ID Cover Page
Summary of WP Student Team

The Launch of an Innovative Water Filtering Solution

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Puraqua – The Launch of an Innovative Water Filtering Solution

How a Water Filter Can Reduce Plastic Waste in Portugal

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Abstract

In Portugal, 54% of people do not drink tap water as their primary water source due to taste, trust, and health concerns. The result is 36,000 tonnes of plastic water bottle waste created annually in Portugal. Puraqua aims to provide an affordable, on-demand water filter solution to leverage water consumption's social and environmental impacts. This thesis uses the lean startup methodology and relevant engineering tools to guide the development process. It shows how learnings from external validation allowed a business model and product to be refined into a minimum viable product, ready to launch for the Portuguese market.

Keywords:

Lean Startup

Agile Product Development

Plastic Waste

Water filter

Impact

Experimentation

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List of Abbreviations

BMC – Business Model Canvas

BML – Build-Measure-Learn

CAD – Computer Aided Design

CAR – Customer Acquisition Rate

CLV – Customer Lifetime Value

D2C – Direct to Customer

HDPE – High-Density Polyethylene

KPI – Key Performance Indicator

LCA – Life Cycle Assessment

MSP – Minimum Sellable Product

MVP – Minimum Viable Product

OBM – Opportunity Business Model

PDS – Product Design Specification

PET – Polyethylene Terephthalate

TLS – The Lean Startup

WTP – Willingness to Pay

1 TLS methodology and Puraqua

In 2008, Eric Ries introduced a new methodology for starting new ventures in one of his blog posts and thereby coined the term *"The Lean Startup"* (TLS). After publishing his book in 2011 and despite many sceptics, his framework was quickly adopted by startups and enterprises aiming to eliminate risks within various industries. Ries states companies can avoid high failure rates by focusing on iterative experimentation instead of building compelling strategies upfront. By shifting early resources towards building a minimum viable product (MVP), risks can be reduced through external validation, prioritising customer feedback over intuition.

Developing a product close to the customers' needs enables shorter development cycles and reduces the time required to create a product market fit. Hence, startups and enterprises build upon Ries' methodology to date. While traditional approaches face the risk of fatal setbacks in case of failure due to previously elaborated planning, detailed forecasting, and upfront investments, TLS methodology lets businesses fail faster (but on a small scale). It enables continuous learning to streamline business activities and allocate financial resources more efficiently (Blank, 2013). The chances of achieving long-term, sustainable success radically increase through intense customer involvement (constant iterations and feedback loops). Continuously challenging the status quo creates room for (external) validated learning opportunities, which are crucial for retaining a competitive edge in the long run.

In conclusion, five aspects make Ries' framework effective for startups and enterprises: time savings (shorter development cycles), waste reduction (efficient resource allocation), risk reduction (external validation), being a systematic approach (metrics-driven), and a sustainable business model (ensuring competitiveness). Yet, the difference lies in companies executing a business model while startups are searching for a repeatable and scalable one.

TLS and design thinking: Businesses use both concepts within the context of problem-solving. However, despite similarities, there is a fundamental difference: Whereas design thinking is about approaching a problem in the best way possible, TLS focuses on developing and testing a solution. Thus, for instance, the diversification of the team plays an essential role in the design thinking approach but not in TLS methodology. Yet, both concepts are agile approaches to dealing with problems (Dorst, 2011) (Ries, 2011).

Startups deal with extreme conditions when managing uncertainty and are therefore designed to be as agile as possible. To survive, it must successfully provide a new product or service which is accepted/needed by the market. Puraqua's case is characterised by its early stage and its product's need for external validation. Puraqua already succeeded in providing a technical proof of concept – yet the market proof of concept is still a work in progress. Getting external validation is crucial to decrease risks and streamline business efforts connected to establishing a consumer-oriented lifestyle brand. Since TLS has proven successful in many famous cases, it must further be examined as an appropriate value-creating methodology for Puraqua.

Various characteristics support Puraqua's growth case. Firstly, its capital savings due to adaptions made from feedback loops allow for the most asset-light business operations possible. Secondly, TLS's "just do it"-attitude matches the founding team's hands-on mentality avoiding overthinking to guarantee that the product is being developed close to the customer. Thirdly, prioritising smart work over hard work when dealing with a high uncertainty exposure is crucial due to its greater leverage. Time is limited, but efficiency is not. Hence, the central question should focus on the product's justification of existence and not on the possibility and capability to build it. Thus, by applying TLS framework, Puraqua can achieve success without needing significant cash up front, in-depth business plans, or a flawless product.

2 Vision to Reduce Plastic Waste

2.1 Start

Puraqua's purpose has always been about identifying the most significant lever to tackle the challenge of plastic waste in Portugal. Studies found that bottled water consumption is a critical contributor to Portugal's plastic pollution as 90% of these bottles are not recycled (D'Ambrières, 2019). Tackling a problem at its origin is more efficient and sustainable in the long run, so it became clear that Puraqua should not focus on the effects of Portugal's poor waste management but on its source. Thus, providing alternatives to the usage of single-use plastic bottles. Since the market for reusable drinking bottles is already saturated, Puraqua's impact would be minimal, which shifted the focus onto the water filter market (Grand View Research, 2022).

Puraqua began by focusing on understanding why people drink bottled water – even though it is not environmentally friendly and expensive compared to other solutions. A common complaint in Portugal is that tap water's taste, which comes from chlorination, deters people from drinking it (Gonçalves et al., 2006). Of the non-tap water drinkers, 11.5% do not drink tap water due to health concerns, 71.4% due to taste, and 13.5% due to trust issues. This is due to heavy metals, pesticides and other chemicals seeping into the water. As a result, Puraqua's research identified that 57% of international students and 49% of the young Portuguese population (age 18-30), which are Puraqua's target market, do not drink tap water as their primary water source.

Even though water filter brands such as Brita are established, they only cover a very narrow customer segment due to their pricing strategy. Existing solutions usually have an unappealing appearance and face problems regarding their convenience during everyday use. This creates an entry hurdle as filters are not being purchased or not used frequently. Puraqua wants to leverage this impact-generation opportunity by providing an affordable, on-demand water filter solution that people love using in their everyday life.

Continente Water Jug *Brita Tap Filter* *Tapp Filter* *Brita Water Jug*

Figure 1: Competitors' Solutions

Puraqua's goal was to develop a hands-on approach that is easy to implement rather than elaborating on detailed specifics of a holistic strategy concept. In the early stages of a venture, it is about converging towards the optimal solution rather than directly coming up with the most compelling one. Since startups are exposed to extreme amounts of uncertainty, deviations from too early developed business plans to reality can be immense. Ries (2011) describes a startup as a portfolio of activities with a particularly high-risk exposure resulting from many uncertain factors that cannot be predicted. To exploit a given entrepreneurial opportunity, the right balance between certain factors (needs of existing customers) and uncertain factors must be found to secure cashflows and retain the ability to innovate (requirement to secure future cashflows).

Startups like Puraqua are exposed to all sorts of risks. The most relevant are: customer, market, and product risks. They must be considered a high priority as they are the main factors deciding a startup's success or failure. This hypothesis is strengthened by the opportunity business model (OBM) introduced by Blundel and Locket in 2011. The OBM can be applied to exploit any given opportunity and is structured in five dimensions (proposition, people, place, process, and profit) and four drivers (societal, commercial, legal, and technological). Customer, market, and product risk can be allocated to these dimensions of the OBM and lay the foundations for further development. Since startups are early-stage companies exploiting opportunities, the first dimensions must be considered more critical, which is why other risks that connect to the subsequent dimensions can be initially deprioritised.

Customer risk is related to the threat that the target group will not adopt the product. Hence, a potential threat is the customer segment the startup interacts with and the early adopters' attitude towards the product and company. Sales channels can play a crucial role in this regard and can affect the success chances of the chosen business model. *Market risk* is critical to profitability planning as it affects the cost structure (bottom line) and revenue generation (top line). The bottom line is initially mainly defined by its procurement which includes purchasing prices and resource availability. The top line depends on the overall market development, which can be affected by market trends, the competitive landscape and solutions that can substitute the product/service offered. Lastly, *product risk* occurs due to misunderstanding the core problem that needs to be solved. This reduces the developed solution's value, resulting in a less attractive value proposition. A failed value proposition harms the customers' willingness to pay (WTP), which reduces revenue generation (Blundel & Locket, 2011).

Puraqua's product, a detachable, on-demand filtering solution, can be assigned to the food & beverages industry. Thus, it requires strict alignment with relevant standards and accreditation before launching commercially. In combination with its complexity from an engineering perspective, it requires significant upfront time investments due to constant iterations through development cycles before launching. Hence, the challenge was to develop a lean business strategy that was flexible enough to adapt quickly.

Environmental Impact: A critical problem of bottled water is waste production. Polyethylene terephthalate (PET) and high-density polyethylene (HDPE) are required to produce plastic water bottles. Both materials are 100% recyclable, but only 10% of plastic bottles are recycled in Portugal due to underdeveloped recycling infrastructures and consumers disposing of bottles irresponsibly (D'Ambrières, 2019). This creates an immense environmental impact that could be easily avoided. Considering an average annual consumption of 115,7 Litres of bottled water per capita (Bottled Water - Portugal, n.d.), plastic waste produced only from bottled water equals approximately 35.800 tons in Portugal, which is detrimental to the environment.

Social and Economic Impact: The vision of Puraqua is to provide an affordable alternative to bottled water while incentivising tap water consumption by making it a healthier and more pleasant experience. From a health perspective, the aim is to give users the same water quality as would be found in competitors' solutions but for a lower price and in a more convenient way. Water filters remove heavy metals, pesticides, and other chemicals which can cause health concerns and remove chlorine, which is why people do not like tap water taste.

Figure 2: Housing & Cartridge

Solution: The Puraqua filter attaches to the end of the user's tap and can be detached easily using a simple pin mechanism when it is no longer required. The filter eliminates the inconvenient user experience of traditional filters by being compact, minimal, and detachable while filtering water on demand. The filter is an economical solution for users by only consisting of essential features. Exposing people to consuming filtered tap water instead of bottled water significantly reduces plastic waste, improving environmental footprint and eliminating potential adverse health impacts. The solution consists of housings and cartridges. The cartridges should be replaced every 200 litres, which opens the opportunity to develop a sticky business model. Customers are retained by providing them with the required filter cartridges regularly.

2.2 Define

Innovation at Puraqua is currently a bottom-up process driven by identifying a problem followed by the required adjustment. To foster the ability to innovate in the long run, working in an enabling, not a regulating, way is essential. Traditional management paradigms must be abandoned in favour of a strong vision and enabling an environment that encourages innovation and experimentation in a build-measure-learn (BML) cycle, which involves building a solution, measuring its effectiveness, and using that data to improve the product iteratively.

The goal of a startup is to understand what products customers want and are willing to pay for as quickly as possible. Consequently, although the order is build-measure-learn, the planning happens backwards by first figuring out what needs to be learned (formulate hypothesis).

Puraqua's core hypothesis is that people have health concerns regarding Portugal's tap water due to its taste. This statement must be validated (measured) to build a strong value proposition. The validation occurred through extensive user experiments, which shifts the focus now on developing the best-fitting solution for the problem by investigating sub-hypotheses (customers desire an affordable, convenient solution with a positive environmental and social impact) that need to be measured and build according to the BML feedback loops.

Beyond innovation and product development, startup environments and ecosystems are crucial success factors and can accelerate or hinder growth. The first critical contributor is the platform and network provided by Nova School of Business & Economics. Its mentorship has a particularly accelerating effect and provides public exposure due to various pitching and networking occasions. Puraqua found its first prototyping facility through these connections. Second, easy-to-access and inexpensive local production opportunities benefited first small batches. Third, even though Lisbon is not the global startup hotspot, it still gathers investors' interest, giving Puraqua a chance to have promising talks with potential capital providers.

3 Steering of Puraqua to Becoming an Accepted Solution

3.1 Learn

The goal during the steering process is to develop an MVP that is supported by learnings that identify who the product is for, the potential customers' needs, and their issues and beliefs around consuming water. As discussed previously, TLS methodology states that just because something can be built does not mean it should. Therefore, a market and target group analysis must be conducted before committing to product development.

An initial study of competitors' solutions showed that lower-costing products lack convenience while the more expensive ones are inaccessible to a large audience. Primary research showed that users find lower-price solutions time-consuming to use and inconvenient due to their inability to filter water on demand. They expressed trust concerns around these solutions due to lacking transparency around brand and product standards. Hence, Puraqua identified the market gap for an affordable, simple-to-use, and well-designed filtering system. Research allowed for experiments and testing phases to be conducted. The process can be depicted as a roadmap:

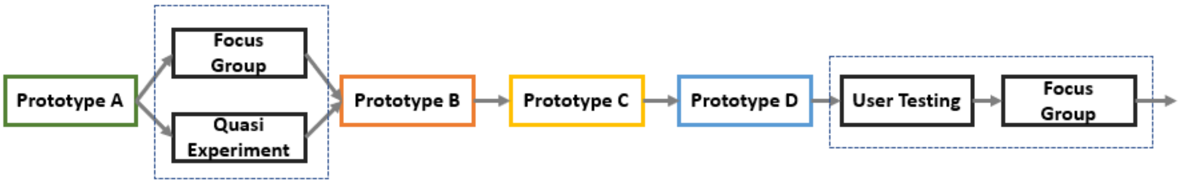

Figure 3: Product Development Process

Testing and experimentation phases heavily relied on developing prototypes which enabled various insights. Shifting from research to prototyping significantly increased the pace at which learnings were made (figure 4). Learnings made in each phase allowed for the requirements and needs of the consumer within the target market to be understood in more depth. Initially, *Prototype A* was produced and developed based on many unknown factors. User-orientated experiments were conducted to understand how users react and interact with the features using *Prototype A*. Developing this prototype was essential as validating a product without this physical prototype would have been time-consuming as assumptions would have been made around its functionality, which is much more complicated than making an initial prototype based on beliefs and testing it. The collected data allowed for quick learning loops from *prototype B* to *prototype D*. Within these loops, the following learnings were made at each stage:

Learnings from Product Testing

Prototype A	Prototype B	Prototype C	Prototype D
			
• Aesthetics too square • Too little water flow restriction • Magnet not feasible • Tolerances too tight • Cartridge not robust	• Mechanism tight and leaks • Tolerance issues • Cartridge clamping is not robust • Flow rate is still too high • Top casing part failed	• Pin mechanism leaking and tolerance too tight • Top casing part failed	No further learnings documented
Learnings reduces as the product is refined			

Figure 4: Product Testing Learnings

As the prototypes became more refined, the number of learnings decreased. *Prototype A* allowed for initial experiments consisting of focus groups and a quasi-experiment. Once no more learnings were made, user product testing followed by other focus groups was conducted. The key learnings from each experimentation phase are documented below:

Learnings from User-Orientated Experiments

	Quasi Experiment	Initial Focus Group	Product Testing Focus Groups
User Learnings	• Portuguese rate the taste of tap water better than internationals • 54% don't drink tap water as their primary source • Health, taste and trust issues present around tap water	• Need quick and easy setup • Transparency around product is essential to build trust • Importance of on-demand water	• Correlation between tap water and filter/bottled water users (not) using filter • Setup process was complex at times • Filter can be challenging to attach • Use of the filter when travelling
Product Learnings	Keep design minimal and cost-efficient due to the target market	• Product looks bulky • Magnet mechanism requires force and is not ergonomic • Use of one multifunctional cartridge	• Mechanism is used more and begins to wear out due to friction • Carbon particles seep through • Dribbling out of the tap after use • Water comes out of the tap at an angle

Figure 5: Critical Learnings from Experiment Stages

The core learning from the initial focus group was that consumers do not want to use the filter if it is difficult to set up. Even if the product filters amazingly, users will not use it if it takes too long to filter or set up. A key learning from a quasi-experiment was that people from foreign countries are not used to the local tap water compared to people who have lived in Portugal for a long time. Therefore, they are more sensitive to its taste and can find it challenging to adjust to it, resulting in them seeking alternative solutions. These learnings allowed the target market to be aligned for the first time: international students and young Portuguese homeowners who would potentially be willing to change their habits.

Once an MVP had been produced that was safe and functioned to a satisfactory level, user testing was conducted to obtain external validation data. Users were provided with a filter they could use in their homes and were invited to a focus group to understand how they interacted with the product. This included the setup, usage and how the product functioned. The main learnings were that the pin mechanism had reliability and consistency issues as it leaked over time. Some users found the attachment and detachment of the filter using the pin mechanism confusing due to the small entry point to attach the filter. Some users found the initial setup intimidating as it required minimum plumbing alterations. From an overall usage perspective, a correlation was observed between tap water drinkers not using the filter and filter/bottled water users being more welcoming to the filter. Based on these learnings, relevant changes were made to the product design specification and engineering frameworks so they could be integrated into the next iteration of the prototype. From there, another cycle of user testing was conducted to ensure that no other failures around the product occur.

Learnings from each stage were integrated into a product design specification (PDS) that structured the product's development process. A PDS converts consumer needs into quantifiable specification points (appendix 1). This document structured product testing by defining what requirements must be met by the product. TLS methodology aims to synthesise a venture's vision and what customers accept. It is not to capitulate to what customers think they want or to tell customers what they ought to want (Ries, 2011). This approach allowed users' pain points to be interpreted and for ideas to grow from them that can be integrated into the product. For example, the mechanism that enables the filter to be detached from the tap was not a feature that users explicitly said they wanted. It was developed because current tap filter solutions were in the way of the user. Hence, the removal mechanism is a feature users did not know they needed.

3.2 Experiment

Experiments focusing on the beliefs, opinions, and interactions with the Puraqua filter allowed for data to be collected that supported the further development of prototype iterations. As mentioned previously, *Prototype A* was used to conduct user experiments. The learnings from these experiments allowed further product development to be undertaken until a satisfactory MVP was produced. From there, the MVP could be used for additional user testing and experiments which can further contribute towards product development.

Based on Ries' methodology, teams must answer four key questions before developing an MVP: (1) Do customers recognize that they have the problem that is being solved? (2) If there was a solution, would they buy it? (3) Would they buy it from Puraqua? (4) Can a solution for that problem be built? Primary market research showed that consumers are willing to pay for new filter solutions, identified what makes solutions attractive to consumers and assumed that the solution could be produced. To further validate these fundamental questions, Puraqua felt it was more effective to validate these learnings with an initial prototype rather than validating before developing the product.

The quasi-experiment provided quantitative evidence of taste preferences and opinions about tap water. In this experiment, a random test person was supplied with one filtered or tap water sample. The results were documented, and further questions were asked to understand the participants' demographics, taste preferences, and opinions (appendix 3). To understand Puraqua's target market beliefs, a focus group was conducted to discuss their water consumption preferences. It provided in-depth and natural feedback through information on perceptions, insights, attitudes, experiences, or beliefs. This is essential to achieve the optimal product-market fit and build a base for a minimum viable product, which customers can test.

The experiments created a more robust understanding towards the consumer, allowing for relevant consumer-orientated design changes for the second prototype. Further concept development cycles did not require additional user experiments as they focused on product safety and function testing. Once a satisfactory MVP was produced, user testing was conducted. This was followed by a focus group session in which an open discussion was conducted to understand how users interacted with the product. This helped identify what areas of the product need improving and what works well.

3.3 Leap

The research was conducted while the business model and product were developed to remain agile and efficient. As a result, developments and progress were made while unknown factors were present. Although there was the risk that developments with no supporting research may need changing or may fail, making these “leap-of-faith” assumptions allowed for a faster pace of development.

Business Assumptions

Past actions at Puraqua relied on the (meanwhile validated) assumption that many people in Portugal have health concerns regarding tap water consumption due to its taste. By building around this hypothesis and tackling the problem of plastic pollution at its origin, Puraqua can be assigned to both the industry of food & beverages and the industry of household supplies. If there is more than one categorisation possibility, both markets need to be analysed to identify the highest potential.

The most important external factors relevant to entering a market are its entry barriers, market size, customer segments, and WTP (Trott, 2017). Both young ventures and established companies should consider these factors and the weight of importance regularly to optimise their business success. In Puraqua's case, the total market size can be neglected for now because there will be various possibilities to expand to other market segments over time. However, especially during the launching period, market entry barriers (such as capital requirements, regulations, customer loyalty, and distribution channels) play a crucial role and must be considered.

To drive top-line growth (the bottom line is primarily independent of the market), the WTP, combined with the customer segment, must be identified for the best market positioning. The market of household supplies can be expected to have a higher WTP than the food and beverages market due to a longer perceived lifetime of products (Breidert et al., 2015). Since everyone relies on drinking water worldwide, the target customer group needs to be narrowed down. Different customer segments come with distinguishing probabilities for purchasing an innovative filtering solution for their tap. This is due to various factors such as problem perception, purchasing power (and thus WTP), and perception of marketing efforts. Before analysing these different factors, matching them to Puraqua's competencies and priorities is crucial to maximising the launch's success. Puraqua identified the most optimal conditions by its positioning as a lifestyle brand targeting primarily young customers such as international students (high perception of the problem) and young homeowners/tenants (high WTP) in Portugal.

When a promising market is found and the right customer group is identified, the focus must be shifted to the model keeping the business alive in the long run. Ries (2011) defined three suitable engines of growth for launching a venture: the sticky engine, the viral engine, and the paid engine. Puraqua's business model builds upon the sticky growth engine. Hence, the business model relies on attracting customers and, ideally, keeping them forever. This can be achieved by leveraging customer retention via repeated purchases.

It would also be more expensive and unsustainable to exchange the entire product when a filter is overused (which leads to an unnecessarily reduced product lifetime). Therefore, Puraqua separated parts with a short lifetime (the cartridge containing the actual filter) from components that can remain untouched for longer (the casing and suspension) to sell them separately. Thereby, the product minimises its environmental footprint and becomes more affordable to consumers, creating more diversified income sources for Puraqua.

For a business model that highly relies on customer retention, the key metrics for evaluating its success must be the customer acquisition rate (CAR) and the churn rate. Customer acquisition refers to getting potential consumers to purchase the desired products. According to Ries (2011), a successful customer acquisition strategy consists of three parts: (1) Drawing in leads; (2) developing those leads to sales readiness; and (3) turning them into (paying) customers. The customer acquisition cost (CAC) is the total price of these actions. Customer churn is the number of customers a business loses over time. Both metrics can compute the number of customers in the value creation/revenue generation cycle.

Business owners should always aim to increase the total number of people paying for their products. This can be achieved by increasing the CAR while simultaneously reducing the churn rate to maximise the number of paying customers. The main drivers of the CAR for a direct-to-customer (D2C) business, such as Puraqua, are word-of-mouth and marketing efforts (targeted advertising and an appealing social media presence) (appendix 11). Concerning a low churn rate, customer satisfaction (discussed in chapter 4.3) is crucial and why Puraqua heavily invests in product development.

Discussing acquiring customers and thinking about sales channels cannot be neglected, as it is crucial for revenue generation. The primary considerations were using retailers as sales partners or choosing a D2C approach using an online shop. Working with retailers would come with the advantage of a higher initial trust level towards the product but the disadvantage of lower margins and the loss of connection between product and brand image. Starting by selling exclusively online has the downside of overcoming the initial hurdles of traffic generation. Still, it has the potential to grow immensely due to its ability to serve a niche market and precisely target its audience (discussed in more detail in chapter 5.2).

Product Assumptions

To align with TLS methodology, a product with only essential features was developed to minimise the risk of failures. This allowed a solution to be produced as quickly and efficiently as possible, reducing interruptions during the process. With fewer technical features present, the number of assumptions made within the product development process could be significantly reduced, and the more complex engineering work could be eliminated. Producing prototypes in this manner allowed assumptions to be validated or rejected through data collected in product testing. Therefore, the number of assumptions in the product system could be reduced.

TLS methodology states that the riskiest assumptions should be mitigated first. In the case of Puraqua, these were consumer needs assumptions made to develop an initial PDS that would help build an initial prototype. Although risks should be eliminated before developing an MVP, deciding to develop an initial prototype before allowed to reduce the time spent on initial consumer research. This is because more clear risk mitigation could be conducted using a prototype. The prototype could then be validated by obtaining more effective user feedback, and the PDS could be adapted after user testing. This resulted in more detailed and valuable external feedback than if all the data had been collected before producing the initial prototype.

Reflecting on this decision, the time spent iterating from an initial prototype to an MVP was far more than the actual development of the initial prototype.

To prevent spending an inefficient amount of time certifying product feasibility, the assumption that the product would work in the intended environment was made once initial research was conducted. During the product development process, criteria such as water pressure, water tightness and filtration effectiveness were assumed to work based on calculations and engineering simulations (appendix 4). This allowed each part to be measured from a theoretical perspective and assisted in mitigating failure. However, with external factors playing a role, the assumption had to be made that they would not exceed the safety factors implemented within the calculations and, if they did, that there were ways to justify them.

3.4 Test

Learnings from initial user experiments influenced the development of further prototype iterations. These iterations were conducted using BML loops, which allowed the product to be refined until an MVP was produced. TLS methodology states an MVP should be the minimum that shows potential to win over customers and is developed as efficiently as possible. Puraqua used analogues and antilogues in the development process. Analogs look at things that are similar and that have worked in the past. Antilogs look at those things that had failed in the past.

Puraqua used analogs in the development process by analysing existing filter technology and materials and used reverse engineering of existing solutions to learn from the technology and mechanisms that could be applied to the Puraqua filter. Antilogues were considered when analysing existing solutions, allowing existing solutions' pain points to be identified. These were converted into user needs that could be integrated into the PDS so that they were not repeated within the Puraqua filter. During the development process, the priority is obtaining validated learnings and understanding what the customer wants/needs as efficiently as possible.

Therefore, the minimum satisfactory quality standards must be met rather than spending too much time refining it. This aligns with TLS methodology, stating that the required quality cannot be known until the customer’s needs are fully understood (Ries, 2011).

Each prototype iteration was first developed in 3D modelling software (CAD) until the tools within the software limited product development. From this, a physical prototype was produced using 3D printing to help understand the product’s functionality, safety, and economics.

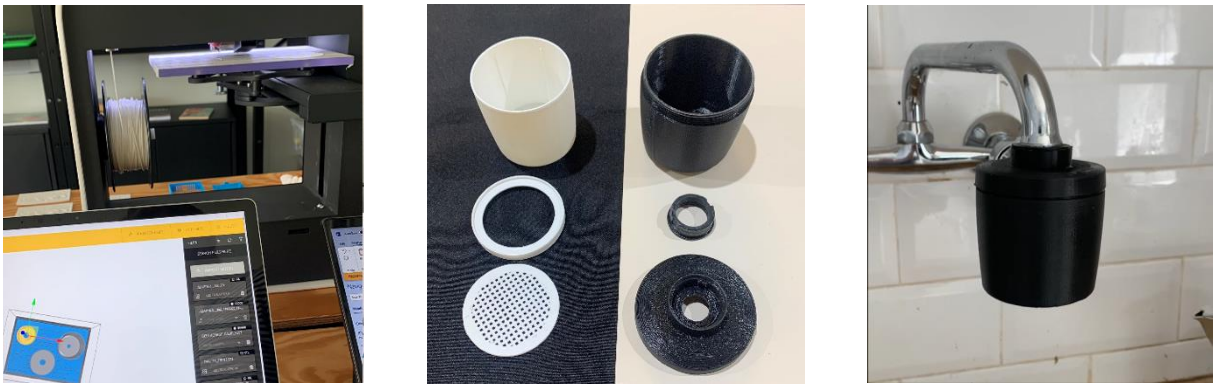

Figure 6: Development of Prototype Using Rapid Prototyping

TLS methodology states that successful entrepreneurs must know what parts of their plans work brilliantly and which are misguided and adapt their strategies accordingly. To understand what works and what does not, engineering frameworks were integrated into the development and testing of the product to ensure failures are identified and can be mitigated more efficiently and transparently. These frameworks were at the core of these processes and guided the BML loops. They consisted of the product design specification and two additional frameworks: a failure mode effect analysis (FMEA) and a failure effect analysis (FEA).

An FMEA focuses on the product’s safety. It allows every aspect of the filter to be evaluated and identifies failures that could be potential safety risks to users. The impact of these failures is assessed, and correction/mitigation processes are documented. An FMEA first identifies failure modes, followed by the documentation of potential causes and effects of these failure modes. Corrections and preventions are recorded for each prototype iteration if necessary to mitigate or eliminate the risk of these failures. If a failure is eliminated or mitigated to a satisfactory level, this is recorded as passing the requirement (appendix 5).

An FEA is used to assess the failures that could compromise the product's functionality and user experience. Failures are identified through product testing, and the effects of these failures are documented. Following this, the effects are analysed, and design changes are made to eliminate these failures. Each requirement either passed or failed, with the goal being to end up with a document with no failures (appendix 6).

BML loops were conducted by developing a prototype based on previous learnings that were then tested against the frameworks. Learnings from testing were documented for the next cycle so that improvements could be made. Using minimal resources to develop each iteration aimed towards conducting the fastest possible cycle through the BML feedback loops with minimal effort. Going through the product testing cycles allowed for a solution that answered product design or technical questions until all PDS, FMEA and FEA requirements were successfully met. This resulted in an MVP. Detailed learnings from this process can be found in *appendix 7*.

From there, the goal was to test fundamental business hypotheses through consumer testing using the MVP. Although there were still areas to improve from a quality perspective, the product was safe and functioned well enough to conduct effective user experience testing. The MVP filters were handed out to potential users to understand how they interact and use the product. To obtain feedback, focus groups were conducted.

Users received all required components, and an installation manual was provided (appendix 8). Users' ability to install the adapter plate to the tap and assemble the filter was analysed as well as the interaction with the pin mechanism and general usage. Following this, focus groups with test persons allowed the overall experiences to be analysed to derive learnings. From this, there is potential to continue developing the product through BML loops. This method allowed Puraqua to rigorously measure where it currently stands and confront the assessment's revelations.

3.5 Measure

Using innovation accounting to develop a solution that could be measured against Puraqua's hypothesis and value proposition was essential. To ensure prototypes meet the core values and to understand the current positioning, quantitative data was used to measure the product's success. This was obtained using external feedback, digital tools and research frameworks. This data allowed the progress to be analysed to which extent the MVP is the ideal solution.

The product's functionality, user experience and safety must be developed to a high standard to provide a solution that the user is willing to pay for and use. To ensure the user experience is satisfactory, user needs were inputted into the PDS as the core measurement tool. The initial requirements within this document were developed through initial research and assumptions but then adapted and aligned through the quasi-experiment and focus groups.

To ensure product safety, the product was aligned with the FMEA and to ensure adequate functionality, the product was tested against the FEA. Although there is always room for improvement, it is not an efficient use of time to continuously focus on the product's development, as the changes will have incremental improvements. The detail of the requirements within these documents defines the limit to which the product must be developed.

To be in line with its value proposition, Puraqua will be an affordable solution. This was quantified through a cost analysis. In this case, costs consist of the initial purchase price and the price for cartridge replacements. The analysis shows the accumulated costs over a consumption of 1000 litres of water:

Litres Consumed	**Time**	**PET Bottles (**Bottled water, 2020**)**	**Tap Water** (EPAL, 2022)	**Puraqua Filter**	**Britta Tap Filter**	**Continente Water Jug**
0	0 months	€0.00	€0.00	€14.99	€75.99	€16.00
200	3 months	€37.50	€0.08	€ 20.98	€84.85	€20.50
400	6 months	€75.00	€0.17	€26.97	€93.71	€25.00
600	9 months	€112.50	€0.25	€32.96	€102.57	€29.50
800	12 months	€150.00	€0.34	€38.95	€111.43	€34.00
1000	15 months	€187.5	€0.42	€44.94	€120.29	€38.50

Figure 7: Cost Analysis of Water Consumption

The results show drinking bottled water is the most expensive option, followed by various filter solutions (including cartridge replacements). The Puraqua filter sits at a slightly higher price than the Continente water jug but is significantly cheaper than the Brita tap filter. Considering the Puraqua filter produces on-demand filtered water and uses a more efficient housing solution, the higher point can be justified to consumers.

To create a positive impact on the environment by reducing plastic waste and a social impact by making water healthier to consume by removing harmful substances from the water, it was essential that these were not assumed and that both the impact criteria were measured quantitatively. To identify and quantify the filter's environmental impact during the product's manufacturing, consumption, and disposal, a lifecycle assessment (LCA) was conducted using openLCA's (2021) software package. The impact was measured per 1000 litres of consumed water as a functional unit. For the LCA, Puraqua assumes that consumers replace the filters five times while the casing remains operational and that filters are replaced after consuming 200 litres of water. The measurements assume that filters are disposed of at the end of the product's lifecycle ethically and correctly. Virgin PET bottles filled with water, disposed of in landfills once consumed, were compared against tap water consumed using a glass and the Puraqua filter. The water consumed by users was not integrated into the LCA based on the above assumptions. The results were as follows (further information in appendix 10) (Detorre, 2009):

Impact Category	Unit	Cartridges	Housings	Method
Energy	Megajoules	4.85	6.54	IMPACT 2002+
Solid Waste	Kilograms	2.10	1.85	IMPACT 2002+
GHG-Emission	Kilogram CO_2	0.27	0.45	IMPACT 2002+
Water Usage	Litres	66.09	60.03	AWARE

Impact Category	Unit	PET Bottle	Tap water	Housing + 5 filters
Energy	Megajoules	4091.87	231.62	262.41
Solid Waste	Kilograms	43.35	2.16	4.36
GHG Emission	Kilogram CO_2	203.69	13.86	15.66
Water Usage	Litres	954	366	756.84

Figure 8: LCA Core Results

Existing water quality testing data comparing tap water to water filtered with activated carbon and ion resin (as done in the Puraqua filter) was interpreted and modelled against the constitution of Portuguese water so that quantities of substances using a water filter could be assessed.

Substance	Tap Water	Filtered
Chlorine	4.0 mg./L	0.131 mg/L
Calciium	9.0 mg/L	0.594 mg/L
Sodium	9.0 mg/L	0.585 mg/L
Magnesium	5.0 mg/L	0.330 mg/L
Potassium	1.0 mg/L	0.067 mg/L
PH	7.53	7.0

Source: (Daschner, et al., 1996), (Grant, n.d.), (Machete, 2015)

Figure 9: Water Substance Analysis

The results show a significant reduction of substances present in water. The chlorine reduction is not as substantial as other elements but still drastically reduces its odour. Chemicals and metals are reduced to approximately 6-7% of the quantities found in tap water.

4 Future of the Puraqua Water Filter

4.1 Pivot

Pivoting is not about changing one small aspect but changing an underlying hypothesis a business is built on. Different kinds of pivots can be made. Some might only optimise a venture's value creation to a small degree, but others change how business is conducted. Pivots are necessary to find the most optimal balance between satisfying customer needs and building a profitable business simultaneously (Ries, 2011). Therefore, continuously challenging the status quo is embedded in Puraqua's DNA and part of its pivot-or-preserve schedule. To be able to anticipate potential future pivots, Puraqua identified areas that are prone to change:

The analysis of focus group results (appendix 2) found that many people can also see a use case of the Puraqua filter when travelling. Thus, as Puraqua grows, it will become more attractive to extend current customer segments to accelerate growth horizontally and strike roots in different market niches. Even though its consumer hypothesis was validated on a small scale, it still requires more testing to justify a pivot (and/or extension) of the current customer group.

Sales channels will likely be subject to future changes starting when Puraqua successfully establishes its brand within its niche market and when the product is more mature. Then, Puraqua is likely to push selling via retail as well. This strategic move should be the main reason to bring more trust to the customer (as the retailer and third party needs to approve the product and its safety) and give the filter another platform for visibility

A technological pivot is likely to be seen soon. This is related to current production facilities' quality and poor time efficiency. Puraqua used rapid prototyping (3D printing) as it allowed for faster iterations through the BML cycles (easy implementation of adaptions). Although it is not the fastest manufacturing method, it is by far the quickest to set up, saves a lot of time overall, and is a resource-light production method. However, 3D printing is not optimal for scaling, especially when creating larger batches of filters for user testing. The effect of the slow print rates was visible. Yet, rapid prototyping methods were ideal for Puraqua's use case as they allowed smaller batches to be validated without high investments in manufacturing.

Once the prototype matches expectations, production can be scaled, and injection moulding becomes indispensable. Still, building up and developing the logistics behind scalable manufacturing is time-consuming and inflexible. It relies on a significant upfront investment to purchase four essential tools, listed at around 500 Euros each (does not consider operational costs) (appendix 12). Before launching, costly NSF testing must be completed to obtain accreditation. Even though accredited technology and materials are used, the entire product system must be tested. Since these costs are currently not bearable, one priority for Puraqua is to obtain the required money to complete the technology pivot as a foundation of scaled production.

Due to the production issues, a pivot regarding the product and business model was also considered. The team looked into finding creative solutions to overcome this initial hurdle. Despite evaluating traditional approaches, such as bootstrapping or raising capital, shifting product accreditation and manufacturing responsibilities onto the consumer seemed more feasible. This would be achieved by selling the blueprints directly to customers that print casing and cartridges themselves (filter granular can be purchased in grocery stores). Also, the need for NSF accreditation would be eliminated as the product is not provided directly.

There are downsides within this model that must be considered: Firstly, the scale would have no limit in theory, but due to requiring access to a 3D printer and the willingness to assemble the filter, the target customer segment is narrowed down dramatically. Second, the possibilities to retain customers are minimal as they can produce large numbers of filters themselves after purchasing the blueprint. Third, the competitive risk of being copied increases due to the publicly available information on the filter's specifications. In conclusion, it cannot be considered a functioning business model in the long run.

4.2 Batch

As production should not be outsourced to customers, Puraqua developed another approach for reducing the required upfront investments. It builds on the observation that people attach/detach their filter on average three to four times a day which sums up to 21-28 contact points a week. To ensure a pleasant and long-lasting experience, these components' quality must be superior to those not touched regularly (e.g., cartridge). Therefore, the investments in moulding forms could be divided into separate batches and adapted step by step according to customer priority. Initially, the team focused only on the casing and attaching mechanism and followed up with the internals over time. This process will keep the production lean and agile while lowering the capital requirements.

In order to move as fast and efficiently as possible, producing in-house is disadvantageous as Puraqua's focus would be shifted away from its core competencies. Hence, outsourcing has been so far and will be a crucial part of Puraqua's production strategy. Besides the lacking expertise, the capital burden of building/buying in-house machinery would be immense. A production facility, in contrast, can take advantage of profound expertise and economies of scale.

Efficiently using production facilities is a crucial success factor for product-driven ventures. Despite aiming at scaling production quickly, generating momentum by increasing batch sizes step by step rather than maxing out capacities from the beginning is beneficial. This is due to the retained agility and ability to iterate through BML loops quickly. Puraqua had a fast-paced product development in the past by using two 3D printing production facilities simultaneously. Through this, the team optimised its blueprints while being economical about resource usage. Going forward, a shifted balance between a larger scale and slightly reduced agility will help maximise impact while exploiting the given business opportunity. However, it is crucial to maintain the ability to obtain and process external feedback when adjustments are required.

A precise demand prediction is a requirement for staying lean and avoiding inefficient resource handling. For this reason, Puraqua is on track to launch its online shop end of January – without stock. If customers order, they will receive an apology for the inventory being sold out and a discount on their subscription when filters are back in stock. This strategy allows Puraqua to have a validated demand prediction. Interested customers are happy and incentivised to sign a filter subscription, increasing customer retention and making future cashflows more predictable. Over- or underproducing can be better avoided, the business can be made even more asset-light, and the overall uncertainty for the launch is dramatically reduced.

4.3 Grow

Due to Puraqua's choice of a D2C business model with a sticky growth engine, the most relevant metrics to consider are customer acquisition and customer churn. The combination of both key performance indicators (KPI) reveals crucial information about the current development state of the business. The CAR must outpace customer churn to grow, which can be kept low if enough incentives for customers to purchase again are provided. For a product-driven venture, this incentive comes down to user satisfaction which is about functionality, reliability, quality, and value for money in the case of Puraqua (Garvin, 1987):

Functionality	The product should be able to perform the tasks that it is designed to do and should be easy to use and understand. This was ensured and externally validated throughout the development and prototyping phase.
Reliability	The product should be dependable and work consistently without problems or errors. High reliability can be ensured high due to extensive testing.
Quality	The product should be well-made, free from defects, and built to last. A functioning quality can be guaranteed, but the haptics can still be improved
Value for money	The product should offer good value for price and be either cheaper or better than competitive products. Puraqua's solution is not in the premium segment, making it a better value for money (no brand-specific price premium).

Figure 10: Dimensions of Customer Satisfaction

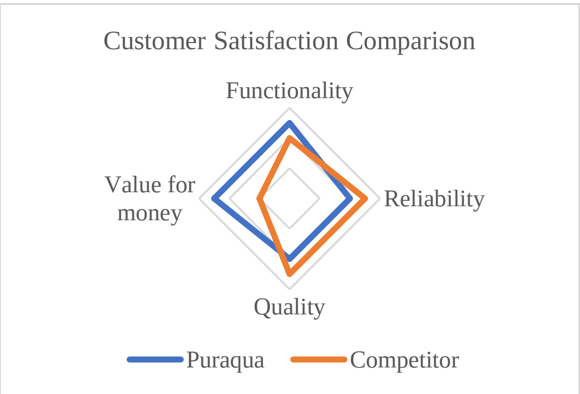

Figure 11: Customer Satisfaction Comparison

Even though the provided customer value (blue marked area in Figure 9) is similar to competitors' solutions, Puraqua's differentiating edge is affordability, leading to higher value for money. Affordability also plays a crucial role in Puraqua's business model. Its sticky growth engine will generate the most cash from subsequent filter sales rather than initial sales. Once the user is engaged, they are expected to replace the cartridge every 200 litres of water consumed (approximately every 2-3 months). Attrition rates must be closely monitored, and the CAR must outpace customer churn to grow. Besides customer satisfaction, their ability to purchase must be given (via an affordable pricing model). Therefore, Puraqua does not focus on driving growth through massive advertising campaigns but instead focuses on growing organically to retain customers in the long run. Selling filter cartridges comes with significantly higher margins compared to the initial purchase of the filtering set (casing and cartridges).

To foster growing organically and sustainably, new customers must be attracted by actions conducted by past customers, such as word-of-mouth. To an extent, international students live in a "bubble" and are highly dependent on interacting with each other when living abroad. This makes word of mouth a potentially effective method of promoting a filter, as the high levels of interaction correspond to students influencing each other. Yet, other growth drivers must be closely evaluated, particularly growth as a side effect of product usage through funded advertising and repeated purchase. Every driver comes with ups and downsides, which is why they can be used to solve different problems. The overall growth strategy is a significant factor in the choice of growth instrument. For instance, products that are trending and/or seasonal face the problem of a limited time frame to generate relevant revenues. For these businesses, the goal is not to retain customers but to generate maximum sales in a minimum time – the exact opposite of Puraqua's strategy.

Growth rates are usually strongly influenced by the capital available. Consequently, Puraqua faced the question of either raising funds or continuing to bootstrap. External funds can provide extensive means that can be used to penetrate growth factors or overcome accompanying hurdles. The most crucial advantage of a cash injection would be the possibility to scale the production to satisfy higher customer demands. This is relevant regarding opportunity costs. It is also essential for capturing market share in the water filter market niche to keep the first mover advantage. Usually, raising capital also comes with the upside of getting industry experts involved (early-stage investors usually only invest in startups if they can provide any form of support besides cash), which is extremely valuable. Capital is either provided via issuing equity or debt. Most banks, for instance, do not offer any loans to startups since they usually do not produce stable cash flows yet and are therefore considered too risky. Venture debt (provided by venture debt funds or business angels) comes with the downside that interest rates can sky-rocket due to the higher risk involved. Debt needs to be then paid back, which slows down growth during the repayment period.

On the other hand, bootstrapping comes with the disadvantage of slower growth and an increased vulnerability of being overtaken by the competition. A driving factor can be the chicken-egg problem regarding production facilities: Since there are not enough customers, Puraqua cannot afford to make the required investments in production, but since the production is not advanced enough, not enough products can be sold. On the positive side is that growing organically leads to fewer hiccups allowing for more efficient business operations. Also, founders remain in the driver's seat and do not give up independence by diluting equity shares.

Puraqua's founding team considered both options. The first discussions with investors (delta ventures, TechStars accelerator program, and two business angels with food & beverages expertise) were held during the summer. However, the focus on organic growth and the absence of strong competitors in the market segment influenced the decision to stay bootstrapped.

4.4 Adapt

According to Ries (2011), an organisation's goal is to stay as agile and adaptive as possible by implementing the BML methodology into its core. Hence, it must develop a framework that allows for a regular review of its operations. It should value adaptiveness and find the right balance between speed and quality when entering or expanding a market segment using the five whys method. The five whys were initially introduced by Taiichi Ohno, a Japanese engineer and key figure in Toyota's production system development. His approach helps to target investment to the root cause of a problem by asking "why" repeatedly rather than addressing its symptoms. By doing so, the underlying issue can be fixed, and the problem can be permanently solved. Ries uses this framework to naturally regulate an organisation's development speed, as investments are directly tied to solving the most urgent issues.

Puraqua recently discovered symptoms of struggling with scaling up the number of produced filters as current production facilities rejected larger orders. Puraqua got in contact with Lisboa's Fablab and asked questions according to the five whys – see simplification below:

- <u>Why</u> *don't you print more filters for Puraqua? They have too little capacity at the moment.*
- <u>Why</u> *do you have too little capacity? 3D printing needs a lot of time, and due to governmental subsidies, many non-profit projects must be supported.*
- <u>Why</u> *does it take so much time, and is this changeable? The old 3D printers are slow.*
- <u>Why</u> *are no new printer models used? New printers are expensive and not profitable.*
- <u>Why</u> *is it not profitable? There is no consistent, predictable printing schedule and blocked on-demand time slots end up not being used by non-profits (leading to fewer subsidies).*

Puraqua was able to separate the problem from its symptoms. The root cause was identified as a combination of outdated, too-slow 3D printers and the fact that they are often blocked but unused. Consequently, the team is currently negotiating with Lisboa's Fablab to advise them on purchasing a new 3D printer. It should have a fixed printing schedule for Puraqua's water filters that, firstly, generates more revenue for them and, secondly, enables them to draw higher subsidies (3D printers will be used more). With these two income sources, the 3D printer is likely to be profitable – and Puraqua will have its current production problem fixed.

4.5 Innovate

Ries (2011) states that teams require autonomy, resource security and a stake in the final accomplishment to innovate. At Puraqua, autonomy and a personal stake in the outcome are provided, but as previously discussed, the capital available can be a bottleneck in some instances. However, since the first satisfactory version of the filter was recently developed, no groundbreaking innovation is needed immediately. The focus must be on revenue generation to gather more resources for upcoming projects. It is also essential to understand that product development has been particularly asset-light and, therefore, not costly due to its leanness. It is expected to remain like this. Ries also talks about innovation sandboxes that allow a team to experiment in a safe environment. However, since Puraqua consists of a two-person team, some team-related parts are not applicable. The BML loops must be continued with regard to:

User experience testing: Even after launching, gather groups of testers to obtain feedback and learn from it. Create an improved version that can go through the same process. *Accreditation:* The NSF will test the product to a set criterion to become accredited. If there are any failures, Puraqua must learn from them and improve the product. *Sales:* Experiment with sales channel penetration to identify the most effective instruments for revenue generation. Also, testing regarding geographics will be conducted. This was triggered by a Brazilian participant of a focus group who outlined that South America still has a problem with various bacteria cultures in their tap water and that affordable solutions do not yet cover their market. *Product(s):* Besides developing the next version of the Puraqua water filter, the team will explore opportunities to launch new products to grow in the vertical. The current ideation moves towards introducing reusable filter balls that can be thrown in every desired vessel to clean the contained water.

6 Individual Part | Alexander Ludwig

6.1 Product Development Methodology

Alexander focused on developing a prototype Puraqua filter that is safe for users, functions to a given standard and meets the user's needs through external validation. Although the project required engineering frameworks and theory, the focus was on using an entrepreneurial mindset (using TLS methodology) and integrating engineering principles into this entrepreneurial framework to assist the product development process. TLS methodology allowed for a leaner product development approach to be implemented compared to the standards commonly used within the engineering industry. Many product development frameworks tend to be more rigorous than lean. They approach a project by intending to fulfil a given brief rather than adapting to the consumer's needs. Using TLS methodology as a core framework allowed for a higher engagement with the consumer so that any research and consumer feedback influenced the decision-making or development process, creating a solution that evolves around the consumer.

Integrating core engineering and product development frameworks into TLS methodology forced traditional product development tools to be more agile. The standard product development approach is based on Herbert A. Simons' (1969) design thinking methodology. Design thinking is an iterative and non-linear process that contains five phases. Although the phases can run in parallel, out of order and repeat iteratively, in product development, it is common for them to run more linearly (Interaction Design Foundation, 2020).

Figure 12: Design Thinking Approach to Product Development

1. Empathise: Obtaining an empathetic understanding of the market and consumer needs.
2. Product definition: Using the data gathered to understand the requirements of the product and summarising these in the product design specification.

3. Ideation phase: Production of concepts that integrate requirements defined in the PDS. Allows for ideas to be experimented with to ensure a broad approach.
4. Product development: the process of refining a solution into a viable product.
5. Product testing: Testing the product to assess whether it functions to a sufficient standard and meets the requirements defined.

The five phases are essential to any product development process. In Puraqua's case, this process began using a linear approach; however, a more iterative and lean approach was implemented once testing occurred. In the case of Puraqua, the aim was to integrate this design thinking methodology into the lean startup methodology to ensure the agile development of the product. One key enabler of this integration was the implementation of BML loops, which allowed the design thinking methodology to be implemented even more iteratively. The loops enabled the production of an MVP, which was developed through multiple product testing and development cycles based on user feedback obtained from experiments conducted with the first prototype. During the product development and testing phases, changes were made based on learnings from previous cycles. Measurements were completed through product testing, and learnings were obtained through the validation of testing or focus groups after external user testing. A loop between ideation, product definition, prototyping, and testing was conducted to develop the MVP. Once an initial prototype was produced through the product development phase, it could be measured against requirements. Learnings could be made to influence different stages within the product development process. This process is depicted in the following diagram:

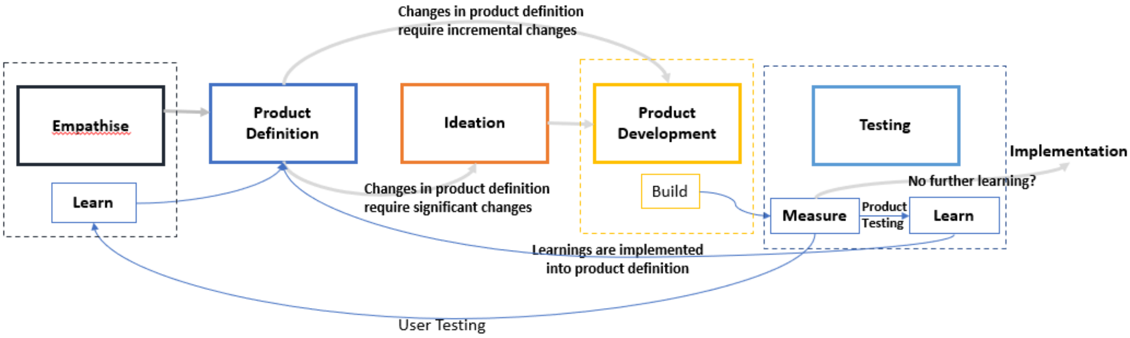

Figure 13: Integration of Build-Measure-Learn Loops into the Design Thinking Methodology

The diagram shows how the BML loops were integrated into the design thinking methodology. Learnings from product testing influenced the “product definition” as they would help identify what functions require redefining due to failure. Learnings from user experiments influenced the “emphasise” category as they allowed a better understanding of the consumer. These user learnings would then impact the product definition by redefining user needs. Significant changes to product definition led to a more extensive product development phase that often required a step back into the ideation phase for a more open-minded approach (a “back to the drawing board” approach), ensuring no restrictions. From there, the product could then shift from ideation to product development. If learnings resulted in incremental changes to product definition, these could be implemented through product development and would not require a separate ideation phase beforehand. These processes are repeated until the product is at a point where it meets all the defined requirements, and as a result, there are no more learnings, and the product can be implemented to market.

6.2 Implementation and Evaluation of Product Development Methodologies

1. Empathise

Collecting data from user experiments, product testing, and secondary research all contributed towards building the foundations to develop a solution orientated around the consumer and create a successful product market fit. Limited primary and secondary data were combined with necessary assumptions to build an initial prototype. This prototype enabled the implementation of the BML loops. Throughout every loop, the cumulative number of learnings gathered about consumers and the product increased. As a result, the assumptions within the product system could be replaced with real insights into user behaviour and their needs. Throughout each prototype iteration, more empathy could be built around the consumer, and a better understanding of the product could be developed, allowing for a more refined product definition. Implementing TLS methodology in this context allowed the learnings to be developed more iteratively.

Being able to evolve the product and market understanding in harmony allowed for more natural product development than traditional engineering processes, which aim to build this knowledge before any product development is conducted.

2. Product Definition

Developing a product definition backed by solid user feedback and data created a strong foundation for the product to be built on. Evolving requirements within the product development frameworks that are consumer-oriented allowed the frameworks to be used more effectively as they empathise with the consumer more, which helped guide the development process. At the core of the product definition was the product design specification. In engineering, the PDS is a rigorous document that is not changed once the ideation process begins. TLS methodology contradicts this. Therefore, for Puraqua, a more flexible PDS was used, allowing specification points to be changed throughout the BML loops. The document evolved with the product and was not limiting the development of the product since the requirements were always aligned with consumer data. A more agile PDS has some disadvantages, as there is no baseline for comparison between prototypes, and constant changes can lead to delays and increased costs. The quality of the finished product can be compromised due to the potential contradiction of requirements throughout iterations. However, in the case of Puraqua, the product is simple enough for these contradictions to be identified and mitigated through transparent and clear communication within the engineering frameworks.

3. Ideation

The ideation phase allows a product to be developed in an open-minded way in which ideas can be combined with product definition criteria to create an initial solution. The initial solution designed for Puraqua was built on assumptions and basic research that resulted in the production of an initial prototype: *prototype A*. This prototype allowed for feedback to be gained from user experiments and initial testing. Obtaining this data allowed for the product definition to be redefined which then allowed for a second ideation phase to be conducted in which the product was reconstructed to meet the updated requirements of the product. An updated iteration could be developed from this second ideation phase, and a prototype could be produced.

Adopting a “learning by doing” approach and moving on from the ideation phase while there are still unknowns in the product system allows product development and testing to occur faster, resulting in faster exposure to learnings within a solution. This is important as it is challenging to visualise most features during ideation, and it is easy to get stuck in this phase, which contradicts the fast-paced nature of TLS. Therefore, moving through this phase as efficiently as possible, even with unknowns present, allows for data to be obtained through testing that can be used to produce a more detailed product definition. In the case of Puraqua, this allowed a second iteration of the ideation phase to be conducted using more refined and validated product requirements. Although this fast-paced approach may be considered a risk, the resources used do not pose any significant risk due to the resource-efficient process of 3D printing.

4. Product Development

A more detailed design of the product was created using 3D modelling software. This allowed all the components to be designed, including mechanisms, dimensions, and forms. While completing this process, requirements from the PDS, FEA and FMEA were considered to ensure that the success of each requirement was as likely as possible when conducting product testing. Additionally, mathematical calculations and flow simulations using CAD software supported in mitigating product failures. Using these digital tools before manufacturing a prototype allowed for prominent failure modes that could be easily avoided to be eliminated. It was important not to spend too much time perfecting the product in this stage as the learning would mainly come from having a physical prototype to test rather than analysing a virtual prototype.

To ensure the fast-paced nature of BML loops, clear boundaries on the quality standards that the product must meet were set. These standards should cover the minimum functionality and safety requirements. They can be controlled by ensuring that the FMEA, FEA, and PDS requirements are not set to unrealistic quality specifications. Spending too much time on product development can be inefficient, as it is likely that changes will be made once the iteration of the product being developed is tested. The time spent on testing and experimentation is more effective, as the impact of these activities is more significant on the project than if they were made during the product development phase. Even though smaller tests, such as simulations, can be performed, testing in a real-life environment is more effective. Therefore, it is essential to push the development at a fast pace to produce a prototype that can be tested.

3D printing allowed several prototyping loops and allowed for prototypes' cost-effective and rapid production. As a result, several iterations of the prototype could be produced quickly. Prototypes could be tested, allowing for user experiments to be conducted and learnings to be made promptly. 3D printing was the core enabler of the development of Puraqua, as without it, production would have been expensive and time intensive. Fewer prototyping cycles would have been conducted, and as a result, fewer learnings would have been obtained. In this case, TLS method would not have been applicable because the development would not be lean.

Partnerships with the digital experience lab at Nova SBE and the FabLab Lisboa were formed to manufacture prototypes. This accelerated the development of the filter, allowing it to become a reality. 3D printing was a core enabler in the project, but logistics were sometimes challenging. To keep costs down, a bill of materials was produced (appendix 9). Parts currently being made for free or at low costs resulted in little bargaining power regarding capacity and production timelines. This became the bottleneck in the project. Initially, the aim was to produce ten MVP filters for user testing, but after negotiating with FabLab, they concluded they could not meet this capacity. Collaborations with professional manufacturing suppliers were discussed, but the quotes received were out of budget. The short-term compromise was to restructure the testing roadmap and reduce the number of filters produced. Working with suppliers highlighted the importance of networking to create value within a project and to adapt to prioritise rapid development.

5. Product Testing

To validate the safety and functionality of the Puraqua filter, product testing phases were conducted to assess whether it functions to a sufficient standard and meets the requirements defined. Relevant test processes were performed for different use cases within the product. For example, to test the product's strength, a pressure test was conducted in which specific pressure rates were produced to see if the product could withstand the force. Each framework requirement was tested to determine whether the filter met the specifications. After testing, evaluations and further development plans were produced and documented within the relevant frameworks.

Product testing with users allowed for incorporating external information and perspectives into the project. This external feedback was valuable, as it highlighted areas for improvement that may not have been immediately evident. This input influenced the project significantly, providing a fresh perspective and insight into potential modifications. Using engineering frameworks during testing creates a structured process for evaluating each product feature. Failures are documented, and evaluations are conducted for further development. This approach ensures a thorough, systematic assessment of the product's functionality. Organisation and transparency are essential, allowing for identifying successful and unsuccessful elements and enabling retrospective analysis of each stage and prototype. This aids development and serves a legal purpose by demonstrating failure mitigation.

6.3 Evaluation of Design Thinking and TLS Methodology for Product Development

During development, it is essential to accept that an MVP may not be perfect. A lack of perfection is favoured in TLS methodology as it exceeds quality expectations, but it can be challenging for engineers to accept. It is crucial to prioritise the pace of production over striving for perfection as long as a satisfactory level of quality is met. Further development towards perfection is inefficient if it is merely incremental compared to the whole product system. It is better to present a solution to users that can be improved rather than holding out for perfection.

One main observation while developing the solution is how individual product development has restrictions. The main reason is that the product is being designed from one perspective, which can lead to narrow-mindedness. External feedback from potential consumers assessing, using and testing the solution to obtain opinions and views on the product is essential. Developing a product from an individual perspective causes features to be accepted without justification because they have been part of the design for so long that they are not questioned, even if there are noticeable improvements. Therefore, obtaining feedback allows for these features to be examined. An example is the magnetic attachment mechanism, which was part of the product for a long time. Potential users suggested an alternative locking mechanism, which would be more convenient, cost-efficient, and watertight. Without feedback, this issue would have been overlooked and made the product more complex, resulting in a complex supply chain, as procuring the magnets was not feasible.

The individual product development process can lead to a lack of direction and cause slower-paced development. Setting goals, targets, and deadlines can bring structure to the project and facilitate its progression. It is crucial to set deadlines for the iteration of prototypes while remaining flexible enough to adapt to unforeseen failures or hurdles. Working with timelines and frameworks can help maintain the project's momentum, and weekly meetings can provide a forum for evaluating outputs and receiving guidance from mentors. Implementing these strategies can help structure the individual product development process and ensure its success.

Unexpected hurdles are a common occurrence in the product development process. This was the case with the development of the Puraqua filter, which required more alterations than initially anticipated. Implementing frameworks such as FMEA, FEA, and PDS allowed the product's readiness for the market to be assessed. If any failures were identified through these documents, a new prototype would be required to address them. This process was initially organic but became frustrating due to the high tolerance for failure. Even minor issues, such as dimensional tolerances, could cause a chain reaction of failures. It took structure and problem-solving to overcome these challenges, and after four prototypes and many component re-prints, a satisfactory solution was achieved.

6.4 Conclusion

In the initial stages of Puraqua, secondary research was used to develop a basic concept. The main limitation of this was that the sources were too broad and were not adding value to the specific case of Puraqua. This highlighted the importance of adopting primary research methods to validate the solution. Integrating TLS methodology guided various experiments and testing processes within Puraqua, providing data from different perspectives and contexts. Additionally, it supported the rapid development of prototypes which allowed a more hands-on approach from an early stage. Not only did this support product development, it also allowed areas of the business model to be redefined as consumer behaviour was analysed. Measurement was critical to quantifying the success of Puraqua. It allowed for the success of aligning the hypothesis and value proposition to be identified through various impact and cost analyses. This helped determine the filter's affordability, environmental impact, and the water's cleanliness.

TLS methodology suited the development of Puraqua on a top level. However, when designing Puraqua's solution in more detail, there was a lack of guidance from TLS, which resulted in implementing other tools and frameworks. This was particularly obvious in the product development process in which the design thinking methodology and engineering tools such as a PDS, FMEA and FEA were integrated. Engineering tools are traditionally more rigorous than TLS methodology. Balancing TLS and engineering methodologies required an adaptive approach so that each contributed the most value. Conducting experiments with an MVP allowed engagement with potential clients and developed a solid product-market fit. Data from experiments supported the identification of effective business strategies including the marketing and branding strategy, a customer acquisition and retention-orientated business model that uses a sticky growth engine model and a focus on social and environmental impact.

In Puraqua's case, most limitations of TLS are insignificant as innovation is currently incremental, and the focus is on short-term validation. It may be necessary to re-evaluate the use of TLS in the future as the company develops new products or takes on more risk. As TLS approach lacks long-term planning capabilities and can oversimplify complex business concepts, the long-term goals of Puraqua should be considered when evaluating whether TLS should be applied. Puraqua will continue prioritising customer feedback and product development experimentation and integrate relevant frameworks to foster innovation. While growing and as the product matures, it is essential to evaluate whether the TLS approach is still suited to Puraqua. As the solution becomes more validated, Puraqua will focus on customer acquisition and retention and explore new marketing and sales strategies to drive growth.

For this thesis, one main limitation is that only one entrepreneurial framework was used to analyse Puraqua. This is due to the capacity and constraints available, making it an unfeasible and inefficient use of time to integrate and experiment with other entrepreneurial frameworks.

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Appendix

Appendix 1 – Product Design Specification

Product Design Specification

Project Puraqua
Responsible Alexander Ludwig

Brief: To provids an and on-demand water filter solution to as many people as possible to leverage social and environmental benefits.

Point	Requirment Point	Heirarchy	Additional Description	A	B	C	D	UX	Justification
	Essential Requirments								Justification
	The Product mustr retail for less than 15.00 and replacement cartridges must cost less than 6.00	Essential							Justification
	The product must be comply with NSF 42	Essential	material selection, filtration methods						Product meets the online requiremetns to ourstandars but needs officially accrediting to pass requirments
	The solution must be removable from the tap using a simle mechanism	Essential							
	The filter must be convient to set up and not obstruct the user during other sink activities	Essential							Setup could be more consistent
	The solution must have a replaceable cartridge	Essential							
1	Purpose of the product								
1.1	The product removes >90% of chlorine	5	Allows the user to quantify their water usage						
1.2	The product reduces the amount of chemicals and metals within water	5							
2	Market and consumer needs								
2.1	The adapter plate should have a smooth thread	4							
2.2	The product should be quick and simple set up	3							
2.3	The product should only requre setting up with avalibale instructions	4							
2.4	The Product should allow for simple and quick adjusment by the user	4							
3	Performance Requirements								
3.1	Must be waterproof and seals do not leak	4							
3.2	The flow tate must be restricted to 1 L/min when opened to a reasonable rate	2							
4	Materials								
4.1	The product should be made from materials and production methods that minimise environmetal impact	3	Use of PLA, ciruclar approach to cartridges						
4.2	The materials should be accessible and cost less than €30.00/ kg	4							
5	Size, weight and compatibility								
5.1	Diameter should not exceed 65mm and a length of 70mm	2							
6	Safety								
6.2	The Product should include a release mechnism incase of failue	2	In addition to NSF requirments						NSF is required. Overcomplicates the design and makes it expensive
7	Environment								
7.1	The product must withstand temperatures up to 48 C	4	PLA Tg is at 50-60 C therefore within tolerance						
8	Quality and Reliability								
8.1	the priodyct should be abkle to withstand a force of 15 l/min	3							Some parts failed but were adjusted within the D cycle
8.2	The product must withsand perpendicular force of 50N	2							
9	Form and apperence								
9.1	Product should be ergonomic and not obstruct the user when using the tap	5	Value propostion - hece the importance						
9.2	The product has a sleek and minimal design	4							

Appendix 2 – User experience focus group

User testing was conducted, and learnings were made through focus groups.

User Experience

- There was a correlation between tap water drinkers not using the filter and filter/bottled water users being more welcoming to the filter.
- The setup process was complex at times. Some taps require specific adapters, and the plate can be challenging to attach to the faucet, occasionally requiring additional support from the Puraqua team. An instruction manual has been created.

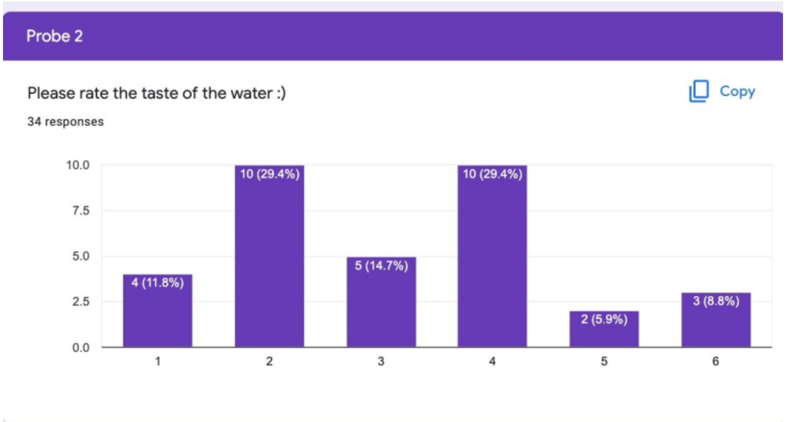
- The filter can be challenging to attach to the tap as the pin mechanism entry point is not wide enough.
- Consumers mentioned the potential use of the filter when travelling. This potentially opens the opportunity to implement the solution within the travel/ adventure market.

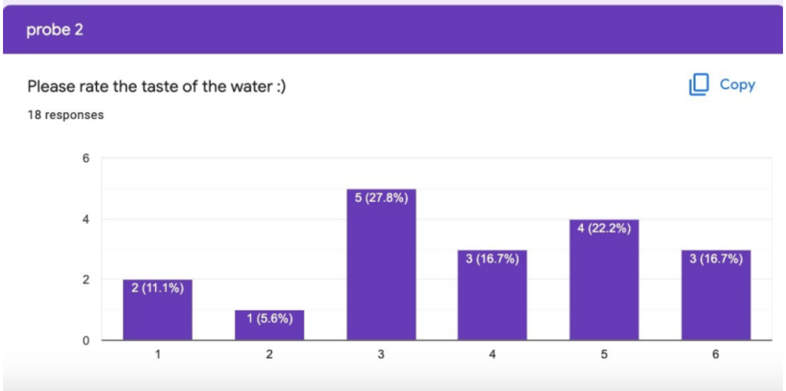
Product functionality

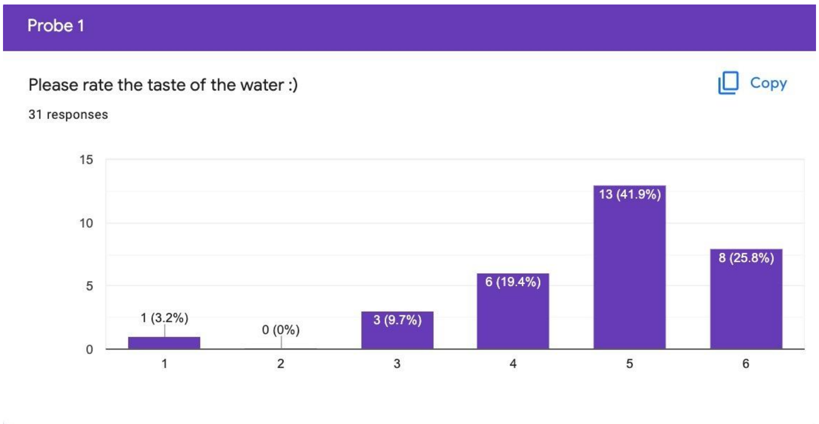
- After a while, small amounts of carbon particles were seeping through the system, which caused a small residue at the bottom of the glass. It could be fixed by replacing the nylon mesh within the filter with a finer weave.
- There is water leaking out of the tap after use. Integrating an aerator within the system is essential to prevent this from occurring and optimise the tap when the filter is not in use.
- As the mechanism is used more and beings to wear out due to friction, small leaks occur around the attach and removal mechanism.
- Water comes out of the tap at an angle at lower flow rates

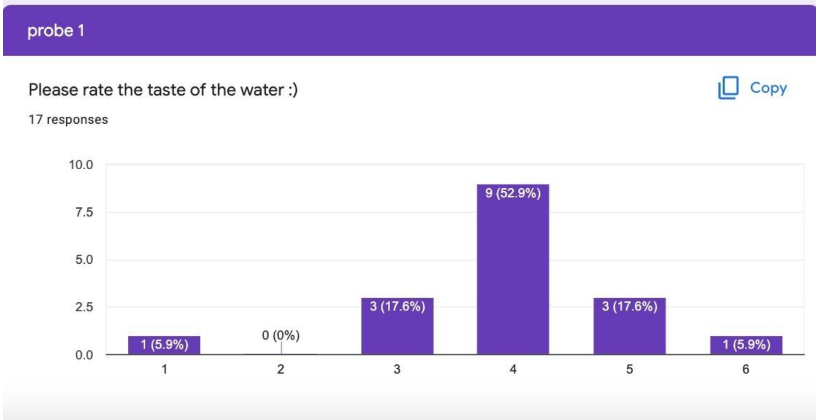
Appendix 3 - Quasi Experiment

Probe 1: Tap water. Probe 2: Filtered water.

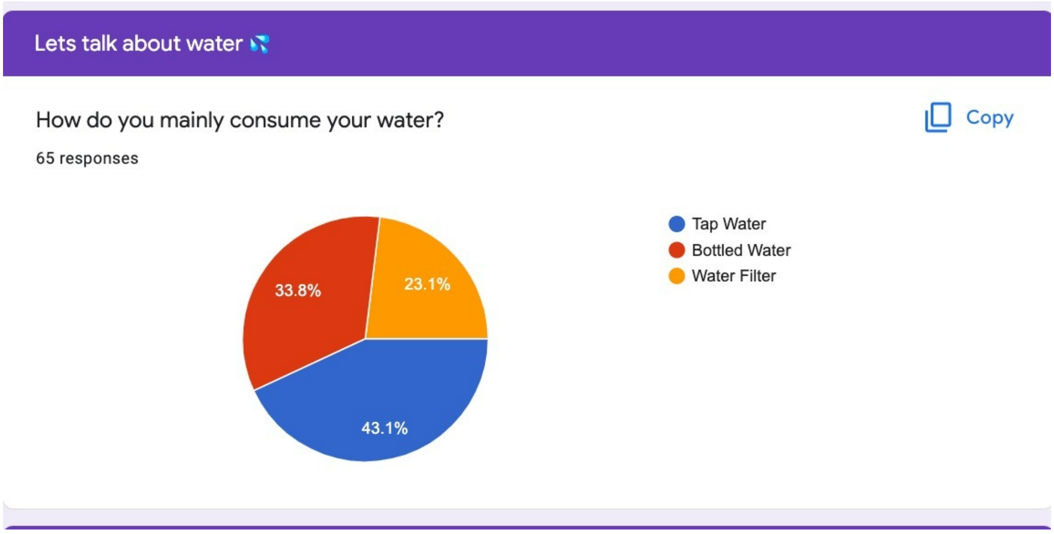




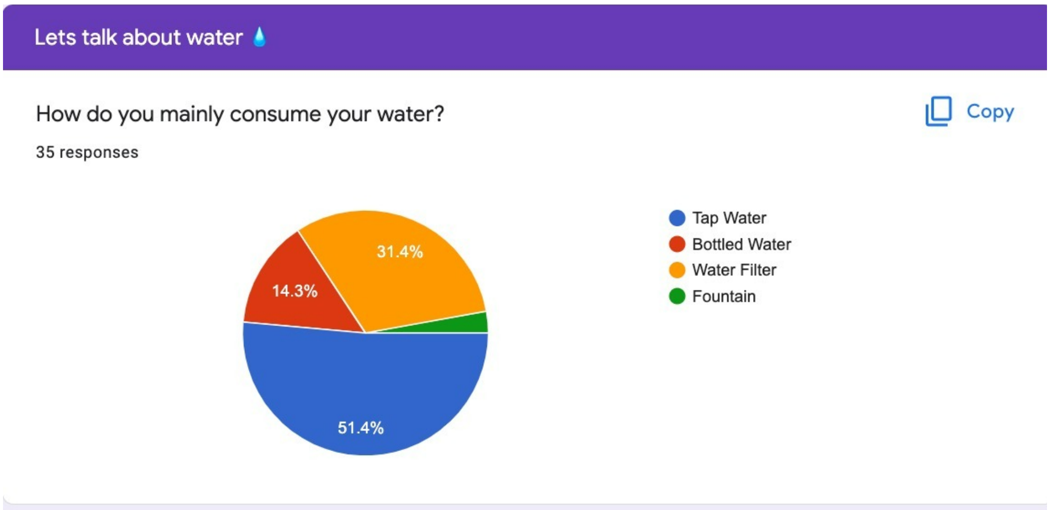


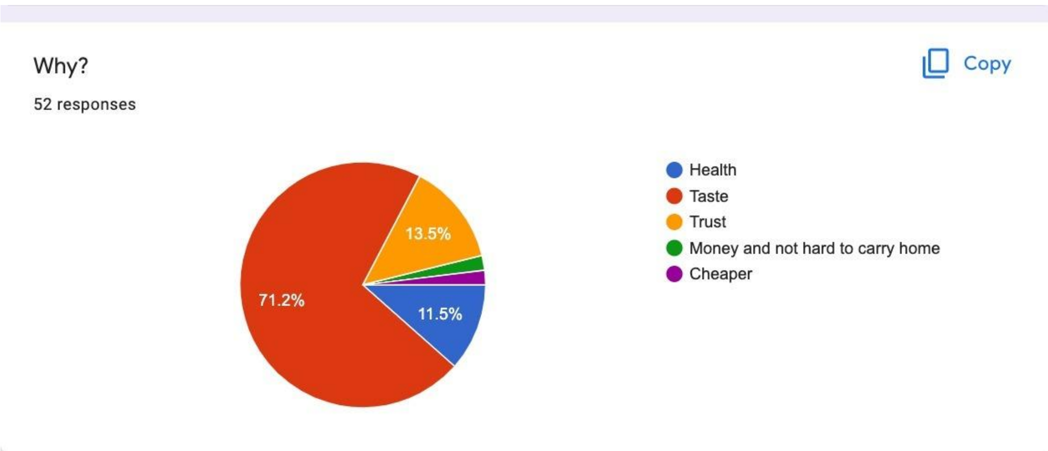


1. International students

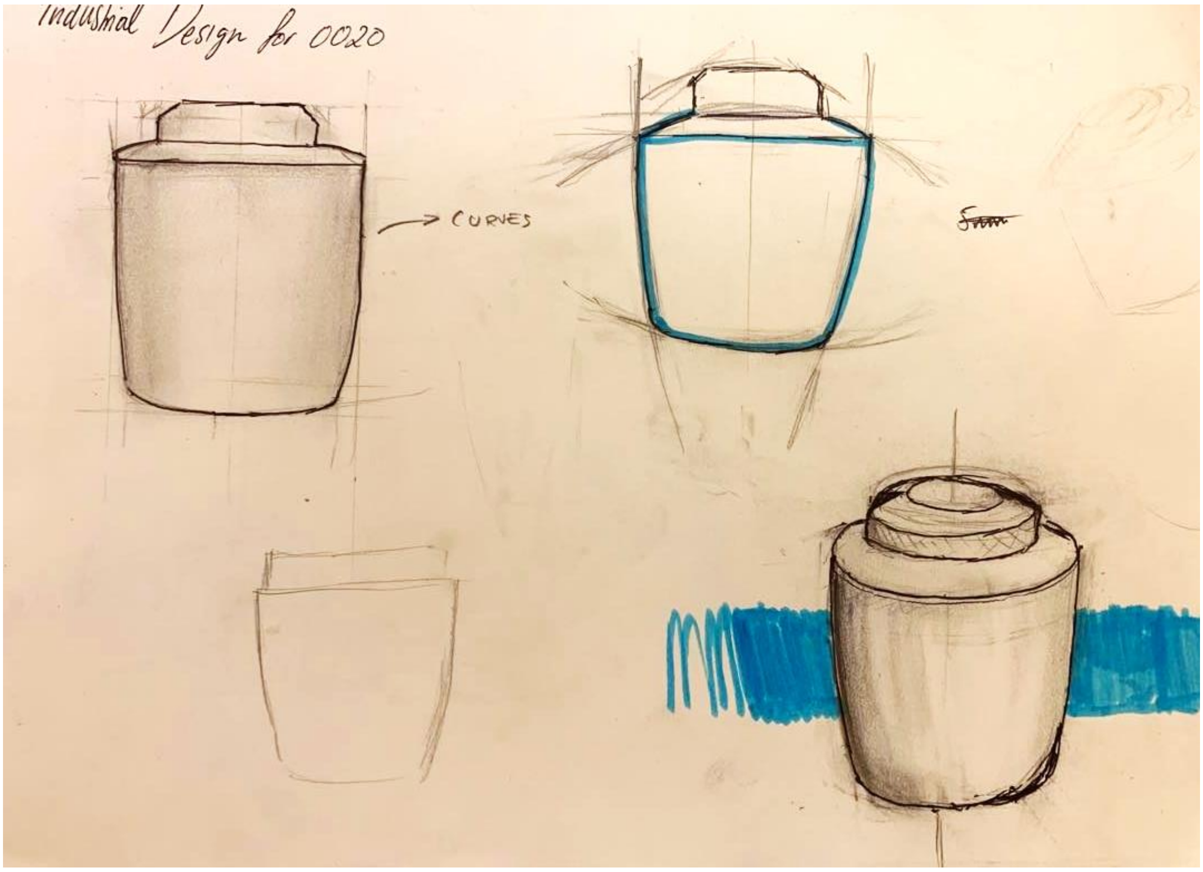


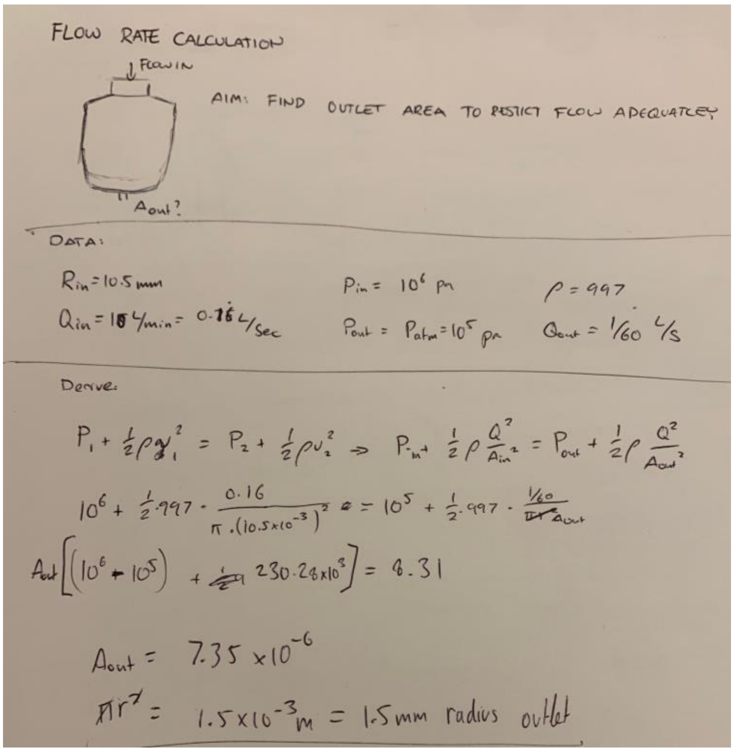
2. Young Portuguese population





Appendix 4 - Product Development





FLOW RATE CALCULATION

FLOW IN

AIM: FIND OUTLET AREA TO RESTICT FLOW ADEQUATLEY

A_{out}?

DATA:

$R_{in} = 10.5$ mm

$Q_{in} = 15$ L/min $= 0.16$ L/sec

$P_{in} = 10^6$ pa

$P_{out} = P_{atm} = 10^5$ pa

$\rho = 997$

$Q_{out} = 1/60$ L/s

Derive:

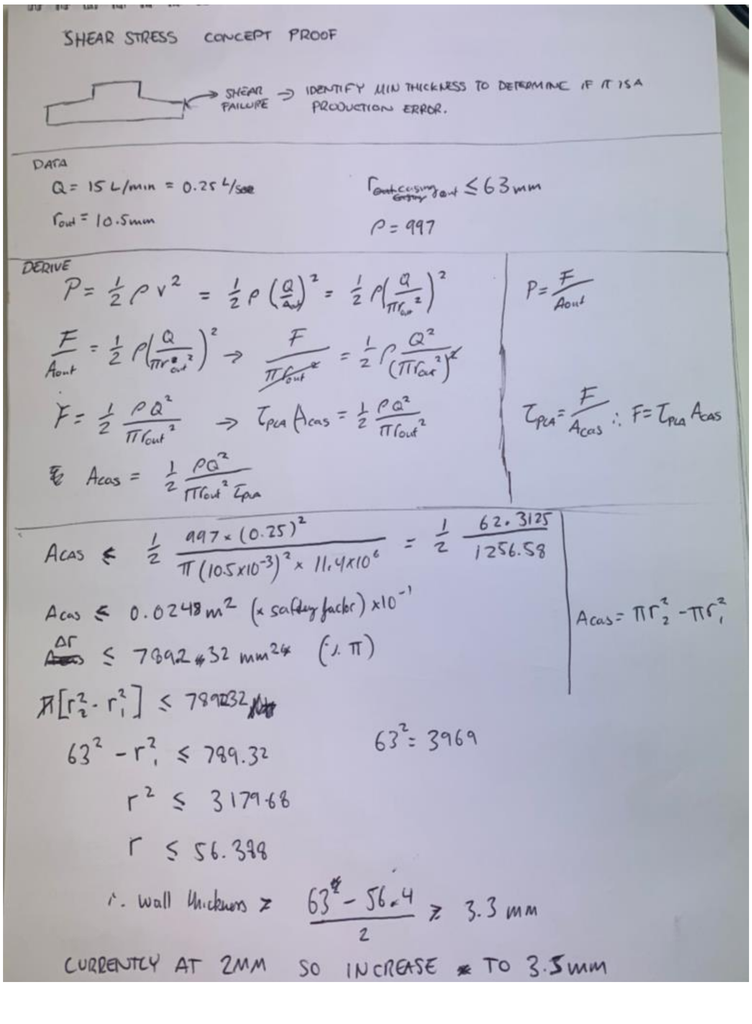
$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2 \Rightarrow P_{in} + \frac{1}{2}\rho \frac{Q^2}{A_{in}^2} = P_{out} + \frac{1}{2}\rho \frac{Q^2}{A_{out}^2}$$

$$10^6 + \frac{1}{2} \cdot 997 \cdot \frac{0.16}{\pi \cdot (10.5 \times 10^{-3})^2} = 10^5 + \frac{1}{2} \cdot 997 \cdot \frac{1/60}{A_{out}}$$

$$A_{out}\left[(10^6 - 10^5) + 230.28 \times 10^3\right] = 8.31$$

$$A_{out} = 7.35 \times 10^{-6}$$

$$\pi r^2 = 1.5 \times 10^{-3} m = 1.5 mm \text{ radius outlet}$$



SHEAR STRESS CONCEPT PROOF

SHEAR FAILURE → IDENTIFY MIN THICKNESS TO DETERMINE IF IT IS A PRODUCTION ERROR.

DATA

$Q = 15$ L/min $= 0.25$ L/sec

$r_{out} = 10.5$ mm

$r_{casing\,out} \leq 63$ mm

$\rho = 997$

DERIVE

$$P = \frac{1}{2}\rho v^2 = \frac{1}{2}\rho\left(\frac{Q}{A_{out}}\right)^2 = \frac{1}{2}\rho\left(\frac{Q}{\pi r_{out}^2}\right)^2$$

$$\frac{F}{A_{out}} = \frac{1}{2}\rho\left(\frac{Q}{\pi r_{out}^2}\right)^2 \rightarrow \frac{F}{\pi r_{out}^2} = \frac{1}{2}\rho\frac{Q^2}{(\pi r_{out}^2)^2}$$

$$F = \frac{1}{2}\frac{\rho Q^2}{\pi r_{out}^2} \rightarrow \tau_{PLA} A_{cas} = \frac{1}{2}\frac{\rho Q^2}{\pi r_{out}^2}$$

$$A_{cas} = \frac{1}{2}\frac{\rho Q^2}{\pi r_{out}^2 \tau_{PLA}}$$

$P = \frac{F}{A_{out}}$

$\tau_{PLA} = \frac{F}{A_{cas}} \therefore F = \tau_{PLA} A_{cas}$

$$A_{cas} \leq \frac{1}{2}\frac{997 \times (0.25)^2}{\pi (10.5 \times 10^{-3})^2 \times 11.4 \times 10^6} = \frac{1}{2}\frac{62.3125}{1256.58}$$

$A_{cas} \leq 0.0248 m^2$ (× safety factor) $\times 10^{-1}$

$\Delta r \leq 7892.32$ mm^2 (÷ π)

$A_{cas} = \pi r_2^2 - \pi r_1^2$

$\pi[r_2^2 - r_1^2] \leq 789.32$

$63^2 - r_1^2 \leq 789.32$

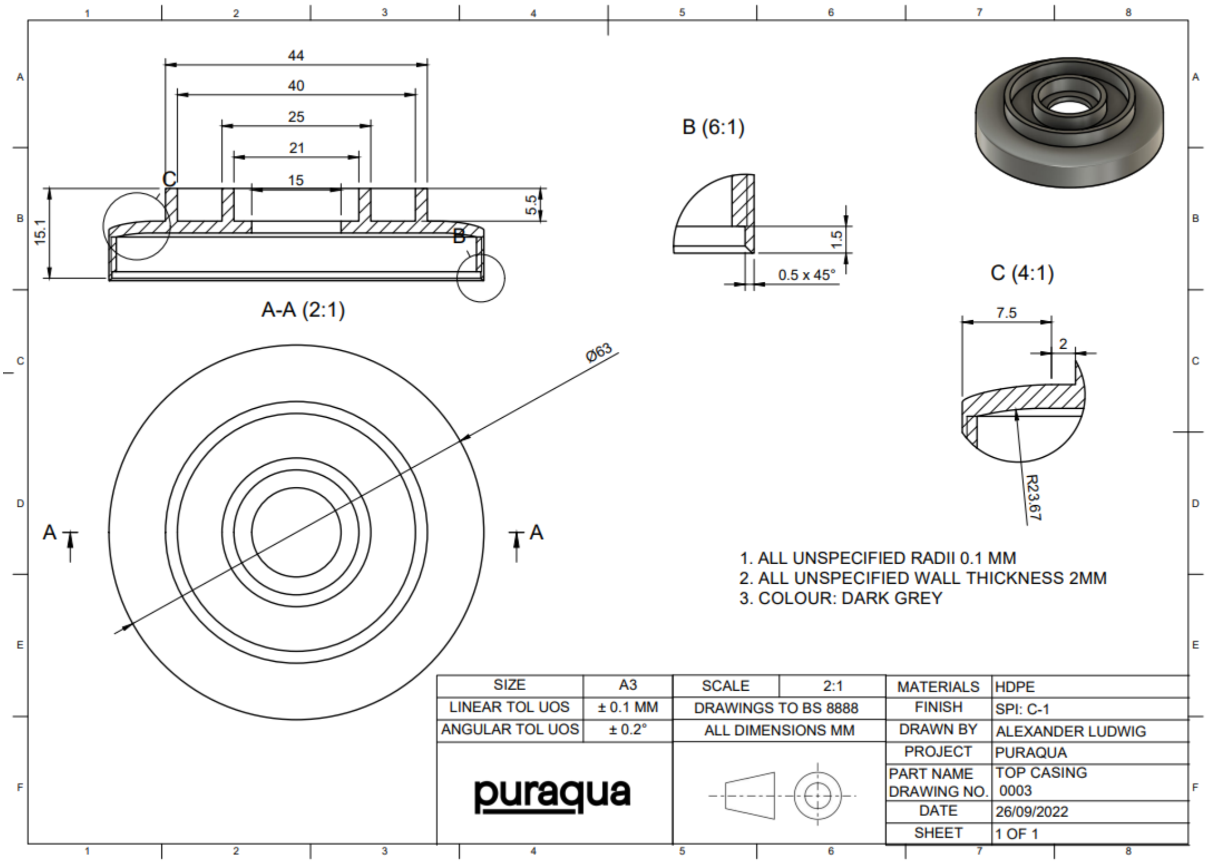
$63^2 = 3969$

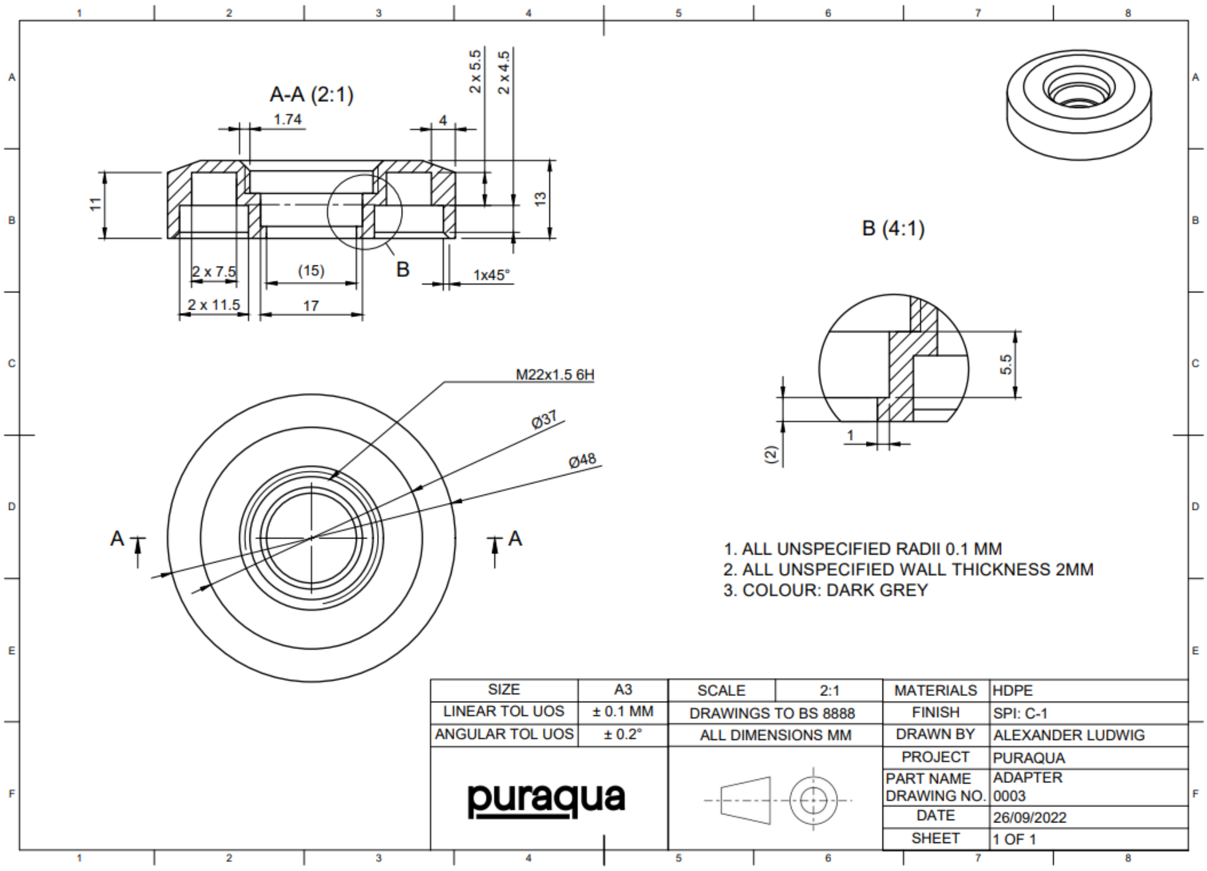
$r^2 \leq 3179.68$

$r \leq 56.398$

∴ wall thickness $\geq \frac{63 - 56.4}{2} \geq 3.3$ mm

CURRENTLY AT 2MM SO INCREASE TO 3.5mm


A-A (2:1)
44
40
25
21
15
5.5
15.1
C
B
B (6:1)
1.5
0.5 x 45°
C (4:1)
7.5
2
R23.67
Ø63
A
A
1. ALL UNSPECIFIED RADII 0.1 MM
2. ALL UNSPECIFIED WALL THICKNESS 2MM
3. COLOUR: DARK GREY
SIZE A3
LINEAR TOL UOS ± 0.1 MM
ANGULAR TOL UOS ± 0.2°
SCALE 2:1
DRAWINGS TO BS 8888
ALL DIMENSIONS MM
MATERIALS HDPE
FINISH SPI: C-1
DRAWN BY ALEXANDER LUDWIG
PROJECT PURAQUA
PART NAME TOP CASING
DRAWING NO. 0003
DATE 26/09/2022
SHEET 1 OF 1
puraqua


A-A (2:1)
1.74
4
2 x 5.5
2 x 4.5
11
13
2 x 7.5
(15)
B
1x45°
2 x 11.5
17
B (4:1)
5.5
(2)
1
M22x1.5 6H
Ø37
Ø48
A
A
1. ALL UNSPECIFIED RADII 0.1 MM
2. ALL UNSPECIFIED WALL THICKNESS 2MM
3. COLOUR: DARK GREY
SIZE A3
LINEAR TOL UOS ± 0.1 MM
ANGULAR TOL UOS ± 0.2°
SCALE 2:1
DRAWINGS TO BS 8888
ALL DIMENSIONS MM
MATERIALS HDPE
FINISH SPI: C-1
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PART NAME ADAPTER
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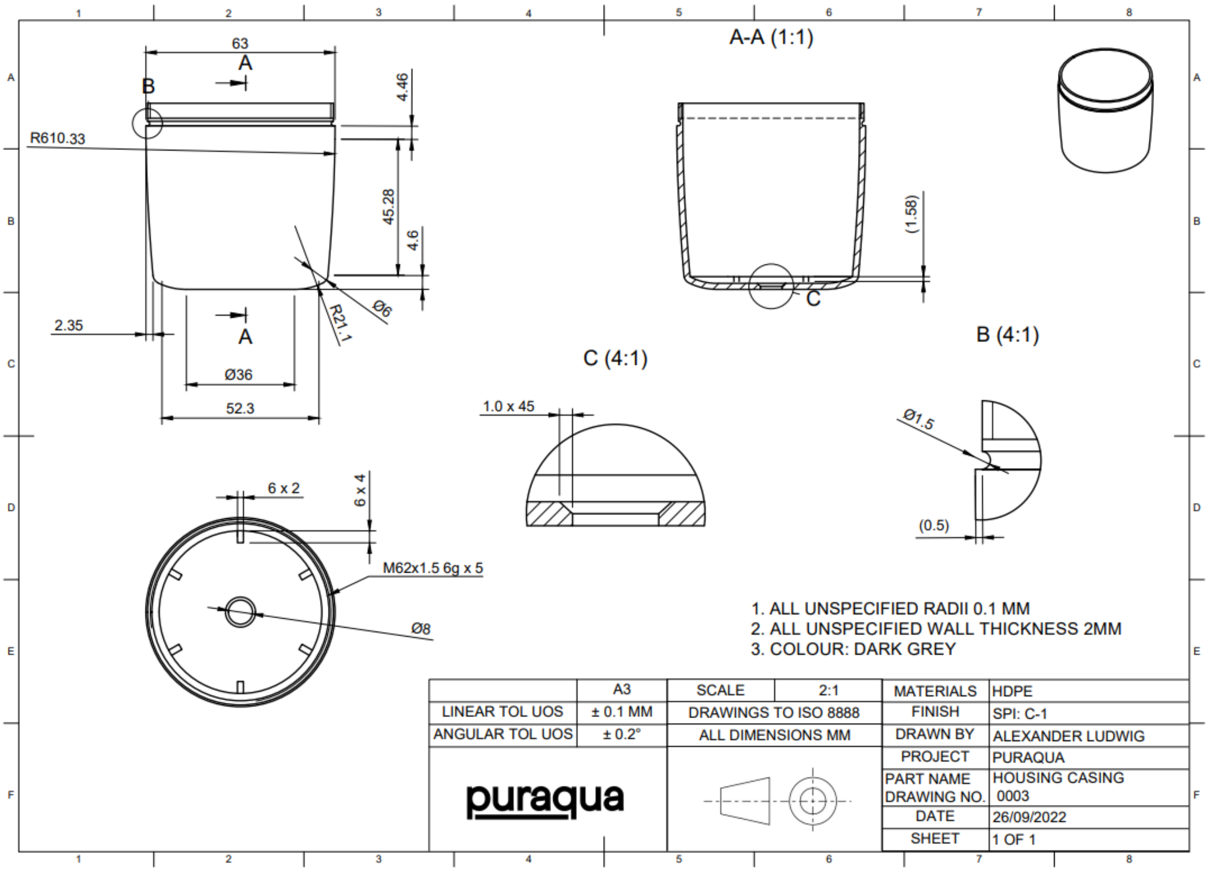
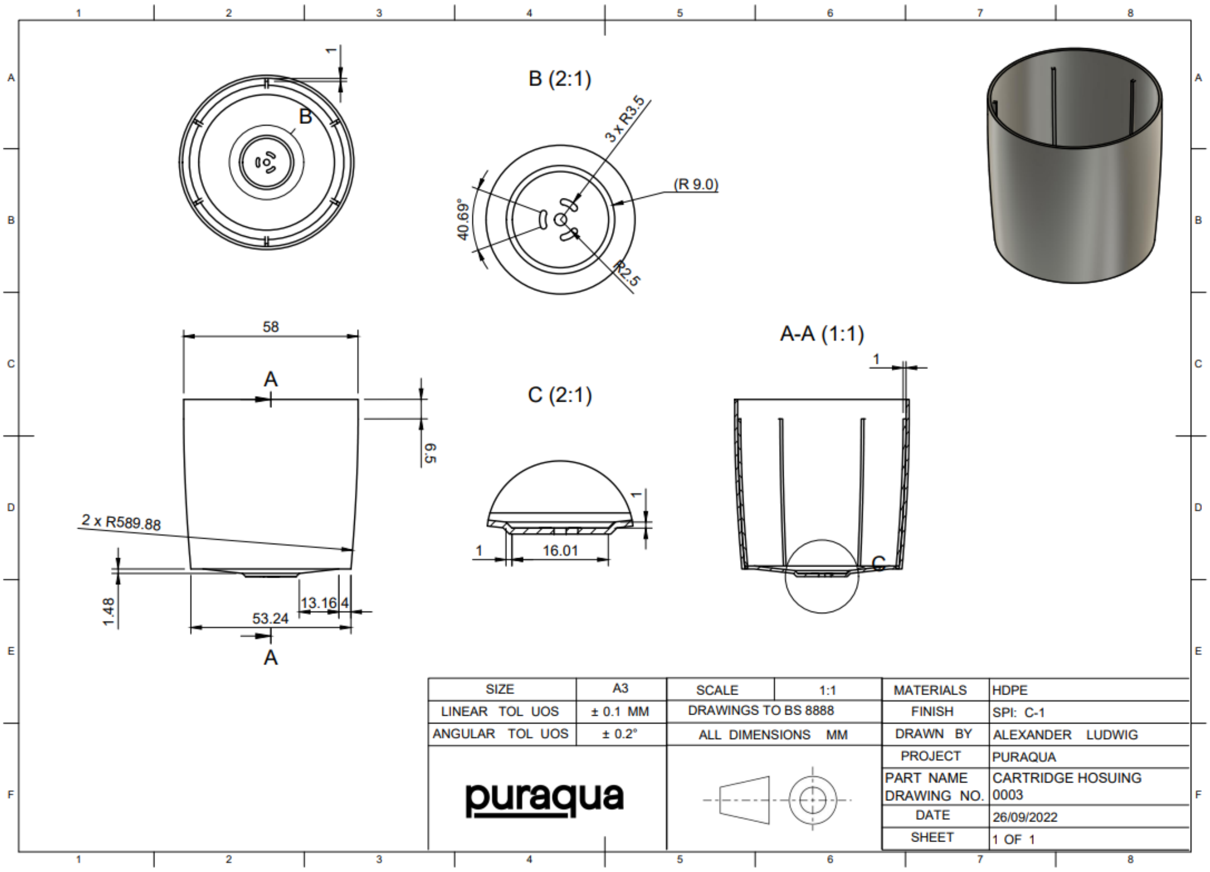
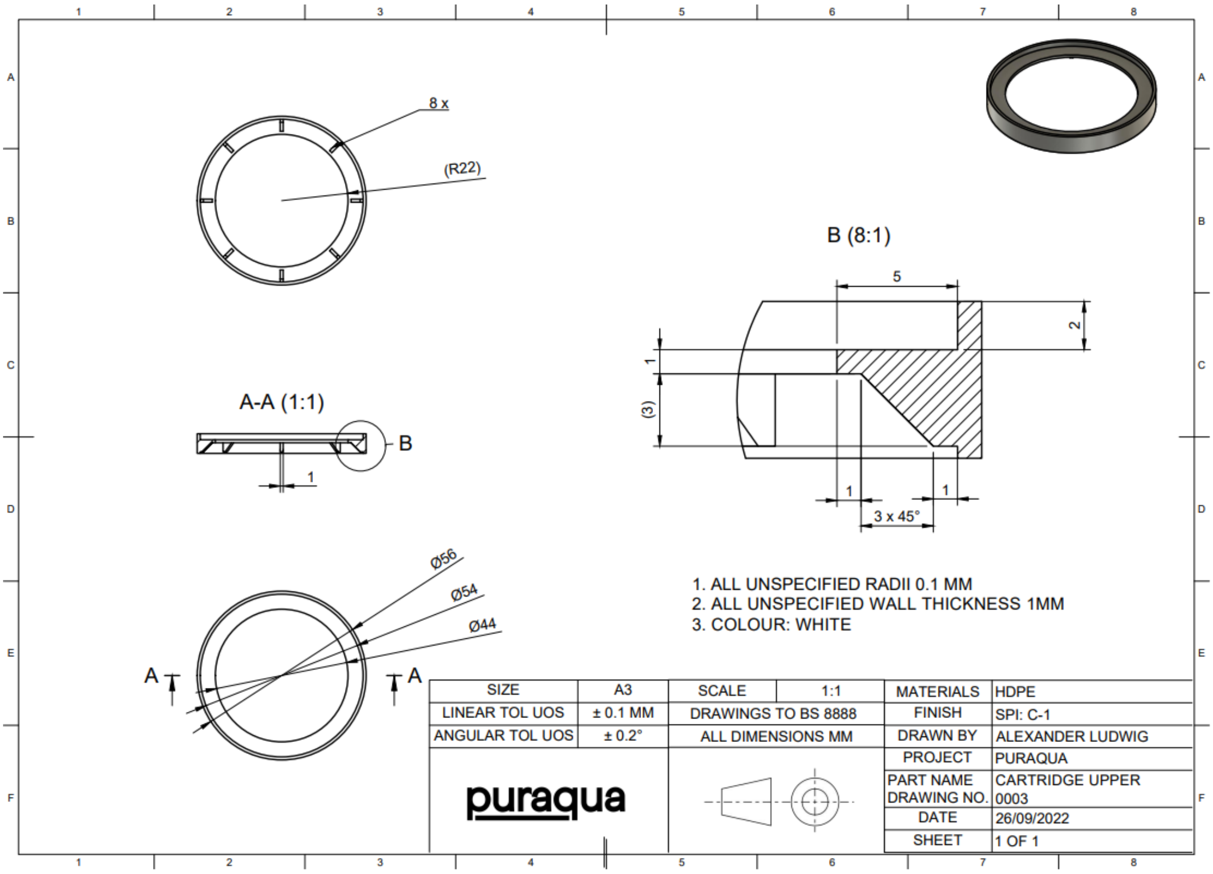
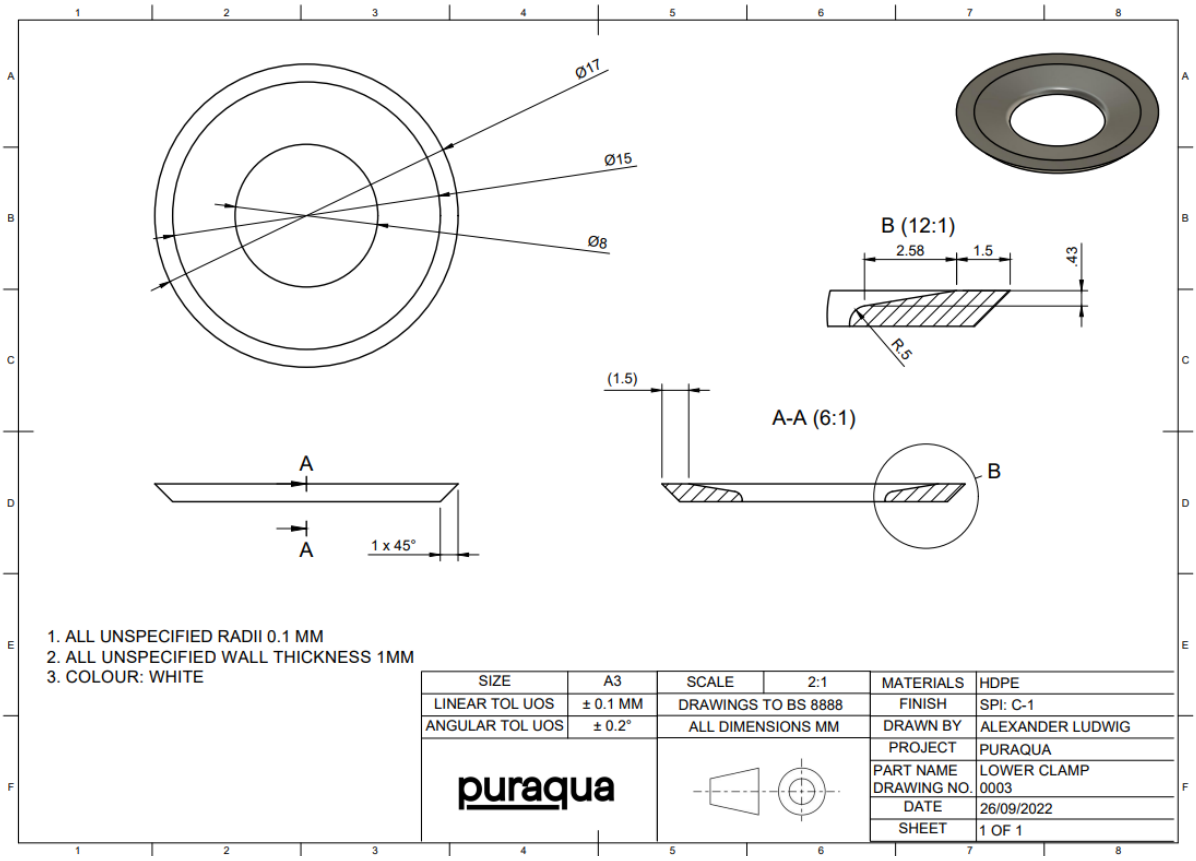
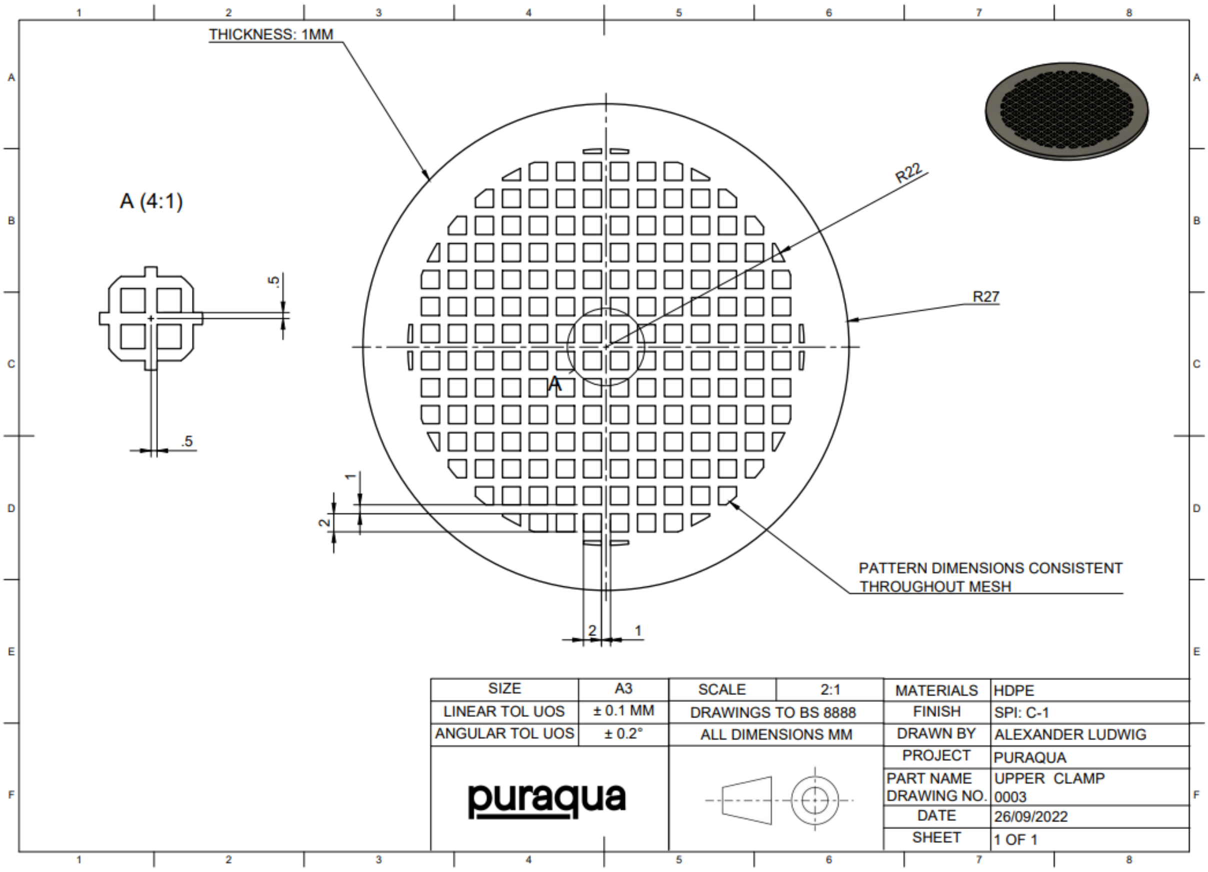
DATE 26/09/2022
SHEET 1 OF 1
puraqua


A-A (1:1)
C (4:1)
B (4:1)
63
4.46
R610.33
45.28
4.6
Ø6
R21.1
2.35
Ø36
52.3
(1.58)
1.0 x 45
Ø1.5
(0.5)
6 x 2
6 x 4
M62x1.5 6g x 5
Ø8
1. ALL UNSPECIFIED RADII 0.1 MM
2. ALL UNSPECIFIED WALL THICKNESS 2MM
3. COLOUR: DARK GREY
A3
SCALE 2:1
LINEAR TOL UOS ± 0.1 MM
DRAWINGS TO ISO 8888
ANGULAR TOL UOS ± 0.2°
ALL DIMENSIONS MM
MATERIALS HDPE
FINISH SPI: C-1
DRAWN BY ALEXANDER LUDWIG
PROJECT PURAQUA
PART NAME HOUSING CASING
DRAWING NO. 0003
DATE 26/09/2022
SHEET 1 OF 1
puraqua


B (2:1)
3 x R3.5
(R 9.0)
40.69°
R2.5
58
6.5
C (2:1)
A-A (1:1)
1
16.01
2 x R589.88
1.48
13.16
4
53.24
SIZE A3
SCALE 1:1
LINEAR TOL UOS ± 0.1 MM
DRAWINGS TO BS 8888
ANGULAR TOL UOS ± 0.2°
ALL DIMENSIONS MM
MATERIALS HDPE
FINISH SPI: C-1
DRAWN BY ALEXANDER LUDWIG
PROJECT PURAQUA
PART NAME CARTRIDGE HOSUING
DRAWING NO. 0003
DATE 26/09/2022
SHEET 1 OF 1
puraqua


8 x
(R22)
A-A (1:1)
B
1
B (8:1)
5
2
1
(3)
1
1
3 x 45°
Ø56
Ø54
Ø44
A
A
1. ALL UNSPECIFIED RADII 0.1 MM
2. ALL UNSPECIFIED WALL THICKNESS 1MM
3. COLOUR: WHITE
SIZE A3
SCALE 1:1
MATERIALS HDPE
LINEAR TOL UOS ± 0.1 MM
DRAWINGS TO BS 8888
FINISH SPI: C-1
ANGULAR TOL UOS ± 0.2°
ALL DIMENSIONS MM
DRAWN BY ALEXANDER LUDWIG
PROJECT PURAQUA
PART NAME CARTRIDGE UPPER
DRAWING NO. 0003
DATE 26/09/2022
SHEET 1 OF 1


Ø17
Ø15
Ø8
B (12:1)
2.58
1.5
.43
R.5
(1.5)
A-A (6:1)
B
A
A
1 x 45°
1. ALL UNSPECIFIED RADII 0.1 MM
2. ALL UNSPECIFIED WALL THICKNESS 1MM
3. COLOUR: WHITE
SIZE A3
SCALE 2:1
MATERIALS HDPE
LINEAR TOL UOS ± 0.1 MM
DRAWINGS TO BS 8888
FINISH SPI: C-1
ANGULAR TOL UOS ± 0.2°
ALL DIMENSIONS MM
DRAWN BY ALEXANDER LUDWIG
PROJECT PURAQUA
PART NAME LOWER CLAMP
DRAWING NO. 0003
DATE 26/09/2022
SHEET 1 OF 1


THICKNESS: 1MM
A (4:1)
.5
.5
R22
R27
A
1
2
2
1
PATTERN DIMENSIONS CONSISTENT THROUGHOUT MESH
SIZE
A3
LINEAR TOL UOS
± 0.1 MM
ANGULAR TOL UOS
± 0.2°
SCALE
2:1
DRAWINGS TO BS 8888
ALL DIMENSIONS MM
MATERIALS
HDPE
FINISH
SPI: C-1
DRAWN BY
ALEXANDER LUDWIG
PROJECT
PURAQUA
PART NAME
UPPER CLAMP
DRAWING NO.
0003
DATE
26/09/2022
SHEET
1 OF 1
puraqua



Appendix 5 – Failure Mode Effect Analysis

Assembly Name	Component Name	Failure Mode	Cause of Failure	Effect of Failure on System	Correction of Problem	Proof of correction
Assembly Name						
Adapter - Top Casing	Magent	water pressure > magnet force	lack of strength of magnet	Water spray	80N <120 N Magents	Product Testing
	Magent	falls out of product	magnet force > adhesion between magnet and	filter wont attatch to product	Glue magnets into top adapter	Product Testing
	Magent	Material Unsafe	Water is exposed to magnet and seeps into	Human health compromised	Ensure material is safe for consumption	ISO/NSF accreditation
	O ring (adapter)	seal leaks	gaps between product and seal	Water leak, spray that could come in contact with theuser	sufficient O rings - testing at given pressure tightten to sufficient clamping froce	Product Testing
	O ring (adapter)	falls out of product	lack of seal support	Water leak, spray that could come in contact with theuser	Support for o-ring. A groove that holds it in place that is as deep as 0.8*radius of	Product Testing
	Assmebly	pin mechanism not fastened prioerly	Incorrect assembly from user, mechanism not ergonomic enough, no instructions	Water leaks, product falls off tap, not effective	Easy thread engament, installation manual. Plastic adapter so that if it goes wrong, tap is not damaged.	Product Testing
Adapter	O ring (adapter)	Material Unsafe	Water is exposed to material	Human health compromised	Ensure material is safe for consumption	ISO/NSF accreditation
	Adapter	Material Unsafe	Water is exposed to material	Human health compromised	Ensure material is safe for consumption	ISO/NSF accreditation
Adapter - Tap	Assmebly	Thread not fitted properly	Incorrect assembly from user, thread engagment not easy enough, no instructions	Water leaks, product falls off tap, not effective	Easy thread engament, installation manual. Plastic adapter so that if it goes wrong, tap is not damaged.	Product Testing
	Too Caising	Sheared material	High pressure	Product splits in 2 and burst of water and filter could direct at user.	Pressure testing and adequate wall thickness analysis.	Product Testing
Top Casing	64mm o ring	seal leaks	gaps between product and seal	Water leak	sufficient O rings - testing at given pressure	Product Testing
	Casing	Material Unsafe	Water is exposed to material	Human health compromised	Ensure material is safe for consumption	ISO/NSF accreditation
Filter	cartridge housings	seeps ion/carbin	granulate seeps through filteration	Human health compromised	Mesh clamping mechanism to 1.5mm contact and and use of a 15 micron mesh	Product Testing and ISO/SF allignment
	cartridge housings	seeps ion/carbin	Granultate exposed when casings come apart	Human health compromised	Tighter tolerance andmore contact surface between parts	Product Testing
	cartridge housings	cartdige opens up	high pressure or external force	exposure to ion.csarbin	enusre tight tolerance and sealed housing	product testing
	cartridge housings	Material Unsafe	Water is exposed to material	Human health compromised	Ensure material is food grade	ISO/NSF accreditation
	polyester mesh	Material Unsafe	Water is exposed to material	Human health compromised	Ensure material is food grade	ISO/NSF accreditation
	Ion and activated carbon	Material Unsafe	Water is exposed to material	Human health compromised	Ensure material is food grade	ISO/NSF accreditation
	O ring	Material Unsafe	Water is exposed to material	Human health compromised	Ensure material is food grade	ISO/NSF accreditation
	O ring	falls out of product	lack of seal support	Water leak, spray that could come in contact with theuser	Support for o-ring. A groove that holds it in place that is as deep as 0.8*radius of	Product Testing
Casing	Casing	Material Unsafe	Water is exposed to material	Human health compromised	Ensure material is safe for consumption	ISO/NSF accreditation
	O ring	falls out of product	lack of seal support	Water leak, spray that could come in contact with theuser	Support for o-ring. A groove that holds it in place that is as deep as 0.8*radius of	Product Testing
Top Casing - Casing	O ring	seal leaks	gaps between product and seal	Water leak, spray that could come in contact with theuser	sufficient O rings - testing at given pressure tightten to sufficient clamping froce	Product Testing
	Assmebly	Seperates	Lack of trhreas enegagment	Product splits in 2 and burst of water and filter could direct at user.	thread toleaceing and pressure testing	Product Testing
	Assmebly	Thread not fitted properly	Incorrect assembly from user, mechanism not ergonomic enough, no instructions	Water leaks, product falls off tap, not effective	Easy thread engament, installation manual. Plastic adapter so that if it goes wrong, tap is not damaged.	Product Testing

Series A	Evaluation	Development Excecution	Series B	Evaluation	Development Excecution	Series C	Evaluation	Development Excecution	Series	UX Testing
	Magnet not required									
	Magnet not required									
	Magnet not required									
	Magnets do not produce adequate clamping force. Swtiching to Pin mechanism will compress the o rings.			Water still leaking	Change o-ring to a larger one and change positionion		Still leaking	Tighter tilerance		
	grooves for o rings require to be deep enough so that they don't fall out			larger o ring with larger support						
	It doesn't fall off but difficult engagment. User may find tough.	Add a chamfer around the start of thread.		issue still present	Add face offsets and higher print tolerance.					
	Threads engage but don't fully tighten. Tolerace too tight,	offset faces and higher print toleranc		Threads engage but don't fully tighten. Tolerace too tight,	Print settings to external not internal in advanced settings					
							Unexpected sher occurred at high pressure	Wall thickness increase, layer analysis and FEA stress analysis		
	clamping force from threads	offset faces and higher print toleranc		Threads engage but don't fully tighten. Tolerace too tight,	Print settings to external not internal in advanced settings					
	Still seeping through mesh. Mesh moved as well so that it is not coverig the outlet	smaller outlet (required for FEA anyway) and new clamping mechanim that hols mesh in plave		Mesh works but hole still not covered and sealed	clampig of mesh with larger surface area (2mm not 1mm)					
	Parts failed. Housingmesh completely failed by shearing and coming apart	Increase wall thickness and strength of assembly		better but still comes apart too easy	clampig of componets done with larger surface area (2mm not 1mm)					
	Parts come apart to easolt. When dropped from a height of 1m it dissasembles	Increase wall thickness and strength of assembly		better but still comes apart too easy	clampig of componets done with larger surface area (2mm not 1mm)					
	Comes off too easy	deeper groove for o ring to sit in		Casing wakks too thin, O ring not significant to the funtion of the	Remove o ring					
	Comes off too easy	deeper groove for o ring to sit in								
	Threads engage but don't fully tighten. Tolerace too tight,	offset faces and higher print tolerance		Threads engage but don't fully tighten. Tolerace too tight,	Print settings to external not internal in advanced settings					
	Threads engage but don't fully tighten. Tolerace too tight,	offset faces and higher print tolerance		Threads engage but don't fully tighten. Tolerace too tight,	Print settings to external not internal in advanced settings					
	Threads engage but don't fully tighten. Tolerace too tight,	offset faces and higher print tolerance		Threads engage but don't fully tighten. Tolerace too tight,	Print settings to external not internal in advanced settings					

Appendix 6 – Failure Effect Analysis

A	Part	Effect	Failure	Development Excecution	B	Evaluarion	Development Excecution
	Assembly	Water goes through filter too fast - not filtering properly	Not enough restriction	flow retricion within system Cartridge			Add more restriction in housing outlet
	Top Casing	Complete failurew	shear stress fracture in top casing	ensure layer bindig during printing is vetter			
	Top Casing	No engagment between threads	Thread tolerance	Change diameter, higher print quality (fablab) and remove material			
	Top casing	Adapter and top caing do no fit into eachother	Tolerance issue	Change diameter and remove material			
	Top casing thread	moves on compmnent	Seal not fixed	Add ridge to support		Not required with pin desing	
	Adapter	Wont fit onto tap	Thread wont engage with tap	Rethread with heated Tap (tool)			
	Adaoter	Magnet water leaking out of pin mechnism	magnet not clamping strong enough	Toleratncing			
	Adapter	large part - inconvinent	magnets increasing diameter	Remove magnets and pin solution			
	Adapter	water flow is not as aerated as hoped	aerator not effective	replace aerator			
	Adapter	Adapter and top caing do no fit into eachother	Tolerance issue	Change diameter and remove material			
	adapter-top casing	Not flush	seal fit tight	push seal in a bit more			
	adapter-top casing	pin mechanism wont close	tolearnce too tight				offset faces on cad model
	adapter-top casing	water coming out of connection	lack of force in connection	pin solution		Still leaking	Replace 1mm seal with 3 seal
	adapter-top casing	water coming out of connection	lack of seals	add 2 seals to design		Still leaking	Replace 1mm seal with 3 seal
	top caing - hosuing	rips appart when pressure too high	week thread engagment	higher printing tolerance		rips appart when pressure too high	Ensure entire thread is engaged
	top caing - hosuing	water seeping out	week thread engagment	higher printing tolerance		Still leaking	Ensure entire thread is engaged so seal is clamped
	Housing	water doesn't come out in a direct stream	hole too wide and not offset	make hole smaller and add an offset region around hole for more direct stream		dribbles out of outlet - doesn't look clean	Decrease siameter from 8mm to 2mm
	Cartridge	Granualte exposed, cartridge failed	Top mesh and lower broke off	Thicker cartridge walls		micon cloth mesh does not seal in granulate	New deign including thicker plastic mesh, mircon cloth mesh clamps and larger engangent areas
	Cartridge	water seeping between filter and cartridge	no seal	add seal groove			
	Cartridge	top comes off	due to cartridge	Thcoker walls		micon cloth mesh does not seal in granulate	mesh clamp require larger engangent areas
	Cartridge	bottom part doesn't	bottom paert doesn't connect in	create a larger part that clicks into the cartridge		micon cloth mesh does not seal in granulate	mesh clamp require larger engangent areas

A	Part	Effect	Failure	C	Evaluation	Development Excecution	D
	Assembly	Water goes through filter too fast - not filtering properly	Not enough restriction		Flow rate still too fast	Add more restriction in housing outlet	
	Top Casing	Complete failurew	shear stress fracture in top casing		Error occurred in protype	ensure layer bindig during printing is vetter	
	Top Casing	No engagment between threads	Thread tolerance		Print quality not consisten	revealuate printing quality	
	Top casing	Adapter and top caing do no fit into eachother	Tolerance issue		Remove material to manipulate diameter	revealuate printing quality	
	Top casing thread	moves on compmnent	Seal not fixed				
	Adapter	Wont fit onto tap	Thread wont engage with tap				
	Adaoter	Magnet water leaking out of pin mechnism	magnet not clamping strong enough				
	Adapter	large part - inconvinent	magnets increasing diameter				
	Adapter	water flow is not as aerated as hoped	aerator not effective				
	Adapter	Adapter and top caing do no fit into eachother	Tolerance issue		Remove material to manipulate diameter	revealuate printing quality	
	adapter-top casing	Not flush	seal fit tight		sand so seal goes in further		
	adapter-top casing	pin mechanism wont close	tolearnce too tight		Decrease contact surface area		
	adapter-top casing	water coming out of connection	lack of force in connection				
	adapter-top casing	water coming out of connection	lack of seals		Still leaking	tolerace between seal and componets	
	top caing - hosuing	rips appart when pressure too high	week thread engagment				
	top caing - hosuing	water seeping out	week thread engagment				
	Housing	water doesn’t come out in a direct stream	hole too wide and not offset				
	Cartridge	Granualte exposed, cartridge failed	Top mesh and lower broke off				
	Cartridge	water seeping between filter and cartridge	no seal		Sealfalls off constantly and system is watertight enough	Remove seal	
	Cartridge	top comes off	due to cartridge				
	Cartridge	bottom part doesn’t	bottom paert doesn’t connect in				

Appendix 7 – Product Testing Learnings

Concept A

- The Aesthetics of the filter were too square and bulky.
- There was too little water flow restriction in the filter causing water to pass through it too fast. As a result, the water wasn't being filtered enough.
- The design of the cartridge was not strong enough, causing it to break too quickly, which caused resin and activated carbon to be exposed.
- Magnet mechanisms were difficult to make watertight and were too expensive. There are more cost-effective and convenient mechanisms that are more feasible.
- Some tolerances were too tight, meaning it was difficult to assemble, and some were too loose, which caused leaks system.

Concept B

- The pin mechanism that replaces the magnets was too tight and inconvenient to use.
- Tolerance issues were still present. They made it difficult to assemble and use the filter.
- The outlet causes the stream of water to be warped, meaning it can miss the glass.
- Cartridge assembly required a more robust clamping mechanism to increase activated carbon and the mesh linings used within the filter as granulate seeps out.
- The flow rate was still too large. More resistance within the filter is required.

Concept C

- Pin mechanism with leaking water. This is due to the o-ring seals not being large enough and the tolerance being too loose between the surfaces in contact with the o-ring seal.
- Identify the compromise between a tight enough tolerance that allows the product to be watertight and loose enough for the pin mechanism to work correctly

Concept D was satisfactory.

Appendix 8 – Installation Manual

puraqua Installation Manual

WARNING

IMPORTANT: **Slowly** open the tap. High pressure will cause system failure.

Before usage, Ensure all the **threads are fully tightened** to ensure filter is water tight.

What's included

Adapter **Housings** **Cartridge**

Setup

1. Ensure you have the right tap

Our tap requires a M22 female thread. You may require an adapter. For more information contact us @puraqua_pt via Instagram.

2. Remove aerator from your tap

Rotate anti-clockwise. If the thread is tight use a cloth or a pair of pliers. Warning: Water may leak out of tap once removed.

3. Attach the adapter plate

Place the adapter plate onto the tap. Rotate until the adapter is mountet tightly to the tap.

Assembling the Filter

1. Insert the Cartridge into the housing

2. Screw the top of the casing until tight

Filter Installation and Removal from Tap

1. Align pin mechanism and push till inserted

2. Rotate clockwise to lock in place

3. To remove reverse motion

4. Place aside to drain

For further information please contact us via Instagram @puraqua_pt.

For urgent technical support please contact +44 7597 131 994 via WhatsApp.

For our live demos on how to setup our product. Scan the following QR code.
Alternatively visit us on Instagram @puraqua_pt.

Appendix 9 – Bill of Materials

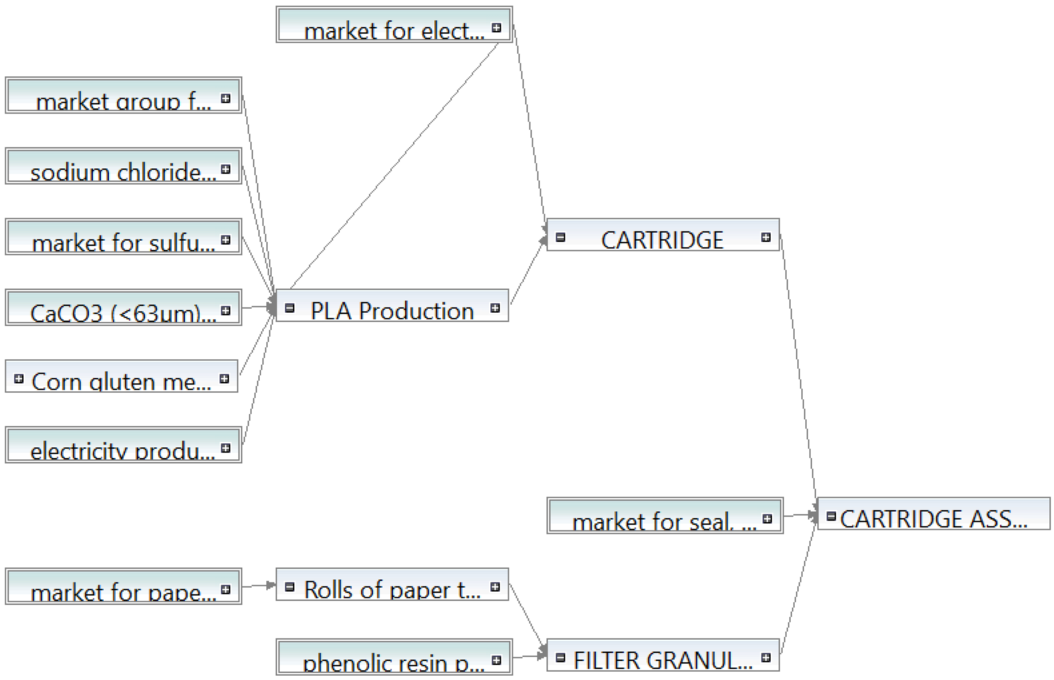
Seri

Bill of Materials (BOM)

	Level	Number	Part Name	Amount	Unit		Cost/ unit		Total Cost
-	0	0000	**Puraqua UX Tesing Package**	**1.00**	**Unit**			**€**	**8.01**
	1	**1000**	**Puraqua Filter (without filter)**	**1.00**	**Unit**		**-**	**€**	**0.17**
	1	**1100**	**Adapter_Assmb**	**1.00**	**Unit**			**€**	**0.15**
	2	1101	Adapter	**1.00**	**Unit**	**£**	-	**€**	-
	2	1102	Seal 18 x 2.7	**0.13**	**Unit**	£	1.18	**€**	**0.15**
	2	1103	Mesh Coarse Cut	**1.00**	**Unit**	**£**	-	**€**	-
	3	1104	Mesh Coarse	**1.00**	**m^2**	**£**	-		-
	2	1105	Mesh Fine Cut	**2.00**	**Unit**	**£**	-	**€**	-
	3	1106	Mesh Fine	**1.00**	**m^2**	**£**	-		-
	2	1107	Aerator	**1.00**	**Unit**	**£**	-	**€**	-
		1200	**Top Casing Assembly**	**1.00**	**Unit**			**€**	**0.01**
	2	1201	Top Casing Thread	**1.00**	**Unit**	**£**	-	**€**	-
		1202	O ring _53mm	**0.02**	**Unit**	**£**	**0.50**	**€**	**0.01**
	1	**1300**	**Casing Assembly**					**€**	**0.01**
	2	1301	Casing Housing	**1.00**	**Unit**	**£**	-	**€**	-
	2	1302	Seal 60mm	**0.02**		**£**	**0.50**	**€**	**0.01**
	1	**2000**	**Filter**	**1.00**	**Unit**			**€**	**7.44**
	2	2001	Cartridge Lower	**1.00**	**Unit**	**£**	-	**€**	-
	2	2002	Cartridge Upper	**1.00**	**Unit**	**£**	-	**€**	-
	2	2003	Ring Clamp Lower	**1.00**	**Unit**	**£**	-	**€**	-
	2	2004	Ring Clamp Upper	**1.00**	**Unit**	**£**	-	**€**	-
	2	2005	Polyester Mesh Upper_cut	**0.02**	**Unit**	**£**	**0.99**	**€**	**0.02**
	3	2006	Polyester_Mesh_Upper	1.00	Unit	£	0.99		-
	2	2007	Polyester Mesh Lower_cut	**0.02**	**Unit**	**£**	**0.99**	**€**	**0.02**
	3	2006	Polyester_Mesh_Lower	1.00	Unit	£	0.99		-
	2	2008	Ion Resin Bead	**0.20**	Unit	**£**	**37.00**	**€**	**7.40**
	2	2009	Activated Carbon Bead						
	3	2010	Britta Cartridges	**1.00**	Unit	**£**	**37.00**		-
	1	**3001**	**Intallation**	1.00	Unit	£	0.10	€	0.10
	1	**3002**	**Box**	1.00	Unit	£	0.30	€	0.30

Appendix 10 – LCA

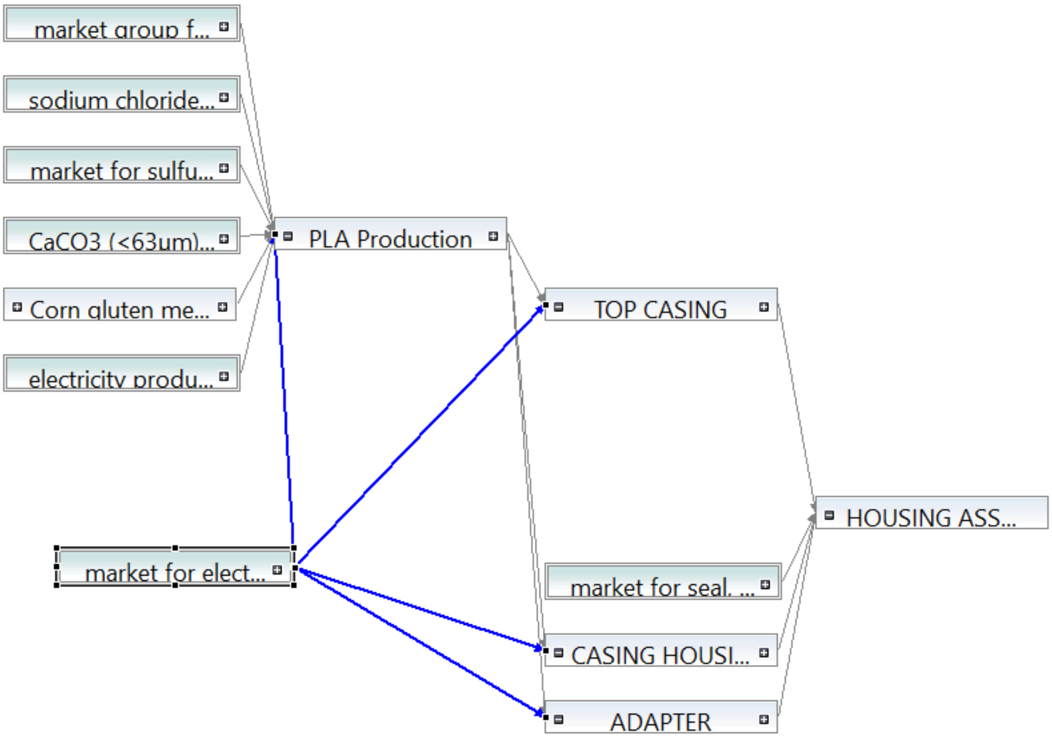
Cartridge System Structure – shows the materials and products used to create the cartridge



Name	Category	Inventory Result	Unit	Impact Factor	Unit	Impact Result	Unit
Aquatic acidification				0.00156		kg SO2 eq	
Terrestrial acid/nutri				0.00439		kg SO2 eq	
Carcinogens				0.00539	kg C2H3Cl eq		
Aquatic eutrophication					4.25184E-5		kg PO4 P-lim
Non-renewable energy					3.78224		MJ primary
Respiratory inorganics					0.00028		kg PM2.5 eq
Global warming					0.21849		kg CO2 eq
Respiratory organics				0.00019		kg C2H4 eq	
Aquatic ecotoxicity				11.73853			kg TEG water

Ionising radiation	0.84441	Bq C-14 eq
Land occupation	0.00035	m2org.arable
Mineral extraction	0.00458	MJ surplus
Ozone layer depletion	9.44501E-9	kg CFC-11 eq
Non-carcinogens	0.00177	kg C2H3Cl eq
Terrestrial ecotoxicity	3.23012	kg TEG soil

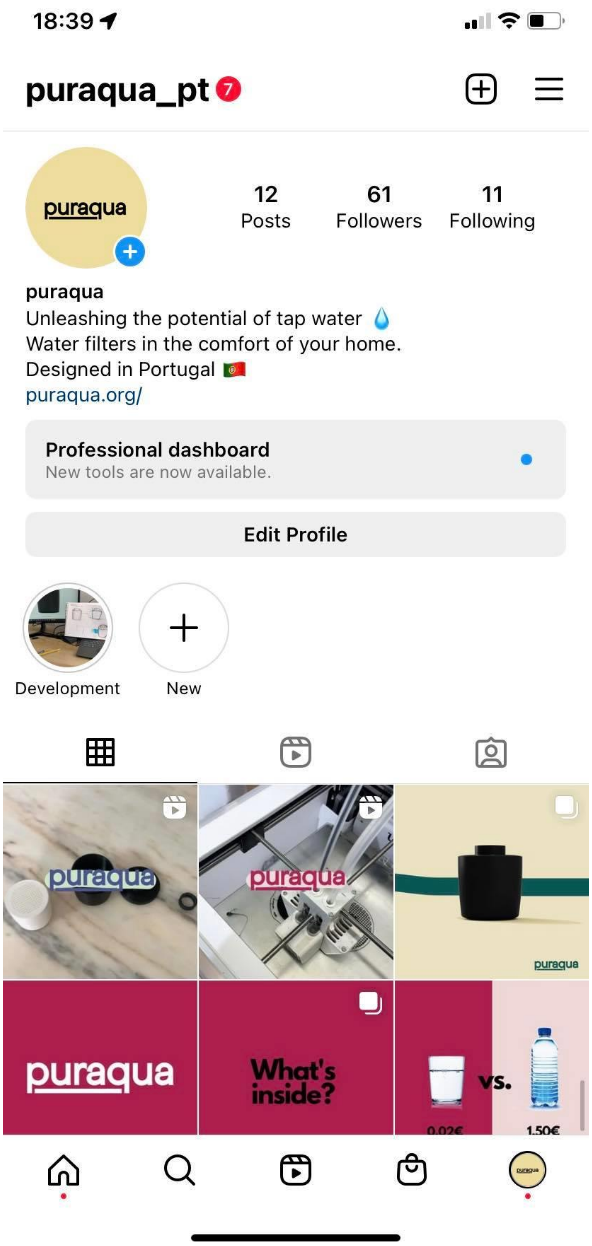
Casing Production

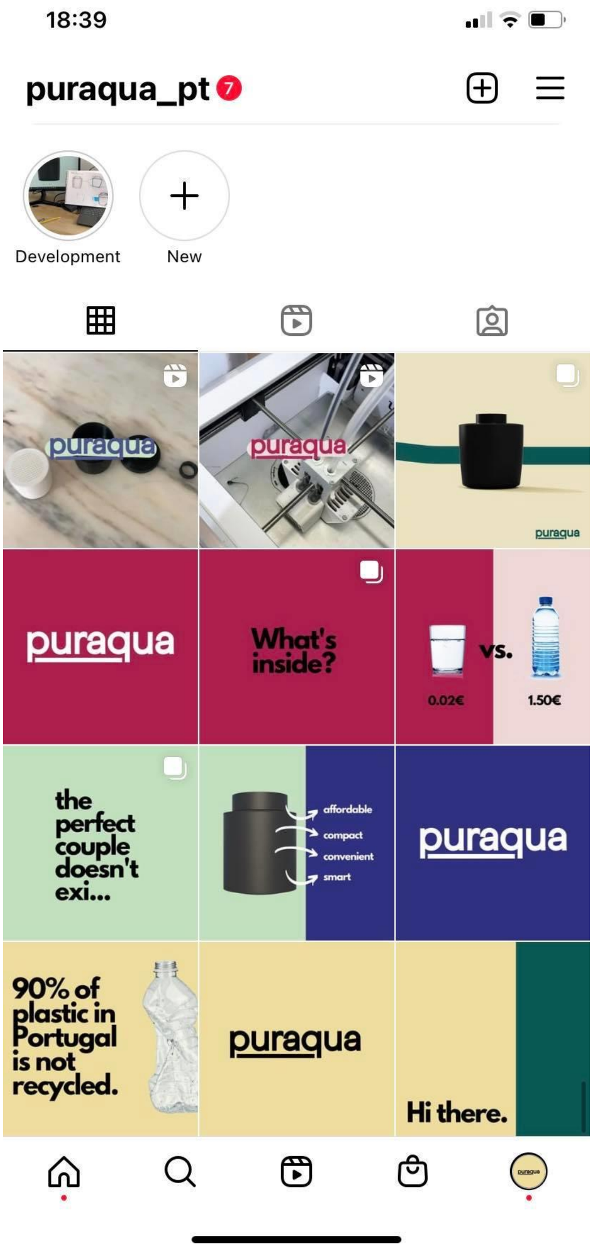


Name	Category	Inventory Result	Unit	Impact Factor	Unit	Impact Result	Unit
Aquatic acidification				0.00255		kg SO2 eq	
Terrestrial acid/nutri				0.00679		kg SO2 eq	
Carcinogens				0.00248	kg C2H3Cl eq		

Aquatic eutrophication	3.26162E-5	kg PO4 P-lim
Non-renewable energy	4.01310	MJ primary
Respiratory inorganics	0.00040	kg PM2.5 eq
Global warming	0.32188	kg CO2 eq
Respiratory organics	0.00031	kg C2H4 eq
Aquatic ecotoxicity	8.62124	kg TEG water
Ionising radiation	0.60747	Bq C-14 eq
Land occupation	-0.00028	m2org.arable
Mineral extraction	0.00361	MJ surplus
Ozone layer depletion	1.30536E-8	kg CFC-11 eq
Non-carcinogens	0.00126	kg C2H3Cl eq
Terrestrial ecotoxicity	2.76207	kg TEG soil

Appendix 11 – Social Media





Appendix 12 – Email Quotes

From: Luis Barroca Monteiro | Zero P <luis.monteiro@zerop.pt>
Sent: 28 September 2022 16:29
To: Alexander Josef Ludwig <50569@novasbe.pt>
Subject: RE: Potential collaboration with Puraqua

Hi Alex,

Do you have any image/picture of the final product?

Are you willing to produce how many pieces?

For moving on with this, we need to produce a mould for each part. Tomorrow I am going to have a meeting with a company that wants to present me a new way to produce fast and less expensive moulds, precisely to the testing phase. Might be something good in this phase.

Or, we can try top produce it with 3D printing.

For you to have an idea, each mold nowadays for this will require around 500,00€.

Best regards,

Luís Barroca Monteiro
Marketing & Sales
www.zerop.pt | +351 965 580 214

EXPLOSION_ASSMB v4.stl
4 MB

exploded seriesb.png
1016 KB

002_aSSEMBLY_2022-Sep-28_03-59-54PM-000_CustomizedView7564365599_png.png

Hi Luis,

I have attached the images to this email. Also, I have exported an .stl file of the explosion so you can see it in 3d as well.

We were hoping to produce 100 units of each of the components (although this number is just an estimate for now). Therefore, the tooling does not to be very durable so a less expensive mould would fit the project well. For our project CNC'd aluminium moulds would be a bit overkill for what we are trying to do so if we could find a way to create less expensive moulds that would be great.

3D printing would be a solution we could look into as well. We are currently using 3d prints for prototyping. If we could figure out a way to efficiently use 3d printing for manufacturing that could be a great solution as well.

Kind Regards,

Alex