					Variant 6			Variant 7		
No.	Criteria	Weight	Description	Units	Value	Point	Weighted Weight	Value	Point	Weighted Weight
1	Weight Distribution	3	Distance of center of gravity	mm	28.09	3	9	92.18	2	6
2	Device Weight	2	Weight of device	g	1112.60	2	4	889.20	3	6
3	Device Size	1	Length of device	mm	194.94	3	3	222.50	2	2
		1	Width of device	mm	145.00	3	3	135.50	3	3
		1	Thickness of device	mm	80.30	4	4	47.70	4	4
4	Ease of Assembly	1	Number of parts required to be assemble	-	49	3	3	35	3	3
5	Swappable parts	2	Number of swappable parts available	-	3	3	6	1	1	2
	Total	11					32			26
	Technical Rating, Rt						0.727			0.591

Table 6.17: Technical Evaluation of Preliminary Design Variants (2/2)

Production Cost		
Variant	**Cost, $C_{variant}$(€)**	**Economic Rating, R_e**
Variant 2	74.79	0.33
Variant 3	48.08	0.52
Variant 6	43.84	0.56
Variant 7	41.07	0.60

Table 6.18: Economic Evaluation of Preliminary Design Variants

Variant	Technical Rating, R_t	Economic Rating, R_e	Total Rating, R
Variant 2	0.66	0.33	0.494
Variant 3	0.57	0.51	0.540
Variant 6	0.73	0.64	0.645
Variant 7	0.59	0.60	0.596

Table 6.19: Total Rating 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 is critical 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 pins to initiate a shutdown sequence for the Raspberry Pi [53]. While effective in bringing the device to a hibernation state, it is essential to note that this method does not completely cut off power. As a result, the Raspberry Pi still draws a minimal amount of power even in this low-power state [54].

A more straightforward approach is recommended to achieve more efficient power management, which involves the implementation of a simple physical push button as switch (refer to Figure 6.20). This implementation directly connects and disconnects 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.

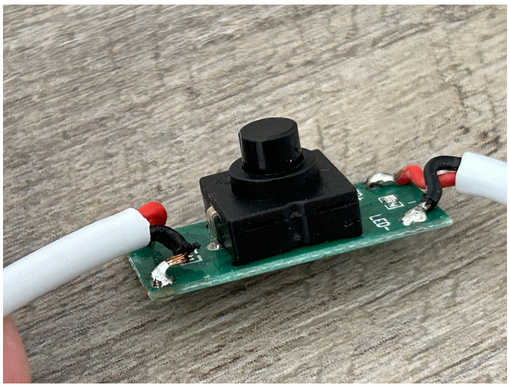


Figure 6.20: Power Switch

Camera Protection

While designing the device, we took great care to ensure the camera component was well-protected. As illustrated in Figure 6.21, the camera is seamlessly integrated into the device's body, with the lens protruding slightly.

However, this design does pose a potential risk. If the device is inadvertently placed with the lens side facing a surface, it could get damaged, severely affecting its performance.

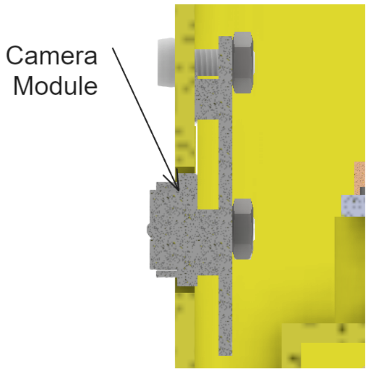
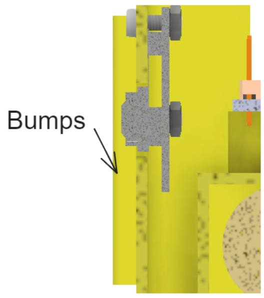
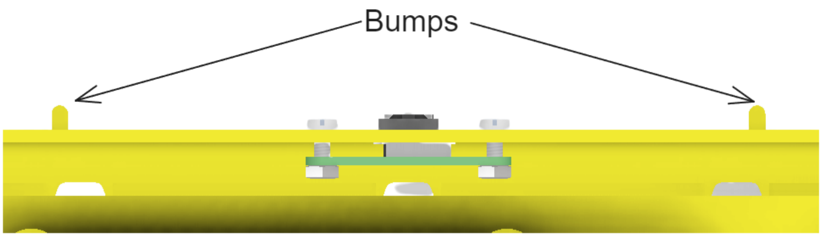


Figure 6.21: Position of the camera component

To address this concern, we have incorporated a 3 mm high bump (as seen in Figure 6.22) as a preventative measure. The bump is strategically positioned to lift the camera lens above surfaces, preventing direct contact.



(a) Left View

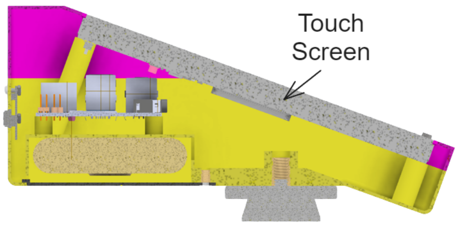


(b) Top View

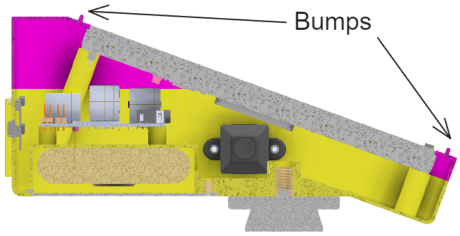
Figure 6.22: Protective bump for camera

Screen Protection

Similar to the camera, the screen of the device also requires protection. Similar to the camera protection, a protective bump has been incorporated around the screen perimeter to address this issue. Refer to Figure 6.23 for a visual representation.



(a) Before



(b) After

Figure 6.23: Protective bump for screen

Column for Threaded Inserts

Previously, in Section 6.3.1, we delved into utilizing threaded inserts alongside screws to firmly attach components to the body. It is crucial to note that distinct sizes of threaded inserts necessitate particular minimum wall thicknesses for the columns and hole depths to guarantee adequate engagement and steadiness. A sizing guide is provided by Ruthex threaded inserts, as shown in Table 6.20.

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 6.20: Sizing guide for threaded inserts [55][56]

LAN Port

To enable easier maintenance of the Raspberry Pi, a Local Area Network (LAN) port is added to the device, which enables the Raspberry Pi to be accessed directly without disassembly. This strategic integration allows seamless connectivity, enabling direct access to the Raspberry Pi's functionalities and resources over a local network. Figure 6.24 shows the LAN port.

The LAN port, illustrated in Figure 6.24, is positioned on the side of the device (as shown in Figure 6.25), making it easy for users to perform maintenance tasks.

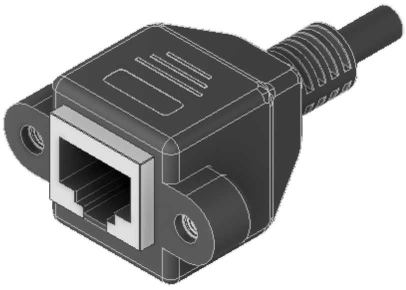


Figure 6.24: The LAN port

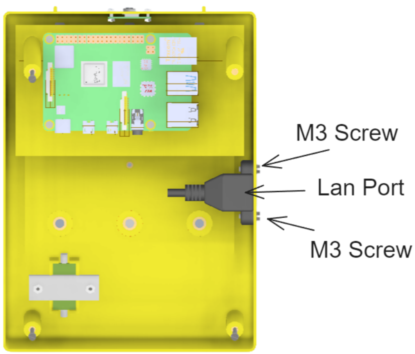


Figure 6.25: Position of the LAN port

Color Scheme

The selection of colors is crucial in making the product visually appealing, especially since the target market is the police force. To achieve this, we utilized the German police logo for inspiration, as shown in Figure 6.26. The predominant color of blue in the logo is used as the primary color for the device. Additionally, we used yellow from the logo as the color for the handle grip and white for the device's top cover. Figure 6.27 shows the device preview with the recolor.

Figure 6.26: Germany Police Logo [57]

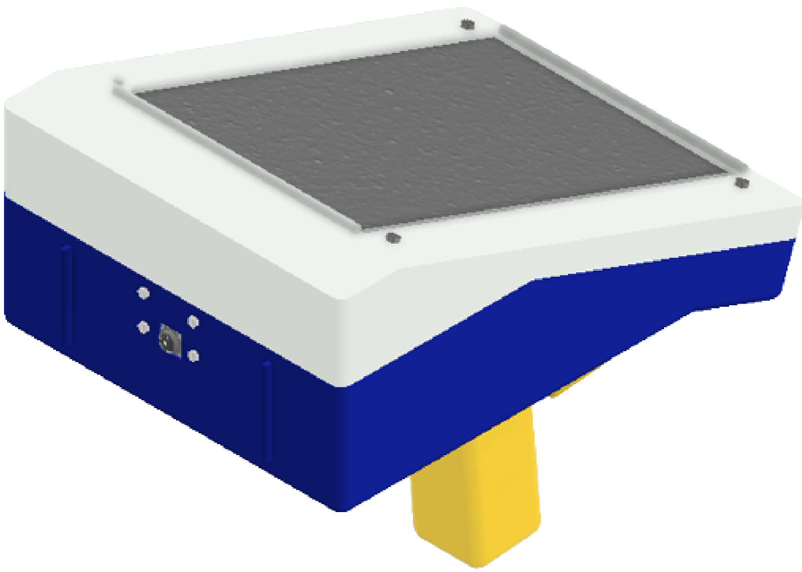


Figure 6.27: Result of recolor

7 Printing and Assembly

7.1 Printing

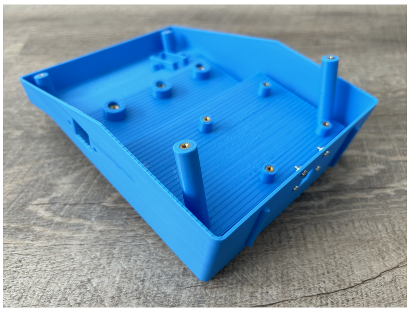
In this section, we will describe the printing process for the prototype. This process was carried out at the Workshop of the University of Applied Sciences Brandenburg using the printer described in Section 3.2.1. The following parameters are utilized for the process.

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

Table 7.1 provides information on the printing time and the weight of filament used. Additionally, Figure 7.1 showcases the final printed parts after removing the support materials.

Part Name	Weight of PLA used (g)	Printing Time (h)
Top Cover	57.71	2.00
Main Body	245.14	9.25
Battery Cover	22.21	0.67
Switch Cover	1.31	0.05
Handle Pistol	64.63	1.98

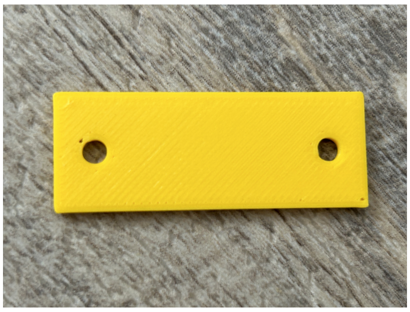
Table 7.1: Printing Time and Filament Used



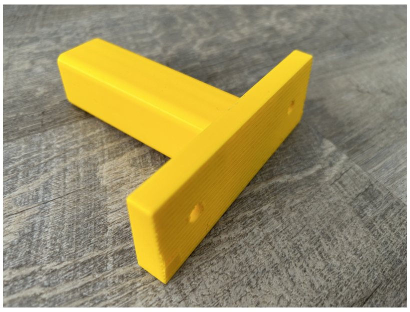
(a) Main Body

(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

In order to securely install the brass threaded inserts into the main body, it is recommended to use a soldering iron [58]. Begin by placing the chosen threaded insert onto the targeted position, aligning it with the desired hole. Heat the soldering iron to a suitable temperature, ranging from 225 °C to 245 °C for PLA material.

Once the soldering iron has reached the appropriate temperature, apply it gently to the top of the threaded insert. This process will transmit controlled heat into the material, causing the wall to soften and allow the threaded insert to be inserted. For a visual representation of how a threaded insert should look once correctly installed into the main body, please refer to Figure 7.2.

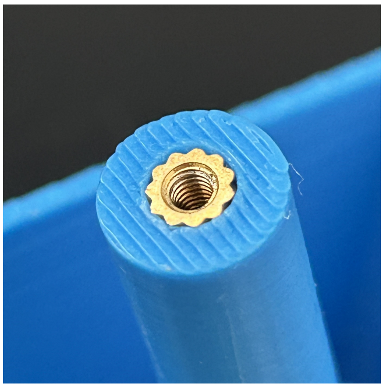


Figure 7.2: The installed threaded insert

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. Position the switch inside the designated switch holder (see Figure 7.3), ensuring that the button faces outward for easy access.

Next, the switch cover is placed on top, aligning it with the switch and the corresponding holes in the main body. Once aligned, the M2.5 screws and nuts secure the switch and the cover to the main body. Figure 7.4 shows the completed installation of the switch.

Step 3: Installation of LAN Port

This step begins by locating the slot of the LAN port on the main body, which is located on the right side of the main body (see Figure 7.5). The LAN port is

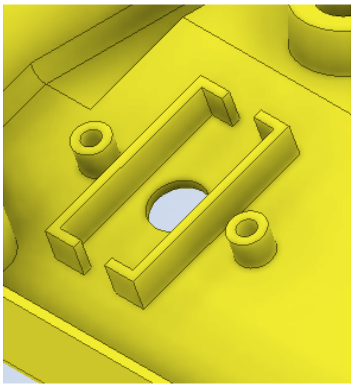


Figure 7.3: The Switch Holder

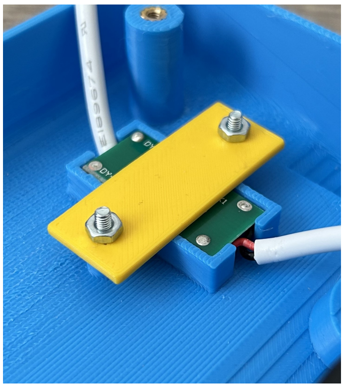


Figure 7.4: The installed switch

inserted into the slot and secured using the M3 screws. Figure 7.6 shows the completed installation of the LAN port.

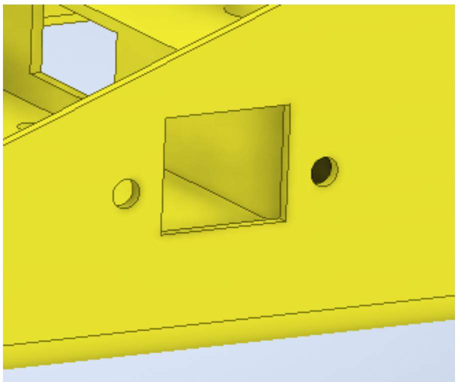


Figure 7.5: The LAN Port Slot

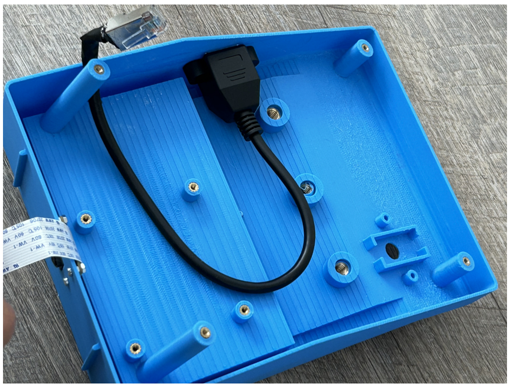


Figure 7.6: The installed LAN port

Step 4: Installation of Camera Module

The camera module is installed to the main body using M2 screws. The camera module is placed in the designated slot on the main body (see Figure 7.7). The M2 screws are then used to secure the camera module to the main body. Figure 7.8 shows the completed installation of the camera module.

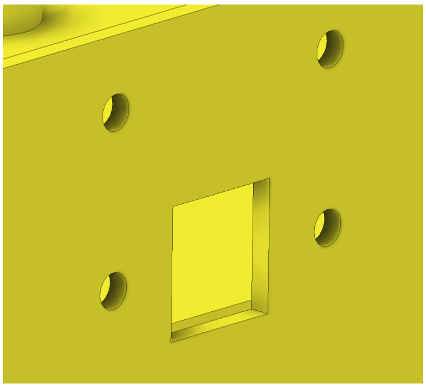


Figure 7.7: The Camera Module Slot

Step 5: Installation of Battery

To start the installation process, insert the battery into the holder as shown in Figure 7.9. Then, connect the battery to the switch with a 90-degree USB-A to USB-C connector.

To fasten the battery to the main body, place the battery cover over the battery

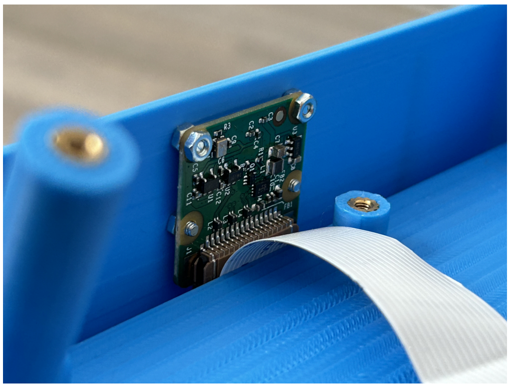


Figure 7.8: The installed camera module

and main body. Use the M2.5 screws to secure the battery cover to the main body. The finished battery installation can be seen in Figure 7.10.

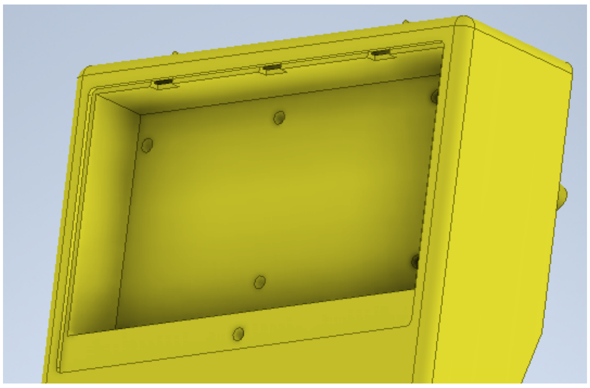


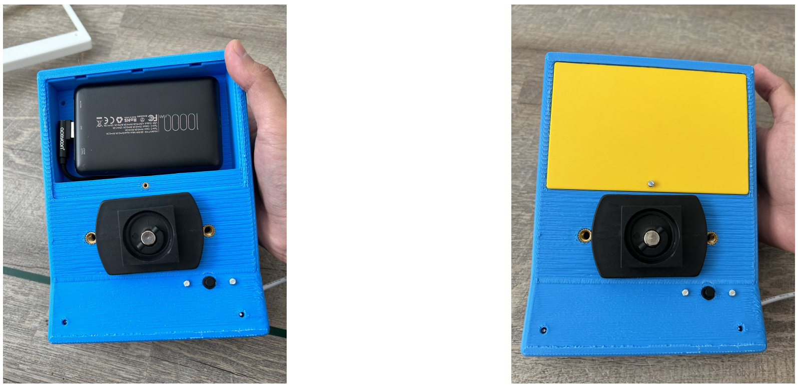
Figure 7.9: The Battery Holder

Step 6: Installation of Raspberry Pi

The Raspberry Pi is installed on the main body by using the M2.5 screws. The Raspberry Pi is placed in the designated slot on the main body (see Figure 7.11). The M2.5 screws are then used to secure the Raspberry Pi to the main body.

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



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

Figure 7.10: The installed battery

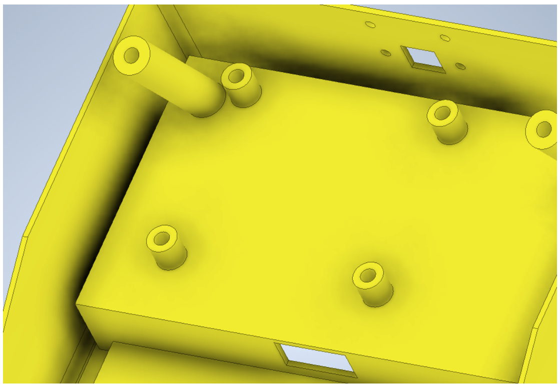


Figure 7.11: The Raspberry Pi Slot

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 7.12) and align 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 7.13 shows the completed installation of the screen and the top cover.

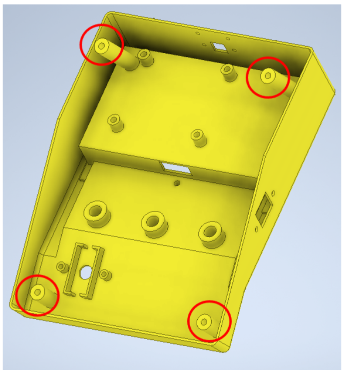


Figure 7.12: The Screen Slot

Figure 7.13: The installed screen and top cover

7.3 Final Product

Figure 7.14 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 7.2 and Table 7.3 respectively.

Figure 7.14: The Final Product

Part Name	Material Cost	Energy Cost	Total Cost
Top Cover	1.73 €	0.04 €	1.77 €
Main Body	7.35 €	0.17 €	7.53 €
Battery Cover	0.67 €	0.01 €	0.68 €
Switch Cover	0.04 €	0.00 €	0.04 €
Handle Pistol	1.94 €	0.04 €	1.98 €
Total	**11.73 €**	**0.26 €**	**11.99 €**

Table 7.2: Total Printing Cost

Parts Name	Amount	Price	Remarks	Total Price
Printing Cost	1	11.99 €	Calculated	11.99 €
RaspberyPi 4B 2GB	1	35.00 €	RaspberryPi	35.00 €
Camera Module v2	1	25.00 €	RaspberryPi	25.00 €
Waveshare 7inch screen	1	53.99 €	Waveshare	53.99 €
Veektomx Battery	1	25.99 €	Amazon	25.99 €
Screw M2x10mm (DIN 84)	4	0.05 €	Wuerth	0.20 €
Screw M2.5x10mm (DIN 84)	7	0.05 €	Wuerth	0.35 €
Screw M2.5x18mm (DIN 84)	4	0.11 €	Wuerth	0.44 €
Screw M3x10mm (DIN 84)	2	0.05 €	Wuerth	0.10 €
Nut M2 (DIN 934)	4	0.04 €	Wuerth	0.15 €
Nut M2.5 (DIN 934)	2	0.04 €	Wuerth	0.07 €
Threaded Inserts M2.5	9	0.13 €	Ruthex	1.16 €
Threaded Inserts 1/4"	3	0.50 €	Ruthex	1.50 €
1/4" Camera Screw	2	1.40 €	Amazon	2.80 €
LAN Port	1	5.67 €	Aliexpress	5.67 €
Switch Pi	1	3.90 €	Amazon	3.90 €
90-Degree USB-A to USB-C	1	2.75 €	Amazon	2.75 €
90-Degree USB-A to micro USB	1	5.99 €	Amazon	5.99 €
90-Degree HDMI	1	2.12 €	Aliexpress	2.12 €
Total				**168.29 €**

Table 7.3: Total Material Cost

8 Conclusion

In summary, this research has developed and demonstrated a highly promising handheld device engineered to measure vehicle speed precisely. This prototype is a cost-effective alternative to the existing speed measurement tools, particularly the conventional speed pistol. By integrating cheap computational components, high-quality cameras, and the power of 3D printing, we propose an affordable, highly accurate, and reliable device.

The design process of the prototype was carried out based on VDI guideline 2221 and divided into three parts: task clarification, conceptual design, and embodiment design. The task clarification phase was conducted by identifying the problem, defining the requirements, and setting the specifications.

The conceptual design phase was carried out by defining function and function structure. The function structure was then used to generate working principles with the help of brainstorming and analysis of existing technical systems. The result of idea generation is presented inside Zwicky's morphological box. The working principles are then combined to form eight different working structures. After careful evaluation, only four were selected for further development.

In the embodiment design phase, the four working structures were developed further by defining their 3D model with Autodesk Inventor. With the help of the 3D model, the working structures were evaluated based on their physical properties, manufacturability, and ergonomics. The estimated cost of manufacturing each variant is also calculated and compared. The evaluation results show that variant 6 is the most suitable to be chosen as the final design.

The final design was then manufactured using 3D printing technology. The prototype was assembled and tested to ensure it worked as intended. The test result shows that the prototype can securely hold the inner components properly and protect them. In terms of ergonomics, the handling of the device seems stable and lightweight. The total cost of the prototype is 168.29 €, which is significantly cheaper than the conventional speed pistol.

A proper Graphical User Interface (GUI) will be developed in the next step to allow the user to interact with the device.

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

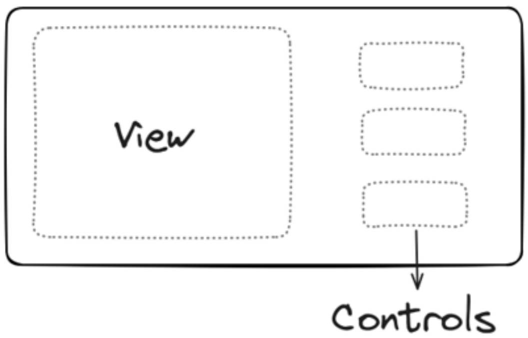
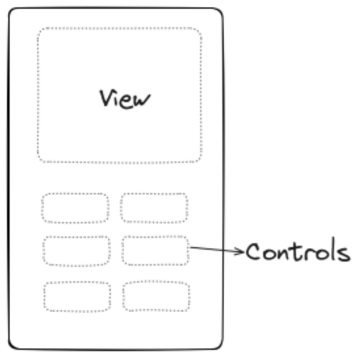
2.1 Landscape	2.2 Portrait
	

Table A.1: Screen Orientation

A.1.2 Battery Type

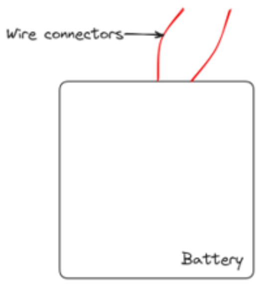
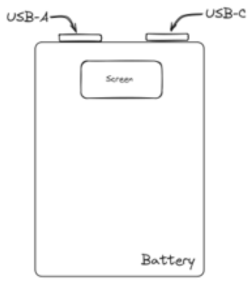
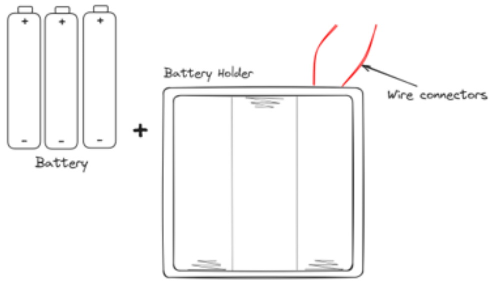
3.1 Battery Pack	3.2 Power Bank	3.3 AAA Batteries with Battery Holder
		

Table A.2: Battery Type

A.1.3 Components Placement

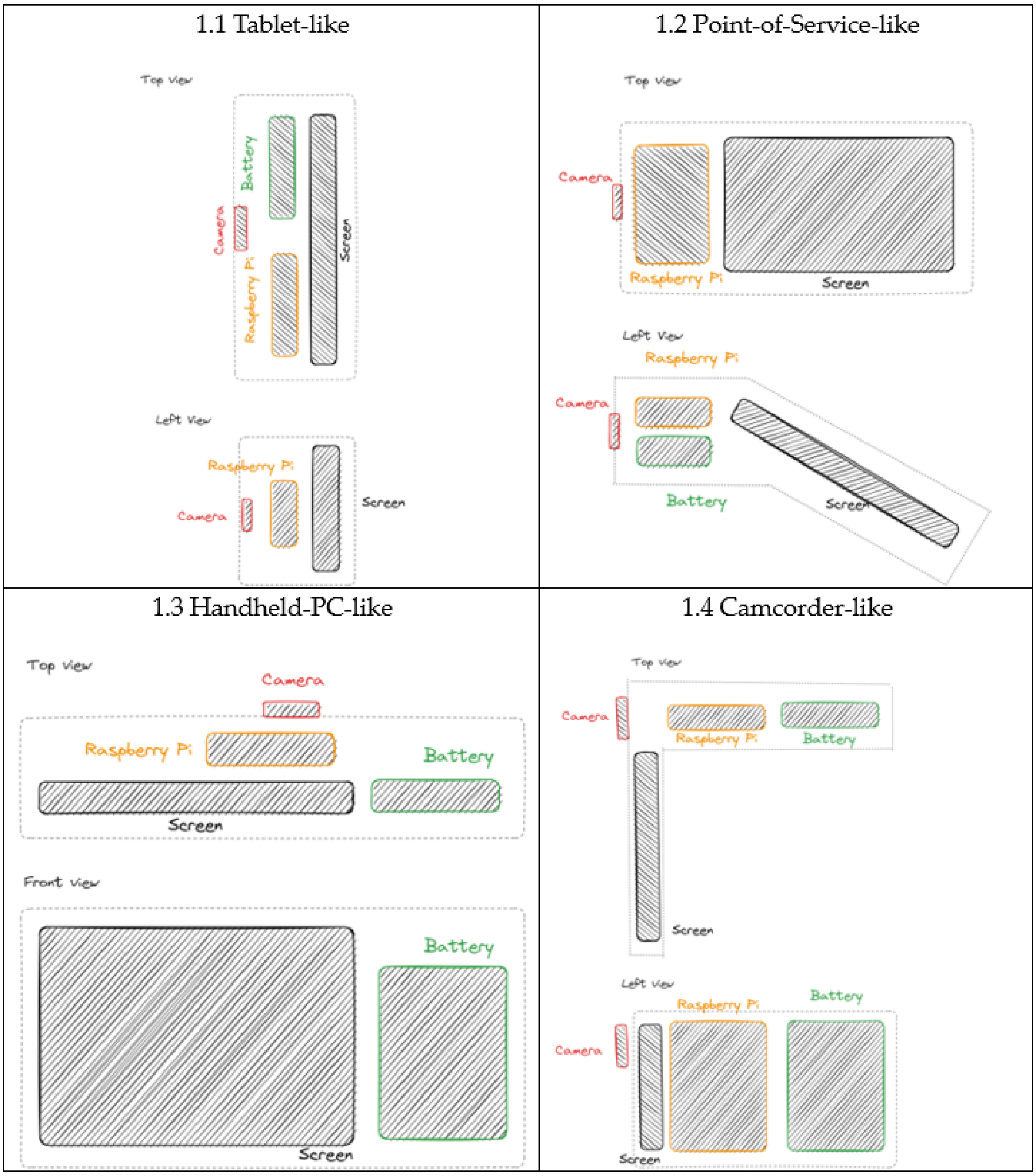


Table A.3: Components Placement

A.1.4 Body Type

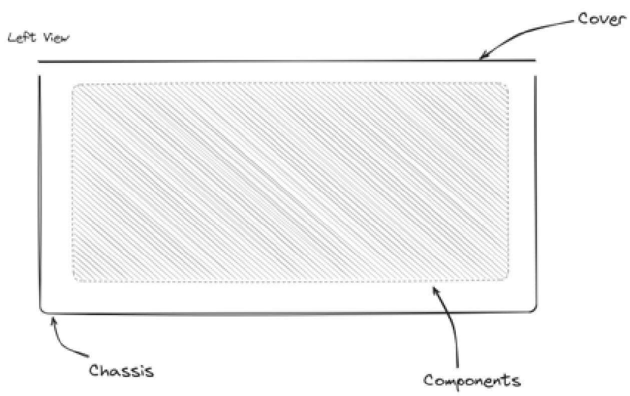
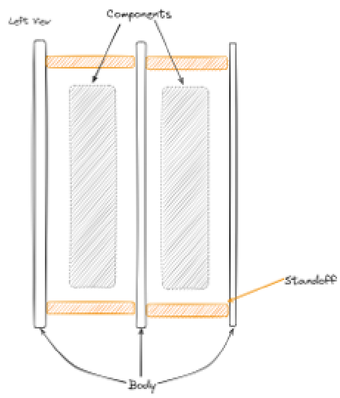
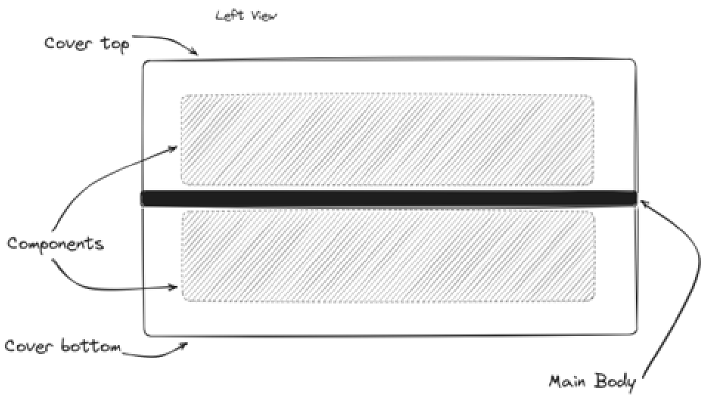
<table>
<tr><td>4.1 Bowl
</td><td>4.2 Skeleton
</td></tr>
<tr><td>4.3 Sandwich
</td><td></td></tr>
</table>

Table A.4: Body Type

A.1.5 Handling

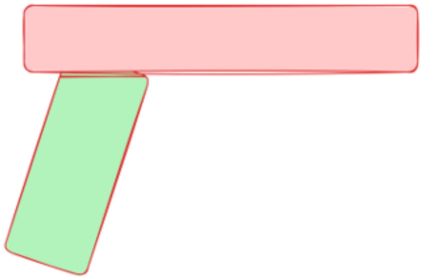
5.1 Body Grip	5.2 Bump Grip	5.3 Pistol Grip
		

Table A.5: Handling

A.1.6 External Mounting

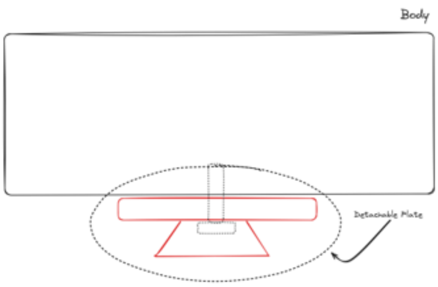
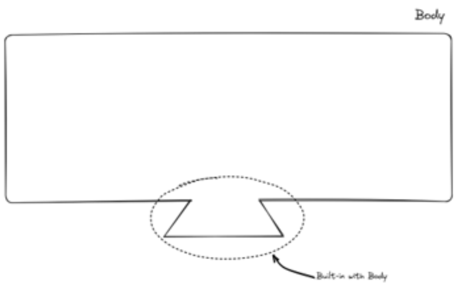
6.1 Detachable Plate	6.2 Built-in Mounting Plate
	

Table A.6: External Mounting

A.1.7 Control Mechanism

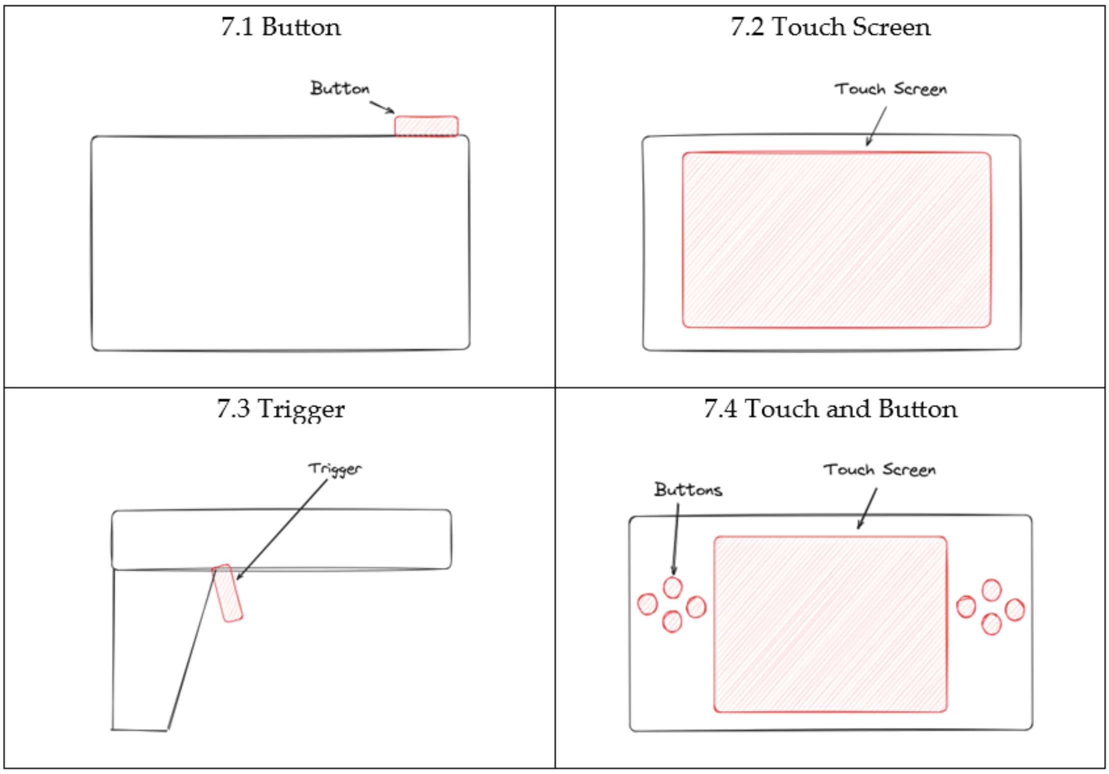


Table A.7: Control Mechanism

A.2 CAD Drawings

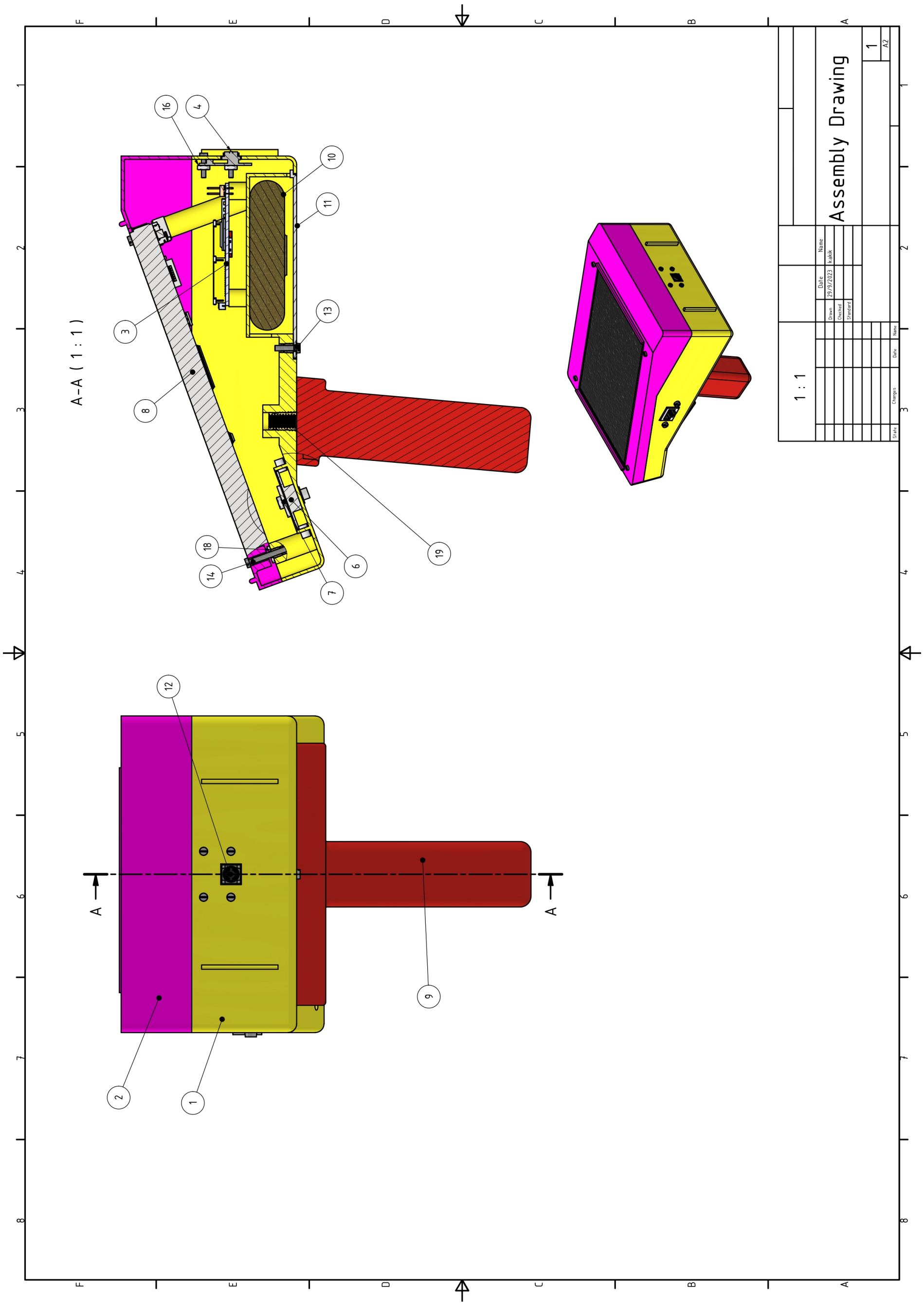


Figure A.1: Assembly Drawing

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Main Body	
2	1	Top Cover	
3	1	Raspberry Pi 4	
4	1	Camera Module	
5	1	LAN Port	
6	1	Switch	
7	1	Switch Cover	
8	1	Screen	
9	1	Pistol Grip	
10	1	Battery	Veektomx
11	1	Battery Cover	
12	4	Screw DIN 84 M2x10	DIN 84 (ISO 1207) - A2-Cylinder head screws, ISO 1207
13	7	Screw DIN 84 M2.5x10	DIN 84 (ISO 1207) - A2-Cylinder head screws, ISO 1207
14	4	Screw DIN 84 M2.5x20	DIN 84 (ISO 1207) - A2-Cylinder head screws, ISO 1207
15	2	Screw DIN 84 M3x10	DIN 84 (ISO 1207) - A2-Cylinder head screws, ISO 1207
16	4	Nut M2	DIN 934
17	2	Nut M2.5	DIN 934
18	9	Threaded Insert M2.5	Ruthex
19	3	Threaded Insert 1/4"	Ruthex
20	2	Camera Screw 1/4"	

1 : 1

	Date	Name
Drawn	29/9/2023	kakik
Checked		
Standard		

Bill of Material

2

A4

State Changes Date Name

Figure A.2: Bill of Materials

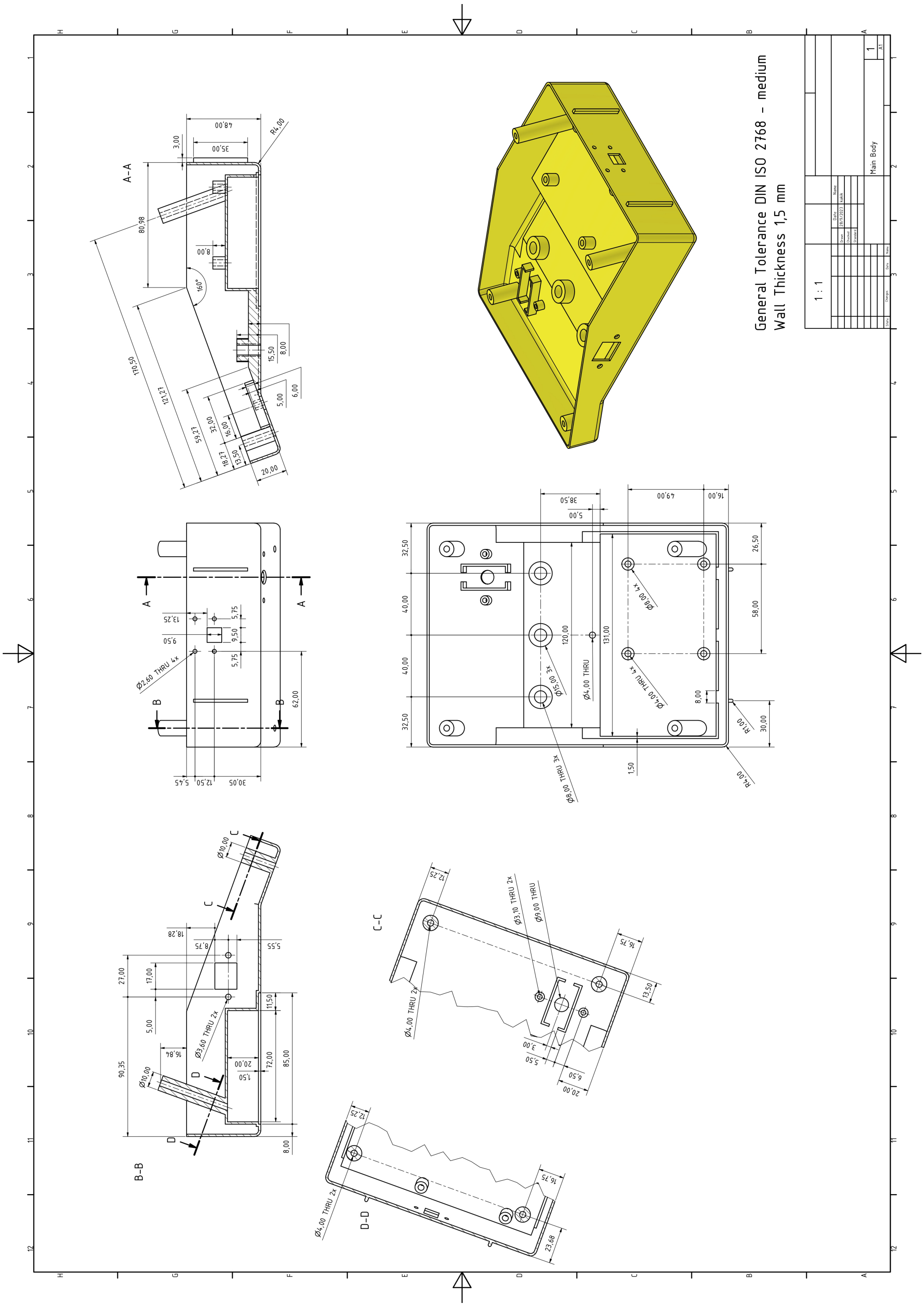


Figure A.3: Main Body Drawing

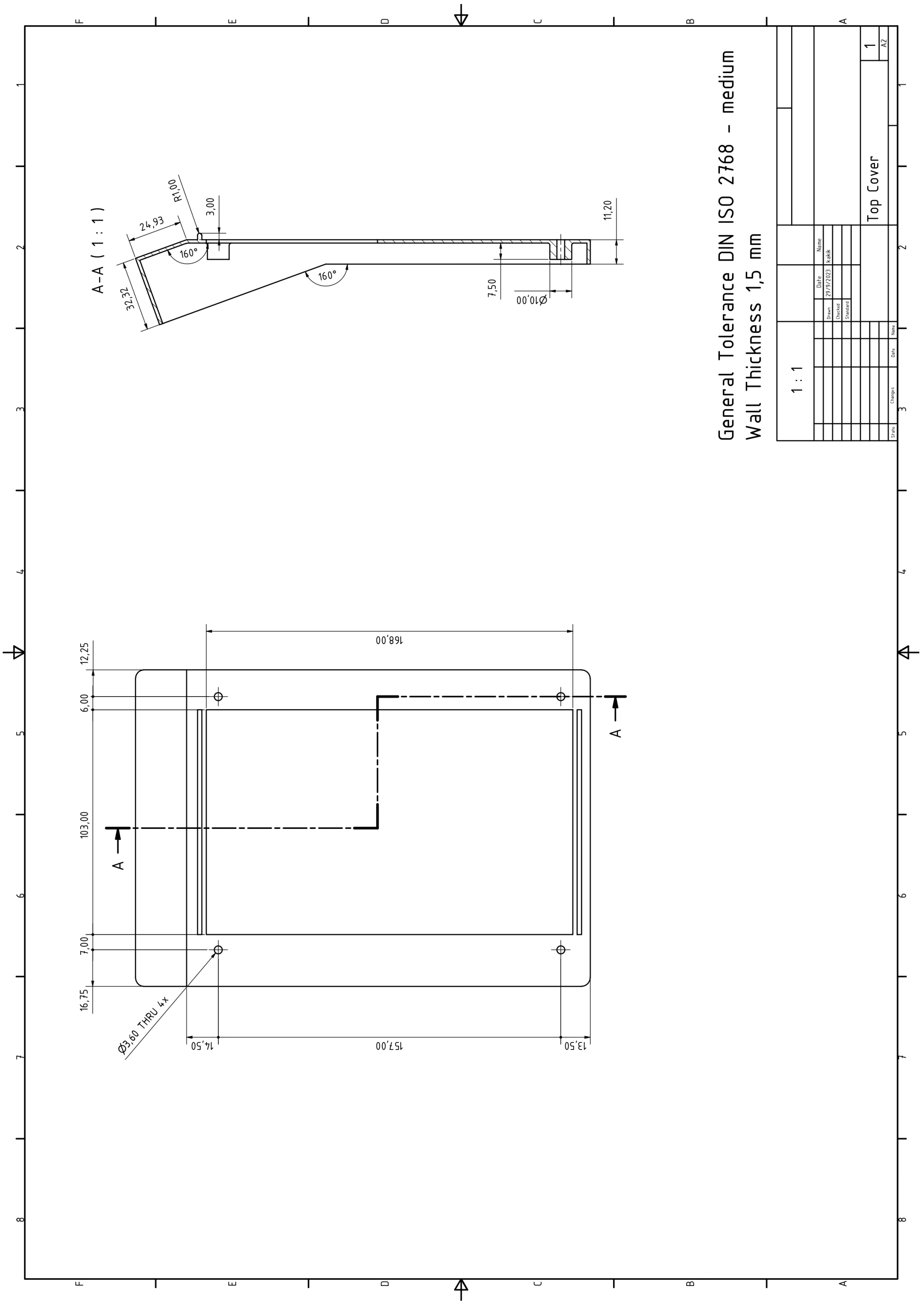


Figure A.4: Top Cover Drawing

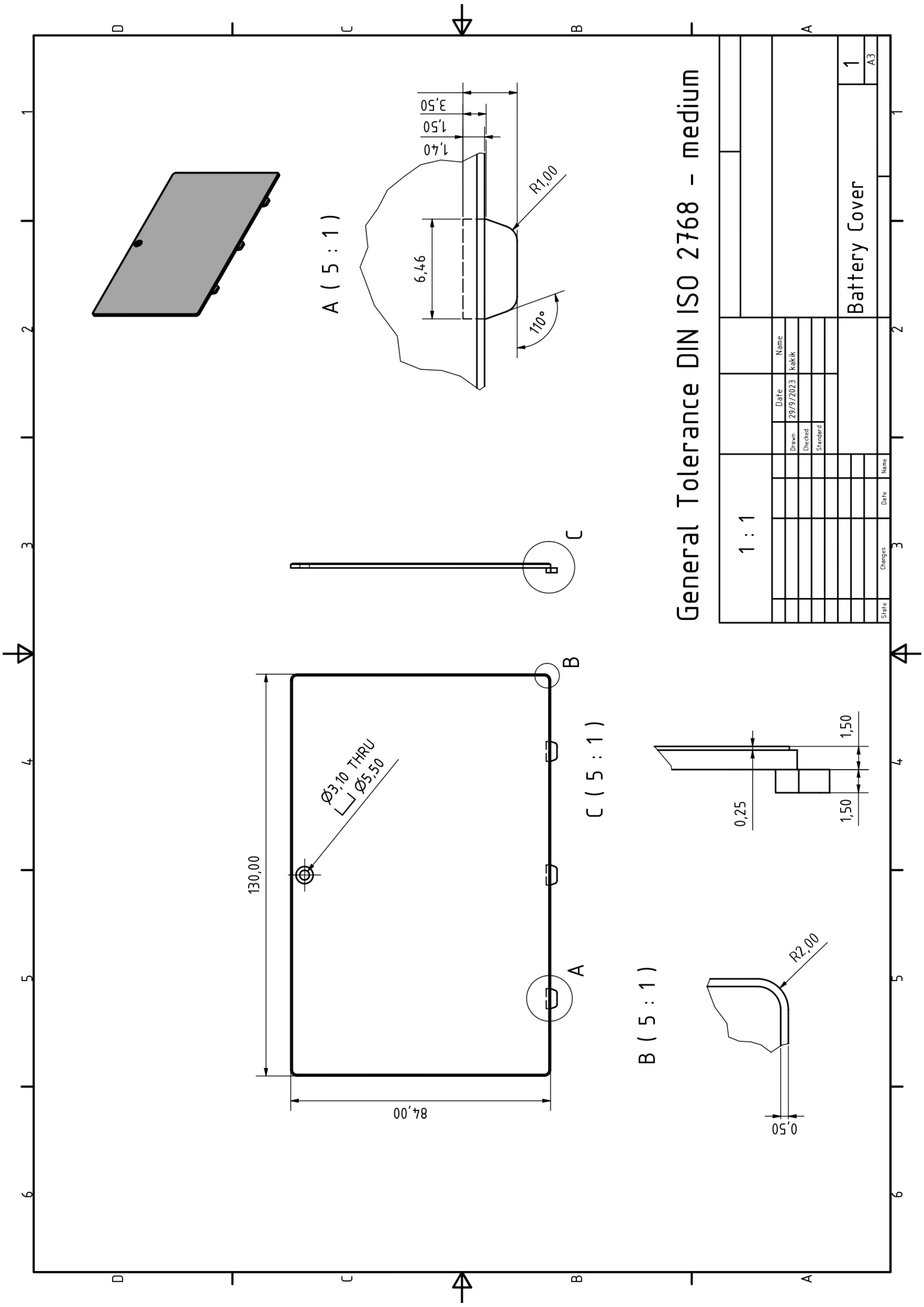


Figure A.5: Battery Cover Drawing

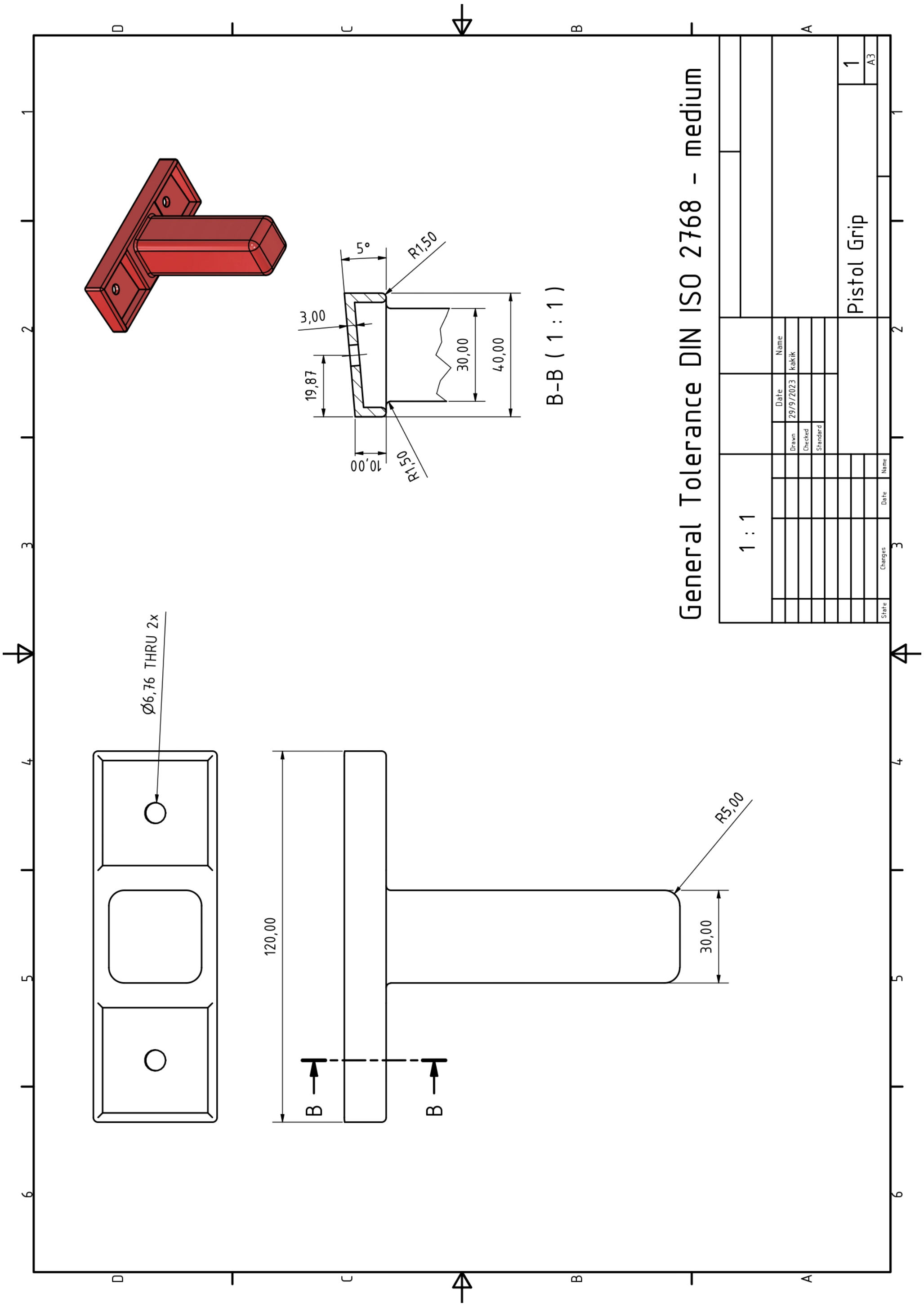


Figure A.6: Pistol Grip Drawing

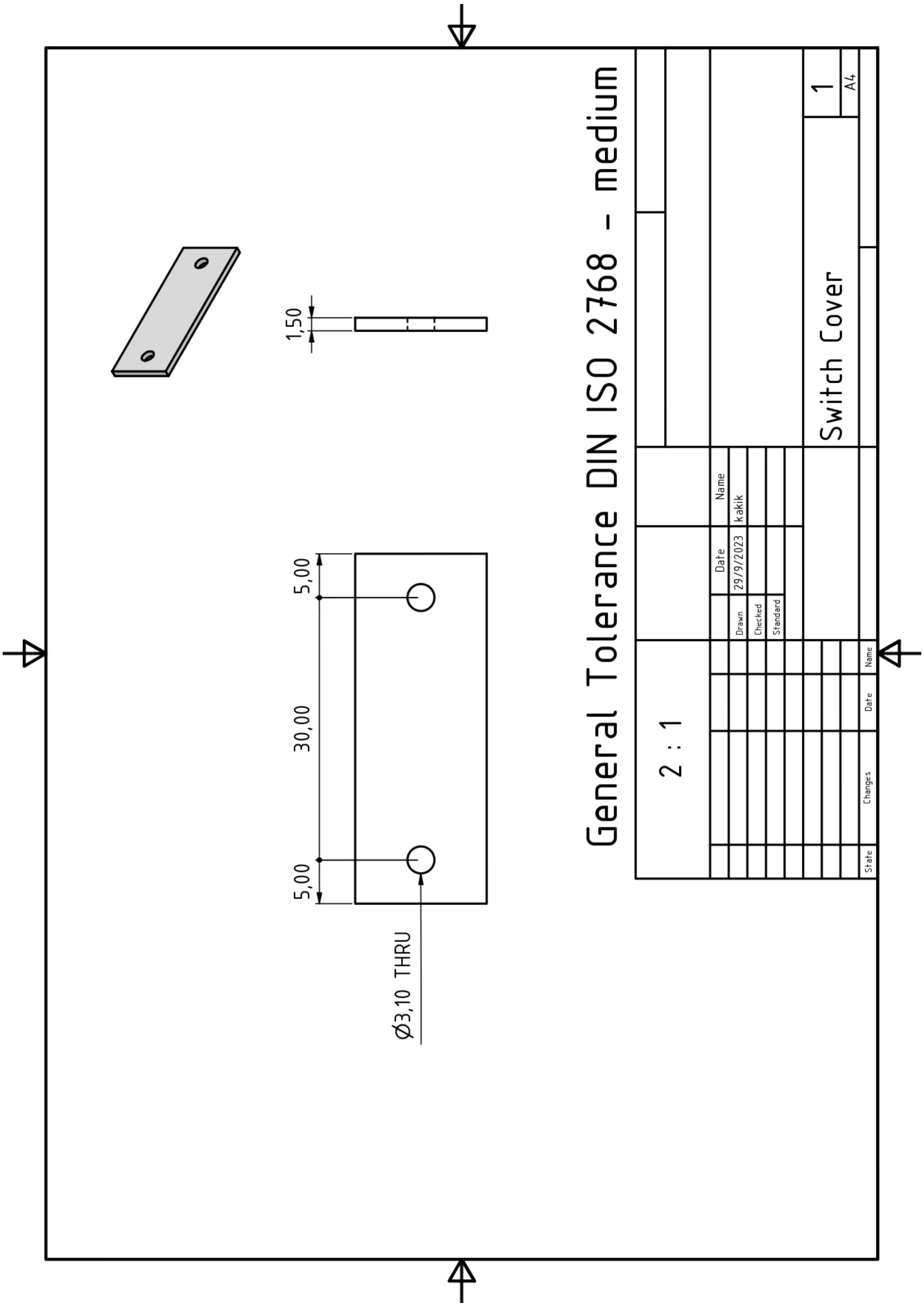


Figure A.7: Switch Cover Drawing

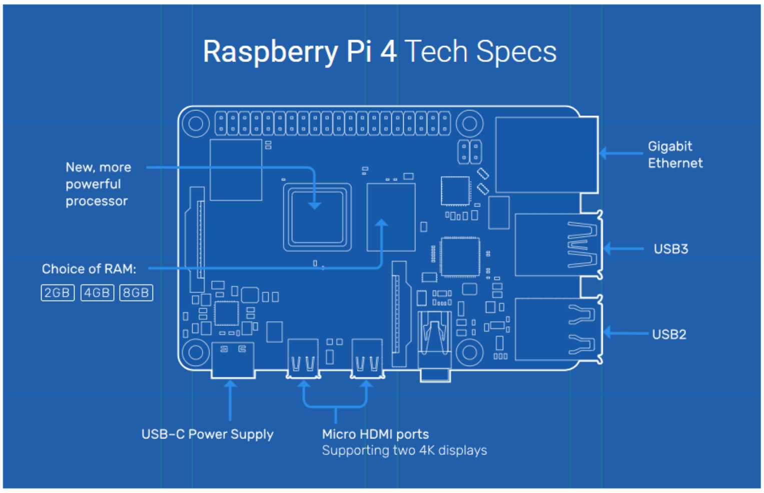
A.3 Original Prusa i3 MK3S+ 3D printer

Technical Parameters

Build Volume	25×21×21 cm (9.84"×8.3"×8.3")
Layer height	0.05 - 0.35 mm
Nozzle	0.4mm default, wide range of other diameters/nozzles supported
Filament diameter	1.75 mm
Supported materials	Wide range of thermoplastics, including PLA, PETG, ASA, ABS, PC (Polycarbonate), CPE, PVA/BVOH, PVB, HIPS, PP (Polypropylene), Flex, nGen, Nylon, Carbon filled, Woodfill and other filled materials.
Max travel speed	200+ mm/s
Max nozzle temperature	300 °C / 572 °F
Max heatbed temperature	120 °C / 248 °F
Extruder	Direct Drive, Bondtech gears, E3D V6 hotend
Print surface	Removable magnetic steel sheets(*) with different surface finishes, heatbed with cold corners compensation
Printer dimensions (without spool)	7 kg, 500×550×400 mm; 19.6×21.6×15.7 in (X×Y×Z)
Power consumption	PLA settings: 80W / ABS settings: 120W

Figure A.8: Original Prusa i3 MK3S+ 3D printer

A.4 Raspberry Pi 4 Model B



Specifications

Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.8GHz
1GB, 2GB, 4GB or 8GB LPDDR4-3200 SDRAM (depending on model)
2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE
Gigabit Ethernet
2 USB 3.0 ports; 2 USB 2.0 ports.
Raspberry Pi standard 40 pin GPIO header (fully backwards compatible with previous boards)
2 × micro-HDMI® ports (up to 4kp60 supported)
2-lane MIPI DSI display port
2-lane MIPI CSI camera port
4-pole stereo audio and composite video port
H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode)
OpenGL ES 3.1, Vulkan 1.0
Micro-SD card slot for loading operating system and data storage
5V DC via USB-C connector (minimum 3A*)
5V DC via GPIO header (minimum 3A*)
Power over Ethernet (PoE) enabled (requires separate PoE HAT)
Operating temperature: 0 – 50 degrees C ambient

* A good quality 2.5A power supply can be used if downstream USB peripherals consume less than 500mA in total.

Figure A.9: Raspberry Pi 4 Model B Technical Specifications

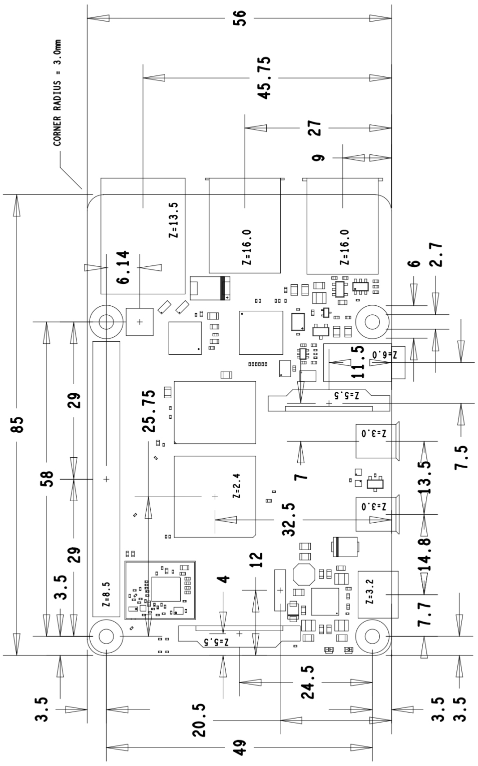


Figure A.10: Raspberry Pi 4 Model B Mechanical Drawing

A.5 Raspberry Pi Camera Module V2

	Camera Module v1	Camera Module v2	Camera Module 3	Camera Module 3 Wide	HQ Camera	GS Camera
Net price	$25	$25	$25	$35	$50	$50
Size	Around 25 × 24 × 9 mm	Around 25 × 24 × 9 mm	Around 25 × 24 × 11.5 mm	Around 25 × 24 × 12.4 mm	38 x 38 x 18.4mm (excluding lens)	38 x 38 x 19.8mm (29.5mm with adaptor and dust cap)
Weight	3g	3g	4g	4g	30.4g	34g (41g with adaptor and dust cap)
Still resolution	5 Megapixels	8 Megapixels	11.9 Megapixels	11.9 Megapixels	12.3 Megapixels	1.58 Megapixels
Video modes	1080p30, 720p60 and 640 × 480p60/90	1080p47, 1640 × 1232p41 and 640 × 480p206	2304 × 1296p56, 2304 × 1296p30 HDR, 1536 × 864p120	2304 × 1296p56, 2304 × 1296p30 HDR, 1536 × 864p120	2028 × 1080p50, 2028 × 1520p40 and 1332 × 990p120	1456 x 1088p60
Sensor	OmniVision OV5647	Sony IMX219	Sony IMX708	Sony IMX708	Sony IMX477	Sony IMX296
Sensor resolution	2592 × 1944 pixels	3280 × 2464 pixels	4608 x 2592 pixels	4608 x 2592 pixels	4056 x 3040 pixels	1456 x 1088 pixels
Sensor image area	3.76 × 2.74 mm	3.68 x 2.76 mm (4.6 mm diagonal)	6.45 x 3.63mm (7.4mm diagonal)	6.45 x 3.63mm (7.4mm diagonal)	6.287mm x 4.712 mm (7.9mm diagonal)	6.3mm diagonal
Pixel size	1.4 µm × 1.4 µm	1.12 µm x 1.12 µm	1.4 µm x 1.4 µm	1.4 µm x 1.4 µm	1.55 µm x 1.55 µm	3.45 µm x 3.45 µm
Optical size	1/4"	1/4"	1/2.43"	1/2.43"	1/2.3"	1/2.9"
Focus	Fixed	Adjustable	Motorized	Motorized	Adjustable	Adjustable
Depth of field	Approx 1 m to ∞	Approx 10 cm to ∞	Approx 10 cm to ∞	Approx 5 cm to ∞	N/A	N/A
Focal length	3.60 mm +/- 0.01	3.04 mm	4.74 mm	2.75 mmm	Depends on lens	Depends on lens
Horizontal Field of View (FoV)	53.50 +/- 0.13 degrees	62.2 degrees	66 degrees	102 degrees	Depends on lens	Depends on lens
Vertical Field of View (FoV)	41.41 +/- 0.11 degrees	48.8 degrees	41 degrees	67 degrees	Depends on lens	Depends on lens
Focal ratio (F-Stop)	F2.9	F2.0	F1.8	F2.2	Depends on lens	Depends on lens
Maximum exposure times (seconds)	6 (legacy) / 0.97 (libcamera)	11.76	112	112	670.74	15.5
Lens Mount	N/A	N/A	N/A	N/A	C/CS- or M12-mount	C/CS
NoIR version available?	Yes	Yes	Yes	Yes	No	No

Figure A.11: Raspberry Pi Camera Module V2 Technical Specifications

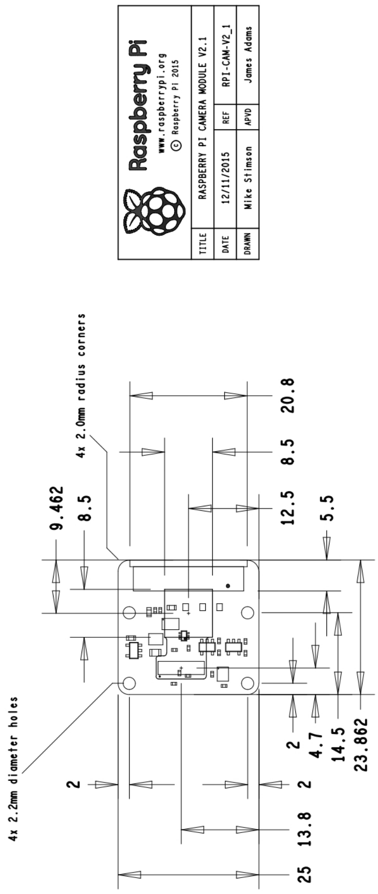


Figure A.12: Raspberry Pi Camera Module V2 Mechanical Drawing

A.6 Waveshare 7inch HDMI LCD (H)

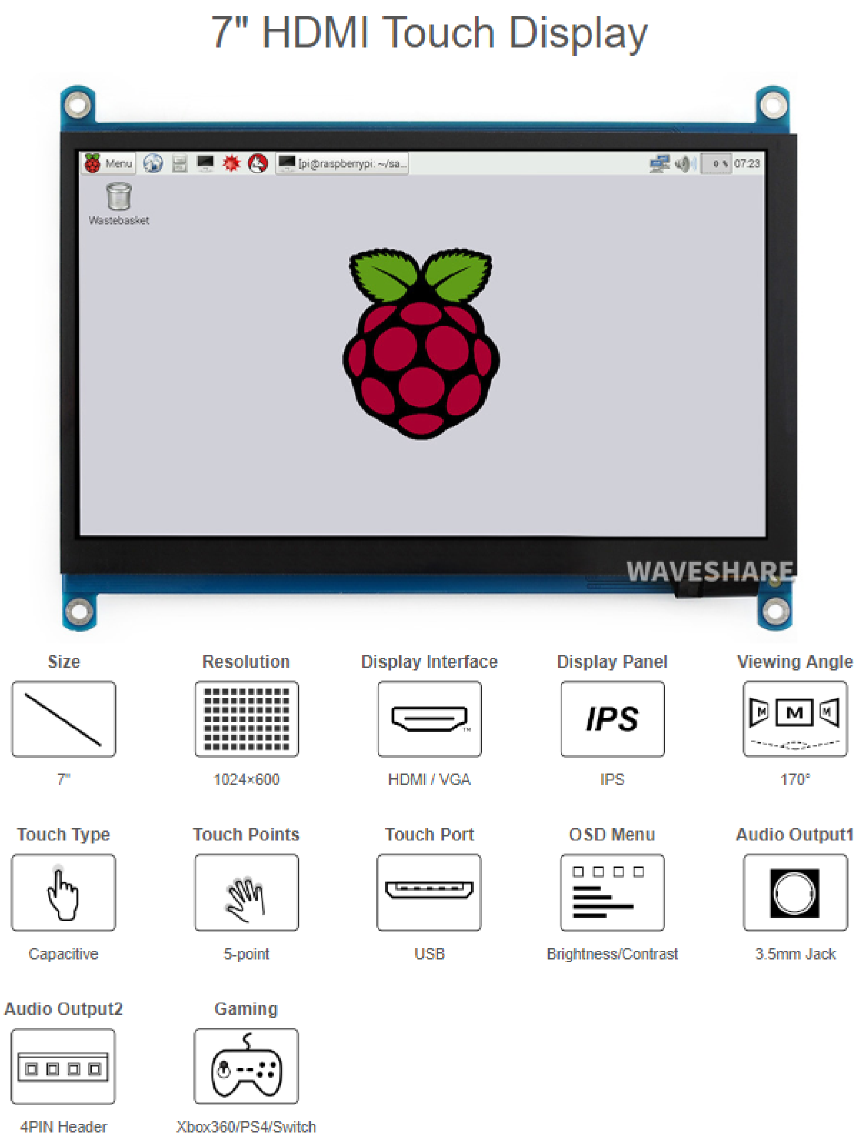


Figure A.13: Waveshare 7inch HDMI LCD (H) Technical Specifications -1

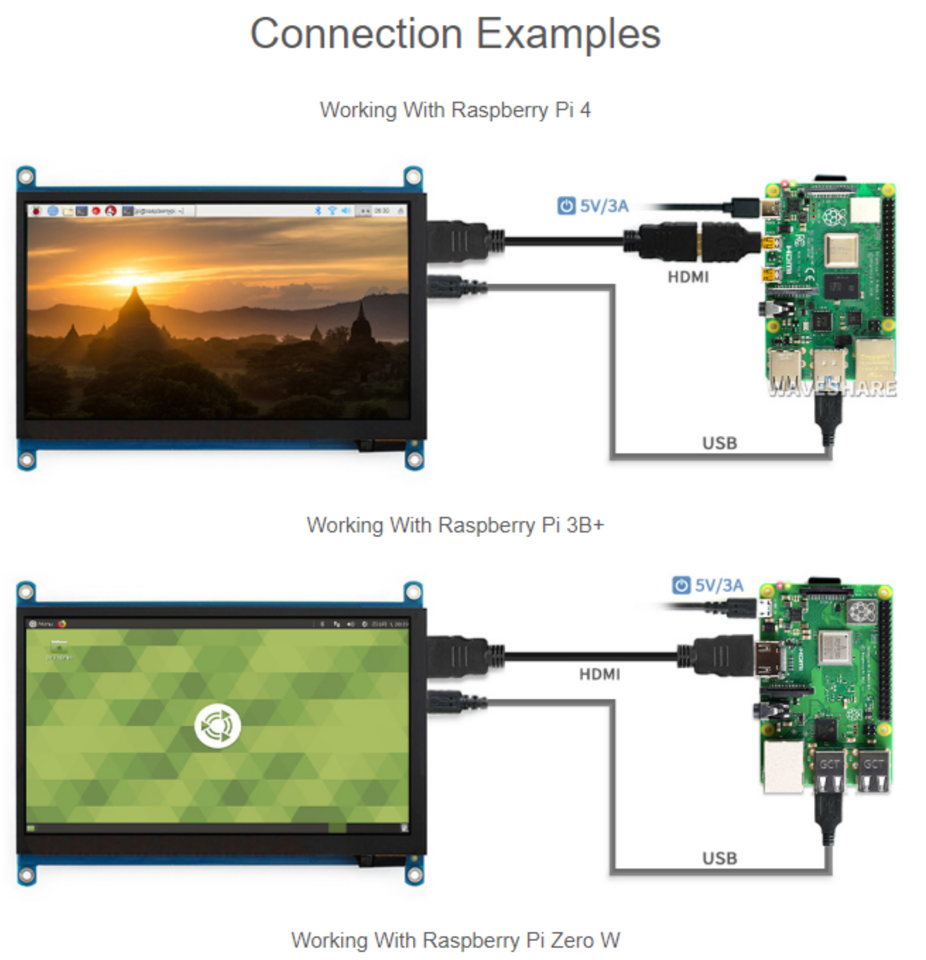


Figure A.14: Waveshare 7inch HDMI LCD (H) Technical Specifications -2

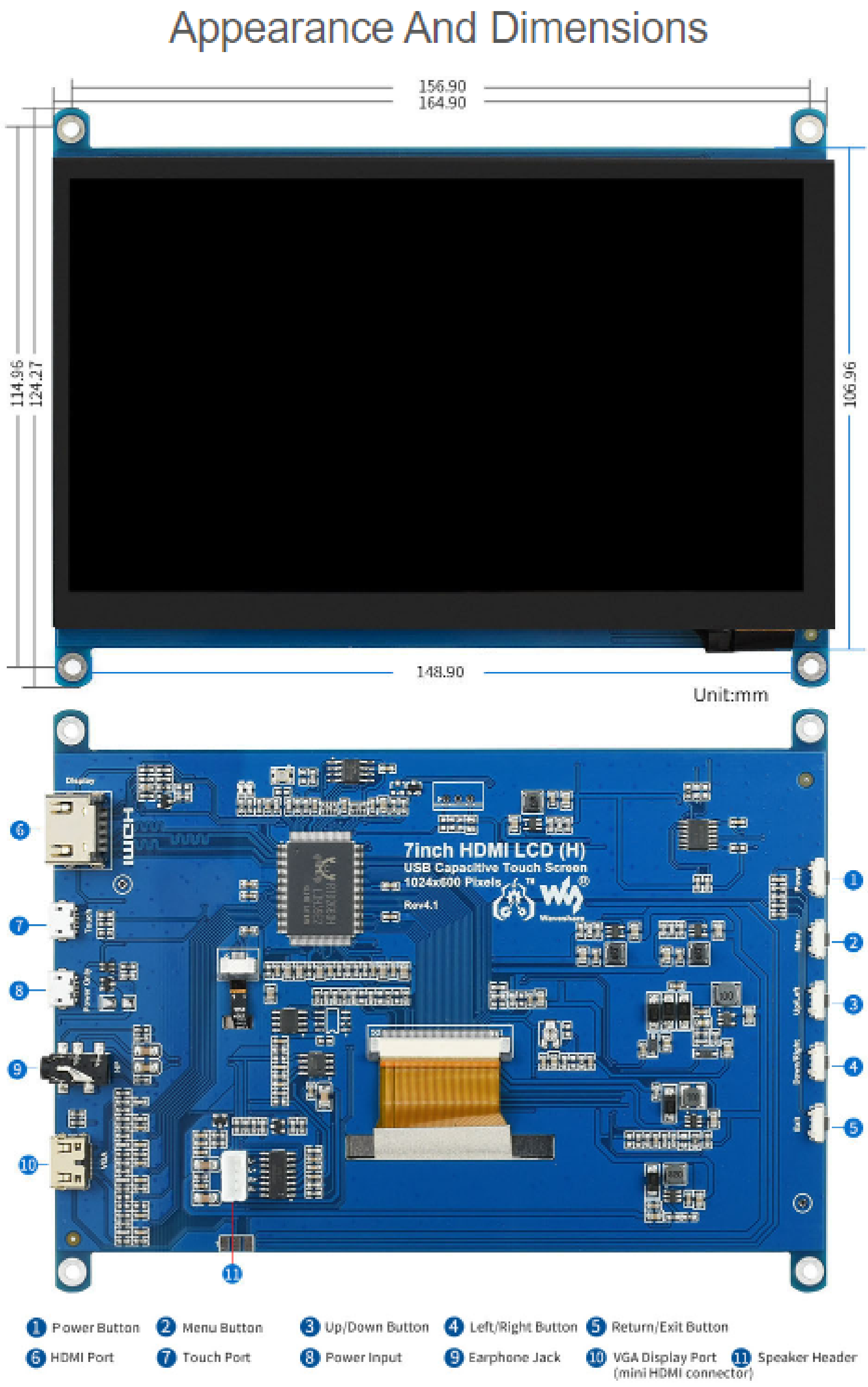


Figure A.15: Waveshare 7inch HDMI LCD (H) Technical Specifications -3

A.7 Veektomx VT103

Figure A.16: Veektomx VT103 Technical Specifications

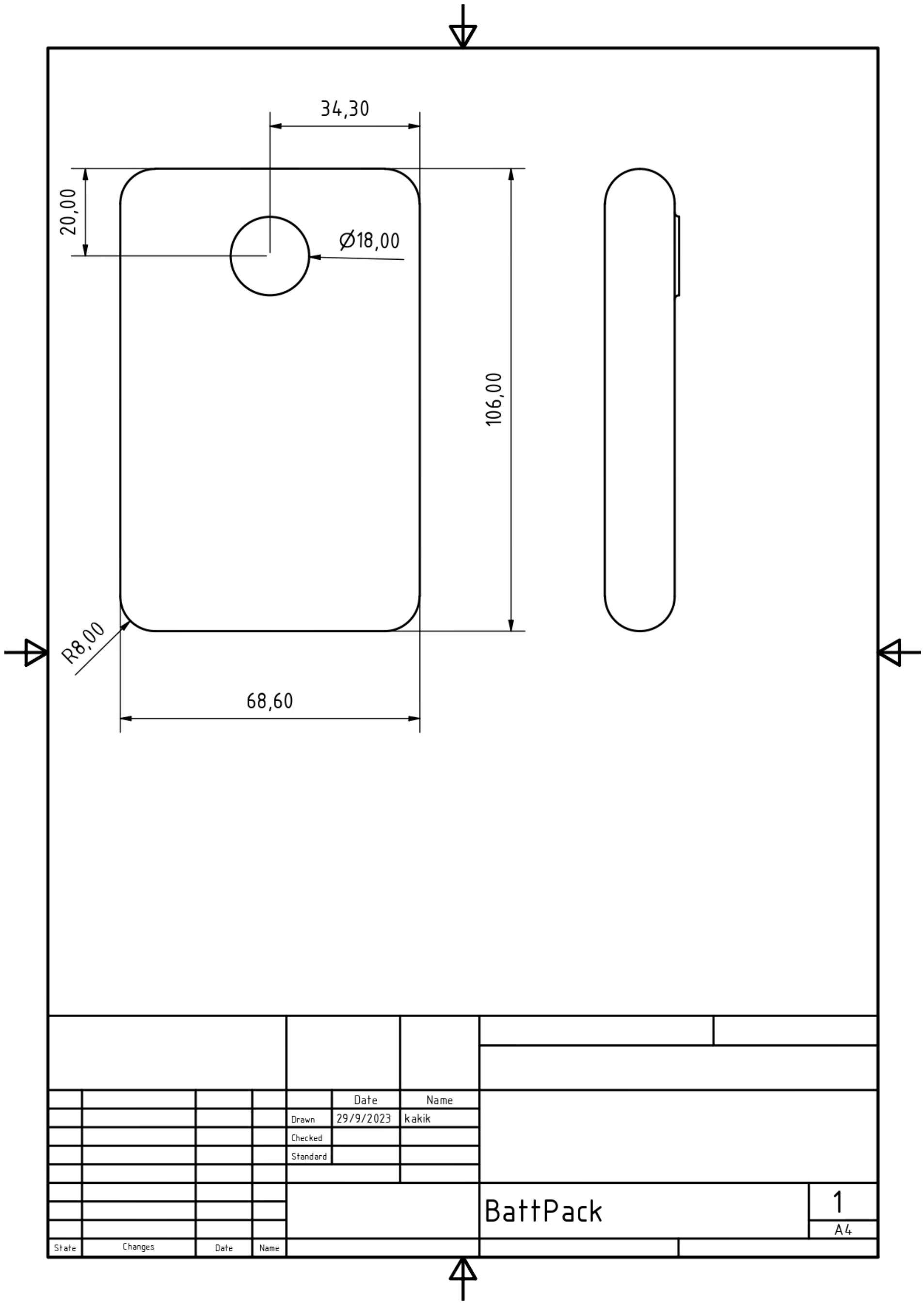


Figure A.17: Veektomx VT103 Mechanical Drawing

A.8 Cost Calculation

Cost Calculation

SetCurrencyUnits(*BaseCurrency*)

1 EUR = 1.0000 EUR

Constant

Filament cost per kg

$C_{fil} := 29.99 \frac{EUR}{kg}$

Printer power rating

$P := 80 \frac{W}{hr}$

Electricity Price

$C_{el} := 0.23545 \frac{EUR}{kW}$

Formula

Material Cost

$C_m := m_{fil} \cdot C_{fil}$

Electric Cost

$C_e := t_p \cdot C_{el} \cdot P$

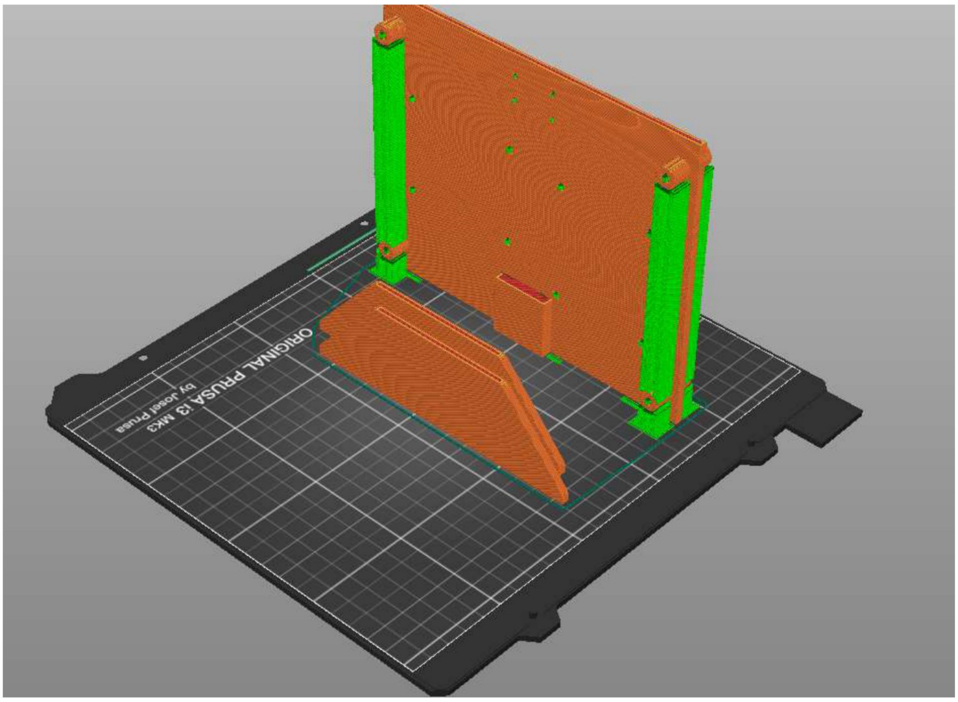
Printing Cost

$C_{print} := C_m + C_e$

Figure A.18: Cost Calculation 1

Variant 2

Base



$m_{fil} := 175.07\ \mathrm{g}$

$t_p := 6\ \mathrm{hr} + 8\ \mathrm{min}$

$C_m = 5.2503\ \mathrm{EUR}$

$C_e = 0.1155\ \mathrm{EUR}$

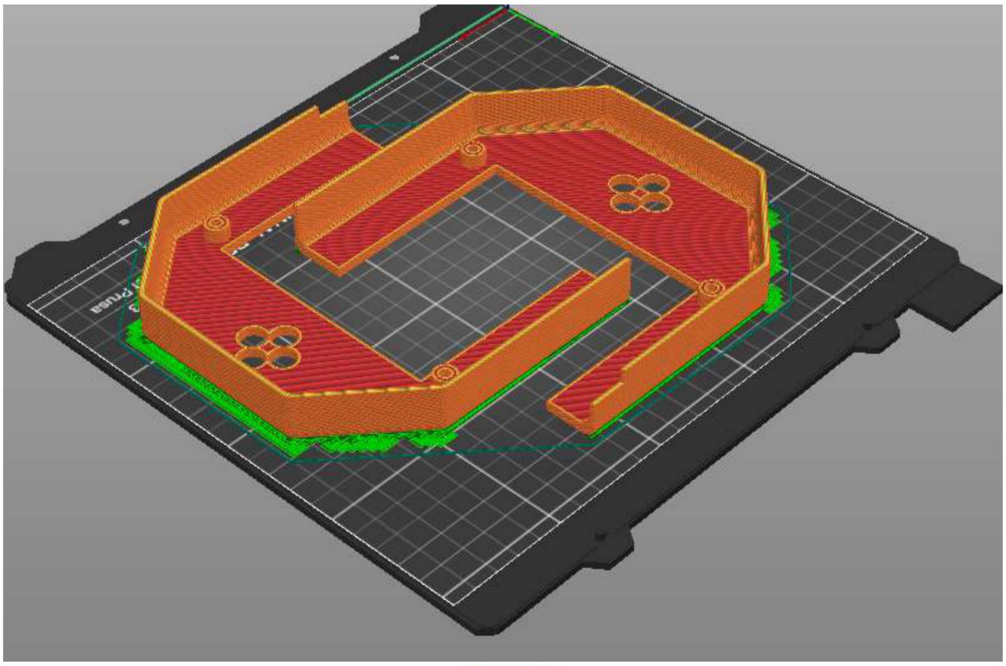
$C_{print} = 5.3659\ \mathrm{EUR}$

Sliced Info

Used Filament (g)	175.07
Used Filament (m)	58.70
Used Filament (mm³)	141185.08
Cost	4.45
Estimated printing time:	
- normal mode	6h8m
- stealth mode	6h17m

Figure A.19: Cost Calculation 2

Top Cover



Sliced Info

Used Filament (g)	105.85
Used Filament (m)	35.49
Used Filament (mm³)	85360.45
Cost	2.69
Estimated printing time:	
- normal mode	3h19m
- stealth mode	3h22m

$m_{fil} := 105.85\ \mathrm{g}$

$t_p := 3\ \mathrm{hr} + 19\ \mathrm{min}$

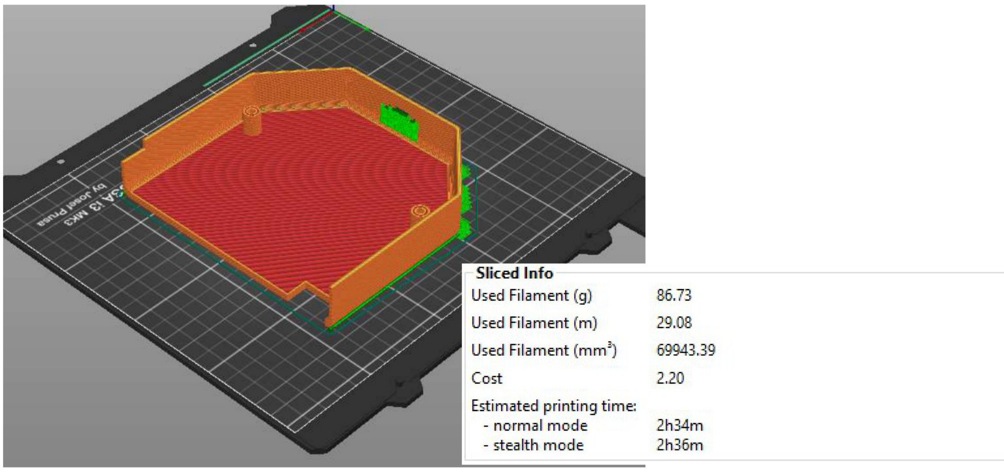
$C_m = 3.1744\ \mathrm{EUR}$

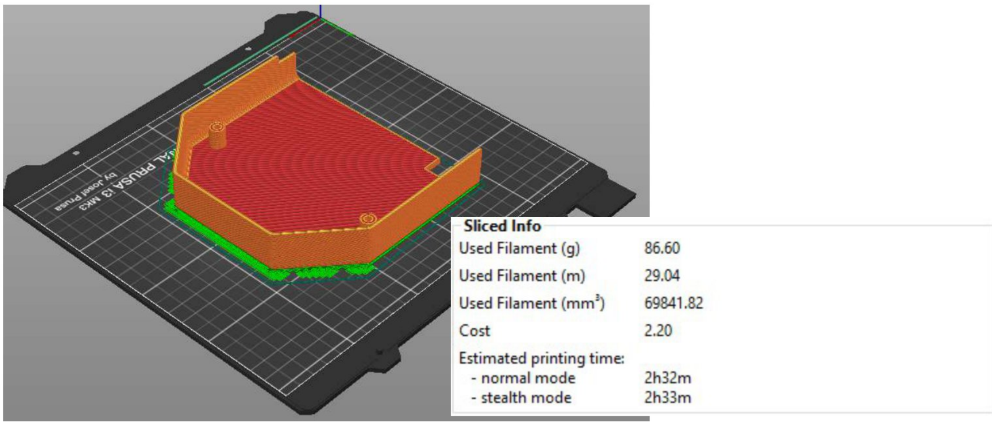
$C_e = 0.0625\ \mathrm{EUR}$

$C_{print} = 3.2369\ \mathrm{EUR}$

Figure A.20: Cost Calculation 3

Back Cover





$m_{fil} := (86.73 + 86.6)\ \mathrm{g}$

$t_p := 2\ \mathrm{hr} + 34\ \mathrm{min} + 2\ \mathrm{hr} + 32\ \mathrm{min}$

$C_m = 5.1982\ \mathrm{EUR}$

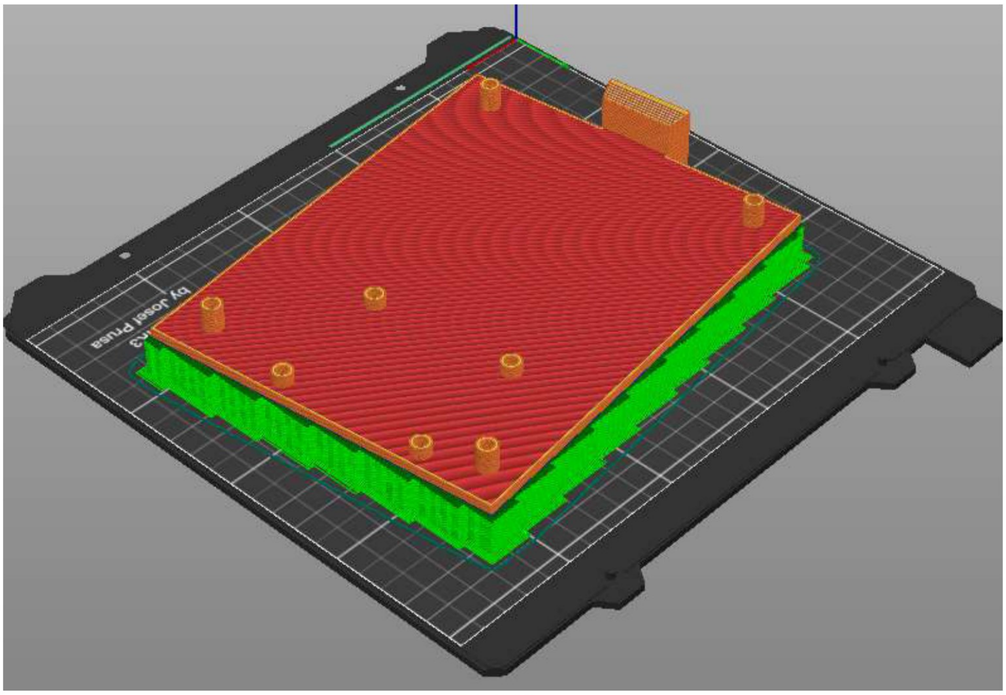
$C_e = 0.0961\ \mathrm{EUR}$

$C_{print} = 5.2942\ \mathrm{EUR}$

Figure A.21: Cost Calculation 4

Variant 3

Base



$m_{fil} := 222.96\ g$

$t_p := 6\ hr + 40\ min$

Sliced Info	
Used Filament (g)	222.96
Used Filament (m)	74.76
Used Filament (mm³)	179809.70
Cost	5.66
Estimated printing time:	
- normal mode	6h40m
- stealth mode	6h44m

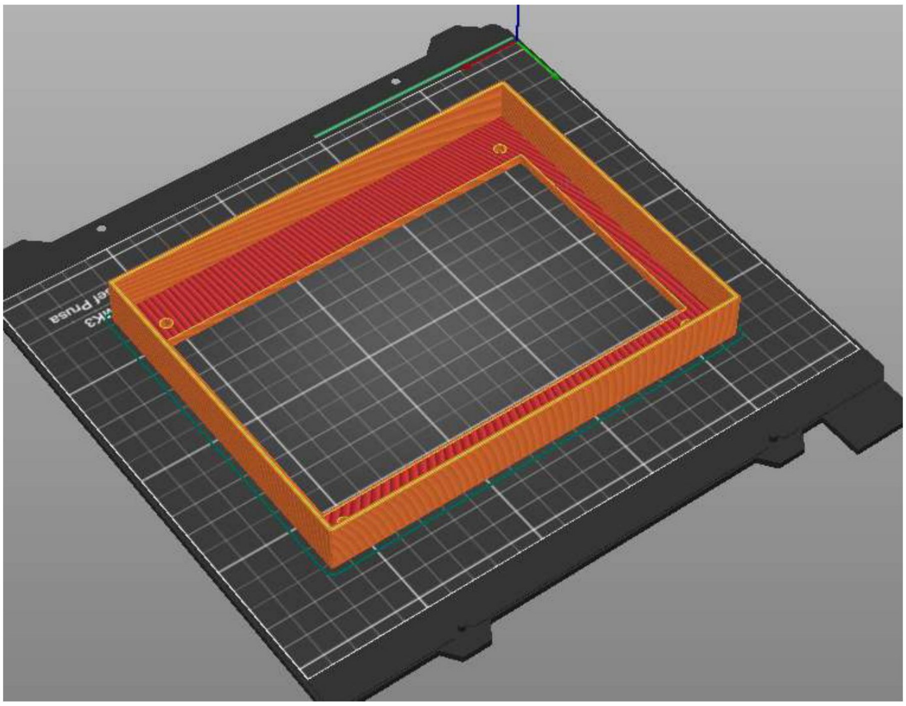
$C_m = 6.6866\ EUR$

$C_e = 0.1256\ EUR$

$C_{print} = 6.8121\ EUR$

Figure A.22: Cost Calculation 5

Top Cover



$m_{fil} := 71.02\ \mathrm{g}$

$t_p := 2\ \mathrm{hr} + 5\ \mathrm{min}$

$C_m = 2.1299\ \mathrm{EUR}$

$C_e = 0.0392\ \mathrm{EUR}$

$C_{print} = 2.1691\ \mathrm{EUR}$

Sliced Info

Used Filament (g)	71.02
Used Filament (m)	23.81
Used Filament (mm³)	57270.69
Cost	1.80
Estimated printing time:	
- normal mode	2h5m
- stealth mode	2h6m

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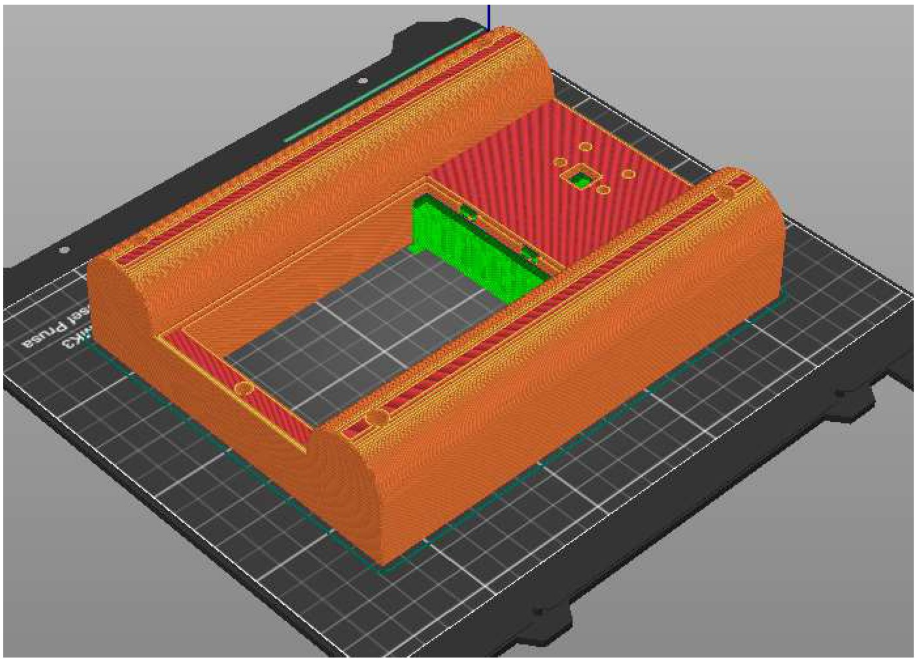
Figure A.23: Cost Calculation 6

Back Cover



$m_{fil} := 303.02\ \mathrm{g}$

$t_p := 9\ \mathrm{hr} + 22\ \mathrm{min}$

$C_m = 9.0876\ \mathrm{EUR}$

$C_e = 0.1764\ \mathrm{EUR}$

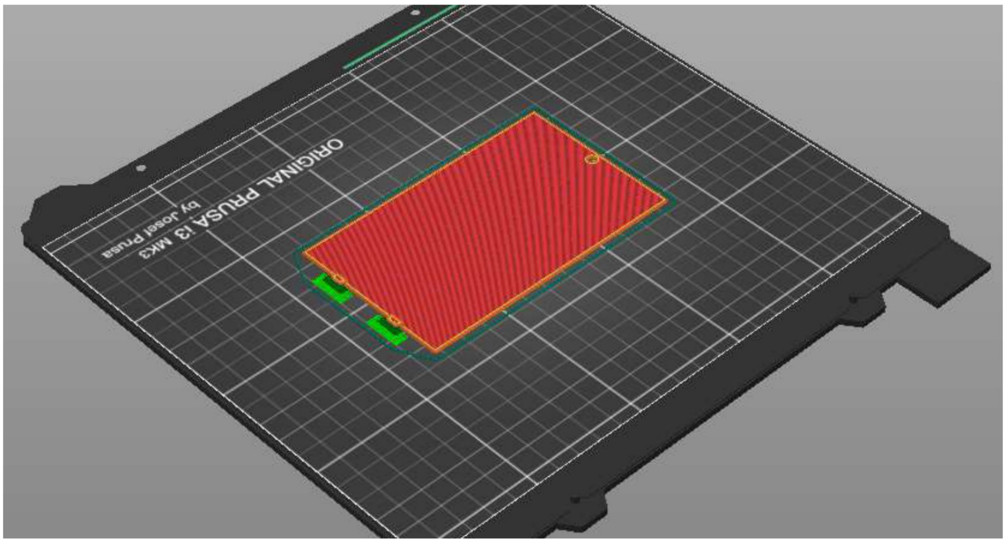
$C_{print} = 9.264\ \mathrm{EUR}$

Sliced Info

Used Filament (g)	303.02
Used Filament (m)	101.60
Used Filament (mm³)	244371.20
Cost	7.70
Estimated printing time:	
- normal mode	9h22m
- stealth mode	9h31m

Figure A.24: Cost Calculation 7

Battery Cover



$m_{fil} := 17.43$ g

$t_p := 0$ hr $+ 32$ min

$C_m = 0.5227$ EUR

$C_e = 0.01$ EUR

$C_{print} = 0.5328$ EUR

Sliced Info

Used Filament (g)	17.43
Used Filament (m)	5.84
Used Filament (mm³)	14056.38
Cost	0.44
Estimated printing time:	
- normal mode	32m
- stealth mode	32m

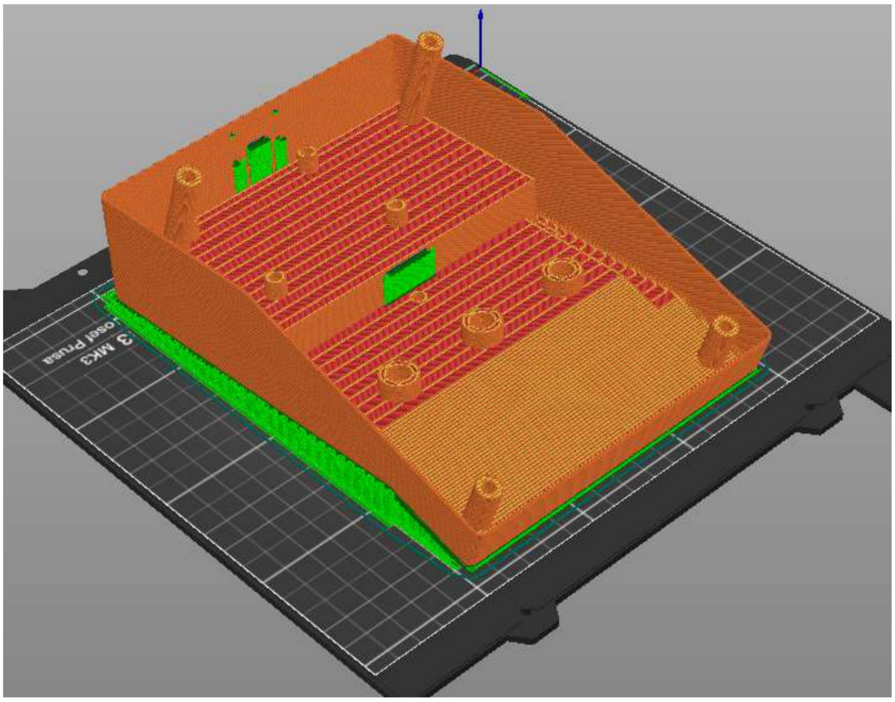
8 / 19

Figure A.25: Cost Calculation 8

22 Sep 2023 08:53:27 - cost.sm

Variant 6

Main Body



$m_{fil} := 240.3\ g$

$t_p := 8\ hr + 53\ min$

$C_m = 7.2066\ EUR$

$C_e = 0.1673\ EUR$

$C_{print} = 7.3739\ EUR$

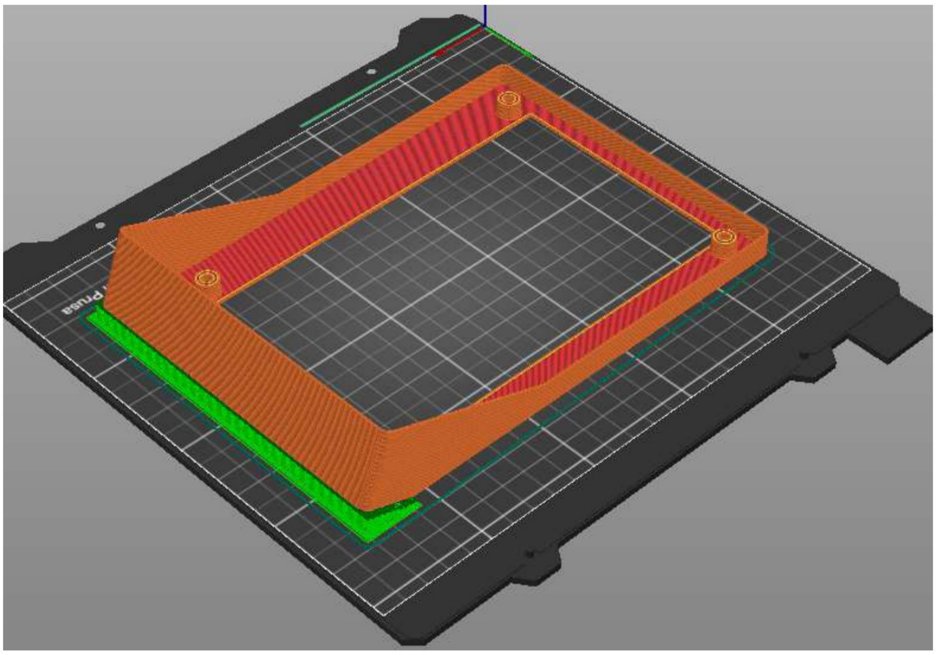
Sliced Info

Used Filament (g)	240.30
Used Filament (m)	80.57
Used Filament (mm³)	193788.10
Cost	6.10
Estimated printing time:	
- normal mode	8h53m
- stealth mode	9h3m

9 / 19

Figure A.26: Cost Calculation 9

Top Cover



$m_{fil} := 55.32$ g

$t_p := 1$ hr $+ 52$ min

$C_m = 1.659$ EUR

$C_e = 0.0352$ EUR

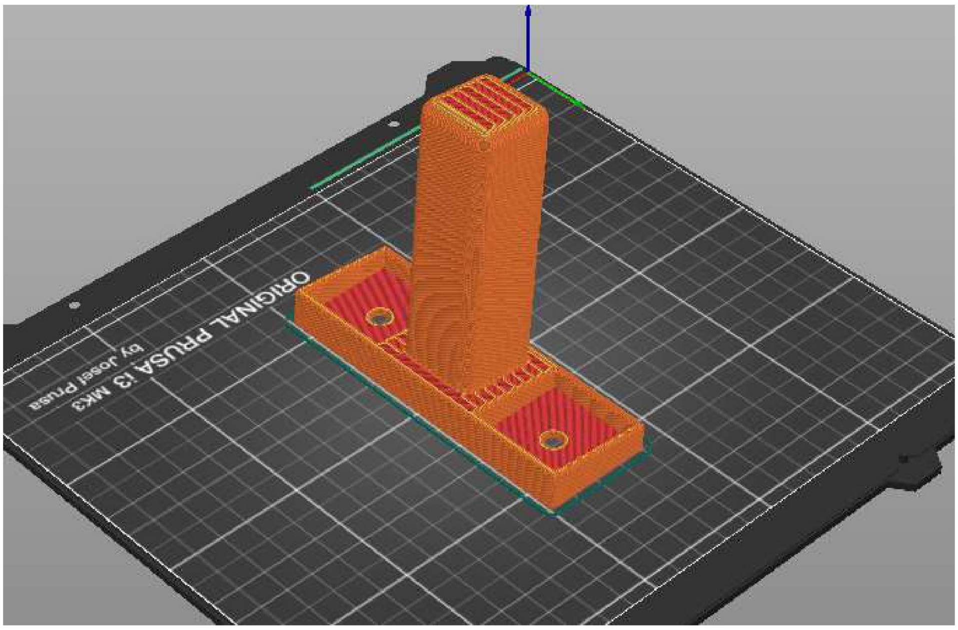
$C_{print} = 1.6942$ EUR

Sliced Info

Used Filament (g)	55.35
Used Filament (m)	18.56
Used Filament (mm³)	44638.88
Cost	1.41
Estimated printing time:	
- normal mode	1h52m
- stealth mode	1h54m

Figure A.27: Cost Calculation 10

Pistol Handle



$m_{fil} := 57.30\ \mathrm{g}$

$t_p := 1\ \mathrm{hr} + 44\ \mathrm{min}$

$C_m = 1.7184\ \mathrm{EUR}$

$C_e = 0.0326\ \mathrm{EUR}$

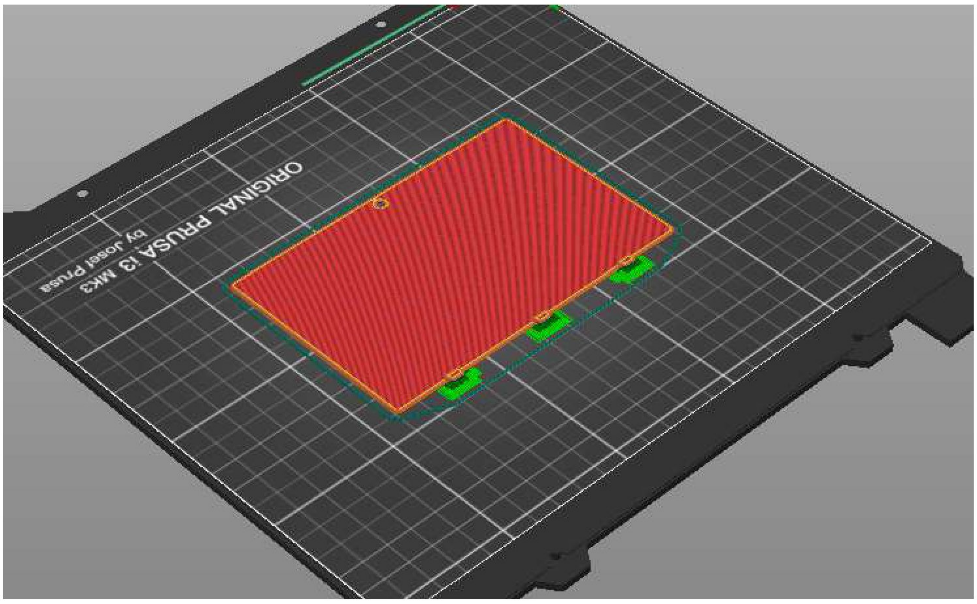
$C_{print} = 1.7511\ \mathrm{EUR}$

Sliced Info

Used Filament (g)	57.30
Used Filament (m)	19.21
Used Filament (mm³)	46212.83
Cost	1.46
Estimated printing time:	
- normal mode	1h44m
- stealth mode	1h45m

Figure A.28: Cost Calculation 11

Battery Cover



Sliced Info	
Used Filament (g)	22.21
Used Filament (m)	7.45
Used Filament (mm³)	17910.60
Cost	0.56
Estimated printing time:	
- normal mode	40m
- stealth mode	40m

$m_{fil} := 22.21\ \mathrm{g}$

$t_p := 0\ \mathrm{hr} + 40\ \mathrm{min}$

$C_m = 0.6661\ \mathrm{EUR}$

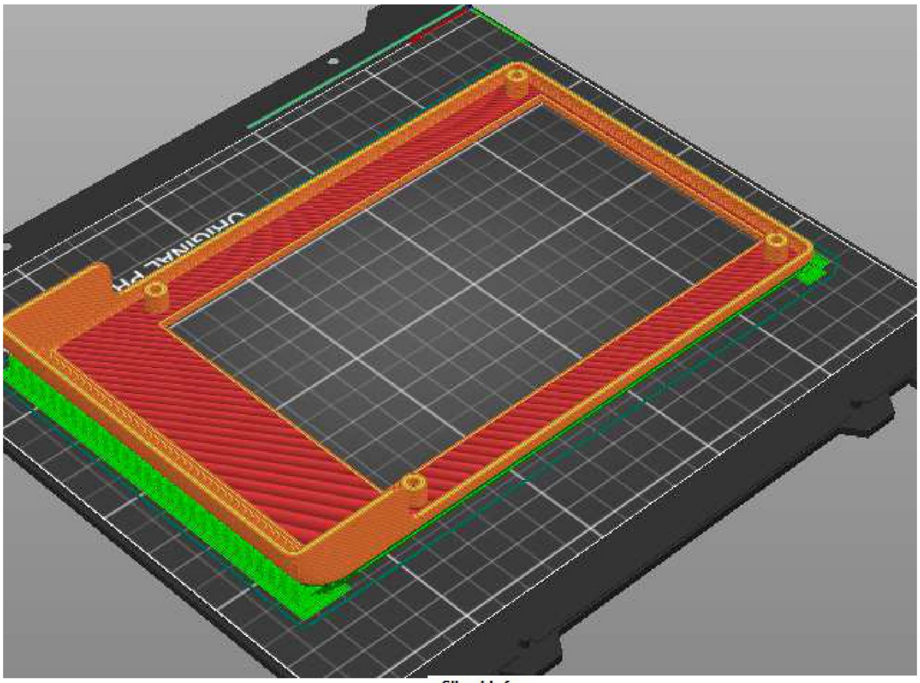
$C_e = 0.0126\ \mathrm{EUR}$

$C_{print} = 0.6786\ \mathrm{EUR}$

Figure A.29: Cost Calculation 12

Variant 7

Top Cover



$m_{fil} := 61.5\ \mathrm{g}$

$t_p := 2\ \mathrm{hr} + 5\ \mathrm{min}$

$C_m = 1.8444\ \mathrm{EUR}$

$C_e = 0.0392\ \mathrm{EUR}$

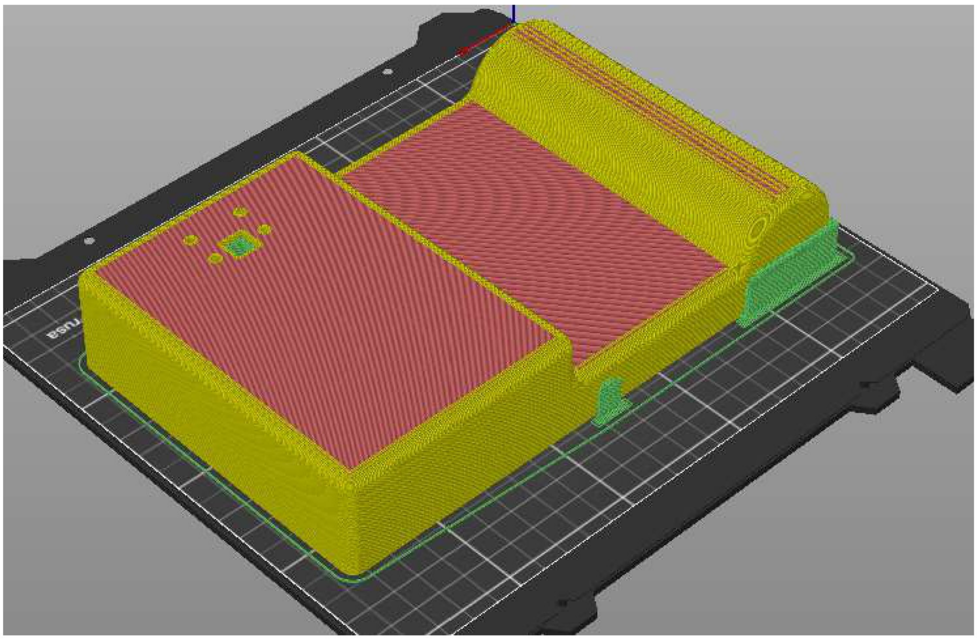
$C_{print} = 1.8836\ \mathrm{EUR}$

Sliced Info

Used Filament (g)	61.50
Used Filament (m)	20.62
Used Filament (mm³)	49593.24
Cost	1.56
Estimated printing time:	
- normal mode	2h5m
- stealth mode	2h7m

Figure A.30: Cost Calculation 13

Back Cover



$m_{fil} := 380.69\ \mathrm{g}$

$t_p := 11\ \mathrm{hr} + 49\ \mathrm{min}$

$C_m = 11.4169\ \mathrm{EUR}$

$C_e = 0.2226\ \mathrm{EUR}$

$C_{print} = 11.6395\ \mathrm{EUR}$

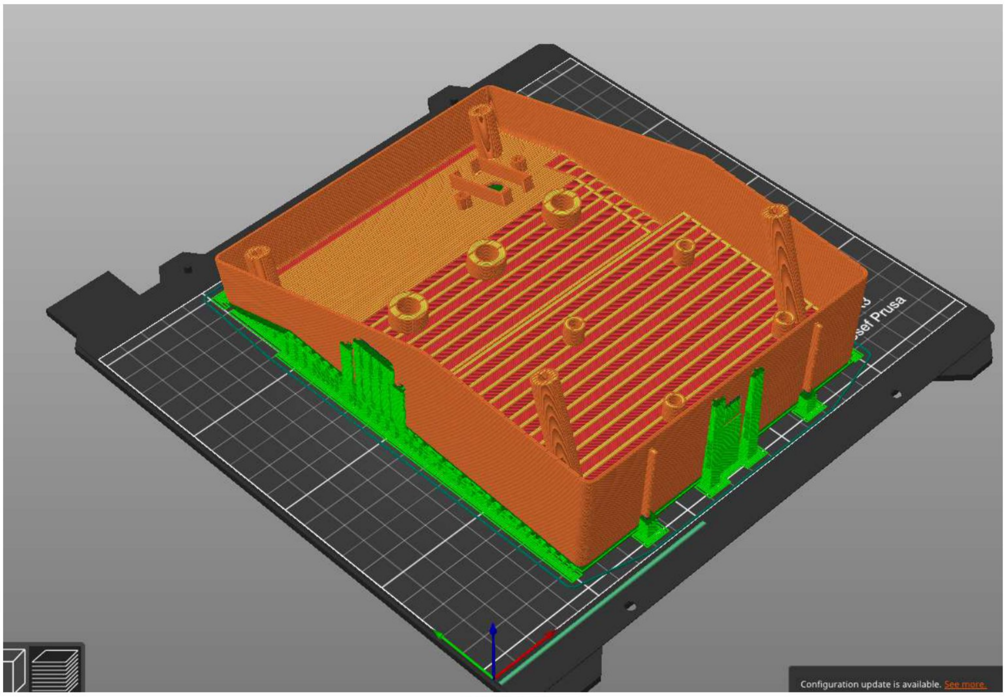
Sliced Info

Used Filament (g)	380.69
Used Filament (m)	127.64
Used Filament (mm³)	307011.60
Cost	9.67
Estimated printing time:	
- normal mode	11h49m
- stealth mode	11h57m

Figure A.31: Cost Calculation 14

Variant 6 Final

Main Body



$m_{fil} := 245.14\ \text{g}$

$t_p := 9\ \text{hr} + 15\ \text{min}$

$c_m = 7.3517\ \text{EUR}$

$c_e = 0.1742\ \text{EUR}$

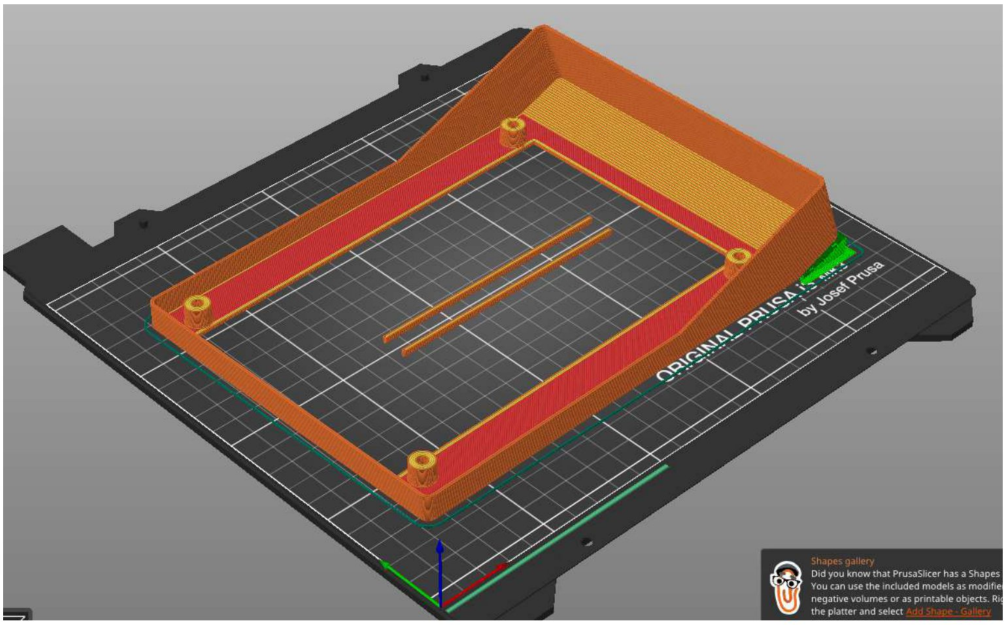
$c_{print} = 7.526\ \text{EUR}$

Sliced Info

Used Filament (g)	245.14
Used Filament (m)	82.19
Used Filament (mm³)	197695.71
Cost	6.23
Estimated printing time:	
- normal mode	9h15m
- stealth mode	9h25m

Figure A.32: Cost Calculation 15

Top Cover



Sliced Info	
Used Filament (g)	57.71
Used Filament (m)	19.35
Used Filament (mm³)	46541.58
Cost	1.47
Estimated printing time:	
- normal mode	2h0m
- stealth mode	2h2m

$m_{fil} := 57.71\ \mathrm{g}$

$t_p := 2\ \mathrm{hr} + 0\ \mathrm{min}$

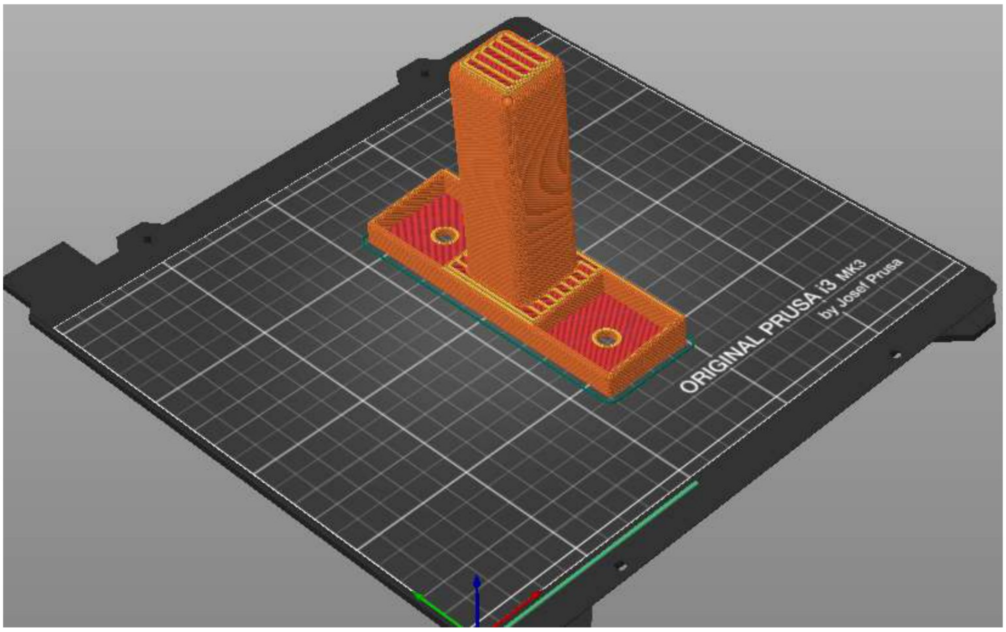
$C_m = 1.7307\ \mathrm{EUR}$

$C_e = 0.0377\ \mathrm{EUR}$

$C_{print} = 1.7684\ \mathrm{EUR}$

Figure A.33: Cost Calculation 16

Pistol Handle



$m_{fil} := 64.63\ \mathrm{g}$

$t_p := 1\ \mathrm{hr} + 59\ \mathrm{min}$

$C_m = 1.9383\ \mathrm{EUR}$

$C_e = 0.0374\ \mathrm{EUR}$

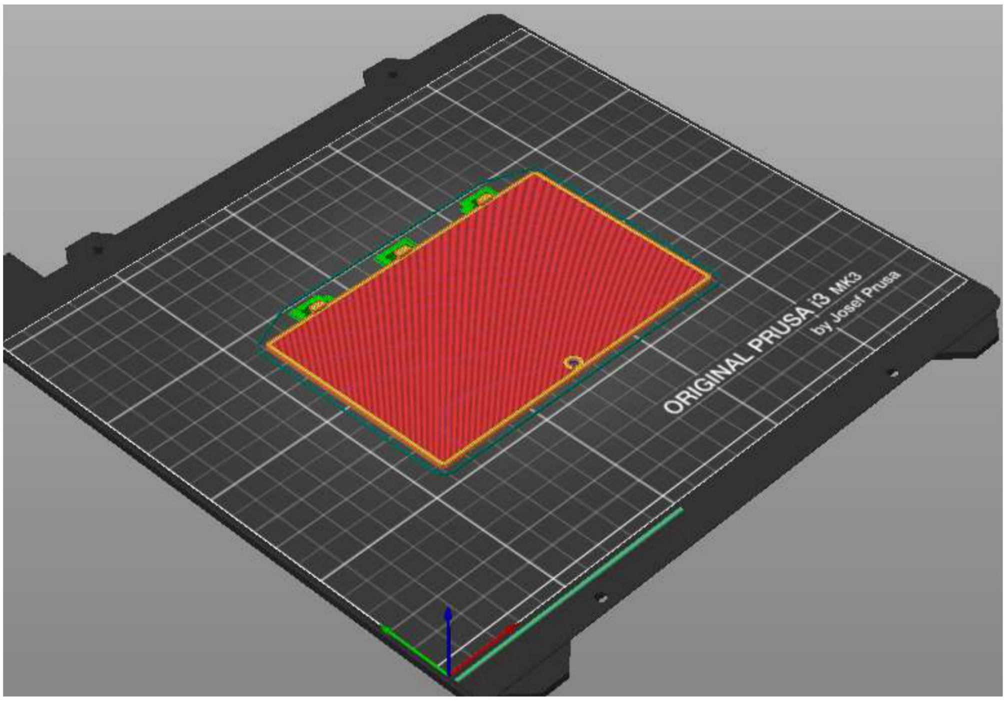
$C_{print} = 1.9756\ \mathrm{EUR}$

Sliced Info

Used Filament (g)	64.63
Used Filament (m)	21.67
Used Filament (mm³)	52121.02
Cost	1.64
Estimated printing time:	
- normal mode	1h59m
- stealth mode	2h1m

Figure A.34: Cost Calculation 17

Battery Cover



$m_{fil} := 22.21$ g

$t_p := 0$ hr $+ 40$ min

$C_m = 0.6661$ EUR

$C_e = 0.0126$ EUR

$C_{print} = 0.6786$ EUR

Sliced Info

Used Filament (g)	22.21
Used Filament (m)	7.45
Used Filament (mm³)	17910.60
Cost	0.56
Estimated printing time:	
- normal mode	40m
- stealth mode	40m

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Figure A.35: Cost Calculation 18

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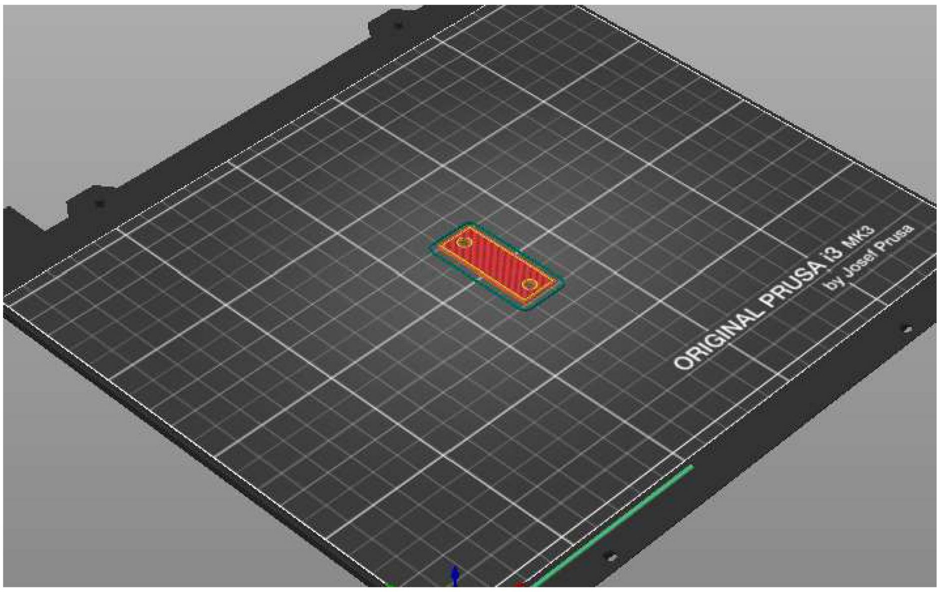
Switch Cover



Sliced Info

Used Filament (g)	1.31
Used Filament (m)	0.44
Used Filament (mm³)	1057.58
Cost	0.03
Estimated printing time:	
- normal mode	3m
- stealth mode	4m

$m_{fil} := 1.31\ \mathrm{g}$

$t_p := 0\ \mathrm{hr} + 3\ \mathrm{min}$

$C_m = 0.0393\ \mathrm{EUR}$

$C_e = 0.0009\ \mathrm{EUR}$

$C_{print} = 0.0402\ \mathrm{EUR}$

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Figure A.36: Cost Calculation 19

A.9 Documentation

- Docs
- Repository

A.10 Code snippets

A.11 Additional information, pictures, handout, etc.

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