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Designed to Keep.

A study in developing customization and added value, through strategic management of product architecture and component modularity in the design of a coffee maker.

A thesis presented in partial fulfillment of the requirements for the degree of Masters of design
at Massey University, Wellington, New Zealand.

Karun Sudhakar
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Abstract:

Environmentalism in design has taken an approach around efficient use, reuse and disposal of materials and energy leading to greener growth. However we are still burdened with an already high and growing (68% increase per day in the last 57 years¹) volume waste stream that creates problems when trying to employ methods such as recycling and biodegradability. Even with best practices, the sheer quantity far outweighs the capabilities of our infrastructure. "Of the 267.8 million tons of municipal solid waste generated by Americans in 2017, only 94.2 million tons were recycled or composted"². "If a recyclable item does not reach the appropriate processing facilities to be recycled it'll be destined for the landfill regardless of its potential to be recycled."³

This study explores a middle ground to reduce the high waste stream within consumer electronics, by employing intrinsic and emotionally durable design strategies to extend a product's usable life. This is intended to reduce the volume of our waste streams over time, minimizing the environmental impact of unrecoverable embedded energy of manufacturing, transport and other energy costs.

This practice-based research explores the opportunity modular product architecture provides in developing: repair and serviceability, encouraging open source and third party component development, extending product life cycles and engendering attachment in the development of a case study coffee machine.

Coffee is currently made in a range of brewing processes, each with their own preferences. This results in many users owning multiple and different coffee machines with many similar parts that perform in similar ways. Coffee culture is diverse and is supplied by a large range of consumer electronic products along with more bespoke batch produced coffee machines for particular requirements of niche market segments. Volume produced coffee machines are part of the 13% of household electronics that gets replaced within the first 5 years of life.⁴

Research was informed by case study analysis from a range of sectors that employed product strategies and approaches that showcased the use of component sharing, modularity and product repairability to extend the meaningful life of products and engagement with the consumer. A design strategy was established that used at its base a modular product architecture. This enabled a product system to be developed that: provided customization of the system for particular coffee brew processes, accessibility for serviceability and repair, and the provision for third party suppliers to contribute customized components to the system.

Four different methods of coffee preparation were developed within an overall system, consisting of a base module of pour over coffee, drip coffee, cold brew, and automatic pour over coffee. A prototyping strategy was employed in the development of the design with a focus on the refinement of individual modular components that made up the product system. An integrated prototype that combined modular components, testing of the logistics and basic functionality of the system was achieved. From this testing,

direct links between user experience and the design of individual components within the system were made. The careful management of design specification for components collectively contributed to the overall desired product experience. Further usability testing would be required to validate aspects of product interaction and this would usefully inform the progression of the products design.

The product strategy approach employed in this case study coffee machine design, would appear to have further application for other consumer electronic products seeking to extend their usable life and lessen the impact on downstream waste streams.



The Case for longer lasting Products

With environmentalism as the forefront of our design responsibilities today, there have been multiple advances in materials, manufacturing and recycling. A modern lifestyle has now started to include these commitments to conscious consumer choices. The industry however has the tendency to focus on the symptoms of our consumerism, with goals in recycling and biodegradability, in attempt to keep the problems at bay. This is undoubtedly important but is a single pronged approach. In my opinion, as well as those such as Saul Griffith⁵, this approach misses a large portion of the problem which is prolonging the useful life of our objects. Griffith proposes, in his publishing "For Keeps" a look at environmental issues as an energy issue rather than a material one. When thought of as a material issue, the focus narrows on the quantity, necessity and post life recovery of objects. Something that is left out of the equation though is the embedded energy in these objects. The energy used to manufacture, transport, sell and then recover/ recycle is all a part of what makes an object and often dwarfs just the material itself when converted into the same units.

This embedded energy can never be recovered in any way other than **by prolonging the useful life of the object itself** and delaying the time before disposal is needed. Therefore material choices for durability above recycle-ability are justifiable if they extend the time before replacement of the overall product. As Griffith Calculates (joules/seconds)⁶ in his example of a cellphone, a 3 year life span results in an energy use of 0.412W versus a 15 year lifespan with 0.082W. I have found this to be described in a few terms such 'transitive'⁷ or 'Heirloom design', where the object is intended to live through a lifetime or longer. There isn't a better way to reduce the result of the equation than by increasing the bottom line, time.

Of course, this can't work for everything in our lives. For instance, this 15 year cellphone example doesn't account for the need for technological development. However, the more of the object we can retain for longer, the better. When objects are split up into their individual components many can be found to remain consistent through development. If these are

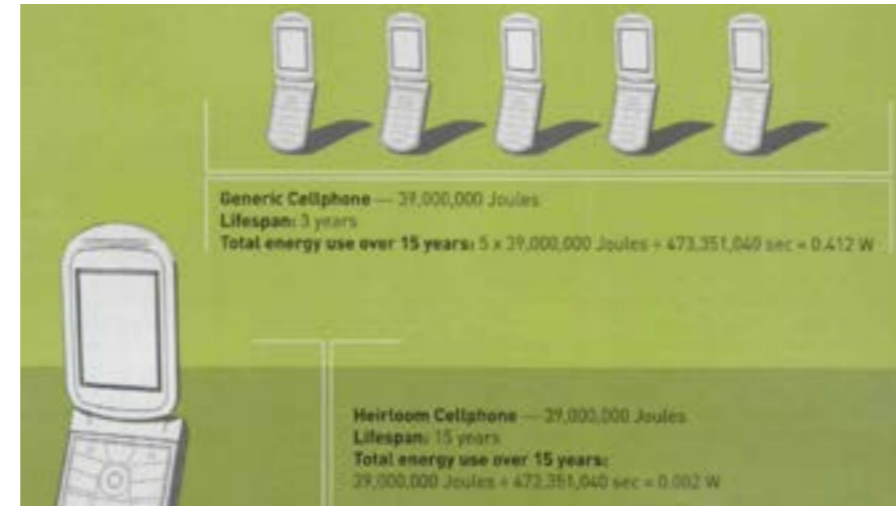


Figure 1- For Keeps, Saul Griffith

Saul Griffith "the energy problem": (Study by Perdue University)

- 18% purchasing energy for homes
- 18% fuel for cars
- 4% retail of stuff**
- 12% retail for services
- 6% production and distribution of energy
- 20% production of stuff**
- 10% production of imported stuff**
- 10% transportation of stuff and services**

Figure 2- For Keeps, Saul Griffith

designed to be kept and reused, the overall waste of the object is significantly minimized. An example of this is the 'Fair-phone' project⁸, where a cellphone is broken down to modular 'chunks'⁹ that can be

Triple bottom line sustainability:

When looking at any change toward sustainability it is important to look at it beyond solely an environmental problem. Triple bottom line sustainability is defined as "a framework that incorporates three dimensions of performance: social, environmental and financial."¹⁰ It was developed by John Elkington in the mid 1990's to involve environmentalism into corporate measurements of success. Today it also functions as a means to understanding the efficacy of environmental initiatives as complex "wicked problems"¹¹ that act as a balance of trade offs.

In the context of longer lasting products, Increased product durability would require a restructuring of industry to accommodate a new type and quantity of demand. As seen in Figure 3 slowing consumption on its own might seem to be an environmentally sustainable solution but would need the use of increased product life spans and alternative sources of income to meet the current needs of consumers and remain economically viable. These alternative solutions could include pricing based on predicted life spans and the revival of the otherwise slowing repair industry. This would shift production from a machine heavy industry of manufacture that produces quantity toward a skill based quality centric method of production. "The OECD noted concerns that a policy to encourage producers to manufacture longer lived products would cause unemployment but concluded

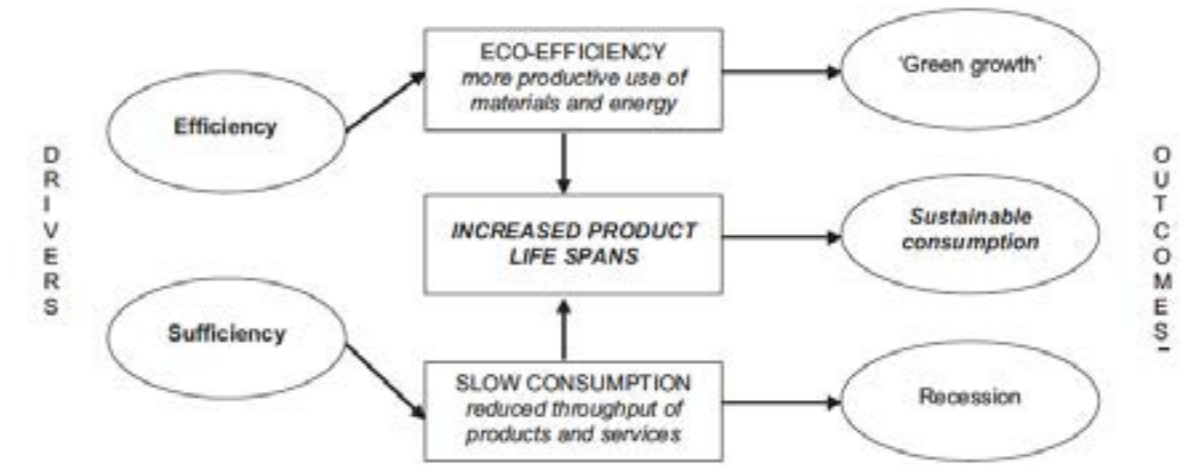


Figure 3- Longer lasting products, Tim Cooper

that product life extensions would benefit employment levels because repair and maintenance work is labor intensive."¹² Questions arise such as if industry will choose to respond without government or consumer demand, as well as if consumers will be willing to pay more for quality if they had better information toward anticipated lifespans. It might require producer responsibility legislation as seen with the auto industry.¹³

Important social issues arise as well, such as the ability to meet the **needs of less affluent households** that might not be able to afford higher initial investment of a higher quality product even when offset by long term value. An answer to this could be a **better structured second hand market such as with the auto industry, where used and refurbished objects continue their use**

within a secondary market. How might objects be created with this as an intentional decision to product life cycle? Objects would have to be built to last and **have the ability to be restored through repair as well as provide pride and dignity to its secondary owners.** "Producers will exploit the existing stock of goods in order to make more money with less resource input. Meanwhile the 'consumer' becomes a 'user' as ownership is replaced by stewardship."¹⁴

Using a strategy similar to Patagonia's "Worn wear" system objects can be refinished and resold by third party vendors at a lower price point. Another option for lower income groups might be buying a lower priced system that can be worked on and added to over time. Third party suppliers may provide cheaper components to integrate with existing systems.

Dealing with time



Image from "Azio corp Retro Classic USB."



Image from "Vintage Pioneer SA-8500 Amp in Beautiful Condition - Photo474341."

Understanding Obsolescence:

"Something that is no longer useful or significant"¹⁵
Product obsolescence can be divided into two main categories, absolute and relative obsolescence.

Absolute obsolescence - "occurs when an object reaches the end of its technical life because its durability is expended."¹⁶

This form of obsolescence deals heavily with the objects construction and the choices that are made for it to withstand a long use-case and the ability to return functionality through repair and upgrade-ability.

Relative obsolescence¹⁷ - is the more complicated of the two where a still functional product is discarded and replaced due to psychological, economic or technological factors.

Relative obsolescence is an area that is difficult due to the compounding, case-by-case issues that cause a person to replace an object. As mentioned previously, reasons can stem from technological factors such as newer more efficient discovery and so a product must

consider and afford for future upgrade-ability if it exists within a rapidly changing industry. The decision for replacement can also be economical whereby the original and replacement cost of product, together with the rate at which product depreciates (and thus any second-hand value), will influence the point at which owners consider it no longer worth maintaining. Most of this however can be addressed through a strengthening in the psychological bond between person and object. In 'Emotionally durable design', Johnathan Chapman writes about producing objects that create more potent sensory and emotional resonance. He attributes wasted objects to being potentially symptomatic of a failed relationships between object and user where the object failed to meet a need for mutual evolution between the consumer and the consumed. The example of art is given where contemplative works rarely surrender all meaning at a single glance, but instead provide layers of meaning to provide a lifetime of incremental revelations. 'It is time for a new generation of products that can age slowly and in a dignified way ... [to] become our partners in life and support our memories.'¹⁸

In order to create longer lasting objects, aspects of both of these have to be addressed. Absolute can be looked at as understanding the object itself and its use, while relative might be seen as an understanding the user. An object needs the ability for maintenance and repair as well as the ability to convince the user to undertake doing so.



Image from California Polytechnic State University and Twitter, "Repair-Ware' Household Gadgets Designed to Last Forever With Easy Fixability."

Design For durability and repair

It is estimated that 80% of a products environmental impact is determined at the design stage¹⁹



Image from "Phonebloks Mobile Phone Concept by Dave Hakkens."



Image from "Repair It Yourself by Eugenia Morpurgo."

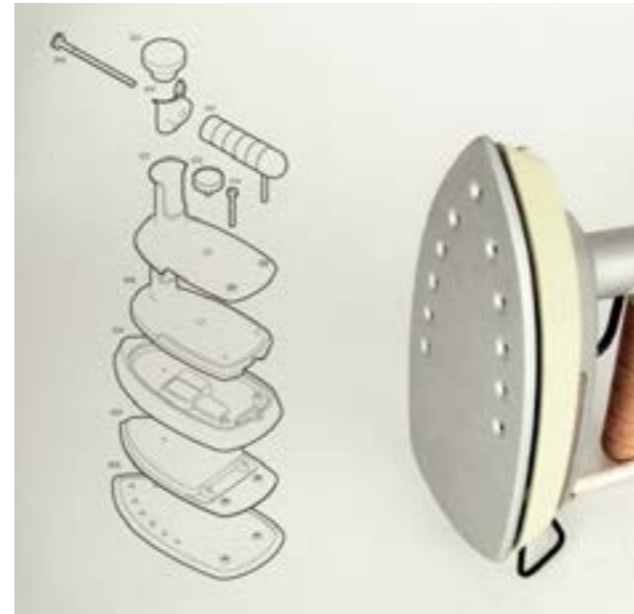


Image from California Polytechnic State University and Twitter, "'Repair-Ware' Household Gadgets Designed to Last Forever With Easy Fixability."

Reparability is a consumer right that has become difficult to attain in recent times. Today's objects seem to be reminiscent of the same 'hostile design'²⁰ principles applied to public spaces for crime prevention, except the crime seems to be attempting to try to fix and restore the things we own. Companies like Apple are known for using magnetized screws and their infamous T2 chips²¹ that serve the sole function as kill switches to the objects they inhabit, or intentionally gluing parts for no reason other than to make them hard to remove without damage. We have also heard of multiple cases now where they promote fear by way of legal action such as the example of Eric Lundgrin²² who spent two years in prison for duplicating and sharing the free software restore discs that Microsoft stopped supporting themselves.

Modern objects have become designed to be easier to replace than repair, creating reliable but unsustainable consumption. These

practices provide all the benefits to a company and none to consumers but are hidden under the guise of protecting people from themselves. Recent push-back such as 'the right to repair bill'²³, consisting of independent repairers like Louis Rossmann and heavy support from conscious companies such as iFixit, move towards a more positive market but still face enormous struggle against corporate interests. These legal battles struggle to find traction for change unless they become consumer driven. "It cannot be said that the law relating to the supply of goods makes a very significant contribution to ensuring that goods are durable. It has taken many years even to establish clearly that goods have to be durable as part of the more general requirement that they should be of satisfactory quality."²⁴ Previous government led initiatives such as the EU Eco Label, struggled to gain traction even with relaxed guidelines.

A once thriving skill based secondary industry of repair has been replaced in a generation, toward manufactured abundance that undercuts economic incentive to make things last without consideration to social or environmental implications. It is time for responsible creation with a true user centered approach, through education and support. Some industries such as power tools and automotive as well as some private organizations such as iFixit and Patagonia (as shown in case studies) have taken it upon themselves to address repair, repackaging it as a major selling point. I hope to learn from them and follow suit.

Durability is defined as the ability for an object to perform its required function over a lengthy period under normal conditions of use without excessive expenditure on maintenance or repair. "Durability is one of the most obvious strategies for reducing waste and increasing material productivity"²⁵. Designing for durability may in some cases seem counterproductive to general environmentally conscious practices. It could require choices such as using thicker gauge surfaces or shells, adding additional diagnostic parts and information, applying non-recyclable tougher material coatings or using non-recyclable materials (e.g. composites, ceramics, certain plastics). These decisions in the larger scheme might mean that the extra embedded energy is outweighed by the extended use they permit.



Image from "Feting Sustainable Design."



Image from "BuyMeOnce | Selling Products That Are Built To Last."

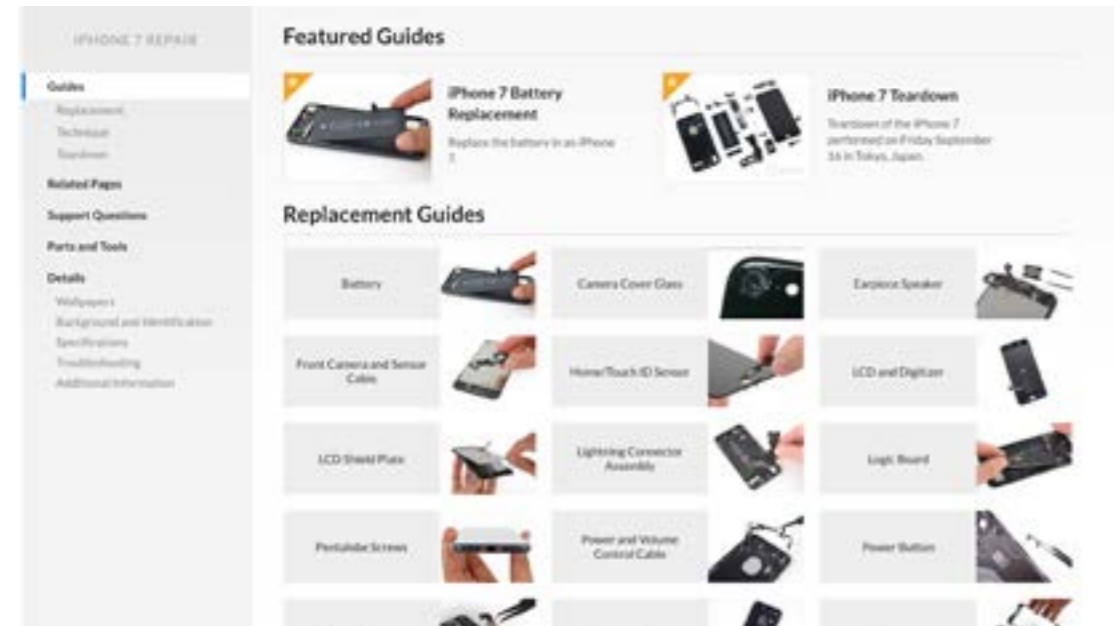


Image from "Muuto Control Table Lamp, Black."



Case studies on repair

IFixit



Images from "iPhone 7 Repair - IFixit."

In the past few years there have been a few outliers that have taken real steps towards repairable as a form of prolonging product life as a business model. One of these outliers is IFixit, a company based as the leader in providing good free information to help not only the DIY community, but also your average user, repair every aspect of their electronic devices. They provide the information for free and charge fair rates for parts and tools that can all now be sourced directly by the consumer from one accessible place.

Initially the company started as a DIY forum community where people shared information themselves. This quickly grew and changed into very cleanly laid out, free instructional videos with no barrier to entry. The business is sustained through providing parts and tools that previously would have been inaccessible to the customers as they had to be directly sourced from manufacturers in bulk. Each repair is rated in terms of difficulty, with a list of particular things to watch out for. This does a very good job of minimizing the risk and potential for failure for the user from the beginning. - Minimize Embarrassment and Risk - "Ensure that 'failure' in the user's interactions with the product will not carry unfortunate consequences. Not to do so may result in a lack of user trust in the product, wrong actions being carried out, product breakage or, in the case of large machinery or high-powered equipment, physical injury."²⁶



Step 4



Image from "Patagonia Wheeled Luggage Repair - IFixit."

Every step can then be walked through in the form of pictures and detailed step by step instructions. Screws and parts are retroactively colour coded digitally in the pictures to minimise confusion. This is a successful technique that is now being used in the manufacturing process itself when companies like Patagonia design in partnership with IFixit. This is a large step forward for repair. I aim to continue this within my final outcome to add elements of instruction that can be used by online tutorials such as this to minimise confusion and the intimidation of repair.

Case studies on repair

A big challenge in repair is combating the stigma associated with older or used things being worse in some way to their new counterparts. The market has naturally started to shift toward it in recent years with the rise in used or thrift clothing and objects with a story. Today it isn't uncommon within the younger generations for used/vintage objects to be highly sought after due to the perceived value in authenticity brought on by use. This has been aided by companies like Patagonia who have been a company closely tied to environmentally conscious design and have been able to make it a large part of who they are with the help of a supportive customer base. They have taken it upon themselves to encourage repair and build pride in an object that is well worn. They aim to try and



WORN WEAR

What is Worn Wear?

Worn Wear is a set of tools to help our customers partner with Patagonia to take mutual responsibility to extend the life of the products Patagonia makes and customers purchase. The program provides significant resources for responsible care, repair, reuse and resale, and recycling at the end of a garment's life.

Images from "Worn Wear - Used Patagonia Clothing & Gear."

Patagonia



Scars Tell the Story

All items are functionally perfect, but may show signs of wear and repair.

Excellent Condition
Looks & feels like it never left the closet.

Great Condition
Small signs of visible wear.

Good Condition
Visible scars from repairs, normal wear & adventures.

re-brand wear as the things that tell stories and the purpose of their products.

Patagonia has been a long time proponent of repair describing it by saying "Why extend the life of gear? Because the best thing we can do for the planet is cut down on consumption and get more use out of stuff we already own."²⁷ Unlike most other brands they are highly supportive of repair and back it up through their 'Worn wear program'. The program aims to encourage repair through a multi pronged approach. Firstly they provide education through detailed Online tutorial videos created in partnership with iFixit, as well as in person traveling workshops that provide all the supplies needed and an offer of being able to keep anything you repair. The second prong is removing the fear of failure by offering comprehensive trade in programs and a promise that repair doesn't affect



Image from "Worn Wear - Used Patagonia Clothing & Gear."

their lifetime warranties. The third part is one of the largest repair and resale programs of their own, repairing an estimated 40,000 pieces²⁸ annually which are then resold at a discounted rate providing access to high quality products to customers that may not have been able to afford them new. They allow customers to send or bring in usable products to be part of a buy back program where they can be resold. The idea is to create a teared pricing system where used goods can be the cheaper alternative, while still allowing everyone access to higher quality well thought out goods. This program is supported by a company called Yerdle who specializes in optimizing resale platforms. They handle collection, cleaning and sorting, photography and seamless integration into Patagonia's existing sales platform. Through support by companies such as Patagonia, Trove²⁹ has been able to expand this model to other like minded companies.

These companies have taken the first steps to establish a moral yet economically sustainable system outside the individual products. I think this will be seen as the beginning to a necessary future of business, and would like to be an example for the way in which my project might be brought to market.

Choosing Consumer electronics

When I began my research, I found that an industry with objects that have a particular inability to stand the test of time is that of consumer electronics. 13% of household electronics get replaced within the first 5 years of life, out of which a mere 29% of the resulting e-waste gets recycled³⁰. The rest of this waste ends up being shipped to landfills in developing countries, thus compounding large social issues on top of an already large environmental one. Due to their functions, consumer electronics also use a larger percentage of our valuable limited materials such gold, silver and copper in complicated structures that make them hard to separate post life. They also create exponentially more complexity thus creating many more opportunities for failure. Repair of these objects tends to have a higher barrier of entry due to a general fear within consumers of damage or injury when performed without adequate knowledge. "Appropriate involvement of the user with the product is essential. Perhaps the greatest current challenge to product designers is to offer formal clues or indicators that reflect appropriate longevity, environmental impacts, durability, use, repair and, finally, discard, particularly for electrical and electronic products. In the case of these products the user has largely been removed from such involvement. The automobile, too, was until relatively recently a product to be tinkered with by users. Now, through electronics and computer controls, users are largely excluded from potentially preventative and operational maintenance"³¹. This fear, along with intentional limiting of access to information, has been perpetuated by manufacturers of objects to create distrust in the repair industry and encourage replacement instead.

All of this makes for a daunting, complicated problem. However, as shown by companies such as iFixit, the user's ability and support in embracing complicated solutions, when provided with the option and proper knowledge cannot be underestimated.

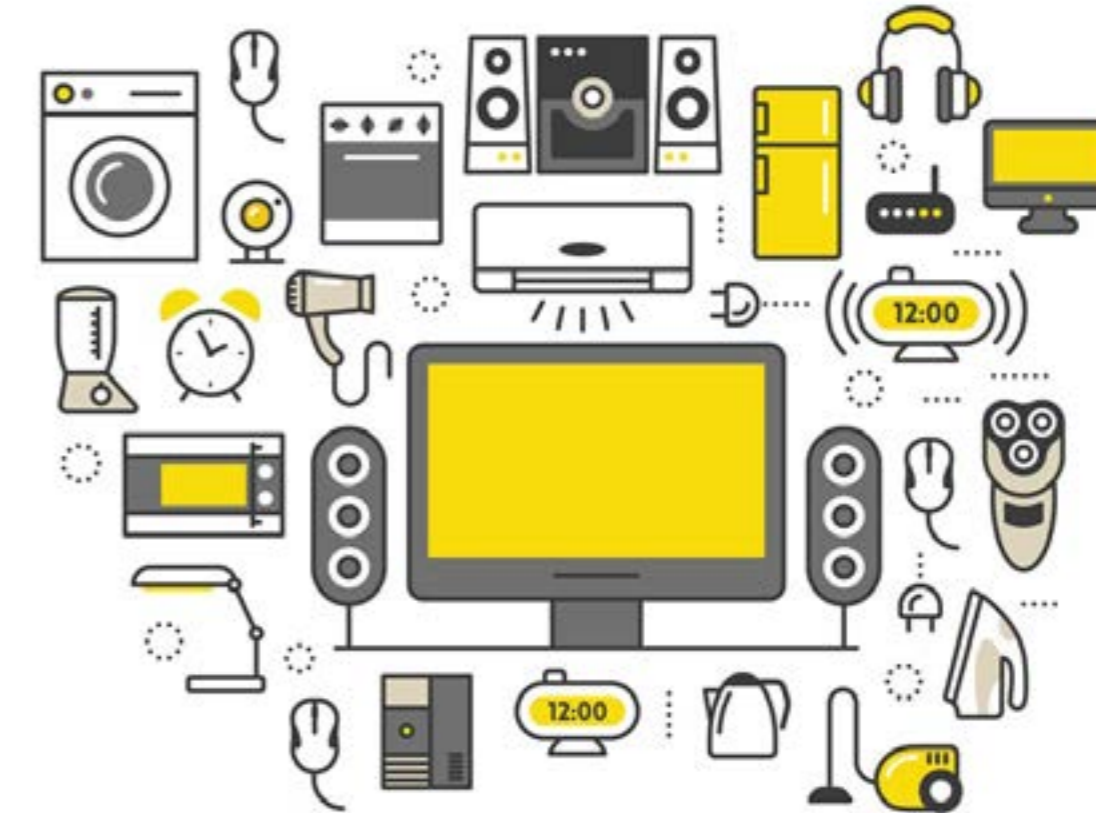


Image from "5 Marketing Strategies for Electronics Shops [> 2020 <]."

The coffee market as an opportunity

The coffee industry provided a unique opportunity for me to create an object that could act as a proof of concept to be applied to the consumer electronics as a whole. The coffee industry has experienced large growth of 8.7% annually in recent years³². A large portion of this growing market consists of prosumer/ hobbyists where more resources, effort and care are allocated to their objects. It is also an industry that responds well to smaller batch produced objects penetrating the market. At the time of writing this 3929 projects on Kickstarter are related to coffee.

Another benefit to designing for coffee is the readily available access to research for functionality and preparation. Many parameters for the process such as water temperature, grind size, even extraction and flow rate have already been heavily researched and standardized, thus giving parameters for an object to meet and be evaluated against. Many objects in coffee have the ability to stay relatively consistent in function. They don't experience major technological obsolescence through changes such as in products like cell phones. A coffee machine from the 80s such as those developed by Braun stay equally competitive and similar to machines created today 40 years later. Therefore, it makes sense to try and design these objects to withstand this consistent function, for longer periods of time and minimize reasons for disposal.



Image from "Espresso Del Real."

Blooming coffee (Pre infusion):

- In order to degas carbon dioxide
- Open up the pores in the cellulose structure
- Allow coffee to reach its saturation point so it dissolves when water is added next
- 30 Seconds
- 2:1 Or 3:1 water to coffee grounds for bloom (Hario V60 technique)

Actual pour:

- Even controlled pour
- Approximately 1 min
- Then pour through last quarter

3 min 30 seconds total brew time.

Ideal water temp: 90- 96 Celsius



Image from "Most Optimal Coffee Water Ratio - Coffee Basics | Friedcoffee."

Product architecture for repair

Another aspect in building user object bonds would be the appropriate involvement of the user with the product. One of the things we can learn from lasting objects of the past was the need for a user to be invested somewhat in the object themselves. This investment added worth by playing on a feeling of pride and familiarity.

-‘Rather than planned obsolescence the goal should be to achieve longer product life-spans by adopting strategies such as the design of up-gradable and repairable products and the production of more durable goods’ -the World Business Council for Sustainable Development

Modularity

Modularity is the division of an object into an arrangement of its separate individual chunks. This arrangement is dictated by a clearly defined language to integrate within. These languages can be divided into three distinct groups; Slot, Bus and Sectional modularity. For the purpose of my project I will be focusing on the relevant slot and bus modularity.

Slot Modular architecture:

Each of the interfaces between chunks in a slot modular architecture is of a different type from the others, so that the various chunks in the product cannot be interchanged. This minimizes confusion of chunks and therefore promotes ease of assembly. It also allows for an object’s chunks to be separated by category when integrating with the common bus.

Bus Modular architecture:

In a bus modular architecture, there is a common bus to which the other chunks connect via the same type of interface. This allows for universality as any chunk can be used with any point on the common bus. It therefore does not provide methods to physically differentiate between chunks during assembly.

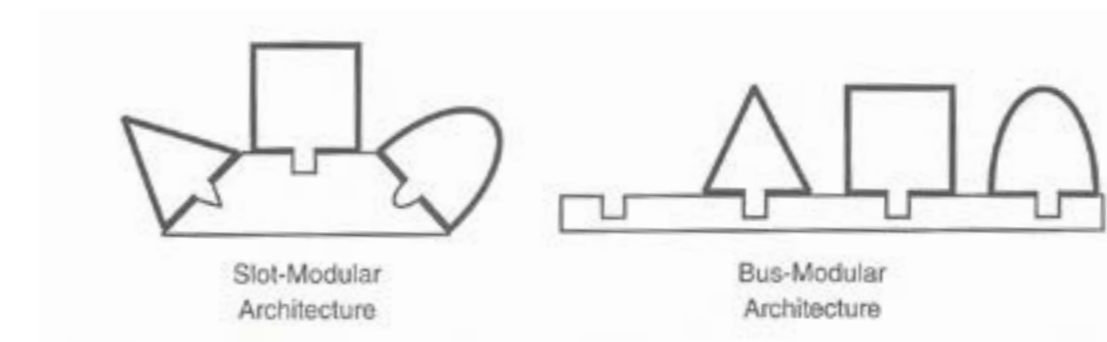


Figure 4 ‘Eppinger and Ulrich, Product Design and Development’.

The opportunity of Functional modularity:

Modularity can be extrapolated from the objects construction as a single unit to that of a larger system. A system can be created where a single central bus can have its functionality adapted through the integration of additional chunks. Multiple modes of functionality can then be achieved by different combinations of chunks. If a single chunk needed to be changed or adapted this could be done with minimal impact to the other chunks while still allowing the object to function in modes not relating to that chunk. This creates an opportunity for easy repair or replacement without disposal of the object in entirety, as well as multiple opportunities to adapt the object to stay relevant.

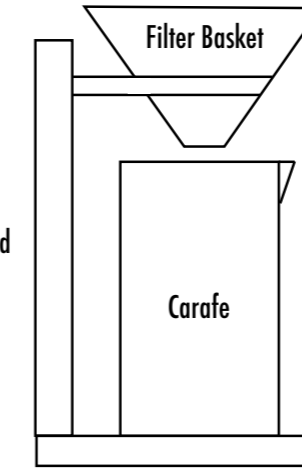
This is where an opportunity in coffee opens up due to its many preparation methods that vary in complexity. When studying these methods of preparation at their core parts I was able to find four methods that shared **similar base arrangements**. The core arrangement seemed to revolve around the Pour Over method due to its relative simplicity. This system consists of a filter-basket to hold the coffee grounds, a carafe or vessel to catch the filtered coffee, and a stand to hold the components. This **Pour over system could serve as the 'Central-bus'**. **From here the object can receive separate chunks as kits** to function as a Cold brew, Drip coffee or Automated pour over in order of complexity. If a specific part or kit were to fail the object can always **continue its function as a base model pour over** or one of the other systems.



Image from "NY Design Week 2012."

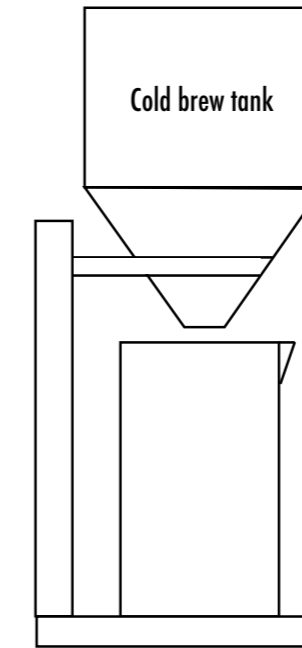
Pour-Over

Hot water is poured over the grounds by hand, creating a controlled clean brew with even extraction of all the coffee. This however requires user expertise.



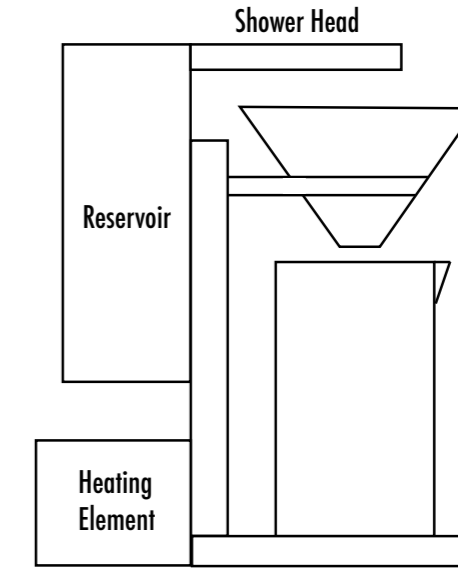
Cold Brew

Cold water is slowly dripped over the grounds over a long period of time. Creating a cold infusion process.



Automatic Drip

Hot water is Automatically dripped over the grounds creating an easy set and forget process.



Automatic Pour-Over

Hot water is poured over the grounds In the same circular motion for even extraction as in a pour over but done so with the same automatic convenience of the drip method.

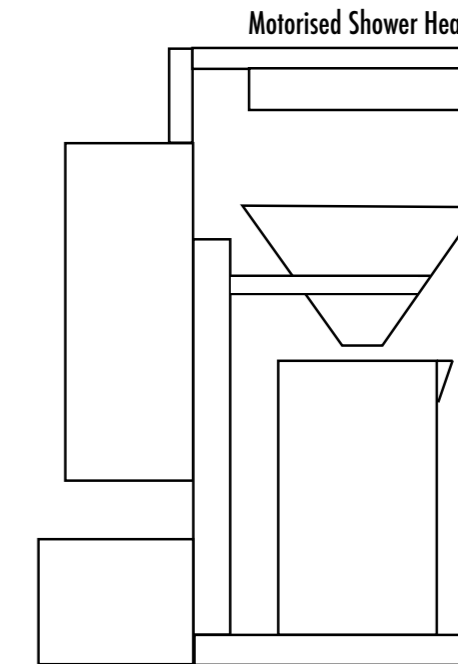


Figure 5 'By Author'

Design For disassembly:

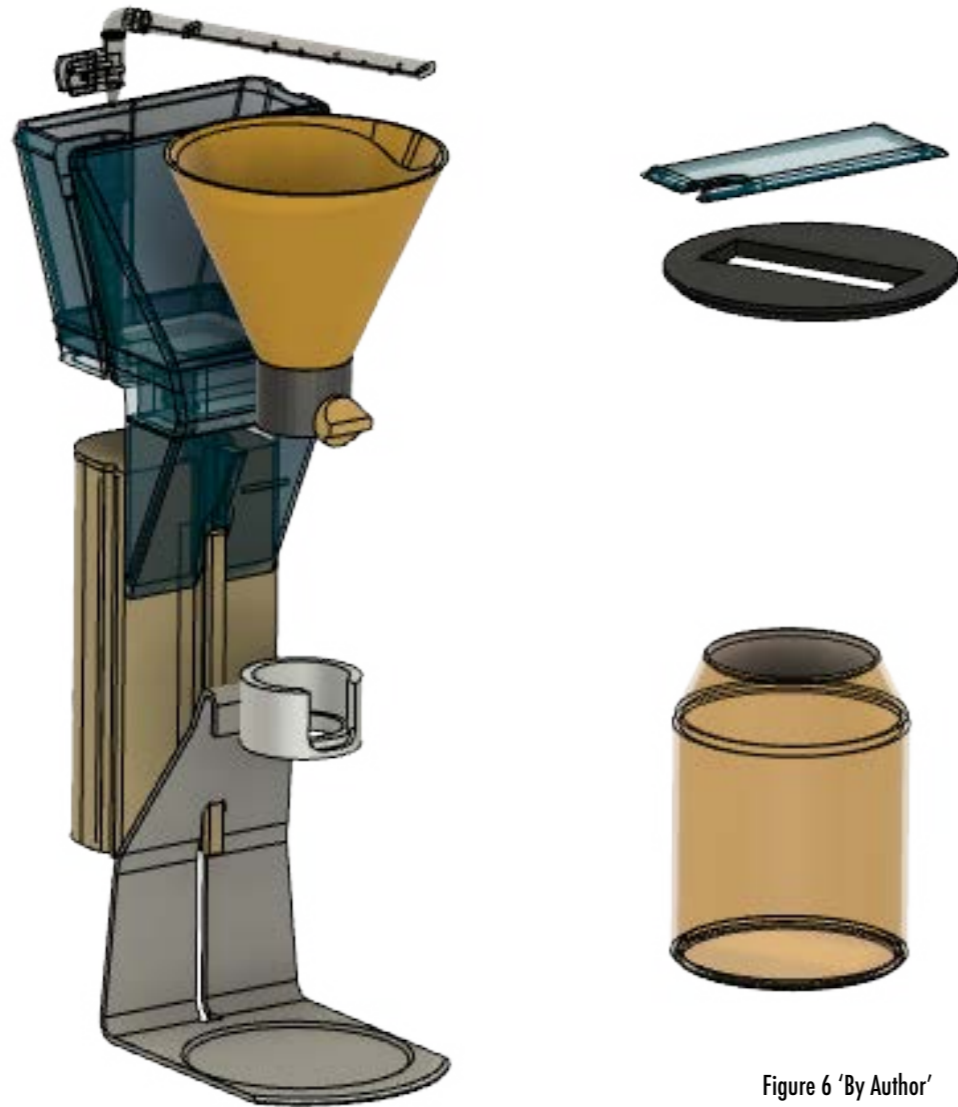


Figure 6 'By Author'

One of the primary barriers of entry for repair of many modern consumer electronics, as shown in the Breville grinder case study, is the difficulty of disassembly. Disassembly can be daunting as it usually renders the object disabled once started. Consumer electronics also tend to be mass produced and machine assembled thus causing objects that have to be disassembled in layers with limited access. There are some design principles that can be applied from case studies in other industries.

The automotive industry can be looked at a particularly good example of repair out of necessity. Cars tend to have a harsh use case with an expectation of maintenance and repair over a very long-life span. The chances of damage is high and the repercussions of failure are high both when measured financially as well as in risk to life. Therefore, the industry has always had repair in their best interest and have always accounted for it. This gives a well-developed example to borrow principles from when thinking about design for repair. Most of the benefits can be found in manufacturing choices starting with those of product architecture types.

Case studies on Disassembly

Monocoque



Image from "The Car That Changed Formula 1 History."

Monocoque Chassis were initially developed for racing applications brought about by advanced material molding and fabrication techniques, allowing for lightweight minimum material fabrication. Monocoque chassis use an external shell that performs both as a visual and functional layer.

Positives:

- Allow for effective use of mold manufacturing techniques.
- Created ultralight-weight objects with minimal material use.
- Can create very rigid predictable structures as there are less moving parts.

Negatives:

- Access can be difficult as components are usually housed inside or around single piece shell.
- Very difficult and expensive to repair as damage or cracks require the entire part or chassis to be replaced. The object cant be broken down into segments easily. Replacements also require industrial tooling due to complex forms.
- Visual (Outer) layer and structural layer are the same and so ware cant be addressed without also dealing with the structural aspects of the system. Therefore overall expertise is required for any repair.



Image from "Williams FW08 Cosworth - Chassis."

Unibody

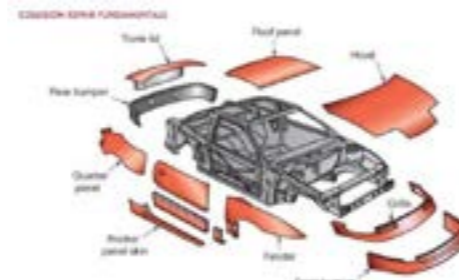


Image from "Chapter 9 Vehicle Construction. Objectives Define the Most Important Parts of a Vehicle."



Image from "Audi A3 - Materials in the Body Structure - Car Body Design."



Image from "Chassis Archives."

Unibody construction is the primary design for most commercial cars today. It consists of a main skeletal frame that components bolt onto, thus creating a main functional structure. That frame is then encapsulated by sectioned body panels that create the outer protective/visual layer.

Positives:

- Allows for easy repair as sections and panels can be replaced or repaired separately as needed.
- Much more flexible material choices that can be based on the function of each layer and segment. For example the bumper can be made out of a polymer to take low speed bumps and scratches as it does not need to be load bearing.
- Repairs can be conducted with minimal investment in tooling. Replacement parts and panels can be purchased.
- Aftermarket bolt on parts can be developed.

Negatives:

- Added processes as components have to be manufactured in different ways and then assembled.
- More material use.

Space-frame



Image from "Car Chassis Vehicle Audi Space Frame, Suspension Hoops Frame, Car, Material, Transport Png | PNGWing."

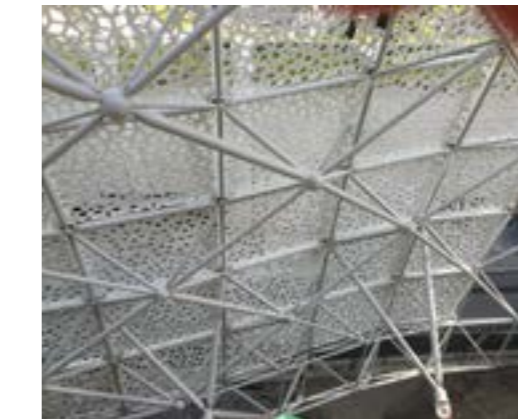


Image from Spaceframes, "Rising Steel Prices Make DSI Spaceframes' Steel Space Frame Structures an Attractive Building System for Today."

Space-Frame construction is a lightweight form of construction similar to the uni-body that utilizes a tubular structure for the frame with external visual panels that bolt on. Unlike Uni-body frames however, external panels in a space frame chassis are purely visual and do not provide any structure. This is all achieved through carefully calculated, cross-braced tubing.

Positives:

- Allows for easy repair as sections and panels can be replaced or repaired separately as needed. Thin flexible materials can be used for the outer layer and bent to shape as not structural.
- Tube frames can be easily cut and repaired with minimal tools. Frame can also be modified easily unlike uni-body.
- Aftermarket bolt on parts can be developed very easily.

Negatives:

- Frame structure can be complicated or restrictive in order to create structure.
- Added processes as components have to be manufactured in different ways and then assembled.
- More material use.



Image from "Tech & Lifestyle, What's Inside a Hammer Drill?"



Images from "iPhone 7 Repair - iFixit."

When Observing the construction of existing electronic objects with automotive construction in mind, we can observe a tendency towards external structures similar to that of Monocoque chassis construction. This provides advantages to manufacturing in cost of materials due to reduced part numbers and material volume, however this does not allow easy disassembly. As seen in the disassembly of the Iphone, components are arranged in a complex, layered arrangement either connected to the front screen or the rear panel. This means that any external damage to the casing or screen would require a full disassembly of the electronics. It also means that access to a single part requires the disassembly of multiple components in layers, thus creating the notoriously difficult object to repair. As seen in the disassembly of the hand drill, all components including the motor and shaft bearings are held in place by plastic tabs molded into the outer shell. This creates a common failure point where any damage to the external housing can cause misalignment of the motor, axle or brushes causing premature wear and failure. For this to be fixed the entire housing has to be replaced needing every component to be transfered over, often becoming cost prohibitive. This is also the case if you want to fix peeling contact points or any external crack, dirt or damage. When disassembling the drill a user would also have to be very mindful of parts falling off and pulling on cables or changing position. A repairer would need prior knowledge of the specific object prior to taking it apart.



Image from "Fairphone | The Phone That Cares for People and Planet."



Image taken by Author

In contrast to this, objects like the FairPhone or the HP Z800 are designed to be highly accessible and repairable. They allow for components to be removed, repaired or replaced without the use of tooling by successfully employing principles of modularity. Both allow for the outer casing to be quickly and easily removed, exposing the functional components. These components remain attached to a central frame, thus retaining functionality and structure even without the external skin. This makes repair less intimidating as it allows a user to explore and learn without needing full knowledge for reassembly beforehand. This is a method of construction that i aim to employ for my product, allowing access to repair of electronic components through removal of external surfaces without having to remove every part. Both objects also effectively employ iconography in order to educate the user and use well designed systems with highlighted touch points and blind mate connectors to mitigate mistakes. This surface application of informative iconography is something i would like to explore in my design.

HP Z800 Workstation

Designed by BMW DesignWorks.

The Hp Z800 was created as Hp's new platform for their work station series. It was designed to work consistently across the line from their introductory price of \$1000 all the way upwards of \$15000. Being a system designed for large fleet applications, the Z series had unique requirements of modularity and easy adaptability. They needed to be easily upgradeable in the large numbers of an office by individual employees quickly. Therefore they were very quick to disassemble without the need for tools. All the objects connect to a central frame similar to that of a uni-body construction in a slot modular fashion so there isn't an opportunity for confusion of parts. All electronics utilize blind mate connectors, which means connection of the electronics were built into the motion of assembly in one simplified action. This means reconnecting cannot be forgotten and false connections cannot be made. All touch points of interaction are donated with a green colouring to create a uniform intuitive language of disassembly. This is aided with useful instructions and information engraved on the inside of the aluminium outer cover plate that is first removed.

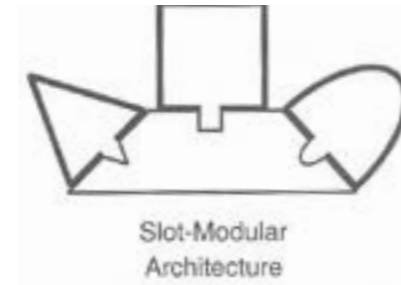


Image taken by Author

Image taken by Author



Image taken by Author



Fair Phone



Images from "Fairphone | The Phone That Cares for People and Planet."



The Fair phone is a very good case study in using slot modularity in an object for upgrade-ability and repair. Fairphone proposes a phone that can easily be taken apart to its base components by the user themselves. Each component functions as its own module that can be replaced or upgraded in the future individually to preserve the whole. Fair phone also provides accessible information as well as connection points that can be easily integrated to allowing for third party adoption. This allows for companies to specialize and develop each component individually, for example Leica could develop their own camera module and Bose could develop a speaker for sale separately.

The design of the fair phone effectively uses transparent material to make the object approachable by showing the user everything. Information is also very clear and informative through effective use of iconography. Just like in the Z800, the fair phone uses blind mate connectors to prevent confusion. The design also uses uni-body construction which is perhaps the most important aspect to their accessible repair, where all parts connect to a center structure which is then covered with an outer panel. This allows for components to be seen and worked on in situation. This is construction is a primary goal within the context of my project.

	Strengths	Weaknesses	Usable Strategies
Automotive Industry	<ul style="list-style-type: none"> - Access to information - Strong Second hand market - Good After-market Support 		<ul style="list-style-type: none"> - Panel on frame construction - Built in diagnostics tools - Use of standardized parts and tooling. - Built for Disassembly - Use of sacrificial/ Replaceable parts
Power Tools	<ul style="list-style-type: none"> - Durable build consumer lead demand - Market Segmented by number of use cycles (home vs Contractor grade) - Backwards compatible and upgradeable - Clear marketing that educates consumer (brush-less, lithium) - Design centered around ergonomics and subtle feel of things, as this is a big deciding factor for brand loyalty. - Brands create long term bond/ Brand loyalty. - Function over form 	<ul style="list-style-type: none"> - External structure tends to support functional components and so can't be refinished (Cleaned up) when product remains functional. 	<ul style="list-style-type: none"> - Well thought out touch points. Ergonomic, durable and satisfying.
Home Electronics	<ul style="list-style-type: none"> - Electronics but still simple enough for the possibility of user involvement. 	<ul style="list-style-type: none"> - Built to a price point, so lots of shortcuts. - Extensive use of artificial market differentiators (Dyson) - Uses integral product architecture. 	

HP Z800 Workstation			<ul style="list-style-type: none"> - Use of Blind Mate electronics connectors. - Green paint to indicate touch points for disassembly. - Very intuitive - No Tools for full disassembly! - Lots of room for expansion. - Slot Modular product architecture - Instructions built in.
Fair Phone	-Completely user Repairable		<ul style="list-style-type: none"> - Effective use of Slot modularity - Good use of product transparency as well as information through Iconography - Use of Blind mate connectors. - Use of Unibody Vs. Monocoque construction.
Patagonia			<ul style="list-style-type: none"> - Embraces supported DIY, so company doesn't have to shoulder all of the repair.

Primary design Criteria for my project:

Continued in appendix

-Object must successfully use bus modularity to create a system where individual components can be removed, replaces and integrated with by third party component manufacturers as done by the Fairphone case study.

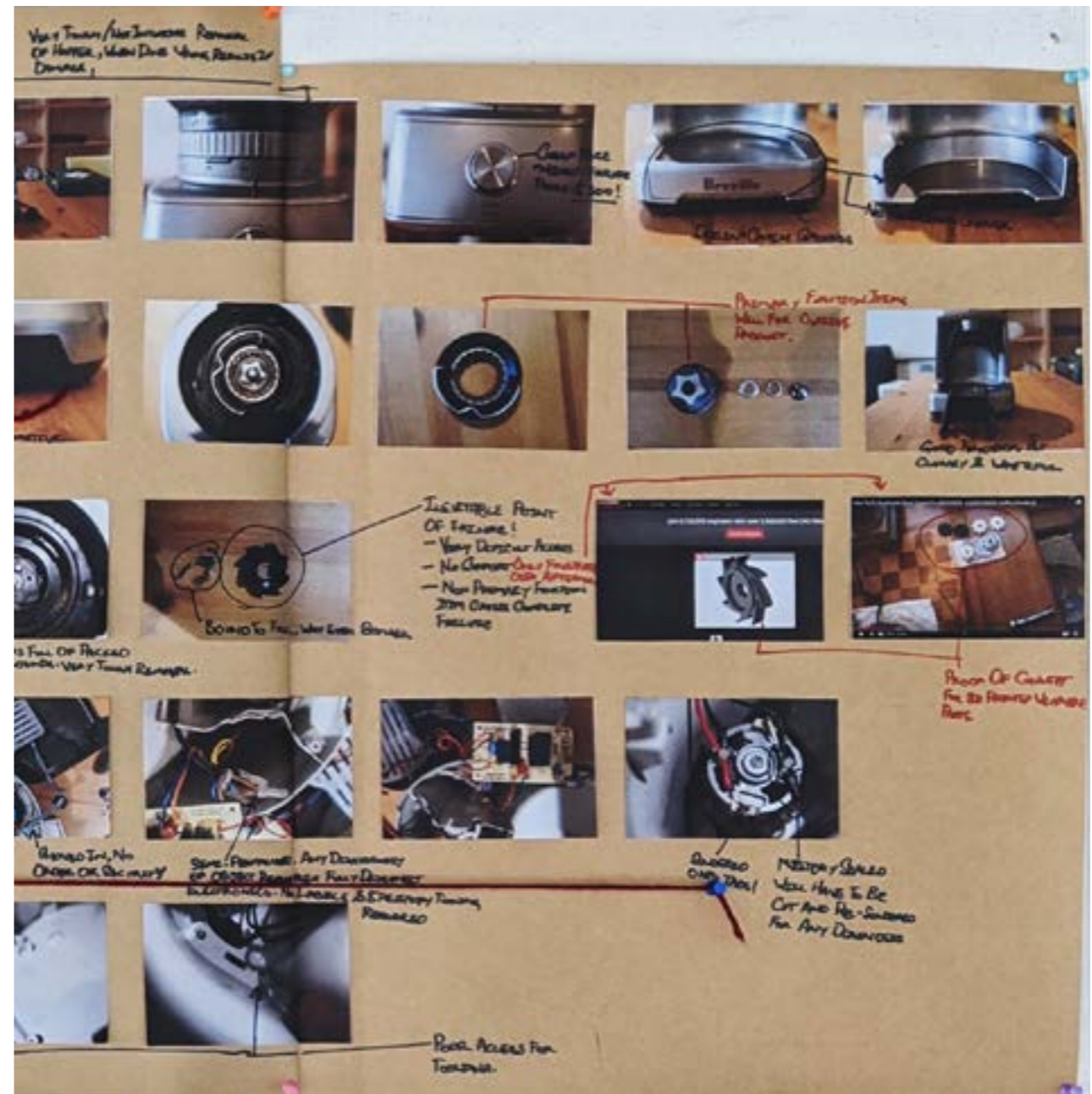
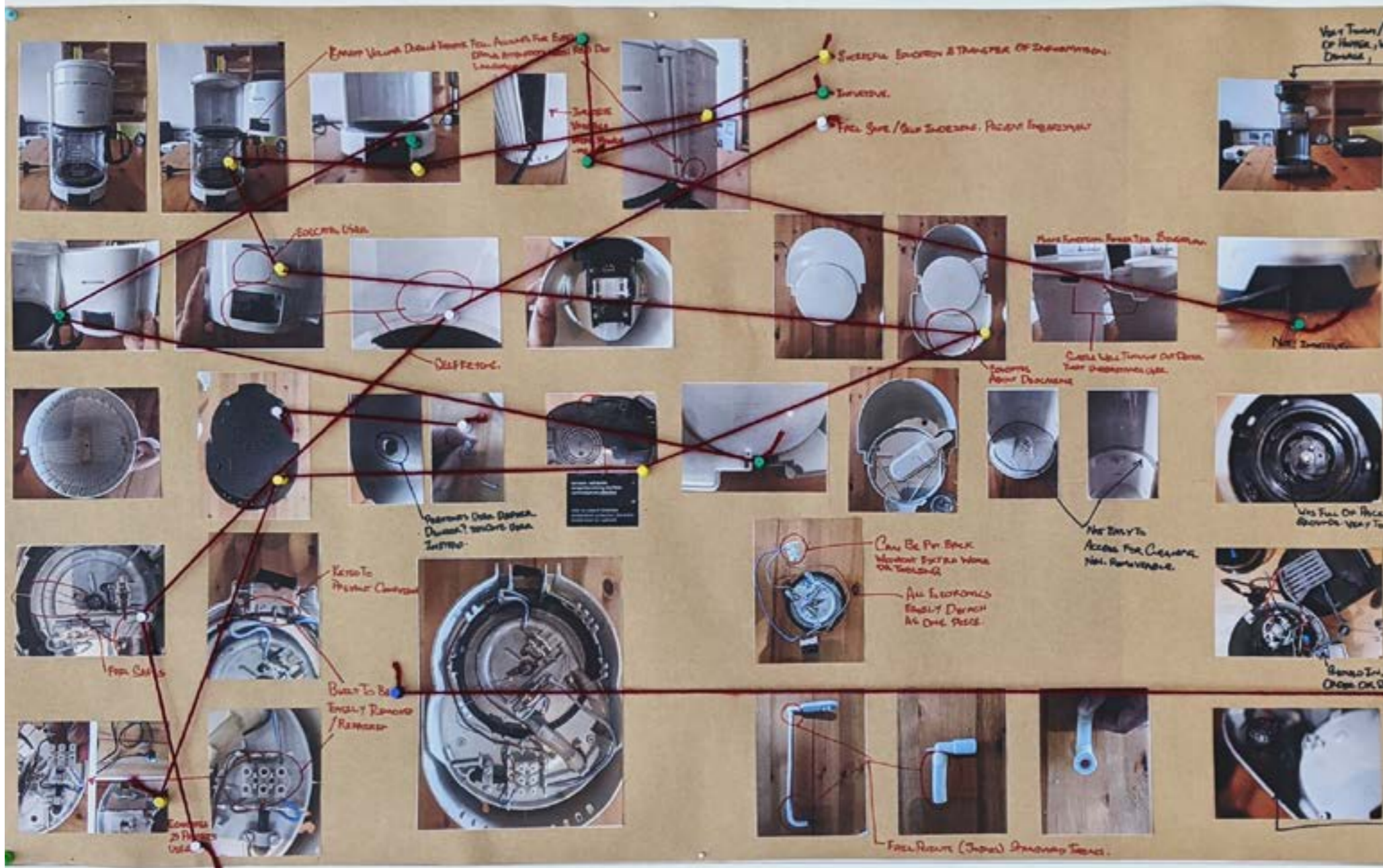
-The product must employ a Uni- body construction as learned from the automotive industry and observed in the Z800 as well as Fairphone. This will allow for individual electronic components to be seen, tested and repaired in situation just by removing surface panels. Components should also easily separate from one another and be built to do so without damage to components.

-Object should employ iconography to help highlight points of instruction to the user during disassembly.

-Object should be made from durable material to try and withstand the test of time. With a focus on design for longevity of the objects usable life to make best use of its embedded energy.

-Product must be upgradeable and adaptable in function as seen in the Z800 and fair phone so as to be changed for potential future requirements.

Braun Drip coffee machine vs Breville Coffee grinder



In order to understand the basic componentry that goes into making a coffee machine, I found and disassembled an original Aromaster manufactured by Braun in the 80's. This served as a good basis as it employed a lot of good design and manufacturing practices when put up against a modern coffee grinder manufactured by Breville. The Aromaster was very intuitive to use and take apart most parts came off without the need for tools and stayed in place so as not to cause confusion. It also aimed to educate the user through diagrams and instructions molded into parts. This was a very effective tool for disassembly. The Breville coffee grinder on the other hand functioned simply but was very poorly built for disassembly. The difference in manufacturing methods were astounding. Disassembly was not intuitive at all and required a lot of research. It aimed to stop disassembly rather than aid it, by using screws hidden behind plastic caps. I noticed through my research that it was common for these to fail due to a very simple part that was not available from the manufacturer. Instead disgruntled customers had resorted to manufacturing their own with the use of 3d printers. The object was also built in layers with difficult access. Unlike in the Braun, Wires were knotted, unlabeled and stuffed into cavities without the ability to be disconnected. The object was impossible to disassemble all the way without damage and the need for excess tools like a soldering iron for reassembly. There was no understandable order of disassembly, and found itself sitting disassembled after the process. The two machines served as surprising polar opposites and provided me with many good methods to use in design.

Technivorm Moccamaster:



The Moccamaster is the best built product I was able to find within the market and price range I will be working in. It retails for about USD \$320 and has been hand made in the Netherlands since 1969. In that time it has remained functionally unchanged, with only cosmetic changes and incremental changes to individual components. Yet it remains a gold standard in drip coffee and one of the longest running products in the industry.



Images from McLellan, "What's Inside This Classic Coffee Maker?"

This success can be attributed to good decisions of putting quality above all else in durable material choices, transparent design, and adherence to the agreed gold cup coffee standards. I found the Moccamaster to be relatively easy to disassemble with care and proper tooling. As a bi-product of being hand made, access and the overall arrangement of the object was very good, however access to information and parts from Technivorm themselves were limited. What aided this though was third party sources due to the product's long standing following in the industry. The components that were chosen made use of high quality materials and do not compromise the capabilities of the machine. For example the heating element uses a mini full copper boiler with multiple dense coils similar to that used on winter pipe heaters. This in contrast to the heating element in the Braun machine provides a



Image from "TECHNIVORM - About Technivorm."

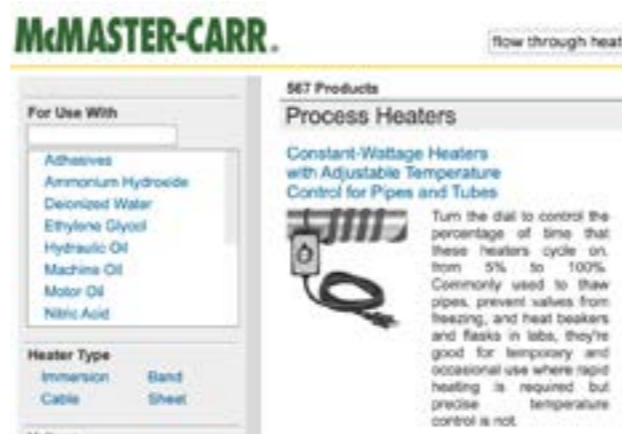


Image from "McMaster-Carr."

much faster and more controlled heat and pressure delivery to the shower head, creating a much more controlled extraction of the grounds.

Another notable observation when researching the Moccamaster, is the tendency for aftermarket / DIY support for modifications. This is easy to do as most connection points between components are simple and easy to interface to. Most of these modifications are around the shower head in order to get more even extraction of the coffee grounds. This seems to be the only improvement on the moccamaster, just as it would be with any other drip coffee machine. This can be improved on with the automatic pour over systems that seem to be popular in some batch produced machines, but can be expensive due to the added complexity of a rotating shower head.



Image from Coffee Pilot, Moccamaster Showerhead Insert.



Image from "Moccamaster Shower Head Hundred House Speciality Coffee Roaster West Midlands."



Image from "Technivorm 9 Hole Water Sprayhead."



Image from "TECHNIVORM - About Technivorm."



Image from "Barista Daily on Instagram: 'Custom MokkaMaster by specht_design'"

Component type	Location	Function	Failure points
Reservoir	Rear or above heating element to allow water to be gravity fed.	Hold water and pass it through heating element using mass of water over low exit.	Seals, Cracking and seams
Shower head	Above basket. Minimal distance from heating element to maintain pressure	Heated water rises to shower head which should evenly disperse water over grounds.	Calcium deposits can restrict flow.
Coffee basket	Below shower head and above carafe	To hold filter and grounds. Valve on the bottom controls flow rate.	Calcium build up can stop flow. Heat can warp
Carafe	Below Basket	Hold coffee and keep it warm	Glass carafes breaking.
Heating element	Below carafe in glass options.	Heat water enough for it to rise and brew coffee. Sometimes secondary function of maintaining carafe temperature	Safety fuses corrode or burn. calcium buildup acts as insulator and restricts water flow.
Water piping	One pipe from bottom of reservoir to heating element and another from heating element to shower head.	Transport water	Can loose seal especially through stretching from repeated heating and cooling cycles. calcium buildup can restrict flow.
One way valve	Between reservoir and heating element	Prevents hot water from flowing back into reservoir, thus providing pressure to shower head	Common failure point when clogged open or closed due to deposits.
Power cable	From heating element to wall.	Provides power	Housing can split or get cut. Connections can oxides and cause loose connections.
External housing	Around other components.	To encapsulate other components and act as the visual layer.	Prone to yellowing/ discoloration. Can crack or become unsanitary/ hard to clean.

Types of heating elements:

Immersion heaters:



Image from Acosta.eu

Monoblock Heater:



Image from "Krupps Coffee Maker Boiler with Heating Element Dolce Gusto MS-622102 Buy for 21.98 EUR | Ziperone.Com."

Flow through heater:



Image from "SANHUA AWECO Appliance Systems"

Technivorm (Constant wattage copper pipe heater):



Image from "TECHNIVORM - About Technivorm."

Types of shower heads:

Traditional:



Image from "12 Cup Programmable Coffee Maker Reviews - Mr.Coffee® vs B&D® DLX1050B Compared."

OXO replaceable shower heads:



Image from "Amazon.Com: OXO On Barista Brain 12 Cup Coffee Maker with Removable Kettle: Kitchen & Dining."

Breville replaceable shower heads:



Image from "A Hands-On Review of Breville's BDC400 & BDC450 Precision Brewers."

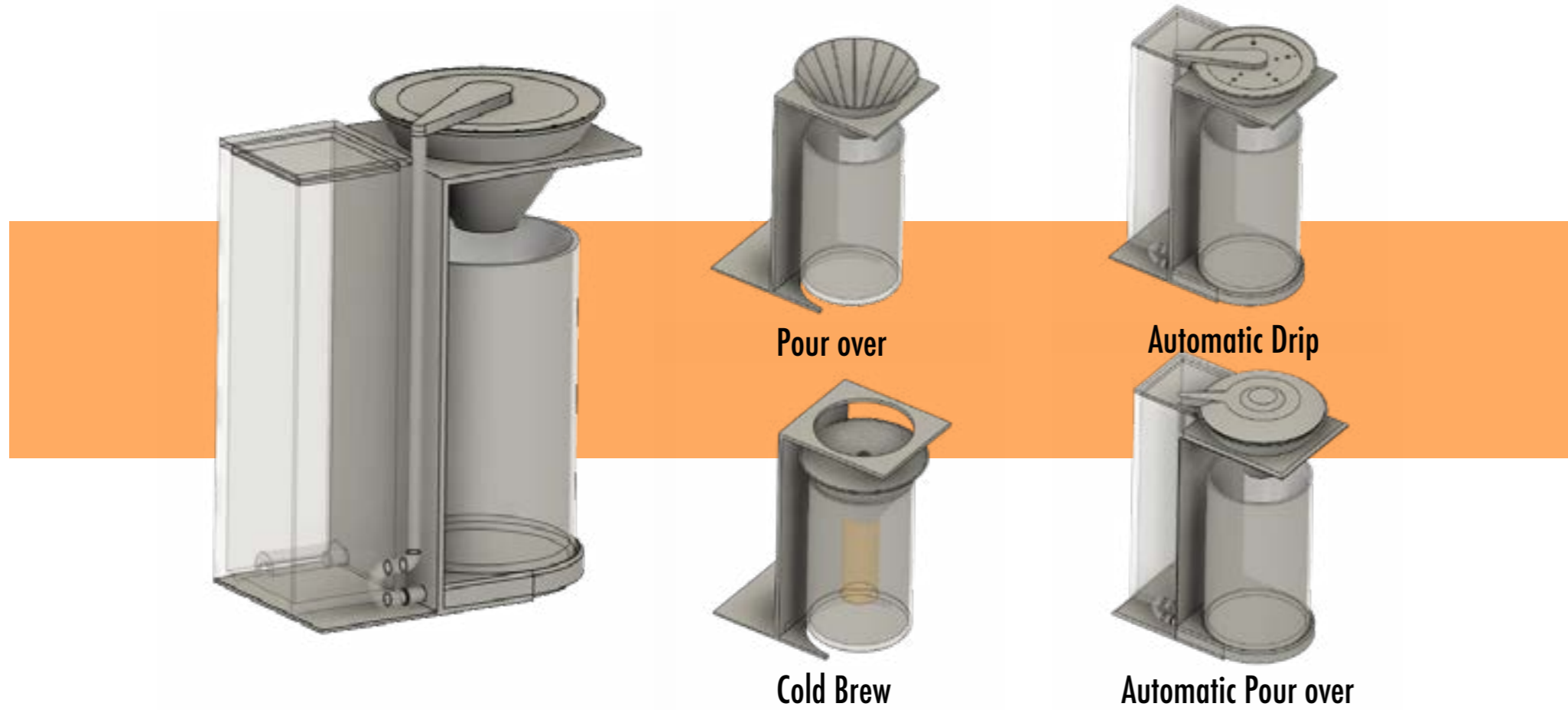
Technivorm Removeable shower head:



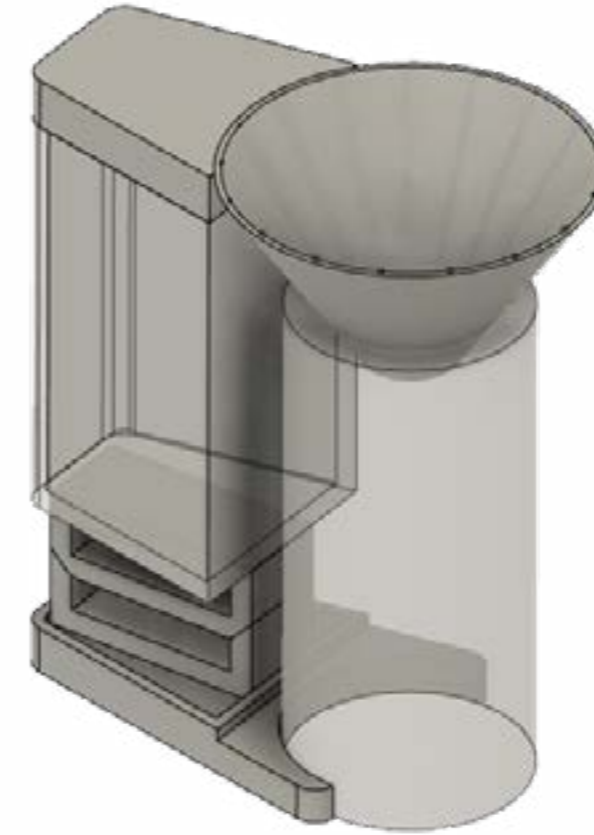
Image from "TECHNIVORM - About Technivorm."

Through the disassembly and analysis of the coffee machines I was able to identify the individual components and extrapolate potential failure points to look out for. I was also able to research individual components to find my best options in the market. I found that, although the flow through heaters were common due to their low price and multi-functionality of being able to heat a base plate, they were prone to failure due to such a small resistance coil heating a large capacity of water. I found that the 'boiler' option used by Technivorm was a far better solution, and provided benefits of better temperature and flow control. Therefore I chose to use this component in my prototype.

Design process: initial models



After my research into individual components I was able to better understand the methods of coffee preparation I wanted to work within. I then started to model rough layouts of what these independent arrangements might look like. This let me visualize how a component would have to interact within each of the separate systems, thus highlighting various connection points that had to be developed.

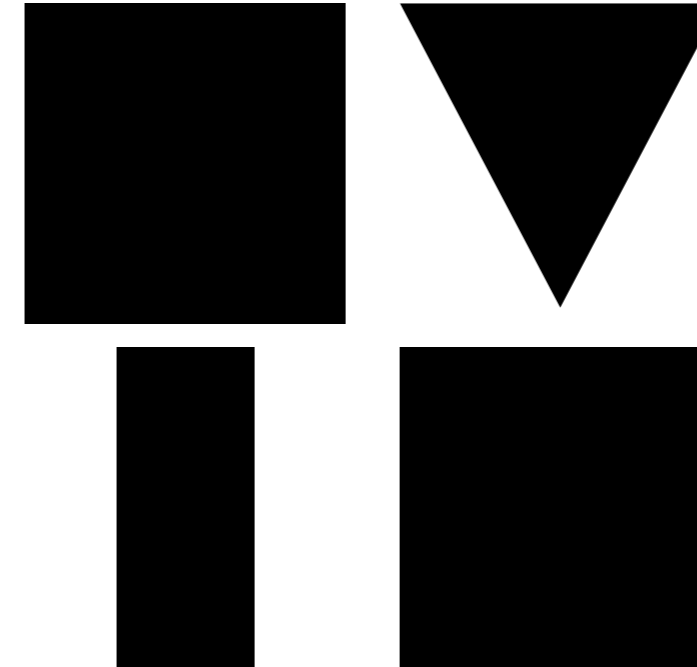


I then started to play with ideas of stacking and different formal arrangements the object could take on. However I quickly found that these arrangements were heavily dependent on the function of the object as a whole and needed a better understanding of the individual components as well as a better sense of volumetric scale. Therefore a basic 'Buck' was in order. This helped me visualize how the components needed interact, giving the object a loose silhouette.



From there I continued to work with physical material in a rougher sense, slowly introducing more ideas of functionality as well as real components to shape the object. During this process I developed the idea of a manual valve instead of the 'automatic' ones commonly triggered by the carafe on injection molded machines. This added a step to the process but allowed for more precise flow control which opened up the possibility of cold brew and slow drip coffee. **This was a significant insight achieved through the iterative prototyping cycle.** It also removed a common failure point that is prone to leaks over time as the springs stretch.

I also started experimenting with the use of colour and iconography as instructions in use and disassembly. I tried to create the model as if it had a primary use to produce coffee and a secondary use of disassembly.



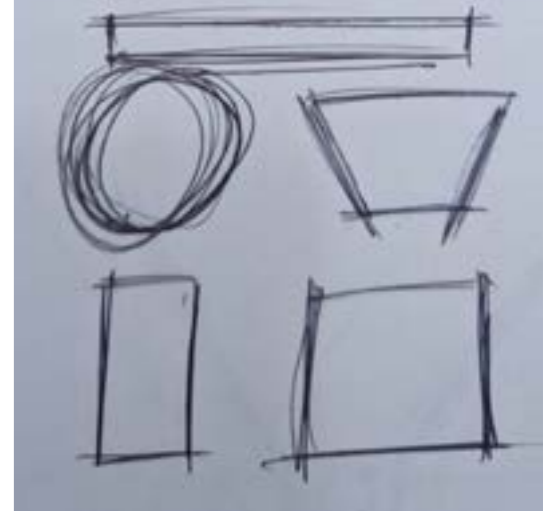
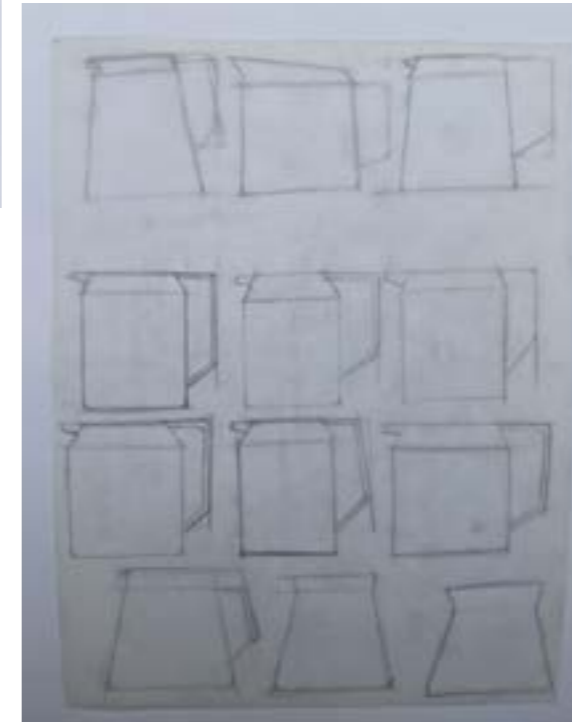
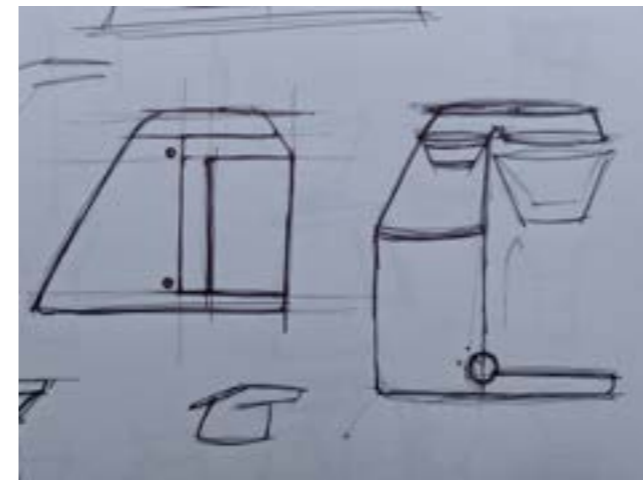
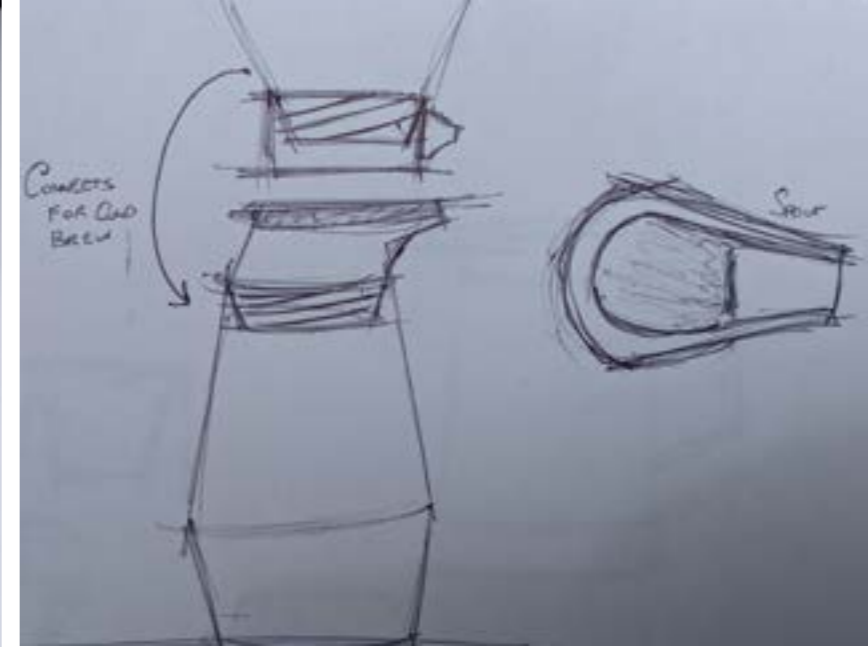
Restrictions on form:

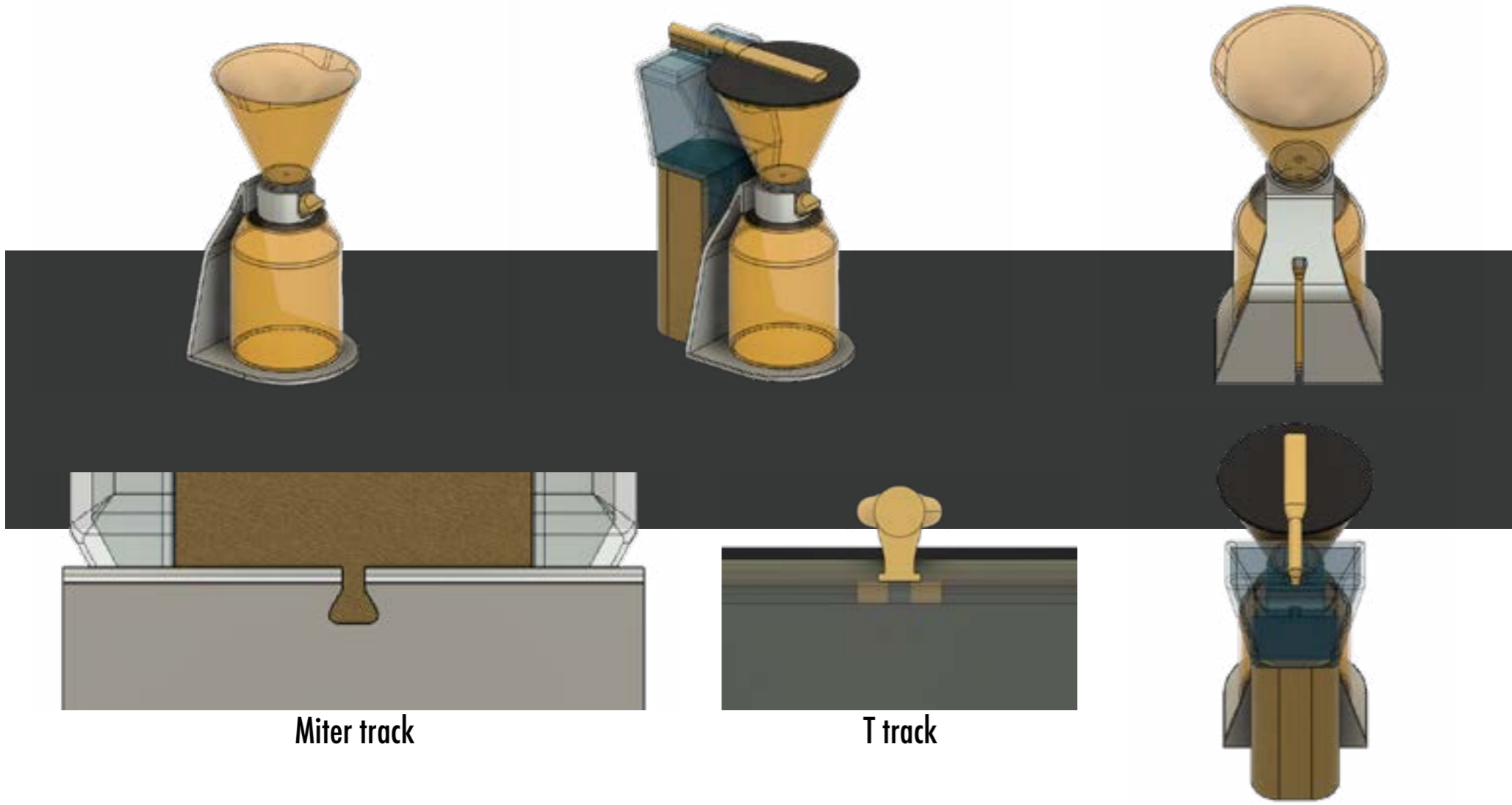
When attempting to deconstruct the object's form further, after seeing the components laid out in space, I found that the shapes and volumes used are heavily restricted by function, as represented in this basic demonstration of the shapes. Both the squares represent the primary containers of water, the top left being the reservoir, and the bottom right being the processed coffee in the carafe. These two had to be volumetrically equal as the water going in had to equal the coffee coming out. The other two sections represent distinct shape requirements. Arrangement of these shapes are also dictated by the flow of water. The tall rectangle represents the long heating element that is gravity fed and therefore has to be placed directly under the reservoir. The water is then transported itself upward once heated and is showered over the conical filter basket. The filter basket has to funnel the water evenly through the coffee grinds and then again uses gravity to drip into the carafe.

Further formal considerations are that of the object in its environment. Minimization of its footprint is essential due to its place on a counter-top. It also needs to be orientated on counter-top such that controls are accessible in either the x or y plane.

Ideas to apply

From here my process of prototyping within real material was unfortunately interrupted due to the Covid 19 crisis. This forced me to return to CAD and sketching as a method of prototyping, which brought its own benefits and challenges. Working in CAD so early required a level of accuracy that forced a function lead design process. This was actually quite beneficial as the object necessitated this way of working to develop an effective system. Continuing a physical prototyping approach impacted my ability of basic usability and interaction of the product concept. Subsequent three dimensional prototyping was a focus to ameliorate this impact on my design process. I attempted to create a base "frame" of a pour over system that the other components could then integrate to. The system I decided to pursue was a rail and track system as it was adaptable as an accessible interface. It also provided structure to the design, giving it a spine to work around.





Miter track

T track



Once I was happy with the overall shape and functionality, I returned to physical materials to visualize scale in the objects environment. It also allowed me to feel the motions of disassembly. I found a dovetail profile to provide more rigidity in multiple directions over a traditional T-Track system and so decided to use this. I also found that the horizontal track became restrictive to functionality as it blocked access to the reservoir placing the shower head through the middle of the object. It also made routing of water hoses complicated and created opportunity for leaks at complicated sealing points. Therefore another method of attachment had to be developed.



The solution I came up with was flipping the axis of the rail and creating a flexible clip attachment that uses the materials inherent flexibility to snap onto locating pins. A standard 9mm hose slides onto a barbed fitting to provide water up the side instead of through the middle of the reservoir, simplifying the overall part for manufacture.



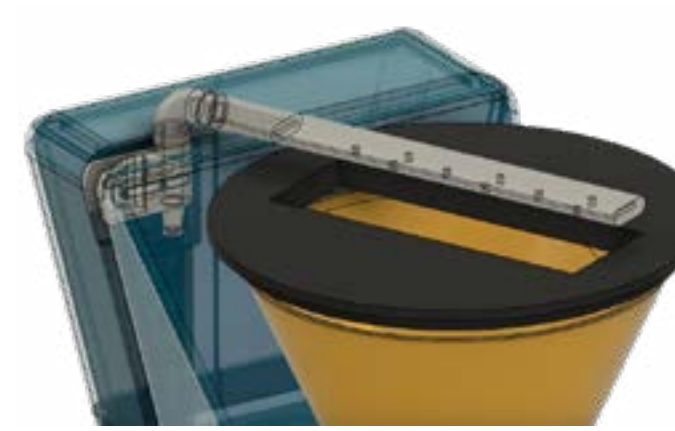
I also had to create room for a float that activates a micro-switch to turn off the heating element when the reservoir is fully drained.



In order to protect the user from heat flowing through tubing to the shower head I recessed it into the reservoir as it flows up the side of the object. I also added ridges for the hose to be squeezed into to be secured.



All parts were shelled to 3mm providing adequate strength while reducing material volume.



Shower head was changed to angle in from the left with adequate height above filter basket, allowing for easy access for water and coffee grounds.



Access to the reservoir is easily achieved by lifting the lid from the opposing side and sliding it passed the shower head. Semi-permanent attachment of the shower head minimizes risk of leaks caused by repeated detachment.



A three part valve was created consisting of a pin attached to a threaded cap passing through a drilled cylinder. The valve is sealed on either side of the hole with standard o-rings to prevent leaks.

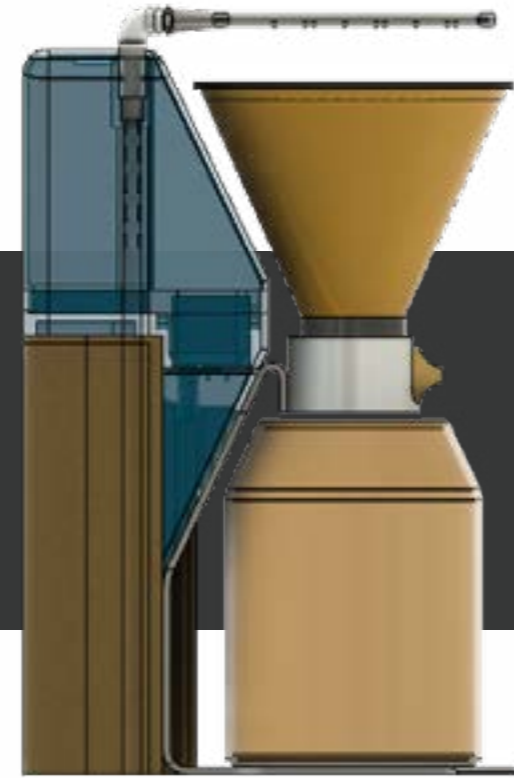
Final model kit options:

Pour over
Base Kit



Stand
Filter basket
Carafe

Automatic Drip



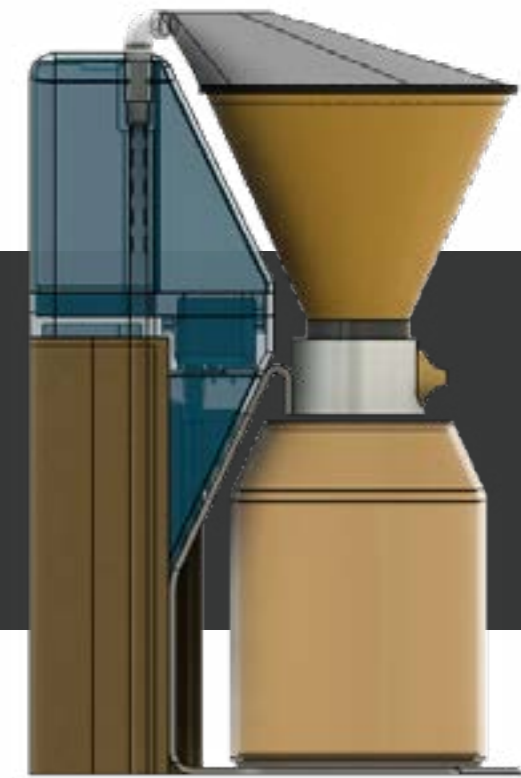
Stand
Filter basket
Carafe
Reservoir
Heating Element
Shower Head

Cold Brew



Stand
Filter basket
Carafe
Cold brew filter

Automatic Pour over



Stand
Filter basket
Carafe
Reservoir
Heating Element
Rotating shower Head

Schematic of total system components and material choices:

- V1- Pour over
- V2- Drip coffee machine
- V3- Cold brew/ Slow drip
- V4- Automatic pour over

#2 Carafe

Slip cast recycled ceramic used. This is intended as one of the available options of preference, with future iterations including double walled stainless steel as a premium option for its insulating properties as well as its durability. Glass can also be offered for its clarity. This is currently the most likely component to break due to its high use case likely hood of being chipped. The intention however is that due to its simple function and minimal interaction with other components, replacement carafes can be sourced in multiple ways and options. They can be obtained locally through use of existing containers or production by local third party ceramicists and glass blowers offering opportunity for customize-ability. They can also be manufactured by larger third party suppliers in stainless steel.



#6 Steam lid

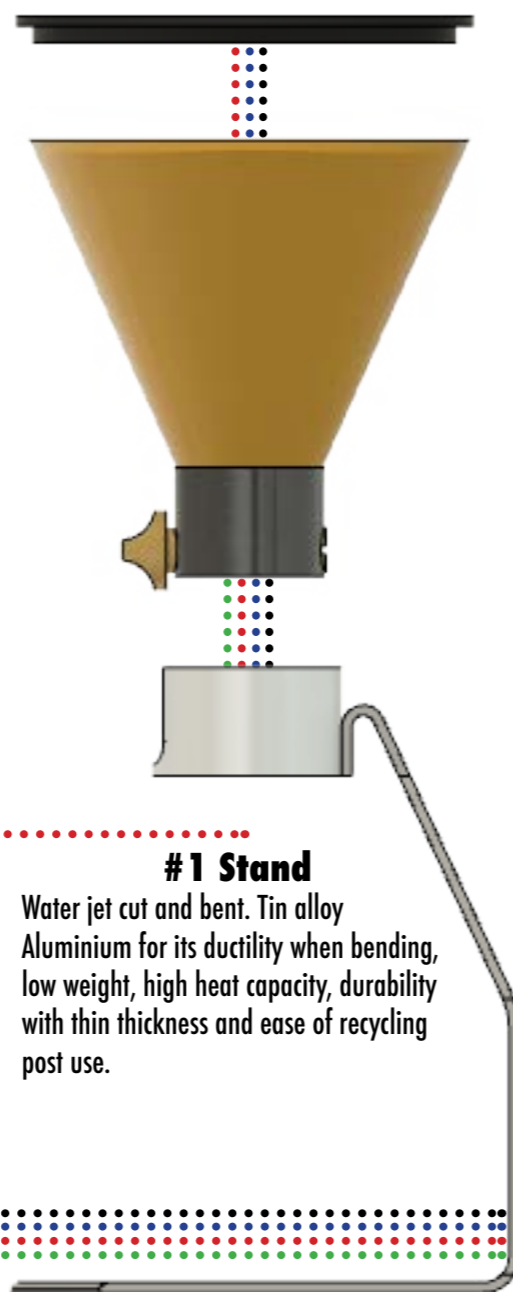
Injection molded Polypropylene.

#3,4,5 Filter basket & flow valve components

Filter basket is spun and then pressure fit onto turned valve. Produced in free-cut aluminum with tin alloy instead of lead for its ductility for turning, low weight, high heat capacity, durability with thin wall thickness and ease of recycling post use.

#12 Cold-brew filter attachment

Perforated stainless or brass mesh.



#1 Stand

Water jet cut and bent. Tin alloy Aluminium for its ductility when bending, low weight, high heat capacity, durability with thin thickness and ease of recycling post use.

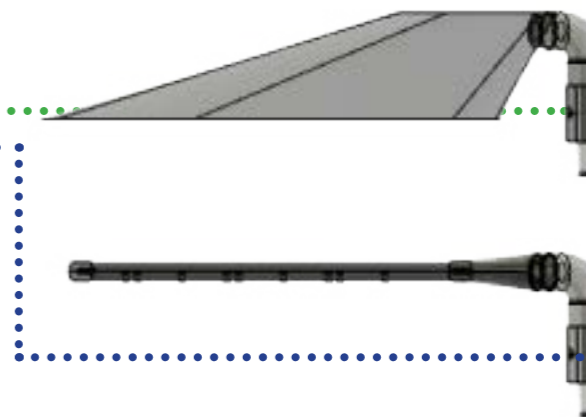
#8, 9 Water reservoir

Injection molded Polypropylene was used for the reservoir and other components due to its ability to be easily molded into complicated shapes needed for accommodating the float, sensor mounts, shower head mount and rail system. The properties that were required of the material in this component was its:

food safe rating and chemical resistance, translucency, good heat resistance, semi rigid structure while still being shatter resistant, its toughness to prevent scratching and marring, as well as its good fatigue resistance so as to not break after repeated disassembly. Materials such as glass (too fragile and expensive) or metal simply could not provide similar characteristics without hindering functionality or long term durability for a central component. That is why plastic was justified for its benefits toward overall durability of the object as a whole and therefore reducing waste. This form of plastic can also be recycled post life.

#11 Heating element enclosure

For the housing of the heating element compression molded granulated cork was used. This was due to its base characteristics of being: a great heat and electrical insulator, being fire retardant for fire suppression, natural water resistance properties, ability to be compression molded into complex shapes as well as the ease in which it can be worked from being machined all the way down to being cut easily and well by basic hand wood working tools. It is both additive and subtractive in that it can be carved, sanded or easily glued to with wood glue. Wood finishes can also be used to refinish its appearance such as bees wax or even water paints. It is also cheaply and easily available in sheet or block forms (including just buying yoga blocks if you cant find suppliers locally). This allows access to third party suppliers, repairers or DIYers to change or modify the housing to suite future changes in component shapes or visual styles as required. This is important as finding exact replacements of these electronic components can be difficult and so modification of housings and mounts make repair much more adaptable and easy. Cork is also impact resistant by dissipating energy (reasons for its adoption in packaging) and relatively durable, therefore protecting expensive electronic components if dropped. Cork is also sustainably sourced as it harvests regrowing bark that doesn't harm the tree. It is also 100% biodegradable and granulated cork can be re-blended and compressed into new objects. Therefore for this component this material was a good fit for longevity as well as other environmental benefits.

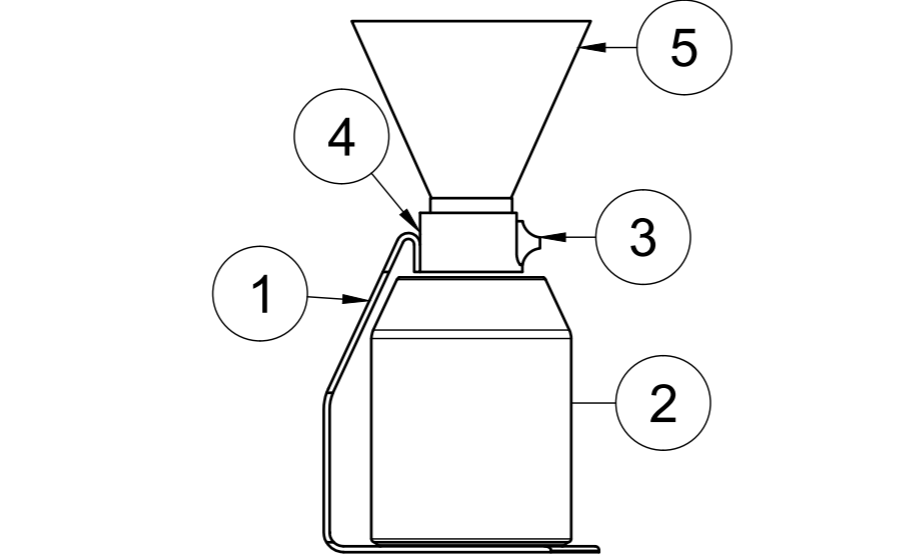
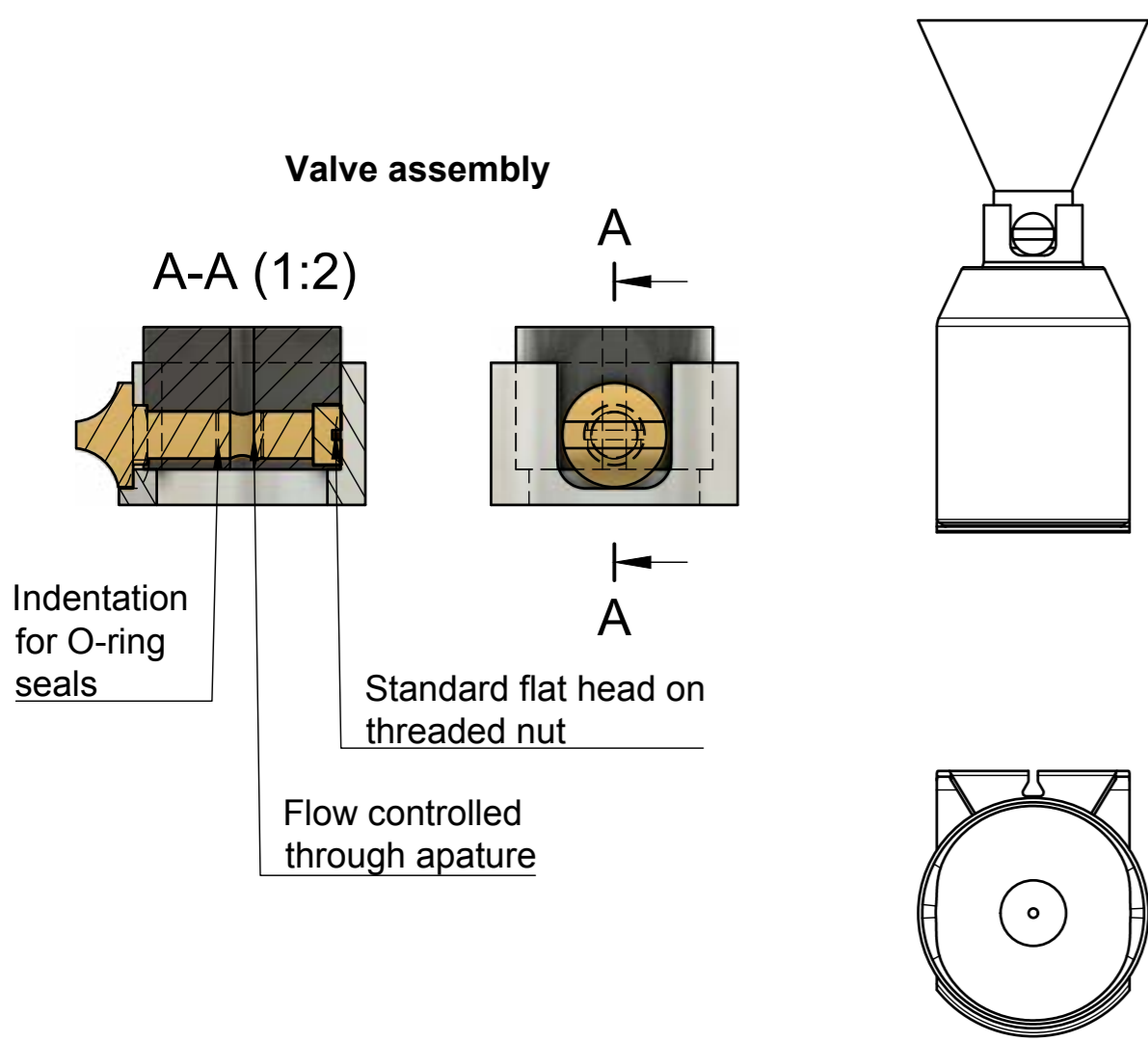


#13 Automatic pour over shower head

#7 Shower head

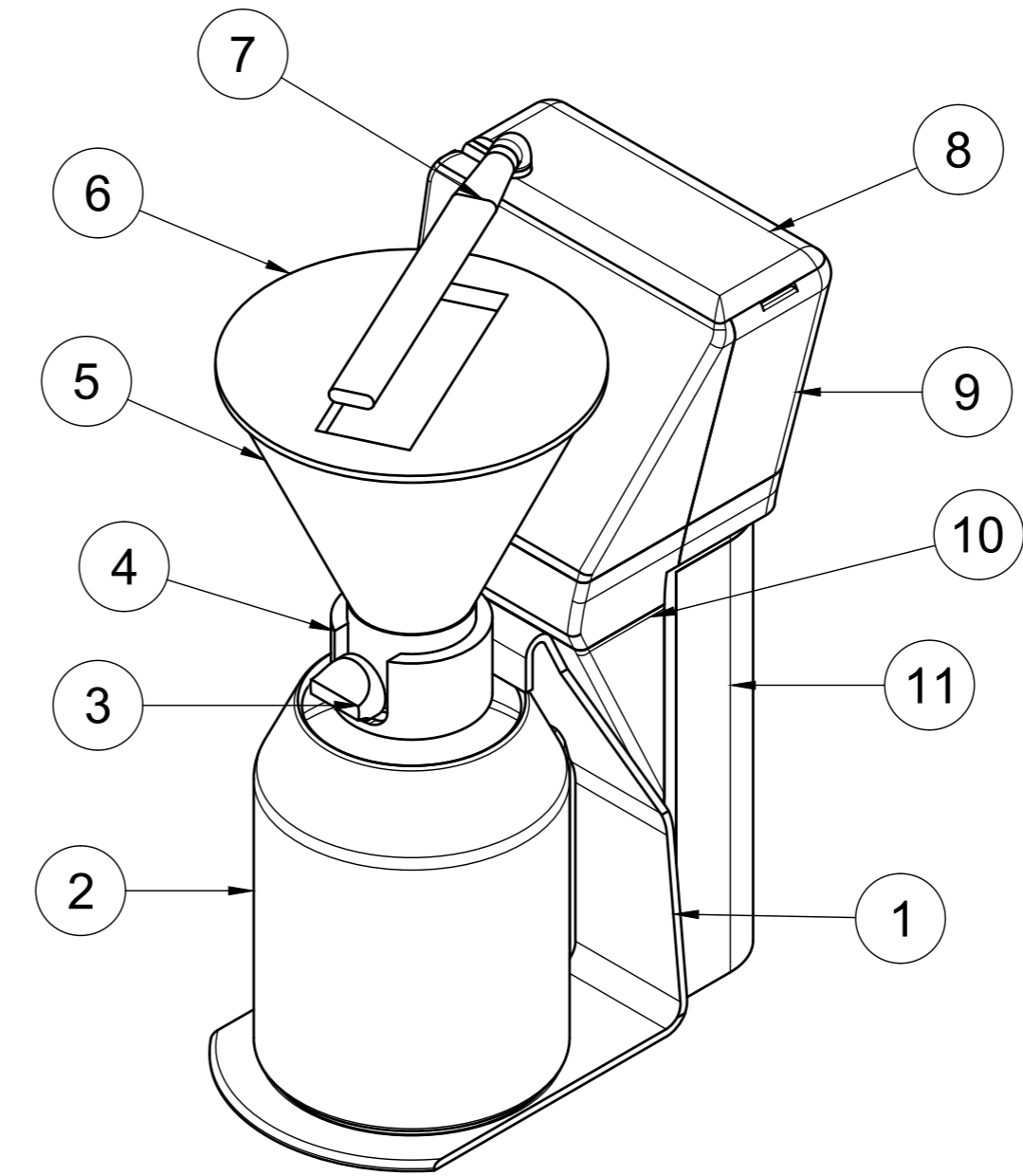
Injection molded Polypropylene was used in the shower head as it had the important ability in this case to withstand the high heat application without deflecting, leaching chemicals or getting brittle unlike the 3d printed resins used for prototyping. It also allowed for a flexible material that had high fatigue resistance which allowed for repeated disassembly without failure. This is especially important in the clip interface with the reservoir and the barb for hose connection which would otherwise crack over time and was a common failure point during prototyping. It is also food and dishwasher safe. Further testing was done to use metals and minimize plastic use and will be a further exploration.

Version 1: Core pour over kit



Parts List			
Item	Part name	Material	Manufacturing Process
1	Stand	Aluminium	Waterjet cut and bent
2	Carafe	Recycled Ceramic	Slip Casted
3	Valve pin	Aluminium	Turned
4	Sleeve	Aluminium	Turned
5	Filter basket	Aluminium	Spun

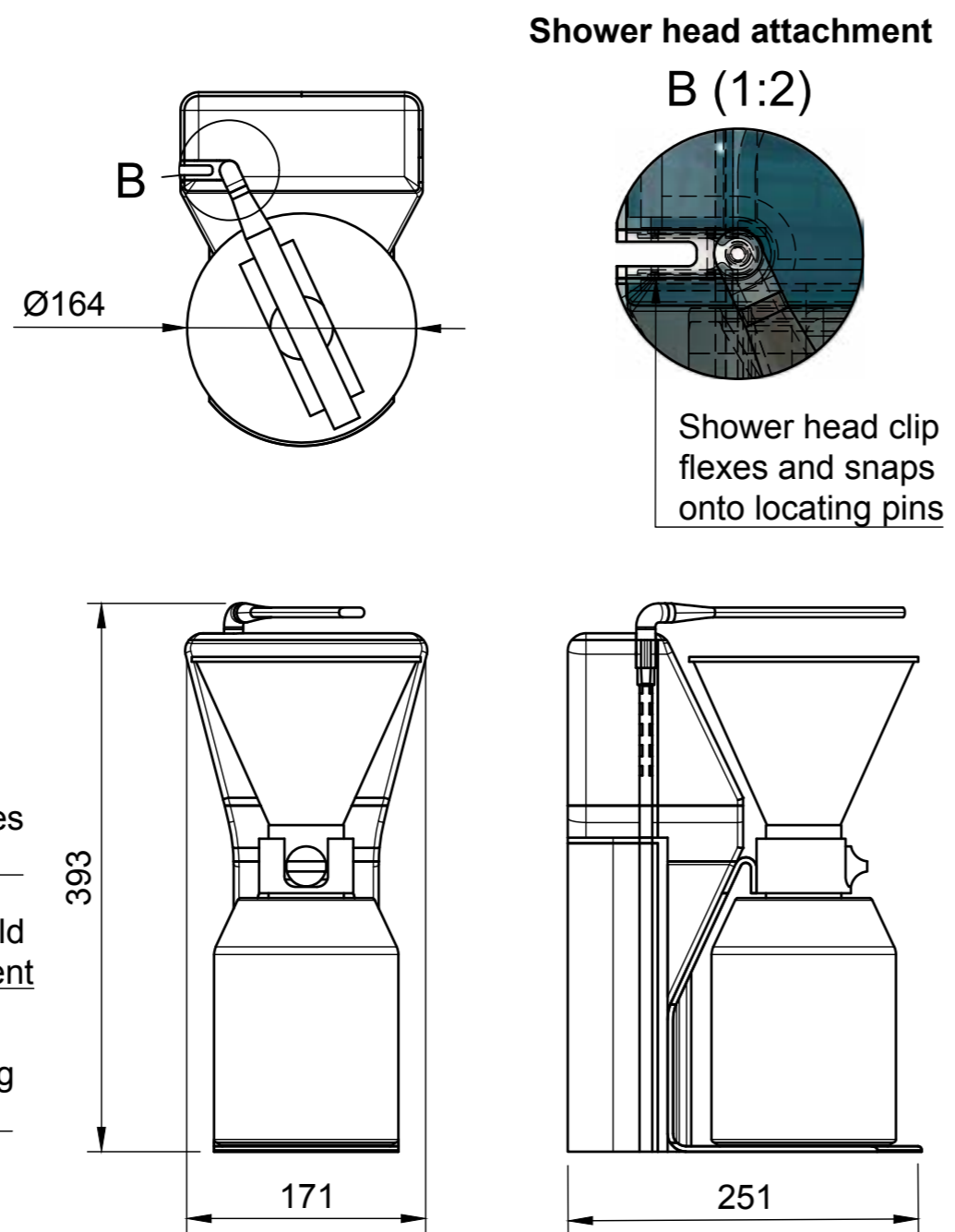
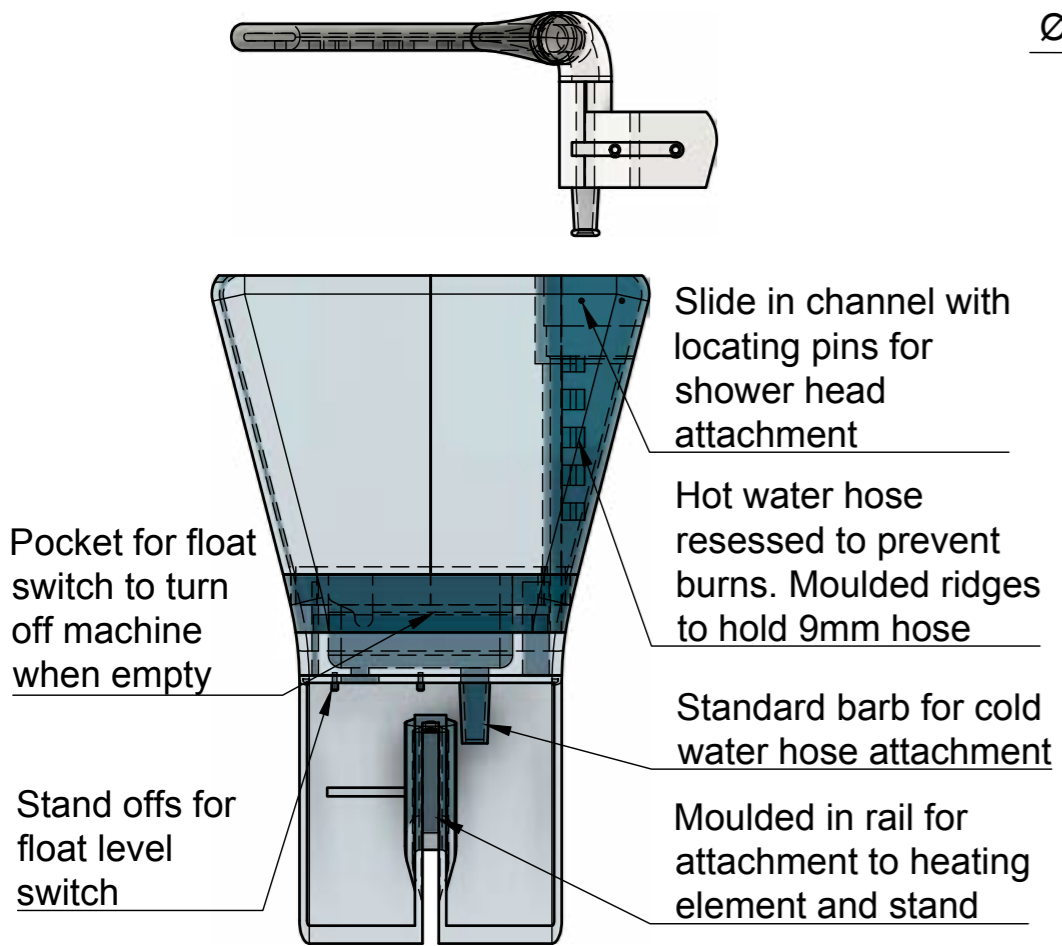
Version 2: Drip coffee machine kit parts diagram



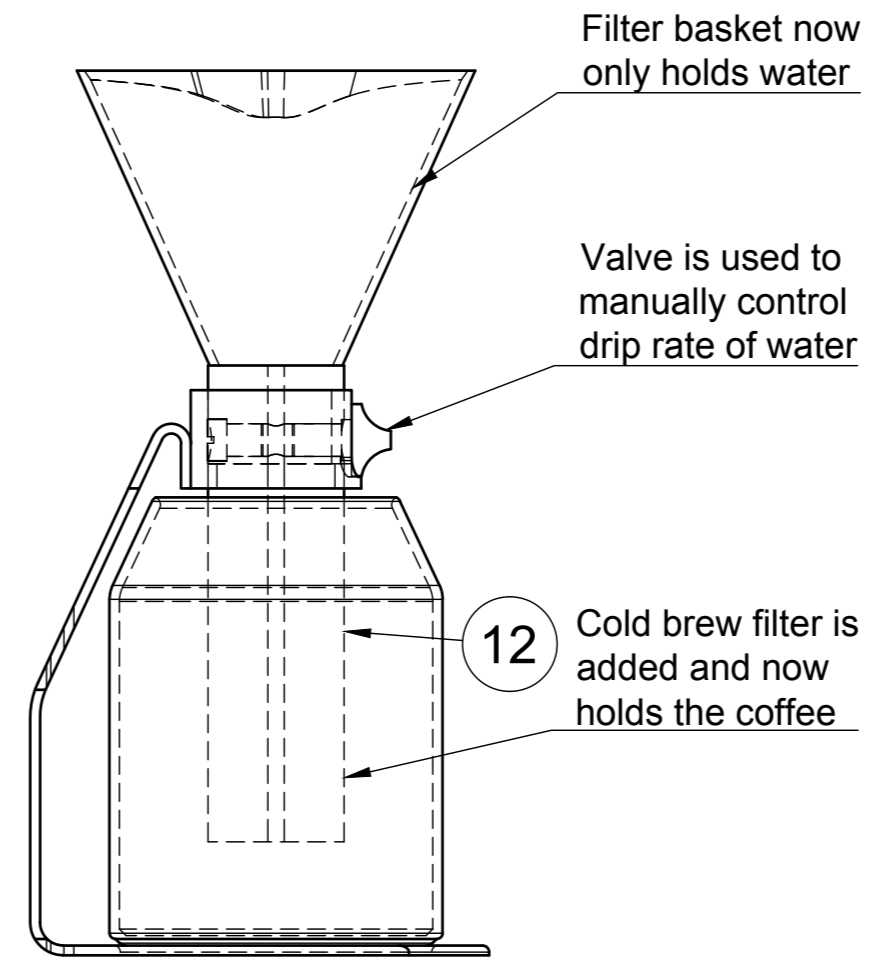
Parts List			
Item	Part Name	Material	Manufacturing Process
1	Stand	Aluminium	Waterjet cut, bent
2	Carafe	Recycled ceramics	Slip Casted
3	Valve pin	Aluminium	Turned
4	Sleeve	Aluminium	Turned
5	Filter basket	Aluminium	Spun, pressure fit on valve
6	Steam lid	Polypropylene	Injection moulded
7	Drip shower head	Polypropylene	Injection moulded
8	Reservoir lid	Polypropylene	Injection Moulded
9	Reservoir	Polypropylene	Injection Moulded
10	water level sensor	NA	NA
11	Heating element enclosure	Cork	Compression moulded

Version 2: Drip coffee machine details

Reservoir and Shower head internal construction

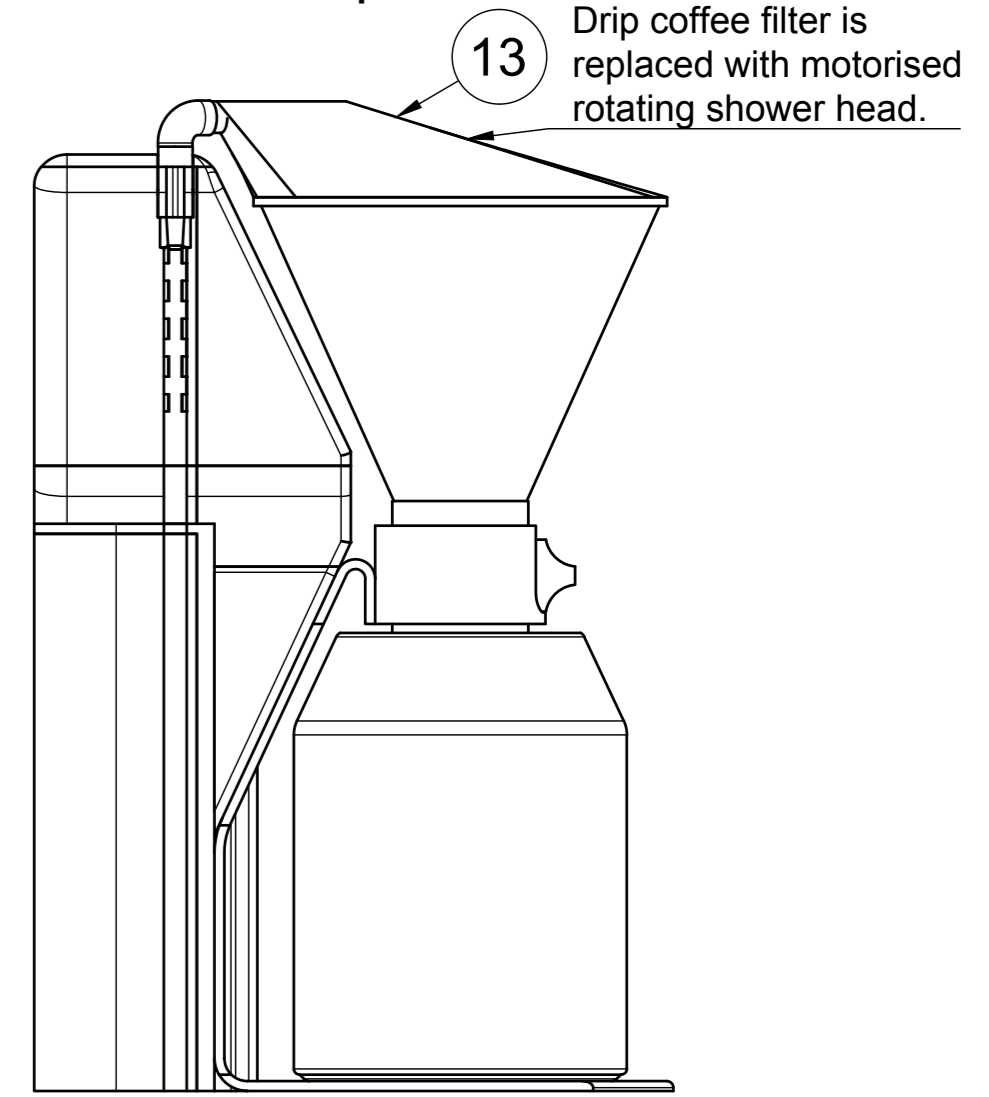


Version 3: Cold brew/ Slow drip coffee



Variation on Pour over setup where cold brew basket is added

Version 4: Automatic pour over



Variation on Drip coffee machine setup where shower head slowly rotates to provide even extraction

Manufacturing final prototype:



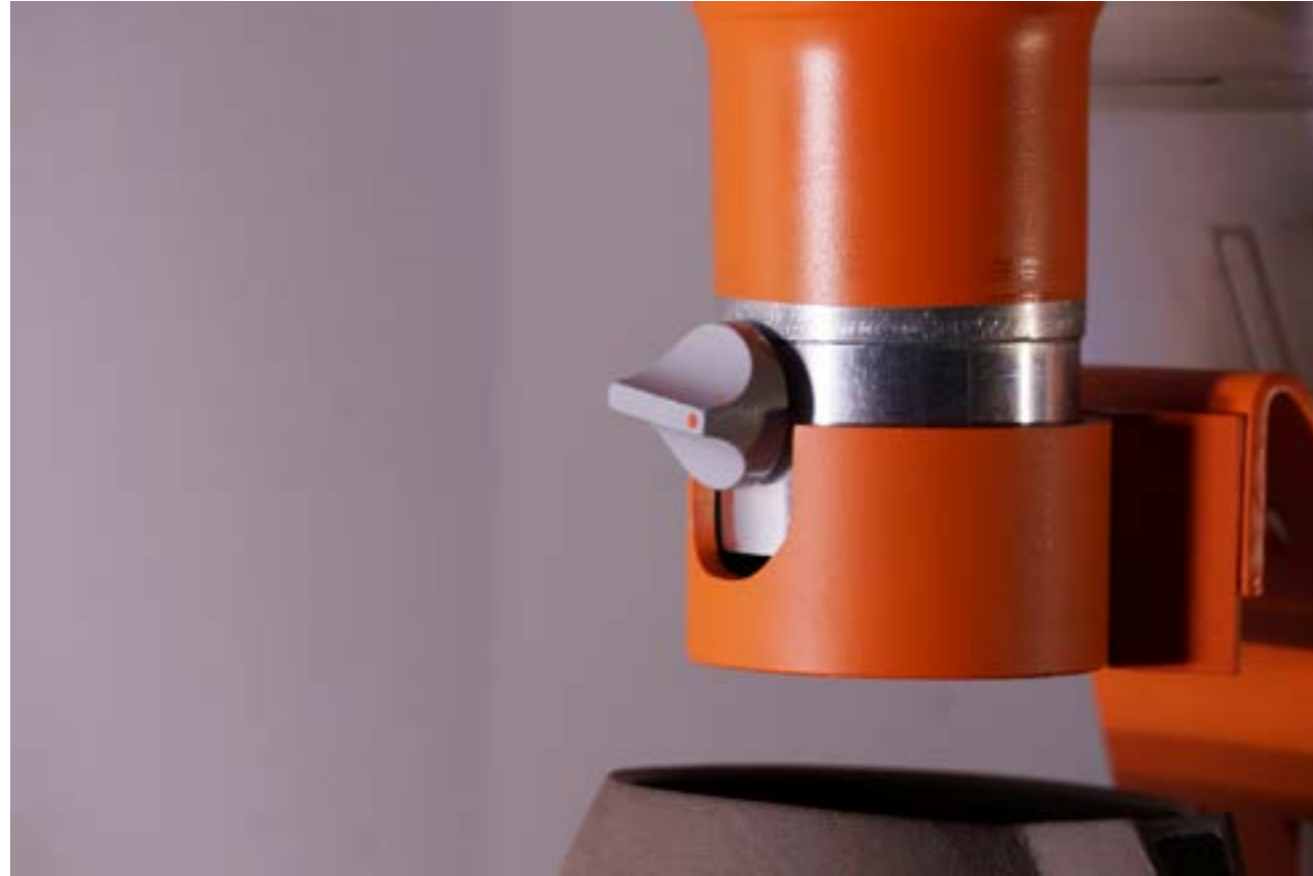
3D printed parts were printed on resin based printer. Standard resin was used on reservoir and lid. Reservoir was split into parts to fit printer volume restrictions with lips to create surface area for glue connection. Real component would be manufactured as one piece. High temperature resin was used for shower head but was expired and very temperamental. It was prone to cracking as it was brittle and would deflect a little bit when heated. It did function, however another shower head was made using copper piping which was bonded to high temp 3D printed clip and pipe section as shown functioning below. This was more durable for repeated testing and has survived many use cycles without damage.



Metal spinning filter basket. Sheared between cylinder and cone due to separate molds. So specific tooling will be required for large quantity manufacture.



Machining valve components:



High wear parts were left unpainted



Valve was found to act as heat sink during testing and will have to be hollowed to improve coffee temperatures.



Removable panels from two sides for access to repair and replacement of components. every component could be disassembled

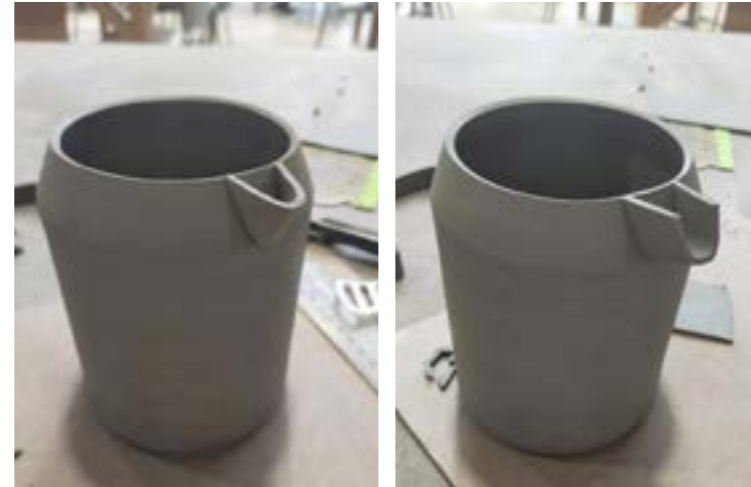
Heating element housing:

9mm piping diameter used was found to be a restriction and would hold water in the boiler longer than needed, causing longer cycle time and excess water loss to steam. The water wouldn't build enough pressure to flow through restriction until it was past the temperature required, thus turning into steam at the shower head. This will have to be changed.

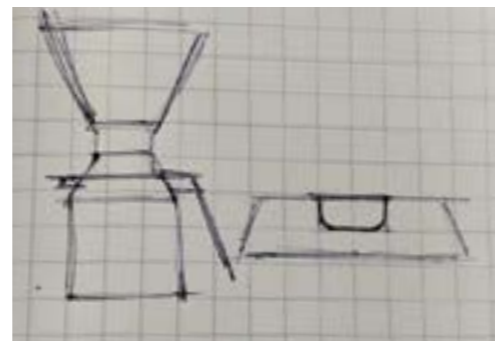


Cork was very easy to work with and machine with wood tools. Was flexible and forgiving however kerf cuts were required to bend and were added on the outside as a formal feature. Vents were created for airflow and heat management. Threaded nut inserts were used for screws to allow repeated disassembly without wearing cork holes. Finished with bees wax.

Manufacturing carafe:



Experimentation of spout, right poured water better and was finalized



Initial design of spout and handle



Initial suspended handle design became chunky to support weight and not sag before firing



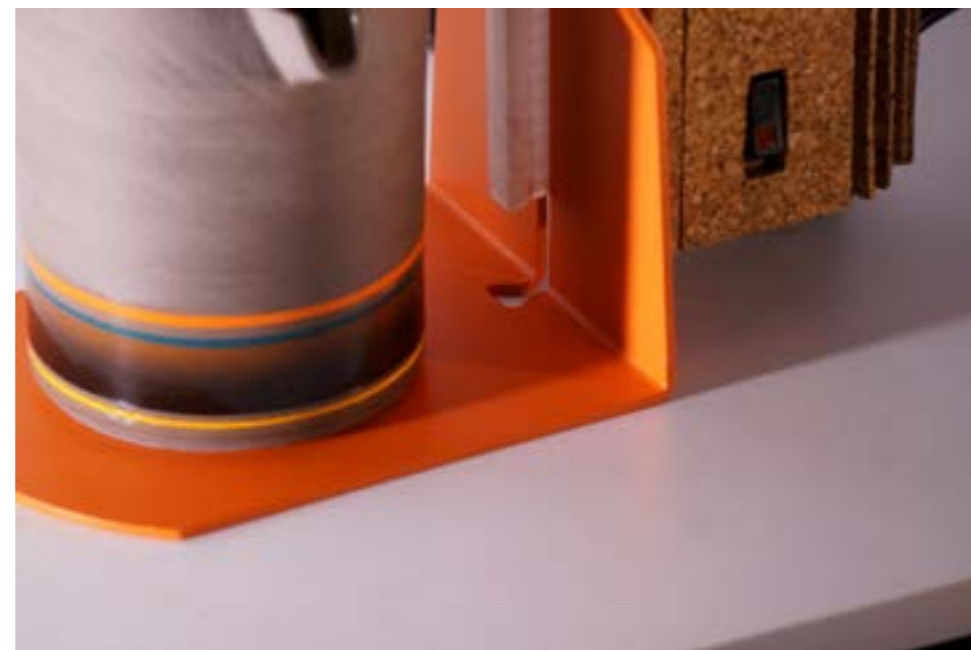
Final handle shape was changed to be supported at both ends so it could be thinned.



Experimentation with airbrushing under-glazes before final firing.



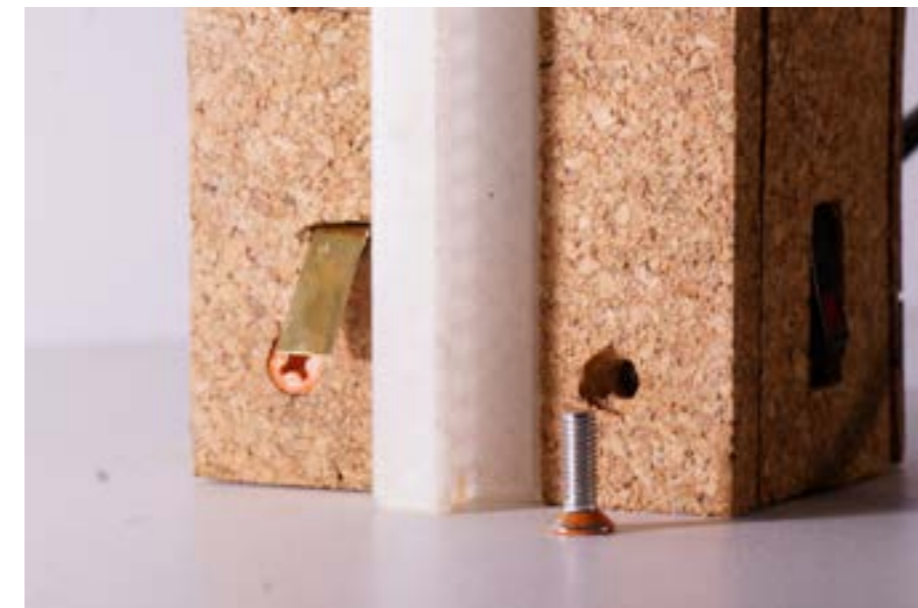
Quick release sliding fittings were used for cables, removing the need for soldering. These had numbers that corresponded to connection points.



Sliding miter rail detail.



Vinyl cut iconographic stickers were created but were too small and many failed so were not used. This was inspired by the HP Z800. Larger painted or water transfer instructions might work better. Better instructions will have to be developed



Screws were large and colour matched to general disassembly iconography colour red. This was a direct inspiration from IFixit. Grounding tab was added to ground metal stand for electrical certification.



Quick disconnects were used for water hoses as well as one way valves to interrupt flow.

Conclusion and discussion

My research into the creation of longer lasting consumer electronics, Identified functional modularity as a significant factor in contributing to extending the life-cycle of a product by: providing accessible opportunities for maintenance, the ability for third party supplier to participate in the development of customized components, and potentially leading to consumer engagement with elevated levels of satisfaction.

Within the coffee machine product area I was able to identify four methods of preparing coffee, which shared similar components in different arrangements to achieve the end users preference. This allowed the opportunity for a kit based modular approach. The core system designed starts with the simple "Pour over" version, requiring no electronic components. The system then expands out to include a cold brew system that adds a filter attachment. The next stage of complexity adds a heating element, a reservoir and a drip shower head to create a drip coffee machine. The final version expands upon the drip coffee machine with a separate motorized shower head to create an automatic pour over system. This method is relatively new to the coffee machine industry, however the modular product architecture that I have developed as the bases for this system provides for this opportunity to be further expanded upon. This is an example of how important product architecture is in expanding a system to accommodate new processes and innovations in coffee making.

The nature of this investigation and the impacts of Covid 19 on this study focused the development of the product system on individual component design, modularity and connection within the system along with achieving concept functionality. As previously mentioned a limited amount of usability studies were completed outside of direct



experimentation with volumetric models by the designer. However as the focus shifted towards achieving a functional prototype, tests were completed in actually brewing coffee within pour over, automatic drip coffee and cold brew versions. This required the prototype to be electrically certified prior to actual functional testing. This usefully informed an initial understanding of the usability of the system and that it did functionally work. The testing also identified material and functional issues that included: A need for specific tooling when metal spinning to prevent shearing, testing of different plastics that wouldn't deflect or get brittle with heat, a necessity for larger water tubing to reduce pressure and proper support for the handle when firing the carafe. This usefully informs the product development aspect of the individual components.

Through the insights from the designers initial usability engagement with the product it was found that the machine took an extended period of time to finish its cycle. This was due to a specification of internal water hosing generating a constriction, however from a usability perspective this was experienced as a delay in the gratification of a cup of coffee and what appeared to be an excessive production of steam. The coffee produced was at a lower temperature than expected, which was attributed to the heat sinking property of the valve component. The basic functional ergonomics and handling of the products and its components as well as its disassembly appeared to be satisfactory, however this would require further investigation from a larger group of users. One of the interesting insights from the testing that was undertaken was understanding the link between user experience and the contribution that individual components made to that experience. Consequently the careful management, design and specification of components should collectively contribute to the overall desired product experience.

The product strategy employed in this design, provides versatility, accessibility for maintenance, and the potential for third party suppliers to participate in the system providing customized components attuned towards a particular style and user preference. This provides the potential for a more intimate customization and specification of the product system. This would nevertheless require further testing and probably a longitudinal study to assess attachment which is an objectives of the design. Unfortunately this particular aspect of the design development falls outside the scope of this particular study.

Moving forward I would recommend that a visual servicing manual, with identification of parts supplies and sources could be developed similar to that done by IFixit as a channel for servicing repair and maintenance of the product. This provides the ability for an individual to take further ownership of the maintenance engendering a personal bond to their own product as well as provide information to independent repairers. Therefore working toward reducing relative obsolescence. Further Development of individual components in different materials could be specified to assist third party manufacturers to participate and contribute to the system, for example the carafe could be specified in regards to stainless steel, glass or ceramic in terms of wall thickness and required material performance. This also allows for the different wear characteristics of particular materials to be part of the longitudinal history of the product.

This product presents as a compact coffee making machine for the contemporary urban environment. It accommodates a range of coffee brewing styles and seeks to develop a longitudinal meaningful engagement with the user. This can be seen as an approach that seeks to reduce to some degree the design obsolescence of contemporary consumer electronics.

Endnotes

- 1 Cho, "Recycling in the U.S. Is Broken. How Do We Fix It?"
- 2 Cho, "Recycling in the U.S. Is Broken. How Do We Fix It?"
- 3 Fairware, "Greenwashing and Recyclability Claims to Watch Out For."
- 4 Ahmed, "The Global Cost of Electronic Waste."
- 5 Griffith "The Energy Problem(s) - Following the Numbers."
- 6 Griffith "For Keeps"
- 7 The term "transitive" is used to designate all those products that connect the past with the future in the name of continuity of change. At the end of the 20th century design saw an increasing emergence of styles that evoke the recent past whilst conjuring up visions of the imminent future.
- 8 "Fairphone | The Phone That Cares for People and Planet." A modular phone that functions as chunks connecting to a main board
- 9 An independent section in a modular system that connects to the whole.
- 10 Slaper, and Hall, "The Triple Bottom Line: What Is It and How Does It Work?"
- 11 Rittel and Webber, "Complex or 'Wicked Issues."
- 12 Austrian research concluded the same, cited in cooper 2006
- 13 Nieuwenhuis and Wells, *The Automotive Industry and the Environment*. Cambridge: Woodhead.
- 14 Cooper, 'Longer lasting products'
- 15 *Oxford English dictionary* 2000
- 16 Cooper "Forms of relative obsolescence - Longer lasting products" P16
- 17 Fels, Falk, and Schmitt, "Social Media Analysis of Perceived Product Obsolescence." P571-576
- 18 Chapman 'Emotionally durable design' P24
- 19 Querol, "Sustainable Product Policy."
- 20 "'Hostile Architecture': How Public Spaces Keep the Public Out - The New York Times." *Additions to architectural structures to prevent specific uses of public spaces*.
- 21 Rossmann, "What Is Right to Repair?"
- 22 Jackman, "Eric Lundgren, 'e-Waste' Recycling Innovator, Faces Prison for Trying to Extend Life Span of PCs."
- 23 Rossmann, "What Is Right to Repair?"
- 24 Cooper, "Longer Lasting Products | Alternatives To The Throwaway Society." P193
- 25 Weizsacker, "Longer Lasting Products | Alternatives To The Throwaway Society."
- 26 Burns, "Longer Lasting Products | Alternatives To The Throwaway Society."

Duplications when same source is used multiple times.

- 27 Patagonia "Worn Wear - Used Patagonia Clothing & Gear."
- 28 Patagonia "Worn Wear - Used Patagonia Clothing & Gear."
- 29 Trove "What We Do. "
- 30 Ahmed, "The Global Cost of Electronic Waste."
- 31 Burns, "Longer Lasting Products | Alternatives To The Throwaway Society."
- 32 "Coffee - United States | Statista Market Forecast."

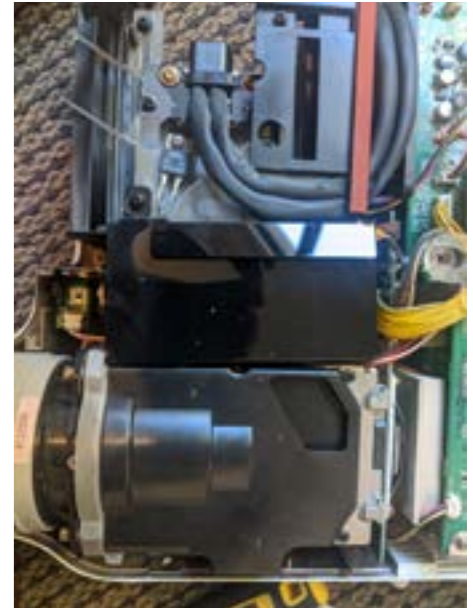
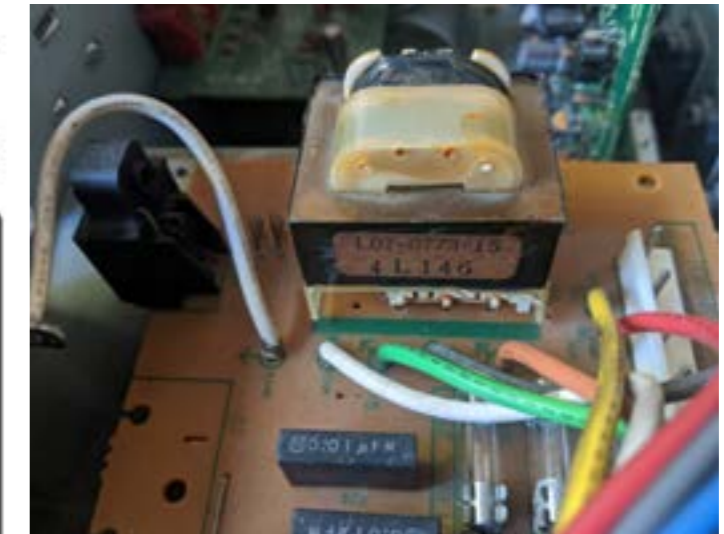
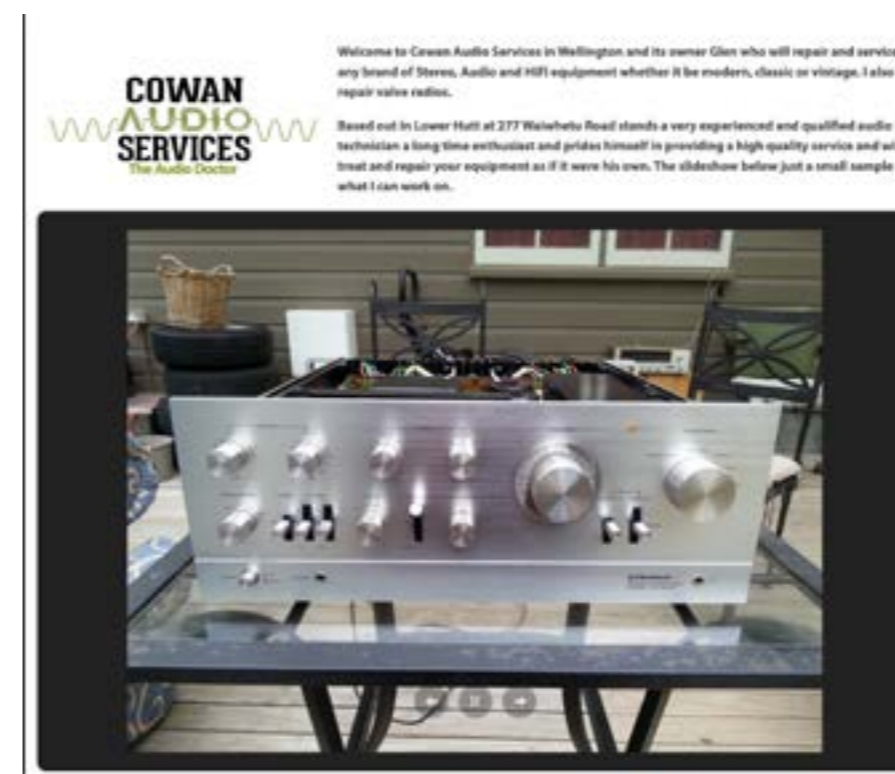
Appendices

Additional disassembly of hifi Electronics with the guidance of Cowan Audio Services. P57

Continued table from Page 34-35. P58

Henry Dreyfus Measure of man. Used during development of dimensions. P59

Definitions of Modularity, Product Design and Development Fourth Edition by Karl T. Ulrich and Steven D. Eppinger P60



Bicycles	-Incremental change for the majority. -Information widely available -Different companies focusing on components. -Uses a Slot modular architecture.		-User approachable repair. Some use of expert repair but primarily can be done DIY.
Watches	-Very long product life cycles. -Constantly repairable	-Expensive. -Requires expert for repair, not user approachable. -Specialty tools -Very Little standardization	

iFixIt			-Educates and empowers users to repair. -Repair by external company
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Henry Dreyfus, the measure of man:

TOGGLE SWITCHES
prefer ON OFF ON OFF
1.25 min. 1.0 max.
.875 min. 4"-6" blind reach.
40° min. 60° opt. 120° max.
10 oz. min. 40 oz. max.
5" min. 2.0 max. 1.5 min. - gloves

THUMB WHEELS
dia. is 1.5 for 1 in.-lb. 2.5 for 3 in.-lb.
1.2 min. .5 max.
7.5 to 1" opt.
90°
alt. drum
sharp serrations
note: avoid markings on wheel which are obscured by fingers

SLIDE SWITCHES
2 min. 5 max.
concave flat or convex 5 min. R
25 min. .87 opt.
serrations
minimum version
.25
.2
.06 sliding flags
25 travel .07

LEGEND SWITCHES
10 to 45 oz. resistance
.75 min. 1.5 max.
1 min. .25 max. displ.
flush if protected
.13 min. .25 max. barriers
*.56 if not recessed
1 min. .25 max. if gloves

GANGED KNOBS
sequential order 1 2 3 assoc. displays
3" opt. 1.75 opt.
5" opt. serrate or knurl
5" 7.5 opt. 7.5 opt.
.25 min.

PUSH BUTTONS - TOUCH SYSTEMS
prefer vertical buttons, fig. B
A 11" opt. 20" max.
B 4-11 oz. .438 max. .5" wide
.187 defl. .312 min. clear.
operation rate: 4.1-5.3 per sec.

ROCKER SWITCHES
legend is possible
7.5 min. 1.37 opt.
.37 min. .87 opt.
30° .56 opt.

ROTARY KNOBS
use 1" for non critical settings. 2-4" for critical settings.
2.5" min. typ. serrations: .08" dia. .22 space. .05 deep
3.75" min. .25 low force 4.0 max.
1 hand 2 hands 1-2" 3-5"
5" min. .875-1" opt. .03 R. skirt
torque: 4.5 in.-oz. max. < 1" dia. 6.0 in.-oz. max. > 1" dia.

PUSH BUTTONS
1 finger 6.25 min. 1.25-2.0
2 fingers .93 min. recess dia.
.375 min. dia. .25 lb. min. force
.5-1" opt. 1-3 lb. opt.
1.5-2 palm 31 lb. max.
.5-2 foot 4-20 lb. - foot rests on it.
.05 R.
.125 min. - 1.0 max. defl. - no gloves
.25 - 2.0 gloves
.5 - 2.0 shoes
1.0 - 4.0 boots * not required

ACCESS OPENINGS

*INDICATES DESCRIPTION APPLIES TO DATA TABULATED BELOW

HANDS				
	empty hand held flat	* bare 4x2.25"	* work gloves 6x3"	* arctic gloves 6.5 x 4"
	min. to wrist	3.5 sq.	5.5 sq.	6. sq.
	clenched hand	3.75 D	5.75 D	6.25 D
	using pliers screw driver	5.2x4.5 4.2x4.6	—	—
	one hand passing object	L=4" A+B=1.75	L=6" A+B=2.5	L=6.5" A+B=2.5
	two hands straight ahead reach = 6-25"	H=4 add for vision	H=6 add for vision	H=6.5 add for vision
ARMS				
	arm to elbow	—	* clothed 4.5"D	* arctic 7"D
	arm to shoulder	—	4.5 sq.	7. sq.
	arm to shoulder	—	5. D	8.5 D
	" " "	—	5. sq.	8.5 sq.
FINGERS				
	one finger	* bare 1.25"D	* gloves 1.5"D	—
	recessed push button	0.93 D	—	—
	twist access eg. hold screw	2. D	2.5"D	—

Modularity:

- **Slot-modular architecture:** Each of the interfaces between chunks in a slot-modular architecture is of a different type from the others, so that the various chunks in the product cannot be interchanged. An automobile radio is an example of a chunk in a slot-modular architecture. The radio implements exactly one function, but its interface is different from any of the other components in the vehicle (e.g., radios and speedometers have different types of interfaces to the instrument panel).
- **Bus-modular architecture:** In a bus-modular architecture, there is a common *bus* to which the other chunks connect via the same type of interface. A common example of a chunk in a bus-modular architecture would be an expansion card for a personal computer. Nonelectronic products can also be built around a bus-modular architecture. Track lighting, shelving systems with rails, and adjustable roof racks for automobiles all embody a bus-modular architecture.

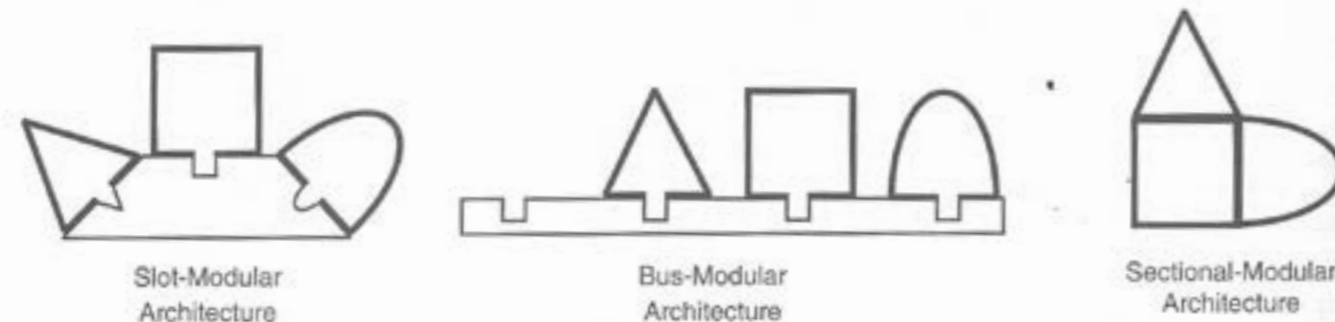


EXHIBIT 10-3 Three types of modular architectures.

- **Sectional-modular architecture:** In a sectional-modular architecture, all interfaces are of the same type, but there is no single element to which all the other chunks attach. The assembly is built up by connecting the chunks to each other via identical interfaces. Many piping systems adhere to a sectional-modular architecture, as do sectional sofas, office partitions, and some computer systems.

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