A research study for improving induction cooktops user interaction

Improving induction cooking

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BORETTI

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In collaboration with Boretti B.V.

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Personal motivation

More and more problems will need to be solved with product service systems and even services, instead of just products. As a product designer I therefore feel responsible for not bringing unnecessary rubbish into the world. During my master's I decided that I only want to design physical products that somehow contribute to the greater good. The purpose of technology in general is to meet a human need or solve a human problem. That is why I will start with a chapter arguing the benefits of induction over traditional cooking.

Out of all products I interact with in day to day life, induction cooktops are the most awkward. Cooking is a human need and as of now induction is the most efficient and safe way of doing so, therefore helping people transition to it would be beneficial to society. Where the heat transfer from to coils to the pan goes elegantly the control can be cumbersome. Touch controls and distractive sounds make the user distanced from the technology and not in control.

I want to bridge that gap and make a more intuitive, fluid and rich control solution that gives the user a sense of what is actually going on, while keeping all current aspects of the interaction that the user is accustomed to and thus do work.

Fig 1: My parents induction cooktop, stuck in some kind of count down mode.

Glossary

Cogging: torque due to magnets within an electric motor
Cooktop: worktop built -in cooking unit
Detent: to resist the movement of a device
Gres porcelain: a ceramic with a non-porous body
Haptic: relating to the sense of touch
Range: freestanding cooking unit
Skeuomorphic: resembling with real-world counterparts
Tacit: expressed or carried on without words or speech
Tactile: designed to be perceived by touch
Worktop: kitchen surface or countertop

Summary

The document begins with a reflection on the commitment to designing products that contribute to societal well-being. Induction cooktops are identified as a focal point, given their efficiency and safety but often cumbersome user interaction. The aspiration is to make induction cooking more intuitive and user-friendly, aligning technology with human needs.

Induction cooktops function by heating the pan itself through a copper induction coil, creating efficient heat through Joule heating. With an efficiency rate of 90%, they surpass traditional electric solutions (74%) and gas cooktops (40%). Environmental considerations are also highlighted, with induction cooking reducing CO2 emissions. However, the learning curve and interface challenges have led to a preference for gas cooking among many users.

The research is in collaboration with Boretti, a renowned kitchen appliance company. The assignment is to design a superior induction control solution, with the potential to become a new industry standard. The "cooking on stone" concept, serves as a focal point for the research.

A hands-on, exploratory approach is adopted, involving the dismantling of an induction cooktop to understand its components and functionality. A feedback loop consisting of action, effect, and user is employed to systematically identify an improved control solution. The development phase involves addressing specific design challenges, culminating in a set of requirements for the final product.

Boretti's brand positioning and product portfolio are explored, emphasising its reputation for quality and Italian-inspired design. The "cooking on stone" concept, involving the concealment of technology under the kitchen worktop, is detailed, along with previous student iterations and concepts related to this idea.

The vision is articulated as creating a more intuitive, rich, and fluid control solution for induction cooktops. The focus is on enhancing the main functionality, such as on/off, zone selection, and power selection. A feature/user matrix is employed to guide design decisions, comparing current gas and induction feature/user interactions.

The document also addresses the economic considerations of induction cooktops, including initial costs, installation, and the need for specific pans. The impact of induction cooking on energy use during peak hours is discussed, highlighting potential challenges in certain regions.

The research provides an in-depth examination of induction cooking, pinpointing areas for improvement and proposing a novel approach to user interaction. Through collaboration with Boretti and the application of a hands-on, iterative design process, the aim is to redefine the induction cooktop experience, aligning it more closely with user needs and potentially setting a new standard in the industry.

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Induction

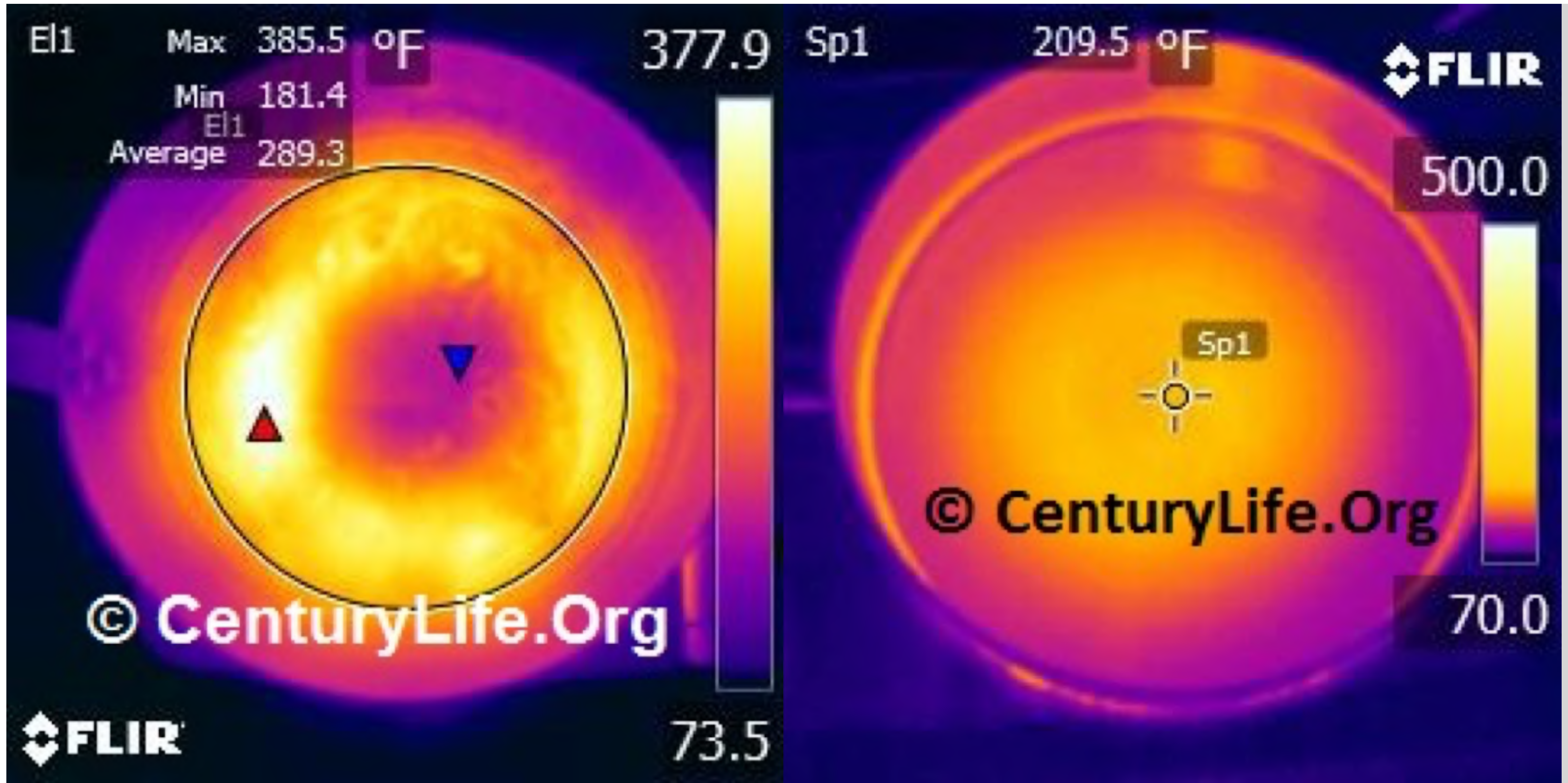
As I have said to want to contribute to the greater good, this short study on induction technology and its effect on the environment is done before I started with this thesis.

In contrast to earlier electric and ceramic cooktops that heat the surface below the pan, an induction cooktop actually heats the pan itself. It does this via a copper Induction coil. The coil has many turns, while the bottom of the pan effectively forms a single shorted turn. This forms a transformer that steps down the voltage and steps up the current. A high frequency (25 kHz to 50 kHz) alternating current gets put on the coil which then creates a dynamic electromagnetic field that induces large eddy currents in the pan producing efficient heat through Joule heating.

Only the pan gets heated with induction cooking which makes 90% of the input energy actually go into heating the food, which is high considering the pan also loses heat. Traditional electric solutions achieve about 74% efficiency. Gas cooktops on the other hand transfer more heat to the room than their food with an efficiency of merely 40% (EPRI, 2014).

While gas burning releases carbon dioxide (CO_2) into the atmosphere, new research shows there is more to worry about. The emission of nitrogen dioxide (NO_2) by gas stoves is severe, not to mention the leaking of methane, which includes the carcinogen benzene. It is for example found that 12.7% of current childhood asthma in the US is attributable to gas stove use (Gruenwald et al., 2022). As of now Dutch yearly household CO_2 emissions associated with grey electricity for induction cooking (60KG) are lower but somewhat comparable to that of gas cooking (75KG). But this weight off will only improve as electricity is getting greener and greener (Milieu Centraal, 2023).

Fig 2: Infrared images showing the difference in heat distribution in a pan between a gas cooktop (left) and an induction cooktop (right) (CenturyLife, 2023).



Considering the learning curve and interface many enthusiasts still prefer gas cooking, but induction is superior given its technical qualities. You are able to cook faster, saver, preciser and more replicable all while enjoying better (indoor) air quality, kitchen temperature and an easier to clean cooktop. So if people still prefer gas there has to be something quite not user friendly about the way users are supposed to interact with the traditional induction cooktops.

While people are using less fossil fuel for cooking, heating and even their cars, that use is just shifted to the already congested grid. While improving on countless factors, induction cooking generates even more energy use on peak hours (ANWB, 2023). This is a problem in the Netherlands, but an even bigger problem in for example southern Europe countries that might not even handle the bulk of energy that is needed for induction cooking in the first place.

Induction cooktops can be fairly expensive with prices starting at around €200, but more high-end solutions costing thousands of euros. An average induction cooktop in the Netherlands costs €600. While some function on 1 group normal electricity, most will need an additional 1-2 groups to get all benefits of the cooktop. Cost of professionally installing these can easily be €600 as well. Induction cooktops only function with magnetisable pans, some households might need to invest in those. Cost of operation is comparable, but as gas has mostly been cheaper the yearly average use associated with cooking of 37M3 of gas comes down to €25 and 175kWh with induction comes down to €36 respectively (Milieu Centraal, 2023). This will most likely improve since geopolitical circumstances skyrocket gas prices and some users enjoy free solar energy. Low budget induction can start at €200 for a simple cooktop on 1 group but can get into the thousands when installing a luxury model.

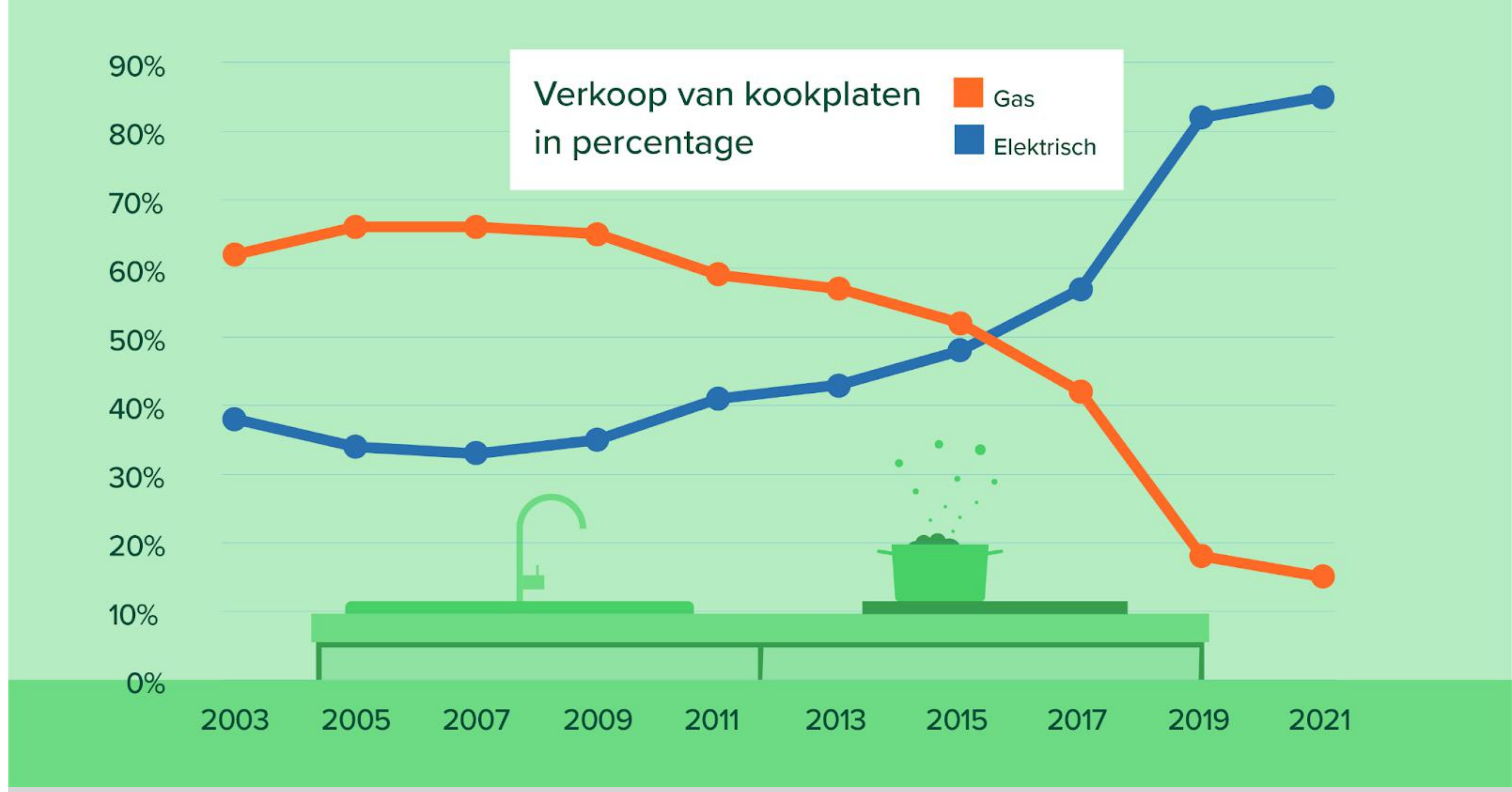


Fig 3: Dutch cooktop sales gas(red) v.s. electric (blue) (Milieu Centraal, 2021).

Context

Introduction

In this chapter, I discuss how I came to the assignment. In what way I planned to solve it. Then I outline the context of the Boretti company and previous developments around their cooking on stone concept. I use all this to set up a project vision, in which I define when my project is successful and how I will present possible solutions.

Context

Assignment

When looking for a kitchen appliance company to propose my graduation idea to, I came across Boretti. They already had a relationship with the TU Delft and even did two projects on the control of induction cooktops. The perfect fit!

When contacting Boretti's designer Jacco Bregonje, he told me that he shared my vision and explained that they had been trying to come up with a similar control solution for an induction concept. In 2016 Jacco developed the Carrara concept for Boretti, which showed 'cooking on stone', a technology that is able to hide the induction coils under the kitchen worktop in a freestanding range. The Carrara ranges were later brought to market without the stone, losing its essence which was reflected in sales. Jacco explained that when introducing a new technology you ideally introduce it within a flagship model, creating desire. Then later make another product that makes the 'dream' more accessible for the mainstream audience. It would be great to introduce the new induction control solution with a flagship model as the 'cooking on stone' concept, therefore this will be the focus of this research.

Assignment: Design a better induction control solution that can ideally become the new standard, but can be brought to market with the 'cooking on stone' concept.

Fig 4: Initial Carrara Prototype by Jacco Bregonje (2016).

Method

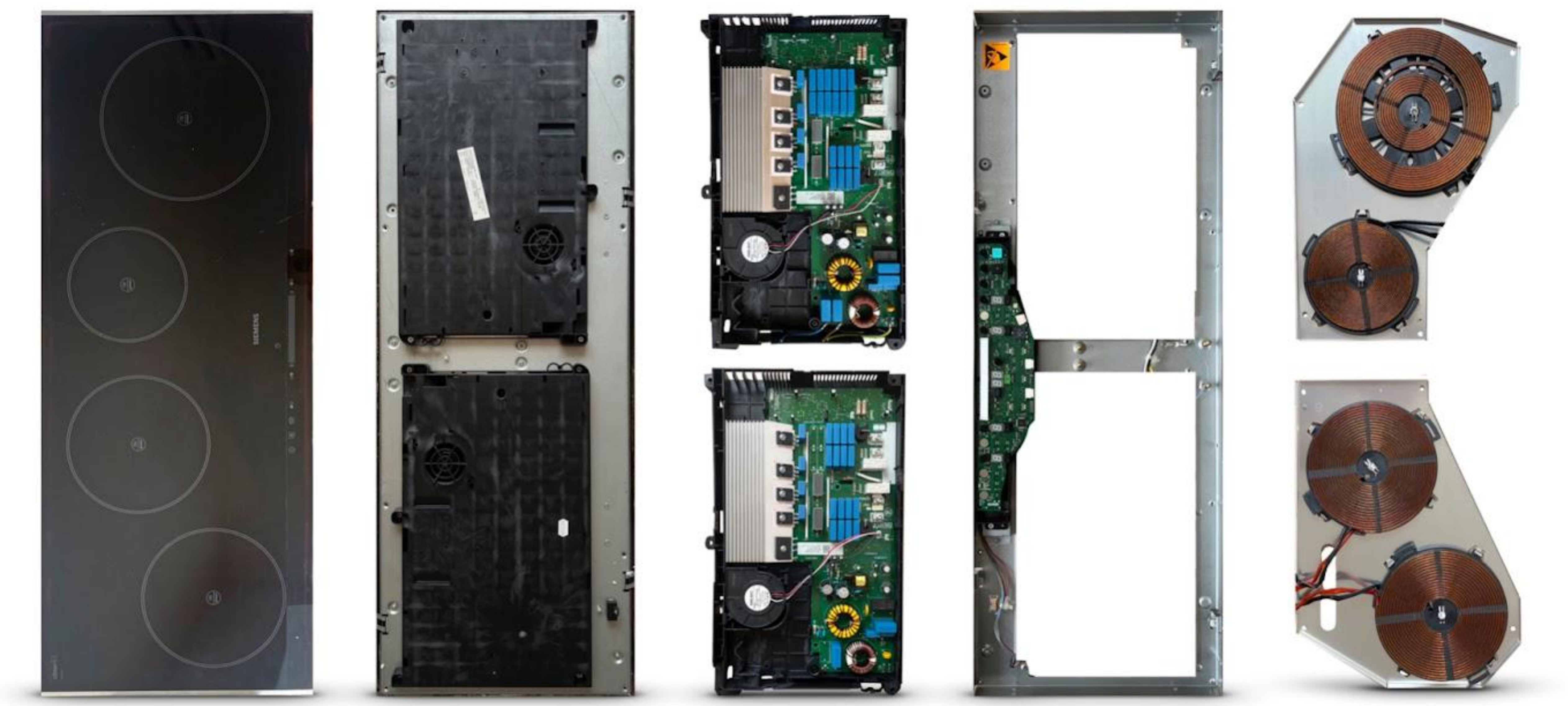


Fig 5: Dismantled Siemens cooktop.

As a curious generalist designer, I like to gain insights by human interaction and translate this to practical solutions. My first goal is **finding the essence of the problem**. I like to do that by taking the problem apart, which I will do in the literal and metaphorical way.

I started off by taking apart a ceramic glass induction cooktop (Siemens) that had the same zone layout as Boretti's prototype, as I was curious how all working parts were configured, how the touch interface functioned and how it was documented in the manual. This is a great example for my **hands-on way of working** in general.

Using a **feedback loop consisting of an action, effect and user** I am able to explain the essence and therewith all future steps taken in this project. By separating main from extra features and visualising in a matrix how exactly these affect the user, an objectively better control solution can be found in a structured manner. Then some background information on Boretti and the cooking on stone concept will be given to explain the direction of research.

During the **research phase** I submersed myself with as many interesting people in interesting places as possible in order to gain insights, through the lenses of action and effect. Information will be clustered in themes. These key insights are then used to formulate a design vision. In order to realise this design vision a couple design challenges need to be tackled.

During the **development phase** these design challenges will be addressed. Each challenge will be introduced with inspiration from examples in other designs that have solved them. Then these more manageable chunks will be iterated until solved using an adapted version of the Build Measure Learn feedback cycles, leading to a list of wishes and requirements that can be used for embodying the product.

During the **embodiment phase** the wishes and requirements will be used to come to a final design in contact with Boretti's current suppliers. The appearance, materialisation and production of the design will be discussed and all main features will be user tested

Context

Boretti

Boretti is a Dutch brand that has become renowned in the Benelux with its iconic gas ranges from Italian manufacturer ILVE, while now selling mostly its own portfolio.

The brand is positioned to make luxury affordable for almost everyone. Since not having any factories itself, the company is able to actually sell Italian produced products. In general the brand has a great name. People were impressed when I told them I was graduating for the brand Boretti. Most know the brand for quality appliances or actions they did as selling knives and cut-boards via Albert Heijn.

'Passione in Cucina'

Boretti aims to bring traditional Italian cooking to the Dutch consumer. This makes it a lifestyle brand. It is also selling a huge portfolio of Italian associated products, such as a period of rebranded coffee makers, wine cabinets, (pasta) cookware, aprons and they have also sold pasta sauce and olive oil as well. Currently the company is also having success selling a wide assortment of barbecues.

Fig 6: Typical Boretti styling presenting the associated lifestyle.

'Boretti is the Alfa Romeo of kitchen hardware, Gaggenau is the Maserati'

- Jacco Bregonje (2023)

Context

Cooking on stone

By the use of gres porcelain and tuned induction coils one is able to hide the technology under the kitchen worktop. The name Carrara refers to a place in Italy (just like their other product lines) that is known for its marble production. Carrara was supposed to first show worktop integration induction or cooking on stone. This will be the third student iteration on the worktop integrated Carrara or cooking on stone concept. Therefore it is interesting to look at the original proposal and the first two student iterations to make sure no work will be done twice. When developing the Carrara concept a worktop integrated proposal was made in 2016. This featured silicon suspended cook-zones and a glass cutout for a traditional cooktop interface. At the time there were concerns of the worktop material cracking under the cooking heat, the silicon centring rings would facilitate heat expansion and in worst case replacement of just these areas. The used interface was a standard part that was used just for proof of concept.

For the Carrara series a special knob was designed by Jacco. Using a stationary centre and a moving ring with indicator the knob is able to show all features without the need of prints on the surrounding stone itself (shown in figure X below on a metal enclosure). Eventually this design was deemed too expensive and did not make it to production. Boretti has a great starting point for developing the cooking on stone as they have relations with Linea Marmi and Lapitec. They could bridge the gap between the electronics and ceramics on the European market, putting them in a great position.

Fig 8: Original Carrara worktop integrated proposal (2016).

Appassionato: graduation project by Jeroen van Rijnberk:
After the development of the initial concept Jeroen was asked to develop the integrated variant for Borreti. Jeroen explored this more holistic kitchen experience and came up with three kitchen concepts, of which he combined two to come up with the final Appassionato concept he presented. This concept featured a lay-out design and a smart knob for controlling the zones. The silicon rings seemed unnecessary and the charging for the knob was wireless.

Fig 8: Appassionato concept render (2020).

La Selce: IPD AED course project by group Cavolo:
The Boretti product department was excited after the concept developments and participated with the AED course to embody the product for planned production in 2022. The group kept the form factor and smart functionality while adding an LCD screen to the interface. A fully functional prototype showed feasibility of the concept. At a CEO's change priorities have been shifted from development to sales and the project was put on hold.

Fig 9: La Selce concept render and physical prototype (2021).

Output
For me the whole cooking on stone concept is about hiding technology under the kitchen worktop, therefore an ideal control solution would also hide its technology under the worktop in my opinion. Therefore I am not going to reiterate on both smart knob projects but rather extract more general implementable insights they have gained.

Insights La Selce
- Aesthetics
    - Logo should be physically implemented and readable
- Size
    - Knob diameter should not be smaller than 55mm
    - Knob diameter should not exceed 75mm
    - Height of the knob should be at least 12mm
- Weight
    - Knob should feel heavy, with a limit of 300 grams
- GUI showing:
    - Selection
    - Power / off / hot
    - Timer

Project vision

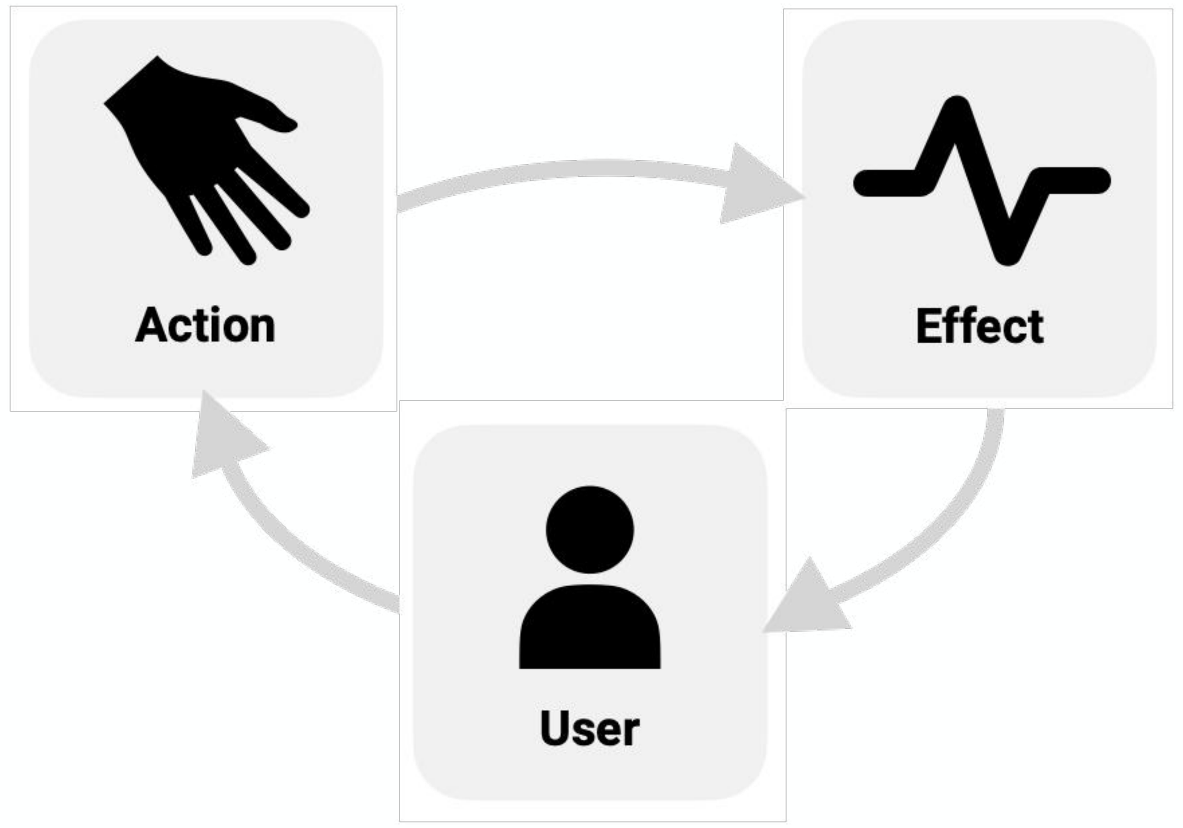


Fig 9: User action effect feedback loop.

In my motivation I expressed that I wanted to design a more intuitive, rich and fluid control solution for induction cooktops. Using a feedback loop I will explain what I mean by that. Intuitive meaning that the user can act instinctively since these actions fit earlier experience, rich meaning that the user gets multimodal notifications of the effect offering information redundancy and being more efficient by enhancing each other for the user to make better judgements (Calvert, 2001) and fluid meaning that this feedback loop can repeat itself as fast as possible (if needed) without any hiccups.

To practise this first all needed actions will be listed as cooktops features and then their effect on the user will be discussed in gas cooking and current and future induction cooking.

Over the years induction cooktops have gotten more and more functionality. New features can improve the user's cooking experience, but it is important that they should never hinder or bring confusion to main features that need to be used more often. Where on/off is used only twice per cooking session, the selection of a zone will be used numerous times (if cooking with more zones and one power control) and the selection of power almost continuously. Therefore the power selection and its feedback is the most important. The selection of zones is only applicable for cooktops that have one shared power control, but will be taken into account since no decisions on this topic are made yet.

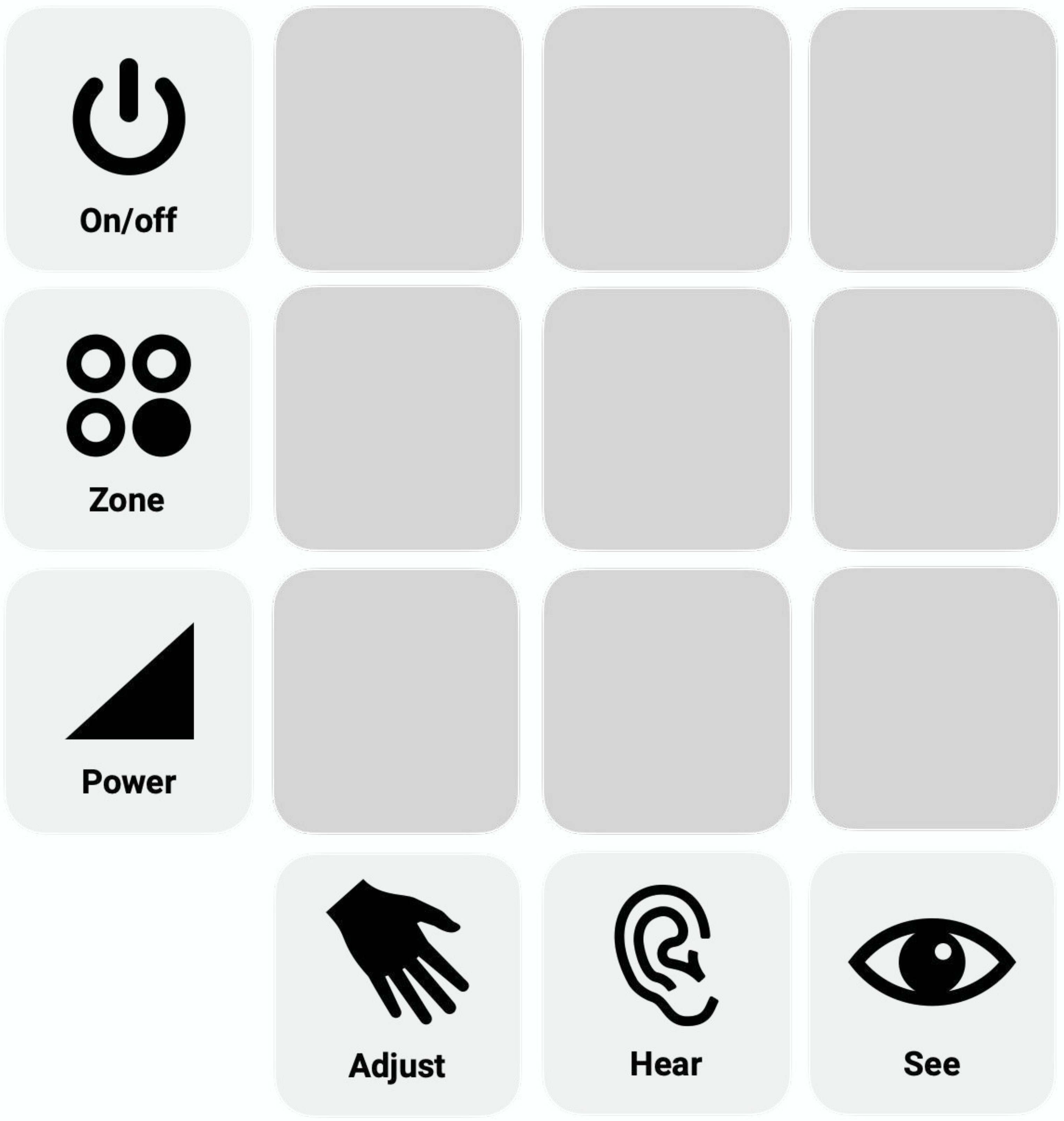
This research will focus on improving only the main functionality of induction cooktops, later on during the embodiment phase the implementation of other features will be discussed too.

Main:
On/off
zone selection
Power selection
    1-9/20 modes
    Boost mode
    Keep warm mode

Often:
Child lock
Bridge zones
Timer
    General
    zone

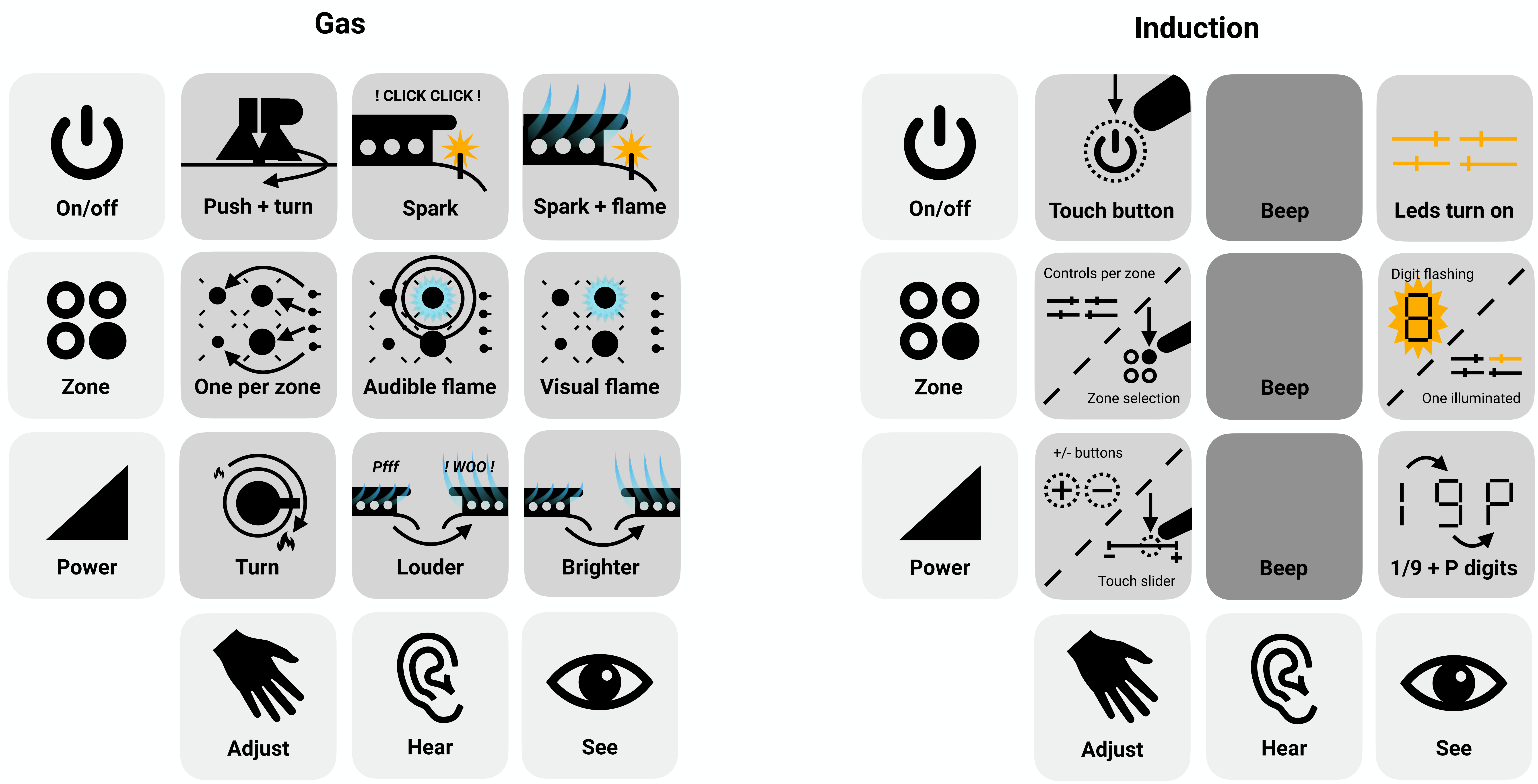
Rare:
Pause
Cleaning mode
Automated temperature control

Fig 10: Icons of the main features.



When putting these features in a matrix together with the action (adjustments) of the user and effect (e.g. hearing or seeing) on the user you get this feature/user matrix. This will be used to explain choices during this project.

Fig 11: Example feature/ user matrix.



In gas cooktops users were able to see and hear the status of all main features. This worked great by giving the user redundancy in the notification of the effect, offering unambiguous communication of the status of these features. In induction cooktops most brands offer some kind of audible effect like a beep. Sadly these will only communicate that something is happening, not what exactly and in what way. Beeps will come from location and will mostly sound the same. In the induction control solution a new and better way of multimodal notification will have to be found.

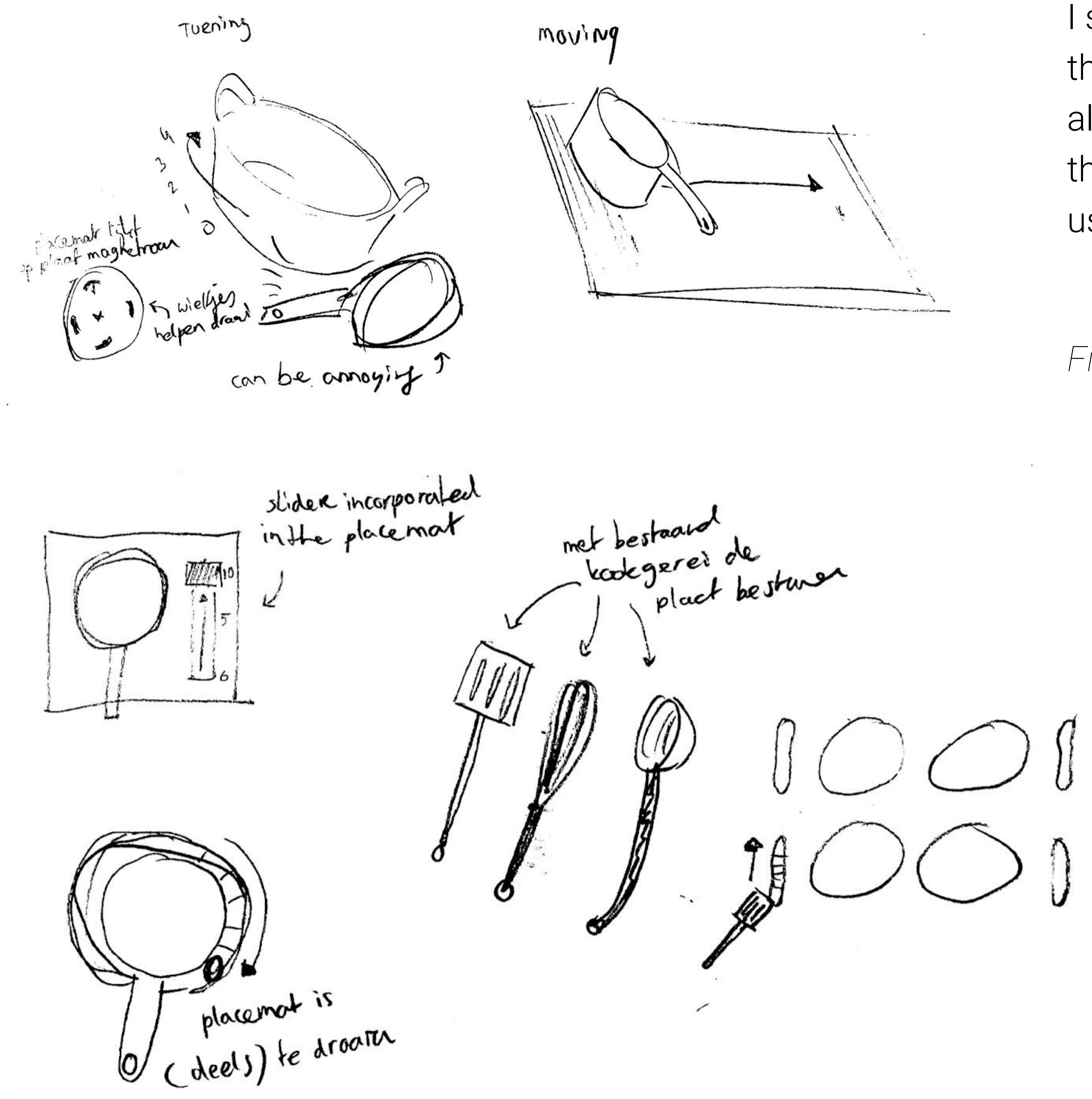
Fig 12: Current gas and induction feature/user matrix.

Research

Introduction

Now I know what an ideal solution should be capable of by diving into cooking on stone concept and formulating a project vision, I can start looking for inspiration to realise that. During my research I have visited 3 fairs, 3 brand stores and 3 kitchen resellers, I consulted 3 induction (cooking) experts, 6 TU Delft experts and 6 home cooks all to gain insights that are used to formulate my design vision.

Scoping



I started off broad with my research, even contemplating if the control solution should be a dedicated physical object at all. Maybe one of the physical objects that is already there like the pan, its placemat or a (metal) kitchen utensil could be used to control the cooktop.

Fig 13: Initial solution sketches.

Pan as control solution:
Just like some professional kitchens use heat zones, the Gaggenau 200 Flexzone series has a Professional cooking function that does this as well. Predefined zones on the cooktop correspond with certain power levels, preventing the need of dedicated controls. Variations of moving the pan but also turning it in order to control the power are explored.

Placemat as control solution:
Early worktop integrated induction cooktops still need some kind of placemat/spacer for the pan not to heat up the worktop surface too much. Since this item is already there why not explore using it as a control solution. A slider of some kind or even using the whole placemat as a knob was sketched.

Kitchen utensils as control solution:
When cooking you are most likely to have some kind of kitchen utensil on hand. This too could be a way of controlling the cooktop. For example the properties of metal utensils are traceable with electronics.

Boretti has been known for their ranges that use distinctive knobs. Some of their ranges sport up to 10 knobs in a row when they feature 6 zones and 2 ovens, making the knob a brand icon. New ranges use the knob for brand placement.

When designing a control solution for the worktop integrated induction cooktop it has to be taken into account that this is the only physical object for logo placement and contact with the brand in general. Therefore the control solution should be a physical object that is able to feature the Boretti logo. Knowing that the control solution should be a physical object I can start looking for driving inspiration to shape it. Using examples of what I think are great applicable solutions.

Fig 14: The Boretti VT946IX gas range showing 10 signature knobs.

Fig 15: Visualising making a full low tech solution possible by having a magnetic coupling.

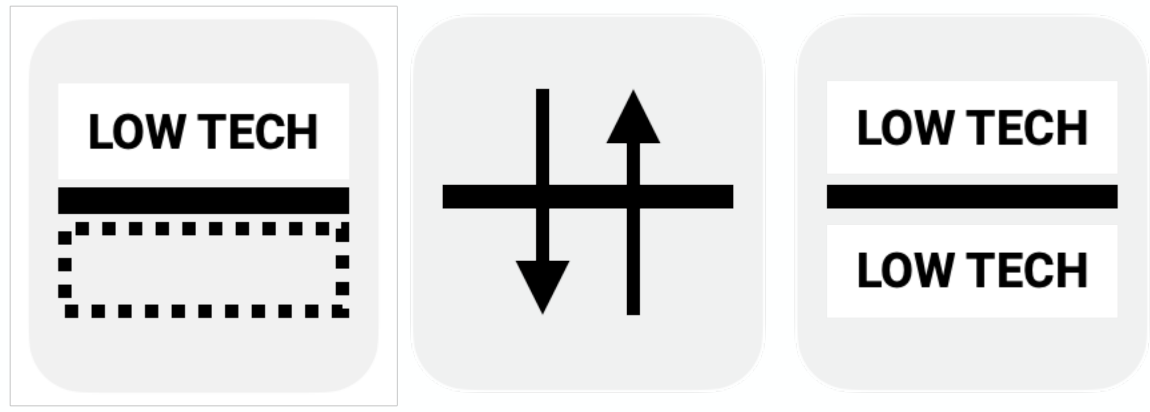
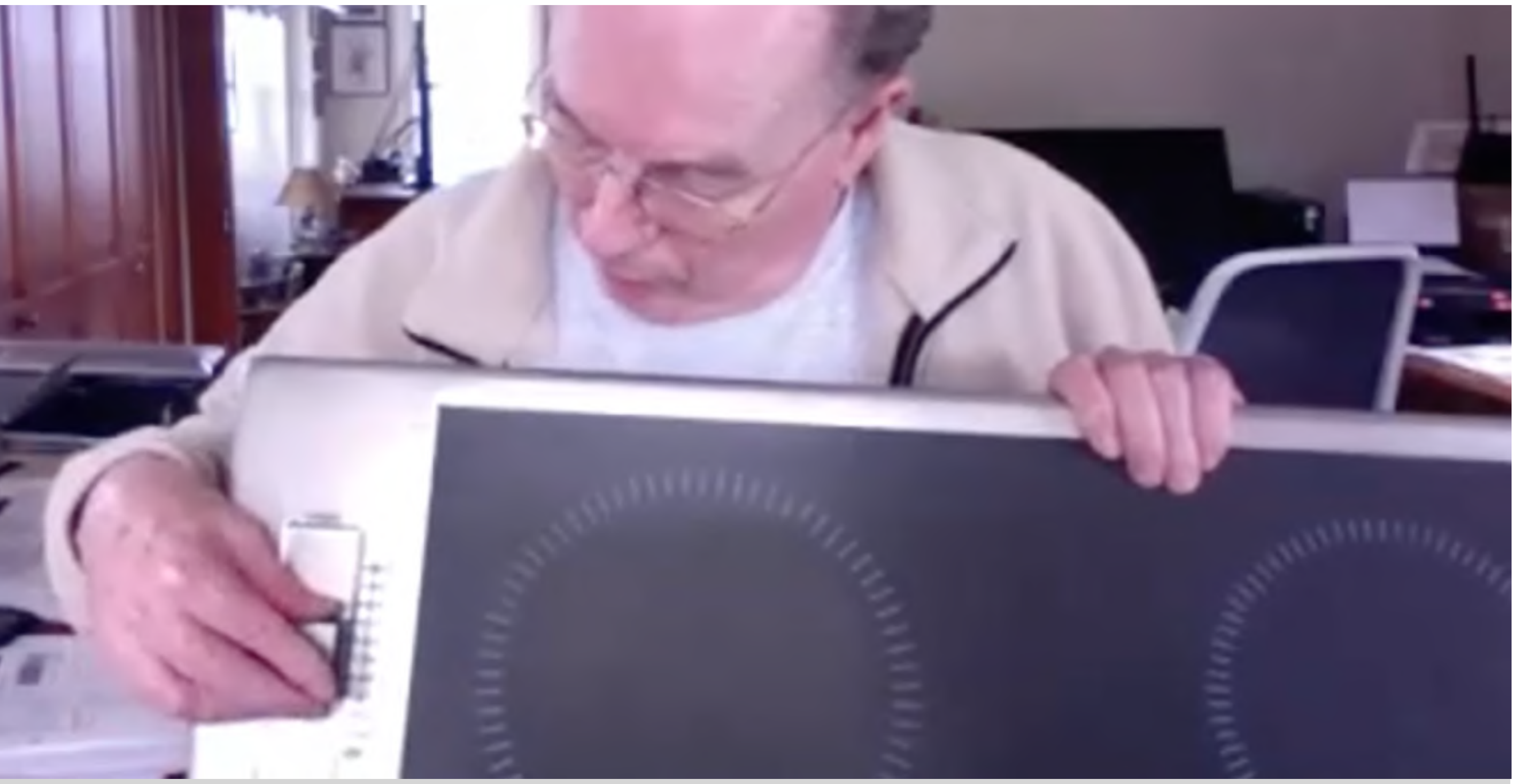


Fig 16: Terry showing the magnetic control knob of the Cool Top 2.



The first modern induction cooktop was the Cool Top 2 developed by Westinghouse through a team led by Terry Malarkey and Bill Moreland in 1972. During a video call Terry explained to me that in the time they developed the technology, capacitive touch interfaces as we know them were not common. Hence they too were looking for a new solution to control the cooktop. They figured out a control slider above the cooktop that connected with magnets and drove a rack and pinion system under the cooktop turning a potentiometer. Because the slider was connected with magnets and it was removable, control of the zones was straight forward, no holes were needed in the surface and it was easy to clean. While functioning great the system did not really catch on, as there was no need to make a switch from gas at the time and the Cool Top 2 was priced at $1500 in 1972 which would come down to about €11000 in today's money (T. Malarkey, personal communication, Feb 23, 2023).

Apple's Magsafe coupling has multiple functions; (bi-directional) wireless charging and (rotationally) locking on their smartphones and gadgets. It does this while looking and operating simple and intuitively. It has high tech functionality while not confronting the user with its complexity.

Fig 17: Apple Magsafe Battery Pack mounted on iPhone 13 and 13 pro.

Using Check's shared e-scooters a lot I noticed that a year ago most would have beeps for turn signals, being annoying to the driver and the traffic, while not communicating more than that something is happening. An update in 2023 changed Check's turning signals by a skeuomorphic one that resembles a turn signal relay clicking. So by showcasing a replication of the original mechanical working, the sound is being less annoying and more informative.

Link to Annoying Check E-scooter turn signal sound
Link to Skeuomorphic Check E-scooter turn signal sound

Users have built their own meanings and developed expectations as devices that they interact with have changed. For many young people, the physical devices that skeuomorphism represents aren't things they've ever experienced themselves.

Neumorphic design seeks to solve this problem by borrowing some of the visual elements of skeuomorphism and combining them with the clarity of flat design.

Fig 18: The original iOS icons using skeuomorphic design.

By merging the analog feel of physical buttons with the visual hierarchies of flat design, neomorphism could build a better experience for cooktop control. Just like for websites or apps it could be refreshing to see design elements in detail when compared with the flat 2D look that's almost ubiquitous now.

When looking for inspiration for the user technology relationship I came across the Calm technology design principles. These address exactly what I think is important.

1. Technology should require the smallest possible amount of attention
2. Technology should inform and create calm
3. Technology should make use of the periphery
4. Technology should amplify the best of technology and the best of humanity
5. Technology can communicate, but doesn't need to speak
6. Technology should work even when it fails (backup system)
7. The right amount of technology is the minimum needed to solve the problem
8. Technology should respect social norms

Touch has a high resolution of human sensation. Information can be conveyed with no visual or auditory requirement. Giving more bandwidth for communication as its feedback would not have to compete with other kitchen sounds that can already be plentiful.

Audi has a great solution for controlling its in-car Multi Media Interface (MMI) without having to look at the controls. The circular control knob that is turnable, movable and pushable gives clicks that confirm actions and is straightforward enough for not needing to be looked at while in use.

The MX Master 3 has a MAGSPEED scroll wheel which gives extraordinary feedback. The implementation of magnetic scroll steps gives quieter, smoother and more precise control when needed and scroll frictionless for maximum speed scrolling as well. This makes tasks more joyful to the user.

Fig 19: Audi Multi Media Interface control knob.

Fig 20: The Logitech MX Master 3 opened up showing the retractable magnetic teeth.

Output
After some broad ideation I noticed that the knob needed to be a physical object, as it is a true icon to the brand and for the Boretti logo to be visible. The first cooktop solution gave inspiration on the area of low tech controls and various other inspirations gave a feeling of how the control solution could work in line with earlier sketched desired feature user relation.

Insights
- The control solution should be a physical object (that can be used for logo placement)
- The control solution can be high tech but should confront the user with it
- The control solution could be turnable, moveable and pushable for basic functionality
- The control solution should confirm actions with clicks
- The control solution should go to maximum power easily
- The control solution can use skeuomorphism to be more informative/less annoying
- The control solution should work even when it fails
- The control solution should require the smallest possible amount of attention

Current interaction

The interaction with current induction cooktops is analysed in order to see what works great and does not to be changed and where things can be improved.

While induction cooktops enjoy superior qualities, traditional electric/ceramic cooktops do not so much. They work by heating the cooktop surface itself. As of today there still is some confusion between these, unjustly giving induction cooktops a bad name. Electric/ceramic cooktops take a long time to warm up and cool down, therefore it is impossible to make quick adjustments on the go while cooking. Afterwards the cooking surface stays hot, pans that need to stop cooking will have to be moved.

Most modern induction cooktops feature some kind of capacitive touch interface. While cheaper ones have buttons for selecting the zone and changing the power output, expensive ones can show a linear or circular slider with gestures. All of them rely on the capacitive touch to be working properly for functionality. Numerous circumstances can hinder this as cooking moisture is fairly common in a kitchen, but also the moisture content, temperature and even age of the skin will impact the ability to use touch (Fender, 2021). Induction cooktops tend to have beeps that confirm user actions. Some will just sound when turning it off and on, while most notify every single user action. Meaning that sometimes 10 beeps will be heard before having the cooktop turned on set to zone and put to power. Numbing the user for when an alert is actually needed and annoying other people in the kitchen with an orchestra of beeps. These beeps are mostly not confirming more than that something is happening, not exactly what and to what degree.

Almost every induction cooktop uses a seven-segment display. While being simple this display effectively communicates the most important states, using '1-9' for power level and 'P' for power mode. These rules for operation and expectations regarding consequences form a mental model that is widely understood and I would like to keep intact. Boretti induction cooktops also have 'A' for automatic, 'H' for residual heat after cooking and one, two or three stripes for food warming modes and 'C' for misfit of the pan.

Fig 21: An website confusingly explaining induction hobs(cooktops) with a picture of an infrared cooktop.

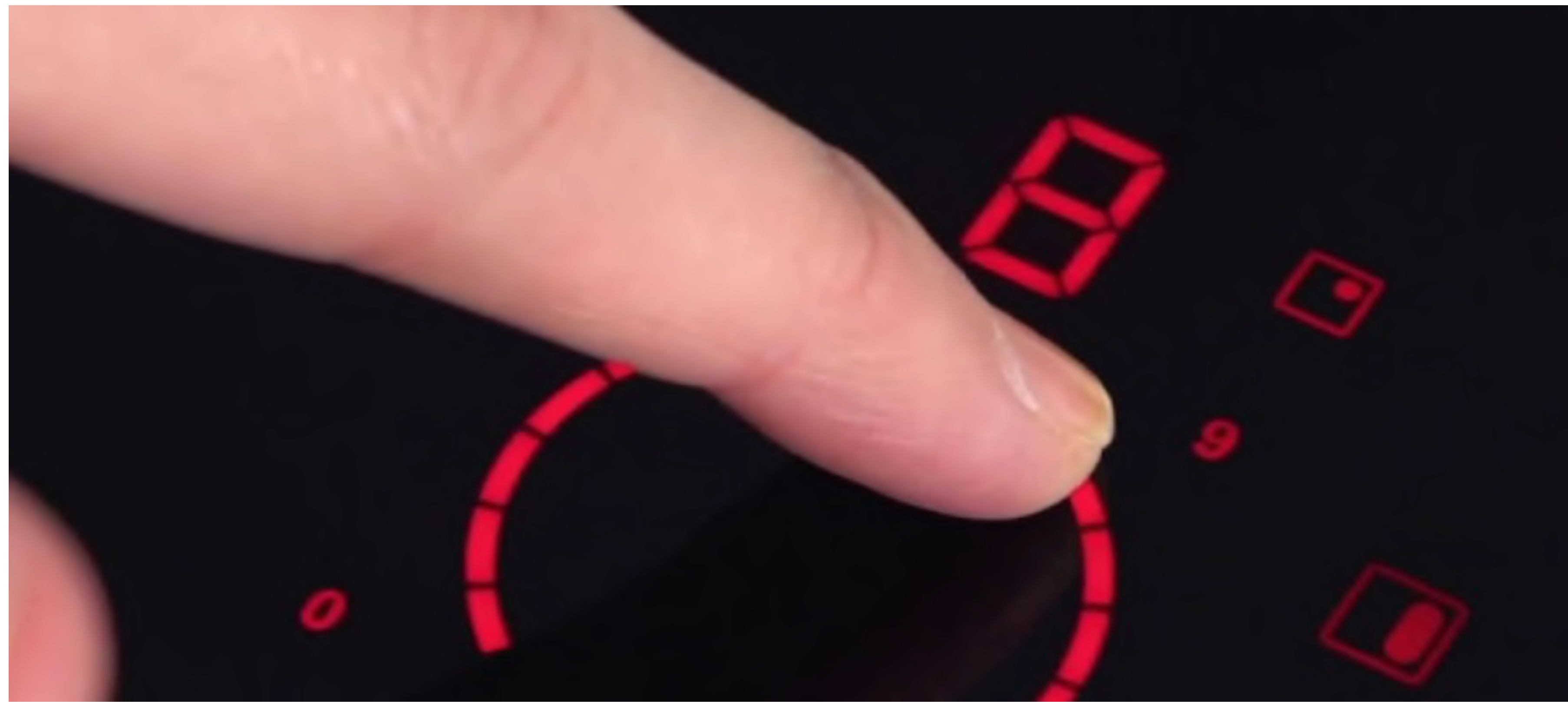
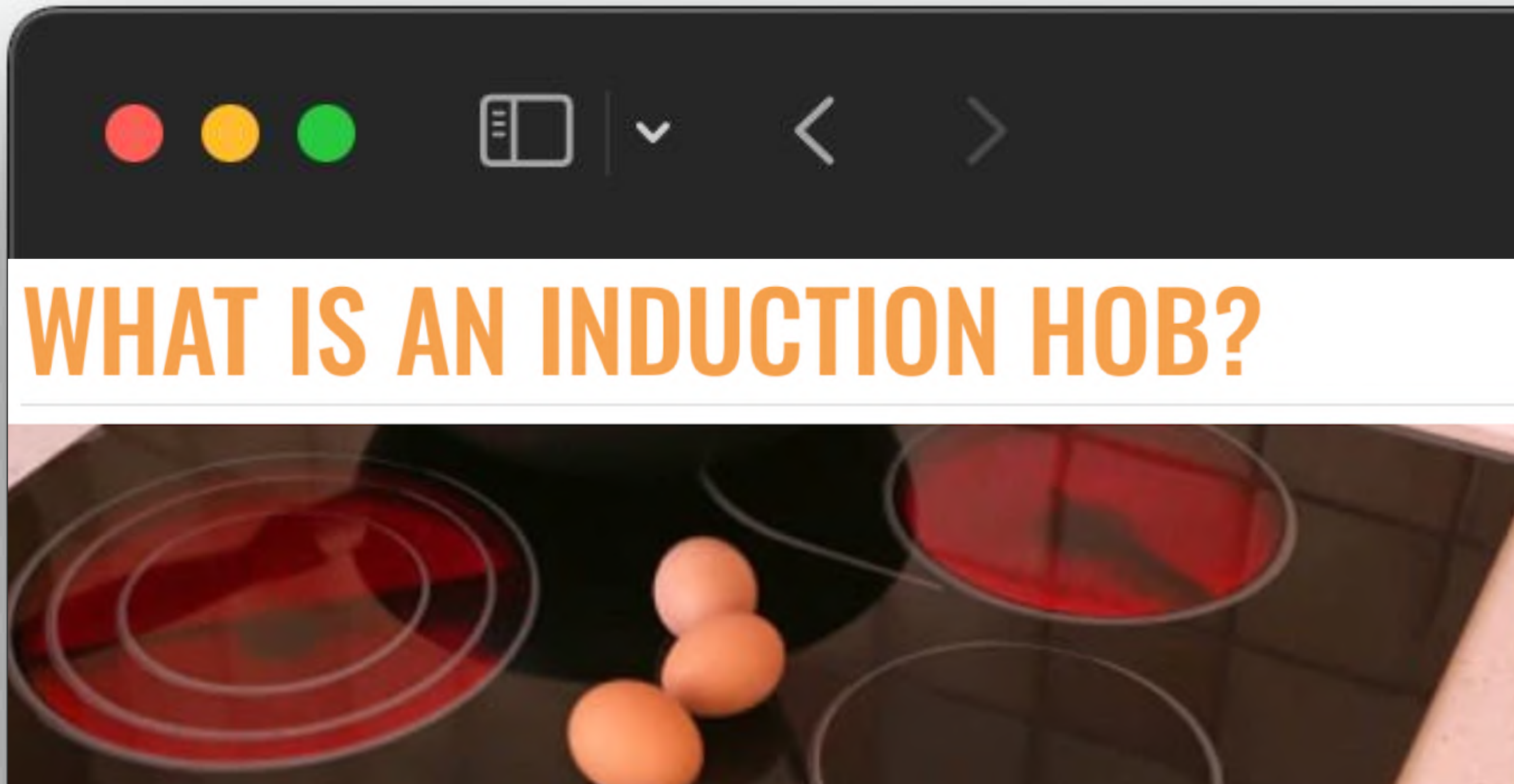


Fig 22: Touch interface showing a slider and 7-digit display.



Simpler is better, Chris Galarza explained. He is executive chef and professional kitchen electrification consultant. According to him and other chefs I talked to, induction cooking is objectively better for cooking, when the controls are not the bottleneck. He likes to advise chefs that are moving to induction cooktops to KISS = keep it simple, stupid! Professional induction cooktops have ridiculous power, simple knobs, no beeps or crazy functionality making them a breeze to use. He explains to chefs that advocate the authenticity of gas cooking, that for true authenticity they need to cook with wood, as gas has only been around for a century (Galarza, personal communication, Mar 10, 2023).

Fitting between the brand currently on display at Duikelman Amsterdam is explained to be a goal according to Boretti designer Jacco Bregonje. When visiting the store and talking to the sales representative I searched for common denominators in their existing in store product portfolio.

Brands on display

- Folgor
- Bertazone
- Wolf
- Steel

Common denominators

- Horeca RVS appearance
- 4 metal options for knobs (enthusing interior architects)
- Straight forward functions

Fig 23: Fulgor Sofia induction range using traditional archetype emblems.

Fig 24: Steel showing 4 metal options at Duikelman.

The Fulgor Sofia stood out as its control knobs and their feel was indifferent for their gas and induction ranges. This meant that apart from some tacit knowledge, the switch for a chef from gas to induction would be as easy as possible. The range did not feature an on/off button, but is turned on by pushing the control knob like igniting a traditional gas range, giving fluid experience and a satisfactory click while doing so.

Output

Induction cooktops should not show elements that can be confused with electric cooktops. The control should not feature touch and non informative beeps. Professional cooktops show that simple control knobs are easiest to use, the brands at Duikelman confirm this. Ideally the knob should be purchasable in multiple metal looks.

Wishes

- Metal knob
    - 4 materials to choose from (like brands Duikelman)

Research

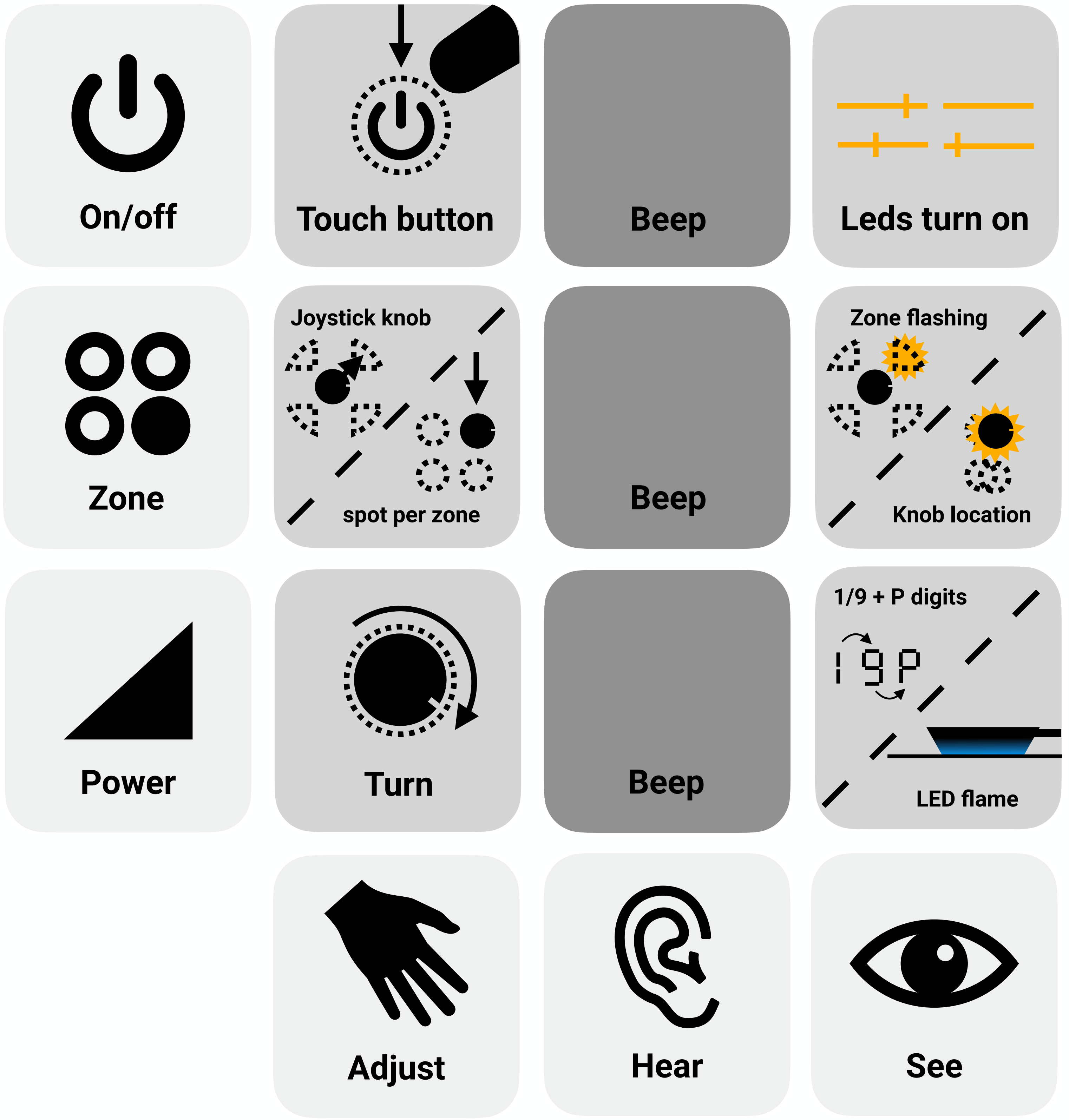
Competitors

Quite some companies are experimenting with integrated induction solutions. While the concept of cooking on your kitchen worktop is very progressive, most existing control solutions are not. They rely on the very thing they are trying to hide; ceramic glass (capacitive touch interface), inelegantly cut out in the worktop. Some have even gone as far as making an extra drawer just to hide the gas interface.

Existing touch solutions are being used for interfaces of most current worktop integrated induction cooktops, apart from being easy to produce and now already familiar to most users they do not have much more upside. TPBtech excels by only having a glass cutout for the power indicator and is the first to feature worktop integrated touch buttons, making their controls blend more naturally with the ceramic worktop.

Fig 24: TPBtech, Invisacook, xxinixx and Lapitec Chef integrated induction solutions respectively.

Induction
(with knob)



A couple A-brands are selling physical control knob solutions for their cooktops. Most have a kind of magnetic coupling and can control power, some can also select a zone but all of them have their quirks. From the lack of any feedback, missing functionality, wobbly control or even leaving scratches. They still improve upon solely touch interfaces. On the left you can find a feature/user matrix with the interaction of current physical knob solutions.

Floris
'Why did you add a magnetic control knob?'

Samsung sales representative
'Cooking moisture can hinder touch functionality, with our knob you can always control a selected cook zone while keeping induction's clean-ability and slick looks intact!'

Floris
'But you still need touch to actually select that cook zone, right?'

Samsung sales representative
'Unfortunately that is still the case...'

All detachable knobs use magnets while some also make use of them for creating detents. Within a brand solutions can vary too. Gaggenau/Neff both coming from the same manufacturer (BSH group) have played with conical, flat and suspended bearing bottom side of the knobs, with the bearing solution working most smoothly. This will be further elaborated in the chapter Development: coupling.

Fig 25: Samsung, Gaggenau, Neff and BORA physical control knob solutions respectively.

Output

New companies are emerging that are trying to bring integrated induction solutions to the consumer, while on the other side established companies are coming up with (detachable) physical knobs in order to improve user experience. These are still far from perfect. As of now no company is combining the best of both worlds.

User groups

In order to understand the importance of design features I defined user groups most likely to invest in a high-end kitchen. How users expect to interact with a product is influenced by their earlier experience. By looking at their values and needs we derange how they can be addressed.

Cooking enthusiast
Age: 30-35
Marital status: Relationship
Work: Self employed creative
Income: €48.000 a year
House type: Studio apartment
Reason: First good kitchen
Needs: Flexibility & personality
Values: Sustainability & uniqueness

Can have cool new features. It will be the first ‘expensive’ kitchen that will be used to get better in cooking. Is seen as a present to oneself after working for almost a decade and buying their first house. Will be the baseline for later kitchens.

Busy parent
Age: 40-55
Marital status: Divorced
Work: Strategy consultant
Income: €60.000 a year
House type: Terraced
Reason: Second kitchen
Needs: Luxury & dependability
Values: Burgundy & passion

Has had great experience with a high-end gas cooktop, but wants to electrify their home. Is looking for at least the same functionality as the earlier gas cooktop, is not interested in fancy features, is willing to adapt to somewhat new controls.

Retired elderly
Age: 70-85
Marital status: Married
Work: Retirement
Income: €33.600 a year
House type: Semi-detached
Reason: Last kitchen
Needs: Accessibility & safety
Values: Family & integrity

Has cooked on mid range gas cooktops for all their life. Want's a system that ideally closely resembles that experience. Is looking forward to the simplified cleaning of the cooking surface and increased safety it provides.

Output
These user groups have helped me confirm the importance of focussing on the main functionality and keeping optional extra features separated. Some user groups might like them, some necessarily want them and some get extremely confused by them. These additional features will be discussed in the embodiment phase.

Design vision

All main functionality will be possible with just the knob. All things good about current induction cooktops will be kept:
- Archetype communication and order
  - _(keep hot), 0/9, P(power), H(hot), C(zone misfit), E(error)
- Turning knob orientation
  - Clockwise (induction standard)
- Location on cooktop
  - In front of the zones

But then a couple things will no longer be needed:
- Sounds
- Need for touching the surface

On/off would ideally feel the same as the igniting of a traditional gas cooktop. Using skeuomorphic design.

Introduce things from other products:
- Connect like Apple Magsafe
  - Clear where to mount
  - Magnetic coupling strong enough but not to strong
- Feel like Audi MMC control
  - Click, rotate and move
- Haptic control knob
  - Able to feel what is going on for all main functionality

Fig 26: Miele cooktop showing control location and archetype communication.

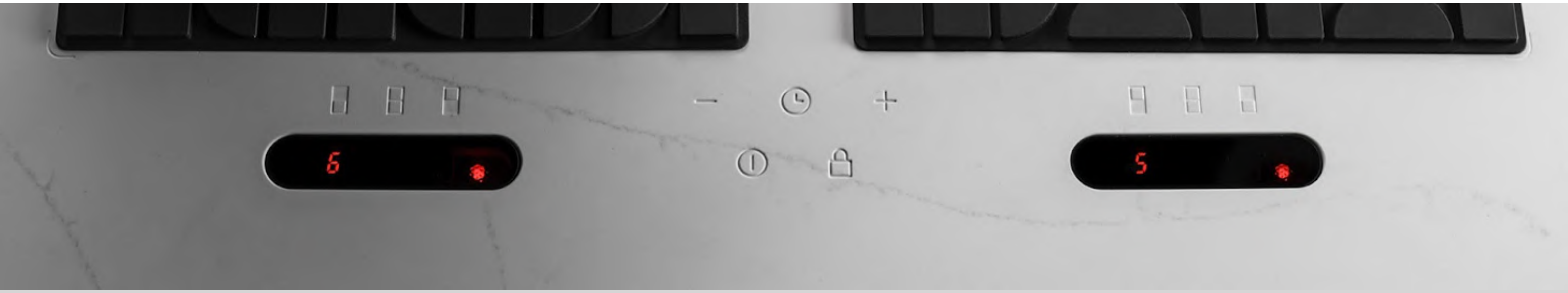
Fig 28: The Cool Top 2 showing fully analog magnetic detachable control knobs.

No tech above the worktop and minimal tech below. This means that transferring light and torque through the worktop needs to be possible. In that way the technical components (e.g. LED's and sensors) could be mounted out of sight. This way the user can enjoy cooking without being confronted by tech. Information redundancy can be achieved by adding haptics as an additional layer of communication. Lastly the new control solution should have a fluent way of using. To achieve this without electrics above the worktop the following design challenges will need to be solved.

Adjusting the power level is easy with a knob as knobs for all types of cooktops work great and even current detachable magnets knobs for cooktops prove that concept. On/off and the zone selection are more interesting as current cooktops with detachable knobs don't yet have that functionality.

As Boretti already has a relationship with Lapitec, they offer Gres Porcelain with translucent properties and have an worktop integrated induction cooktop solution, they are the perfect partner. For keeping this project as viable as possible I will base my design on the system of the Lapitec Chef.

Fig 27: Lapitec Chef showing visible controls on a hidden induction cooktop.



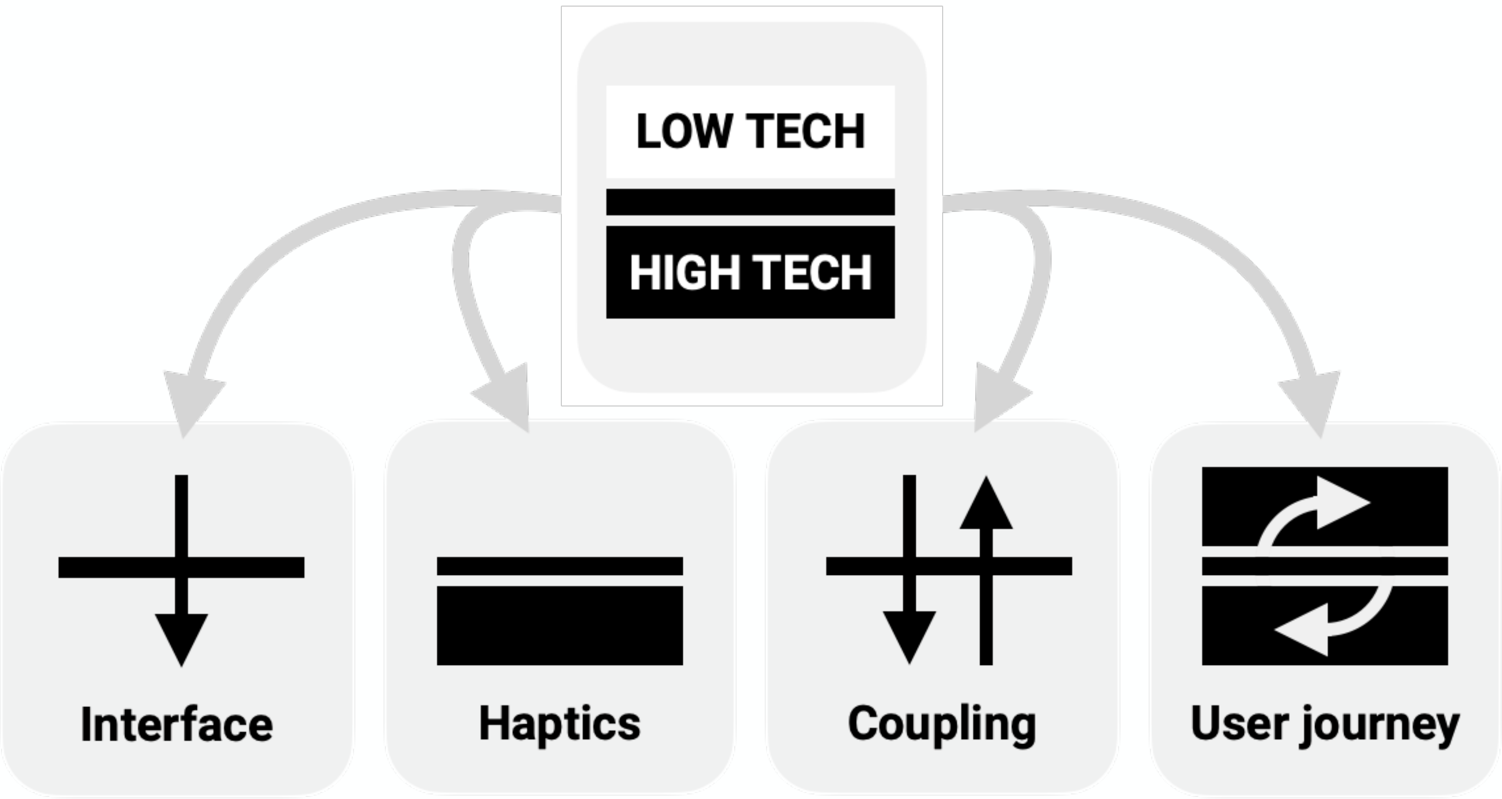


Fig 29: Design principle causing design challenges.

Development

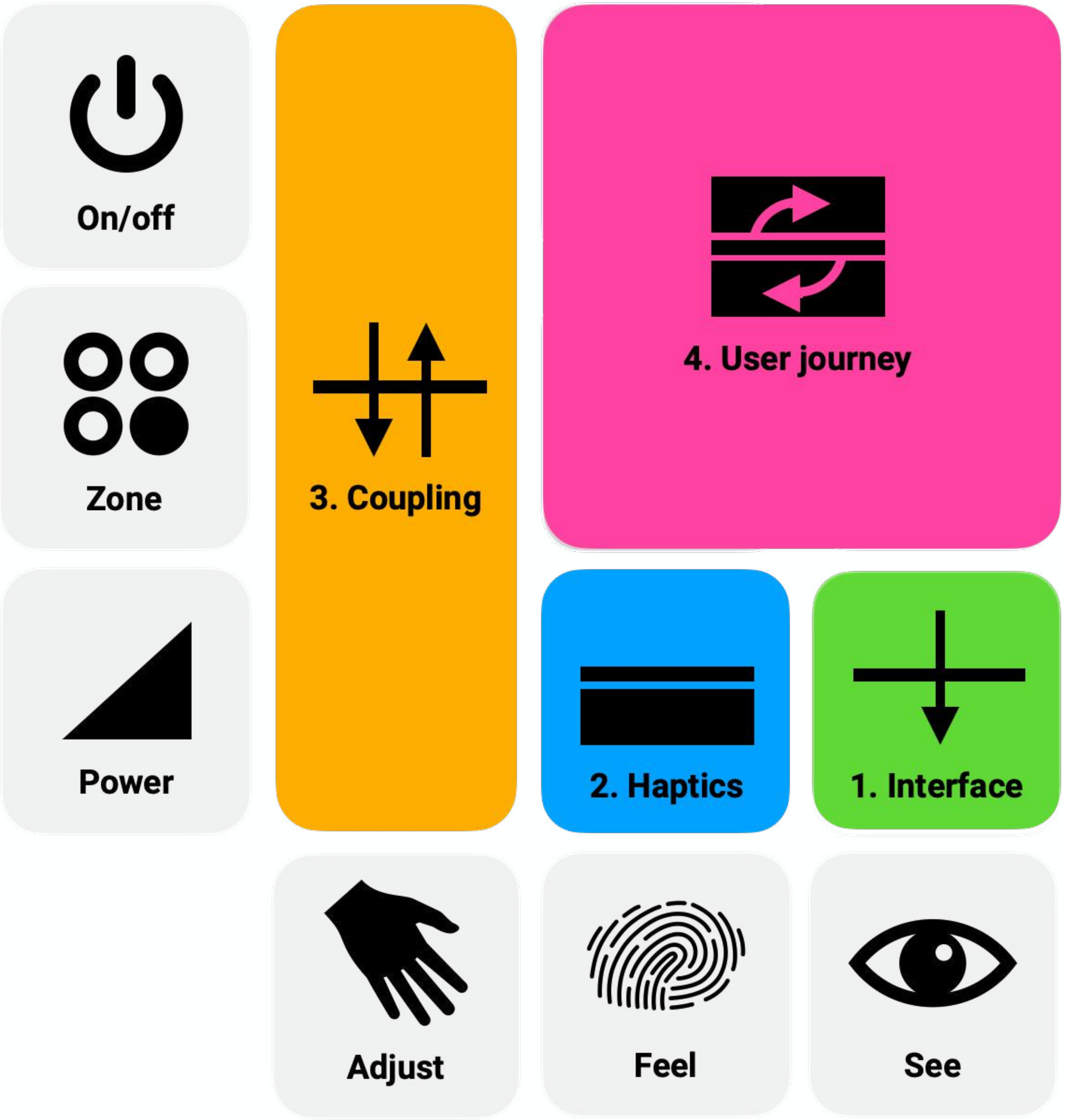
Introduction

The four design challenges are worked out by providing literature/examples/inspiration as a starting point and Build Measure Learn iterating from those. While solving the design challenges, learnings are translated into requirements/wishes. The updated list with requirements and wishes then forms the outlines for the embodiment phase.

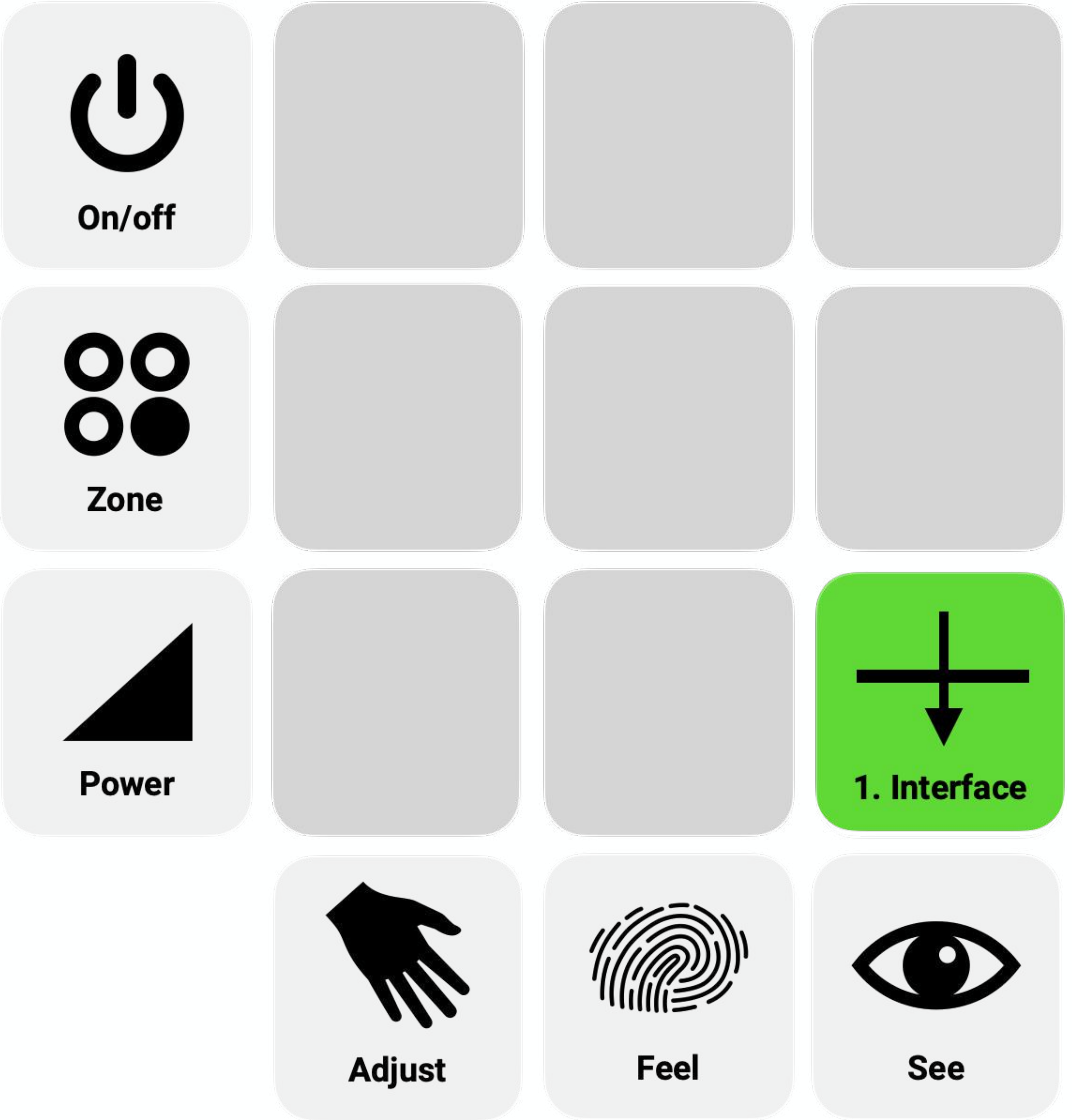
Assignment: Design a better induction control solution that can ideally become the new standard, but can be brought to market with the 'cooking on stone' concept.

As read here the solution would ideally become the new standard, meaning it would also need to work on ceramic glass instead of just gres porcelain. Ceramic glass for cooktops is ~3mm and transparent, so interface is not a problem. The coupling will be harder for gres as the material is a tad bit thicker (when milled) than glass at ~4mm.

Interface
Haptics
Coupling
User Journey
Requirements



Interface



Being able to see the state of each or the three main features through visual cues through the worktop surface.

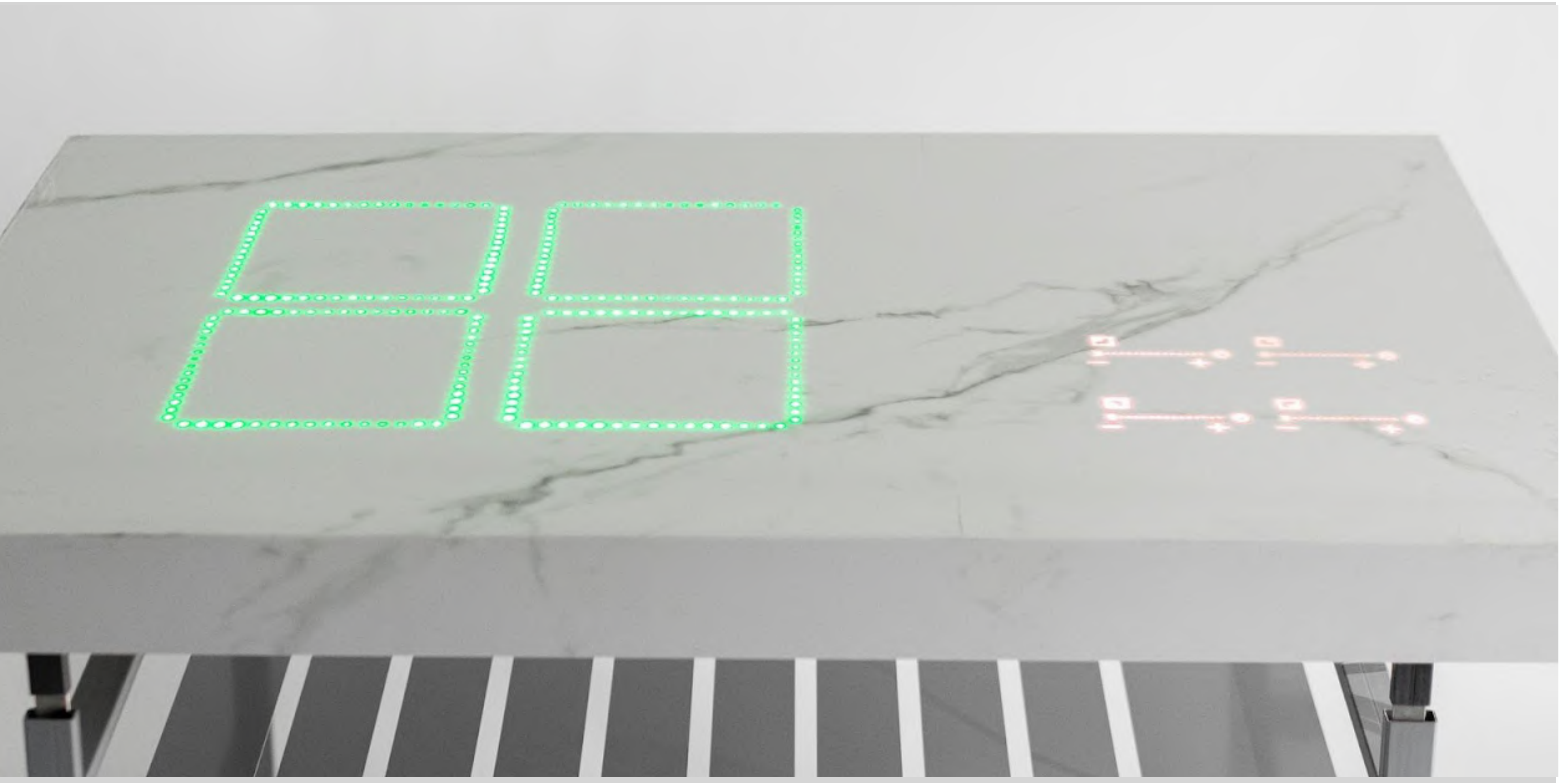
Inspiration:
When cut in thinner panels the alabaster stone has translucent properties making it usable for smaller windows. Popularised by Byzantine and later medieval churches in Italy (Schibille, 2016), the use of these translucent properties fits their culture.

At the SICAM 2018 Lapitec presented a range of 'hi-tech' uses of their material. They showed a touch interface, wireless charger and even some lights passing through the worktop. In comparison to other ceramic worktops that use printed designs the Lapitec material is homogenous to the core. So while the material is available in only 12 & 20 mm slabs, there is the possibility to mill it to a desired thickness and at a couple millimetres even let light pass through. RAK just launched their Luce line which comes at a thickness of 6mm and also has translucent properties.

Fig 30: Lapitec at the SICAM 2018 showing lights passing through.

At ALCOVA during the Milan Design Week 2023 Bettina Bessinyei showcased the SHANGO concept, a marble outdoor induction cooktop. The cooktop features an interface developed by Sensonic Design, a Hungarian company specialised in high tech stone solutions. The interface consisted of a led matrix combined with touch sensors.

Fig 31: SHANGO full marble outdoor cooktop with LED touch interface.



Build-Measure-Learn 1: Light through the worktop
How bright should a light be to shine through the worktop?

Learn:
The light source needs to be brighter in order to be visible throughout the material. Only then can I worry about the definition of the display.

Build-Measure-Learn 2: Definition of light
How to position the LED’s for making the display possible?

Learn:
LEDs with a power handling of 60mA at 5V (0.3W) are bright enough for shining through the material. If the LEDs are 2mm apart the bright spots will join nicely. Combinations of colours work great as long as they are not more than 50% blue.

Fig 32: The Lapitec sample being milled by hand with diamond headed drill.

Fig 33: Three segments at full brightness.

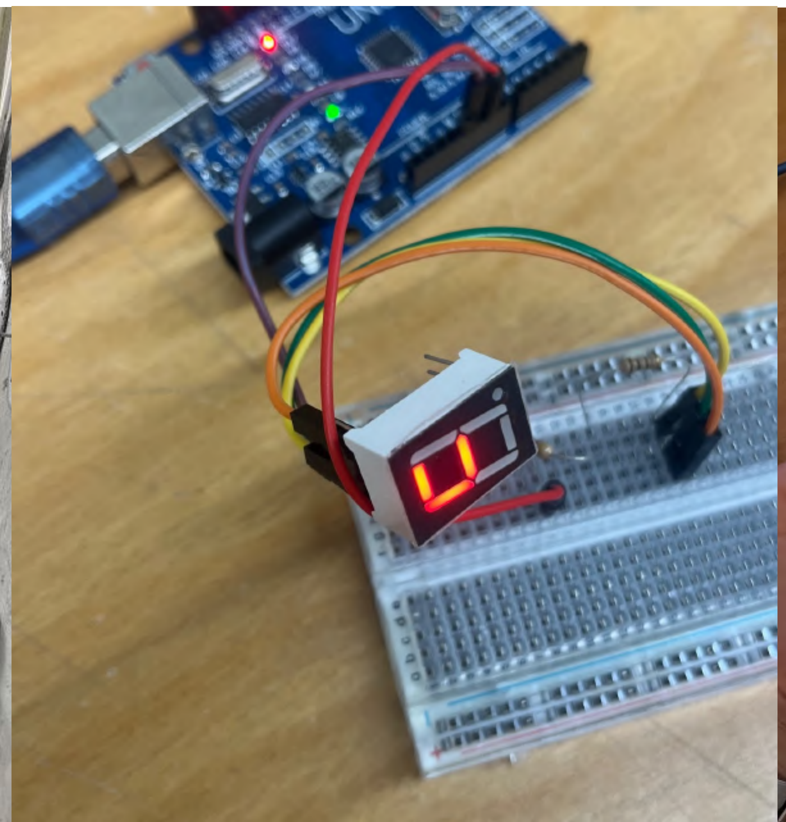


Fig 34: NeoPixel circle at (255,0,0).

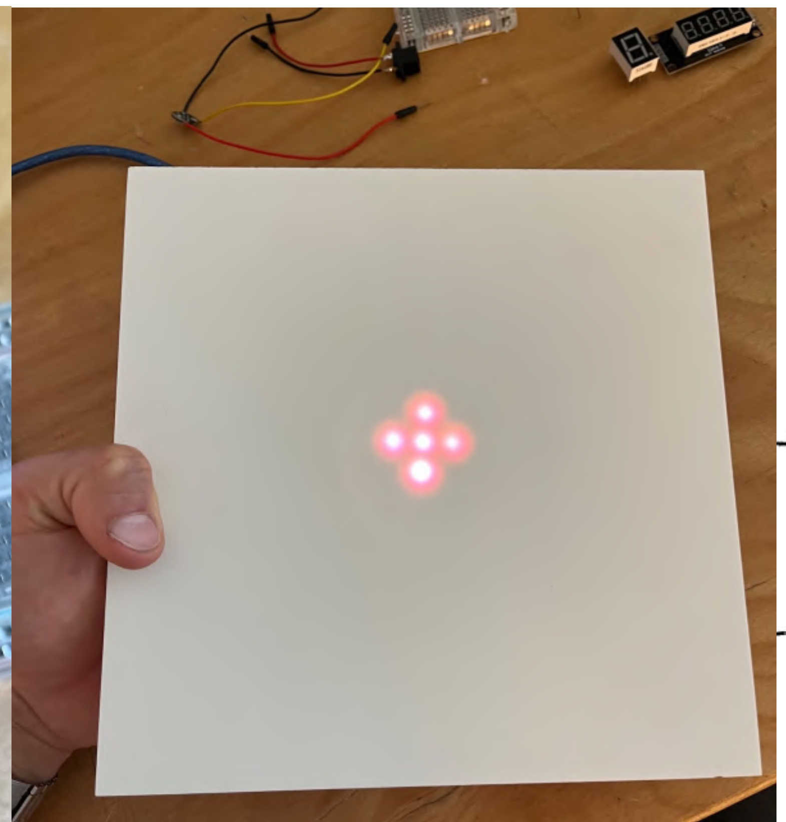
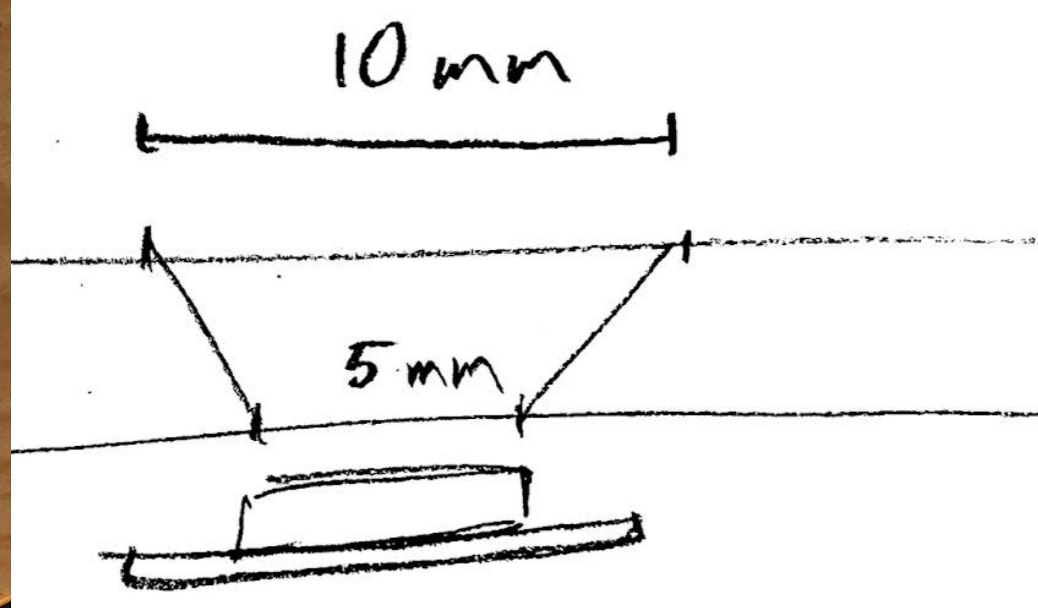


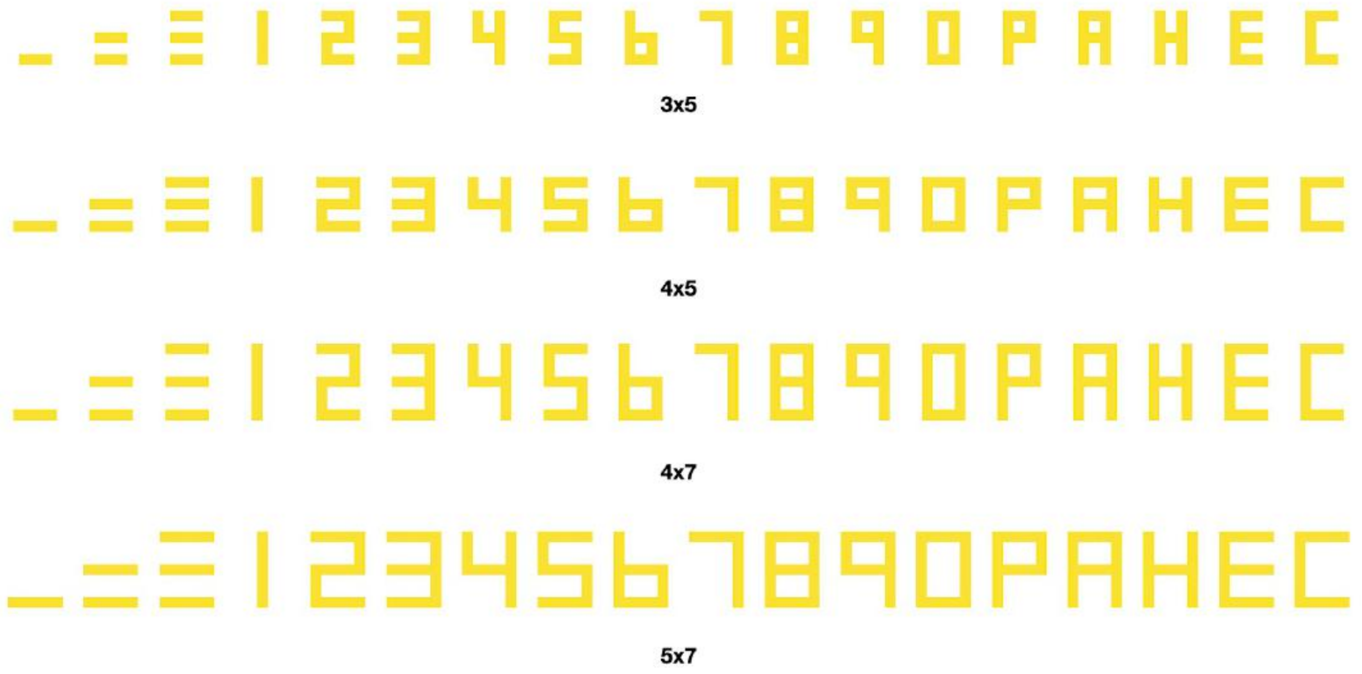
Fig 35: Drawing NeoPixel light projection through the worktop



Build-Measure-Learn 3: Pixels needed for numbers
What is the minimal display resolution for numbers?

Learn:
The minimum amount of pixels in height for a number is 5, 7 will give more detail. Minimum width is 3, but 4-5 gives more detail. Since 5 pixels in height does not seem to be a problem, this is the size that will be experimented with more in depth.

Fig 37: 3X5, 4X5, 4X7 and 5X7 essential archetype characters.



Build-Measure-Learn 4: Preferred matrix size
What is the preferred display resolution for numbers?

Learn:
I will continue with the 3X5 font as this leaves me the most room for the lay-out. This will be done in the 'Fat' font in a square configuration surrounding the control knob. For the design I will continue with the 5,87mm/pixel density of the FeatherWing 4x8 as this product proves that it is feasible.

Fig 38: Custom 4x7 matrix.

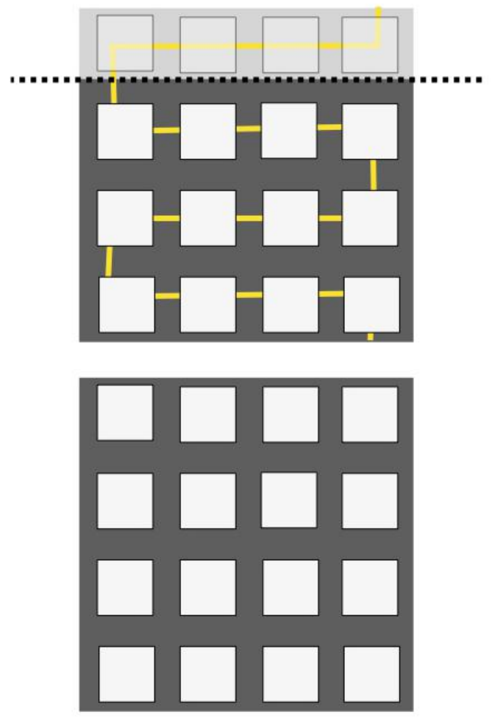
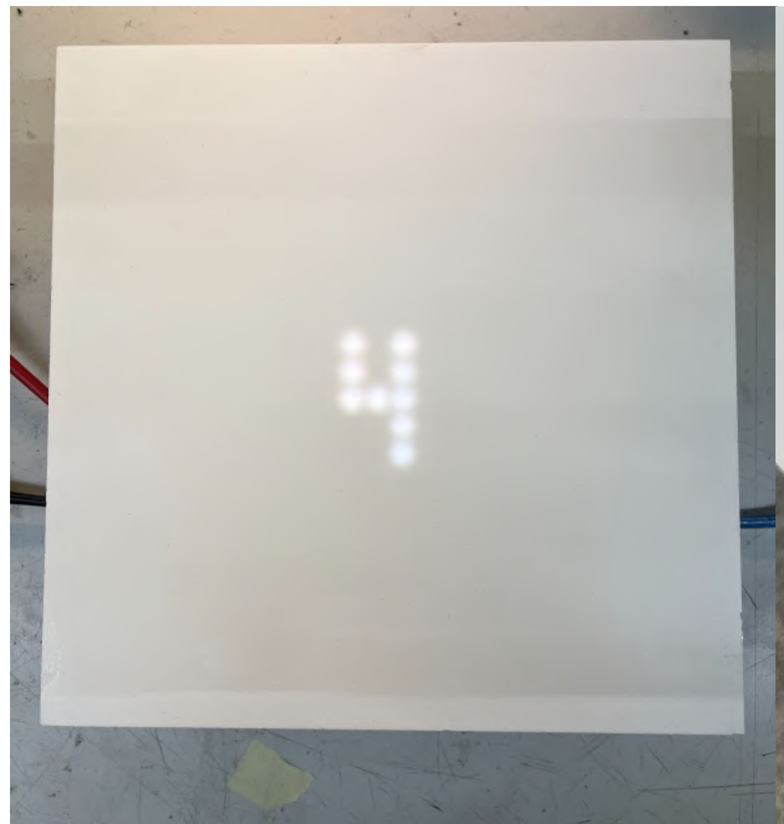


Fig 39: 3X5 font at 100% brightness).



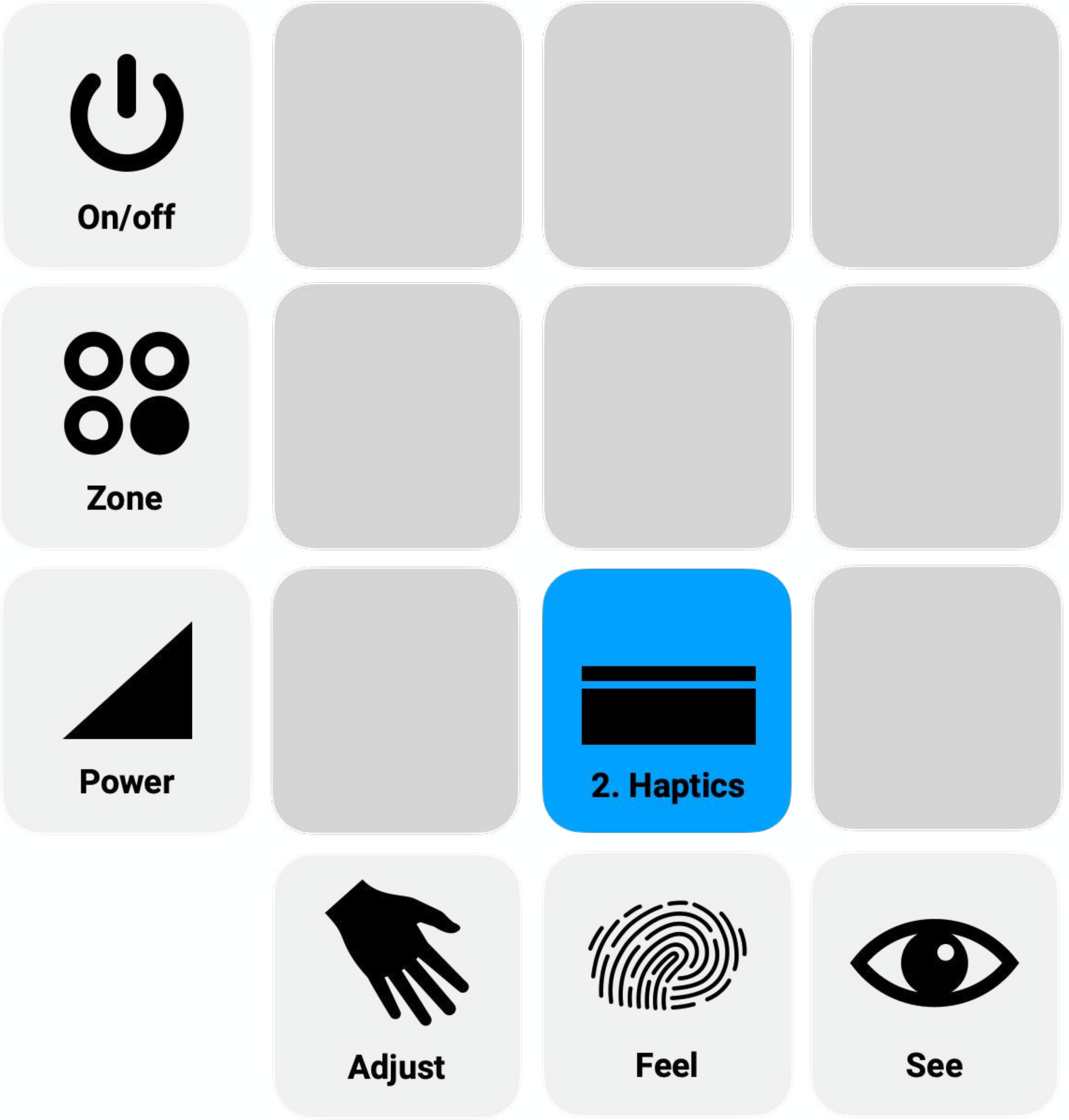
Build-Measure-Learn 5: Different materials/settings
What is the influence of worktop material and brightness?

Learn:
With increased brightness the matrix was visible and thus readable at direct sun behind a window. Now it is even barely visible while in direct sunlight, a situation which will never occur as the cooktop is developed for indoor use. The other Lapitec samples sadly gave no light pass through at all.

Fig 40: 250% brightness at 125000 lux ambient light.

Fig 41: Endless diamond drilling for the LED fitment.

Haptics



Being able to adjust and feel the state of each or the three main features through tactile cues. Where there is first focussed on the adjusting and feeling of the power, as this feature will be used most often.

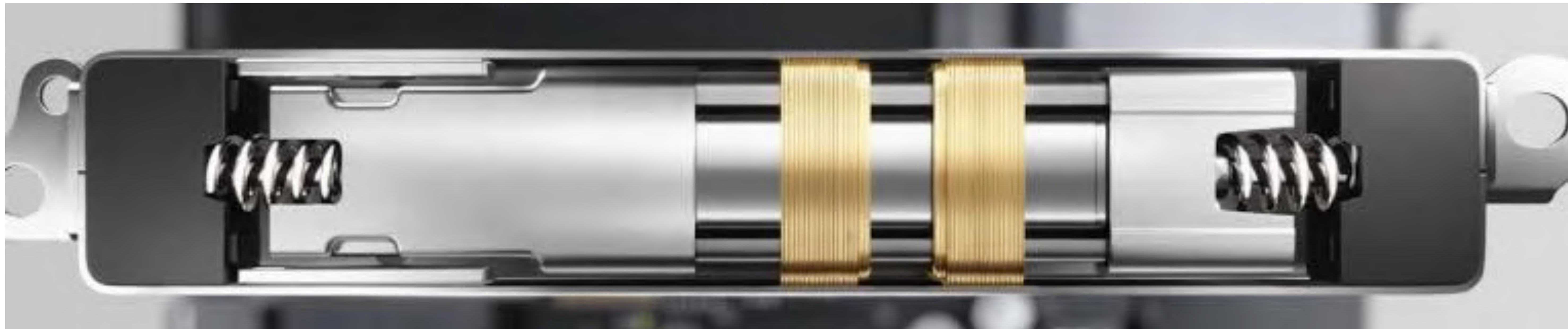
Inspiration:
Vibrating haptic feedback refers to the use of touch to communicate with users. Popularised with vibration motors in phones or game controllers this allows for an extra level of communication. When Apple made the Taptic engine, a powerful and more precise Linear Resonant Actuator (LRA), they also made some guidelines for the app developing community to use it. LRA, while great for notifying users, are not able to apply torque.

Apple Haptic Design Guidelines (Apple, 2021):

- Causality, for the feedback to be useful it must be clear what caused it
- Harmony, it should feel just as the same way as it looks
- Utility, add haptics that provide clear value in the experience

Haptic force feedback is used for example in racing simulator wheels. Using a motor they are able to apply torque on the wheel. This can be used to make steering heavier or making the wheel unable to turn any further, ideal for the hard end stops at a normal rotary knob for cooking.

Fig 42: Apple's Taptic Engine.



Scott Bezek developed the SmartKnob: an open-source haptic knob with software-configurable endstops and virtual detents. The knob uses a Brushless Direct Current electric (BLDC) motor that is controlled using Field Oriented Control (FOC). While FOC is normally quite complex, this project uses the SimpleFOClibrary algorithm. Jack Eichenlaub translated this to an Arduino project the FidgetKnob for his graduation. His knob too consists of a BLDC gimbal motor with built-in diametric magnet, a motor controller (TMC6300 BOB) and a magnetic encoder (MT6701) working in closed loop with an ESP32, but running Arduino. He built prototypes of these for the IDE faculty, of which I could use one for a test.

Build-Measure-Learn 1: Testing current solutions
Are current solutions are convincing enough for me to use?

Learn:
The feeling of the FidgetKnob was convincing! The motor had zero cogging and the detents were strong and accurate enough to give the illusion of an analog knob. The maximum amount of torque that is transferred during operation is during the end stop. This results in a torque of 0.04Nm that corresponds to the maximum power use of ~13W. Neglectacble in the shadow of the cooktop itself.

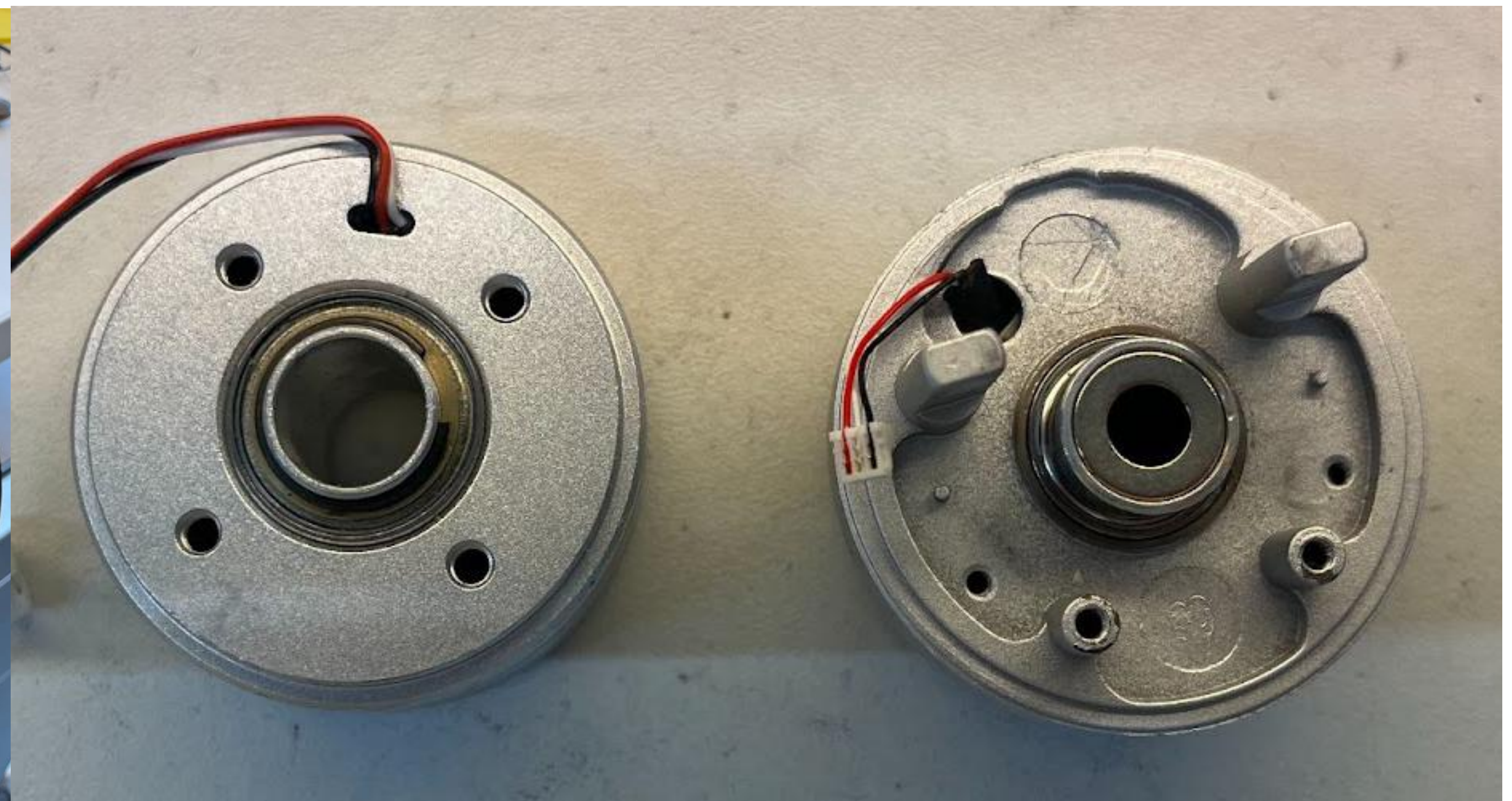
Build-Measure-Learn 2: Testing adaptation
Is there is an easier way to achieve the same effect?

Learn:
Use the BLDC 12V 3205 3-phase Motor with diametric magnet. I will start to look for another way to get a hold of the TMC6300 BOB and developer ESP32, to keep as many things code wise the same, in order to simplify prototyping.

Fig 43: Scott Bezek' fully customisable SmartKnob project.

Fig 44: Testing the FidgetKnob made by Jack.

Fig 45: The new 2804 motor (left) and the 3205 motor (right).



Build-Measure-Learn 3: Testing code

How to change the code in order to test desired variables?

Learn:

Degrees per detent should be no more than 14 degrees as that will hinder some users from putting the cooktop to full power in one fluid movement. As the motor used is quite small, changes in detent strength are quite subtle. They are still noticeable and could improve user experience in the long term.

Build-Measure-Learn 4: Influence of weight and diameter

Will a larger knob weight and diameter still be convincing?

Learn:

A knob diameter of 60mm with a combined weight up till 500g will still give convincing detents with the 3205 3-phase 260KV motor driven at 10V.

Build-Measure-Learn 5: Definition of feedback

What is the minimal angle for the detents?

Learn:

With all angles I was able to change the mode successfully, but below 7 degrees it became a lot harder to do it in one go. As the last thing i want is to further complicate movements this will be the lower limit.

Fig 46 Explainer applied hand movements.

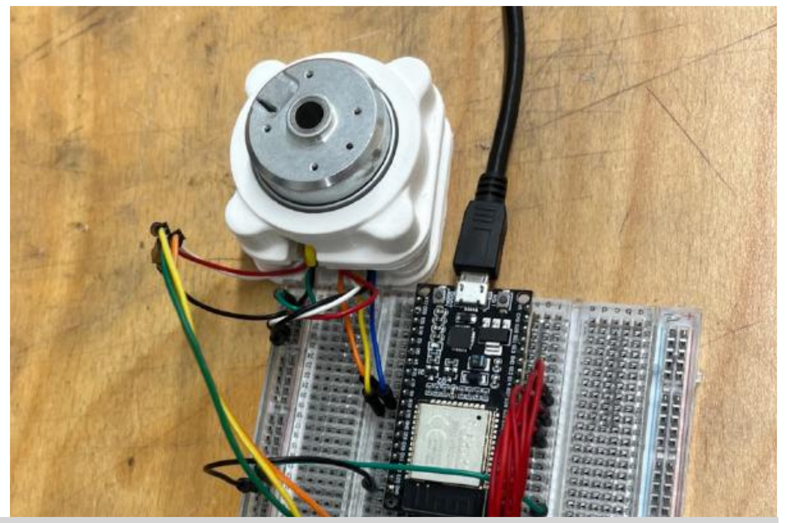


Fig 47: Total assembly haptics prototype.

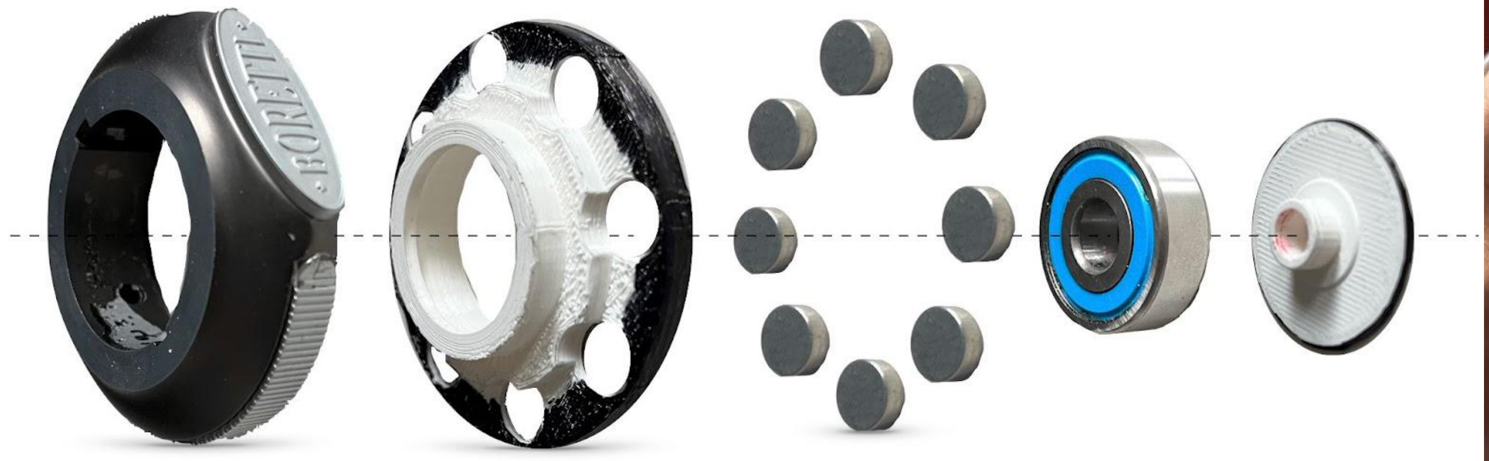
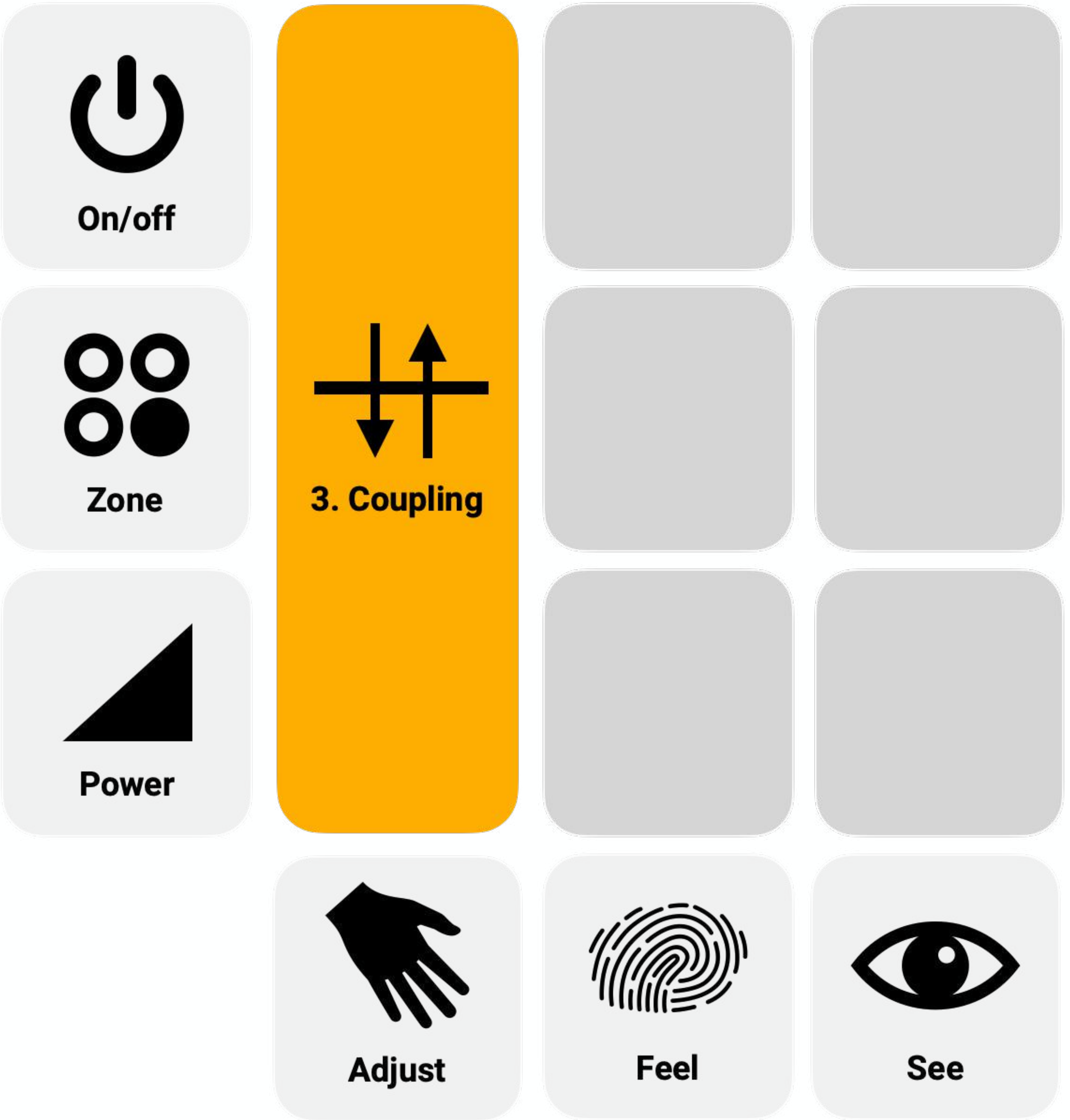


Fig 48: Full size/weight prototype using parts of the Carrara knob.

Fig 49: Fully 3D printed prototype with a glass of water in order to test a high weight scenario.

Coupling

Fig 51: HOVE 41533100 26V water pump and its inner magnetic coupling.



Being able to transfer the adjusting and feeling of the state of the three main features through the worktop surface.

Inspiration:
Other brands that have developed magnetic control knobs, only use magnets for keeping the knob in place or sensing rotation. There is no torque transferred through under the worktop surface. This keeps the connection simple but hinders the use of any hard end stops or other haptic cues.

While looking for magnetic connection in a DIY project I found a quick release focussing module that could be connected to a telescope for fine tuning its focus. The coupling allowed for torque transfer as well as easy dismounting but did not pass through material.

Telescope coupling info:

- Two disk with 8 magnets each with interchanging polarity
- Magnets: Neodymium 10mm diameter
- PTFE pad to avoid friction

While looking for magnetic connections that can transfer torque through a material, I came across a water pump for an industrial espresso machine. The turbine of the pump is magnetically coupled to its electric motor, making the pump less prone to failure by having a fully closed water system.

Water pump coupling info:

- Two disk with 4 magnets each with interchanging polarity
- Magnets: Neodymium 10mm diameter and 4mm thick
- Transfers torque through 1mm RVS disk
- PTFE piece to avoid friction

Fig 50: Magnetic coupling posted by Markse68 on the Stargazers Lounge forum.

With basic physics something about the dimensions of the magnetic coupling can be told. Quite some torque is needed for a convincing end stop.

$$F \propto 1/R^2$$

F = magnetic force
R = distance between magnets

The distance is quadratic, meaning that if it doubles the magnetic force will be quartered, therefore it should be as small as possible.

$$\tau = r * F$$

T = torque transferred
r = radius magnets
F = magnetic force

Since the magnetic force degrades by distance, it makes sense to use it wisely. By increasing the radius of the circle in which the magnets, we can transfer more torque without increasing the disconnect force of the coupling.

$$F = \mu * N$$

F = friction coupling
μ = friction coefficient
N = normal force due to magnetic force

Lastly, the coupling should transfer torque smoothly. Friction caused by magnetic force should be minimised. A bearing or material with a low friction coefficient could be used for this.

Build-Measure-Learn 1: Coupling strength
How much force is needed to disconnect is the coupling?

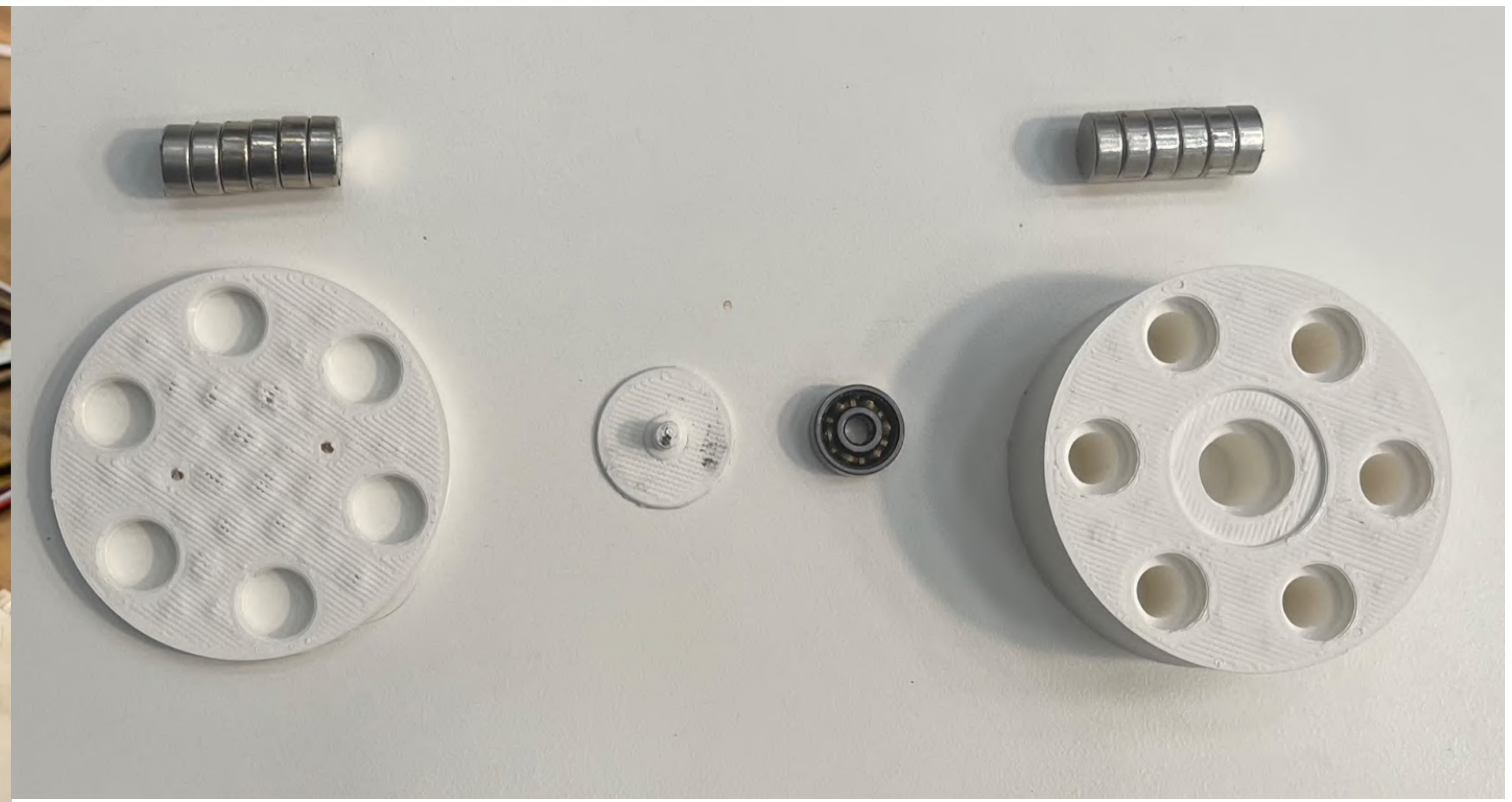
Learn:
2-3 mm were best for parallel disconnect force and perpendicular disconnect force. As the material of the worktop can never be of this thickness, the coupling will need to be stronger. This can either be done by choosing magnets of a higher magnetisation grade or by adding more of them. Torque transfer was hindered due to the friction created by the magnets rubbing against the perspex. Next version will need a bearing in order to prevent this friction from occurring.

Fig 52: Measuring perpendicular disconnect force with a digital newton meter.

Build-Measure-Learn 2: Smooth torque transfer
How can the friction in the coupling be minimised?

Learn:
Future couplings will all make use of ball bearing for at least the worktop side of the coupling. The next generation will need a bearing on the bottom side as well or a better way of spacing.

Fig 53: First designed 3D printed magnetic coupling with ball bearing.



Build-Measure-Learn 3: Torque transfer through material
How much torque can be transferred through the worktop?

Learn:
The coupling's smoothness improved greatly from adding a bearing on the bottom side. In order to achieve the torque that is needed for convincing end stops (0.06Nm), more magnets need to be added if I want them to be slightly covered for production. As the coupling would ideally be 50% loaded, just before failing the control gets wobbly and awkward.

Build-Measure-Learn 4: Polarity and amount of magnets
Do the amount/polarity of magnets effect torque transfer?

Learn:
4 magnets transferred to little torque and 6 magnets interchanging transfereed just enough. 8 magnets in interchanging polarity seem perfect if they want to be covered later, as the provide more than enough torque transfer.

Build-Measure-Learn 5: Variables friction
How can the friction with the worktop be minimised?

Learn:
Having a bigger ball bearing on the bottom side of the coupling greatly improved the smoothness of the torque transfer. 4 magnets uniformly mounted suffice now!

Fig 54: : Bottom coupling mounted on milled Lapitec worktop sample.

Fig 55: Bottom prototype 2 for 4-6-8 magnets.

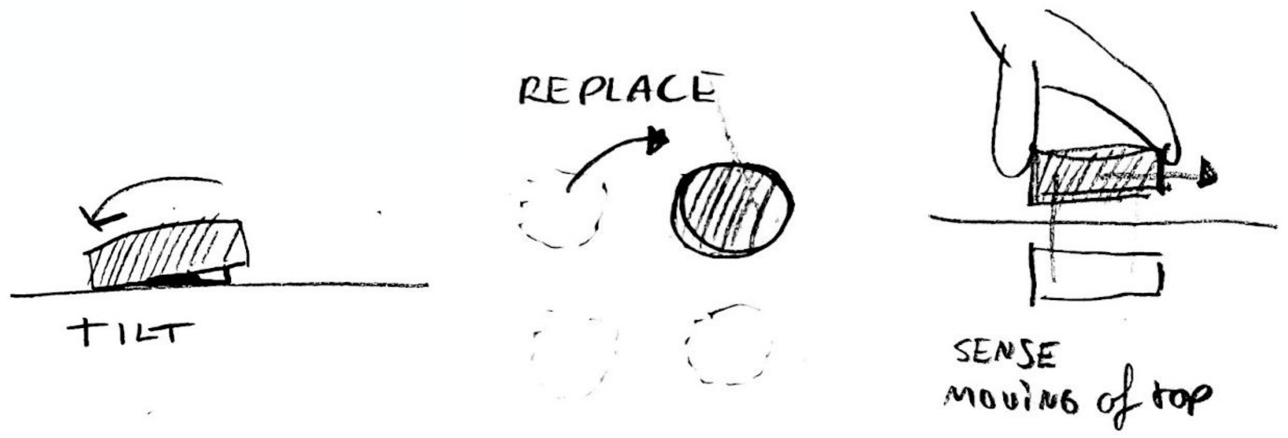
Fig 56: Top prototype 2 for 4-6-8 magnets.

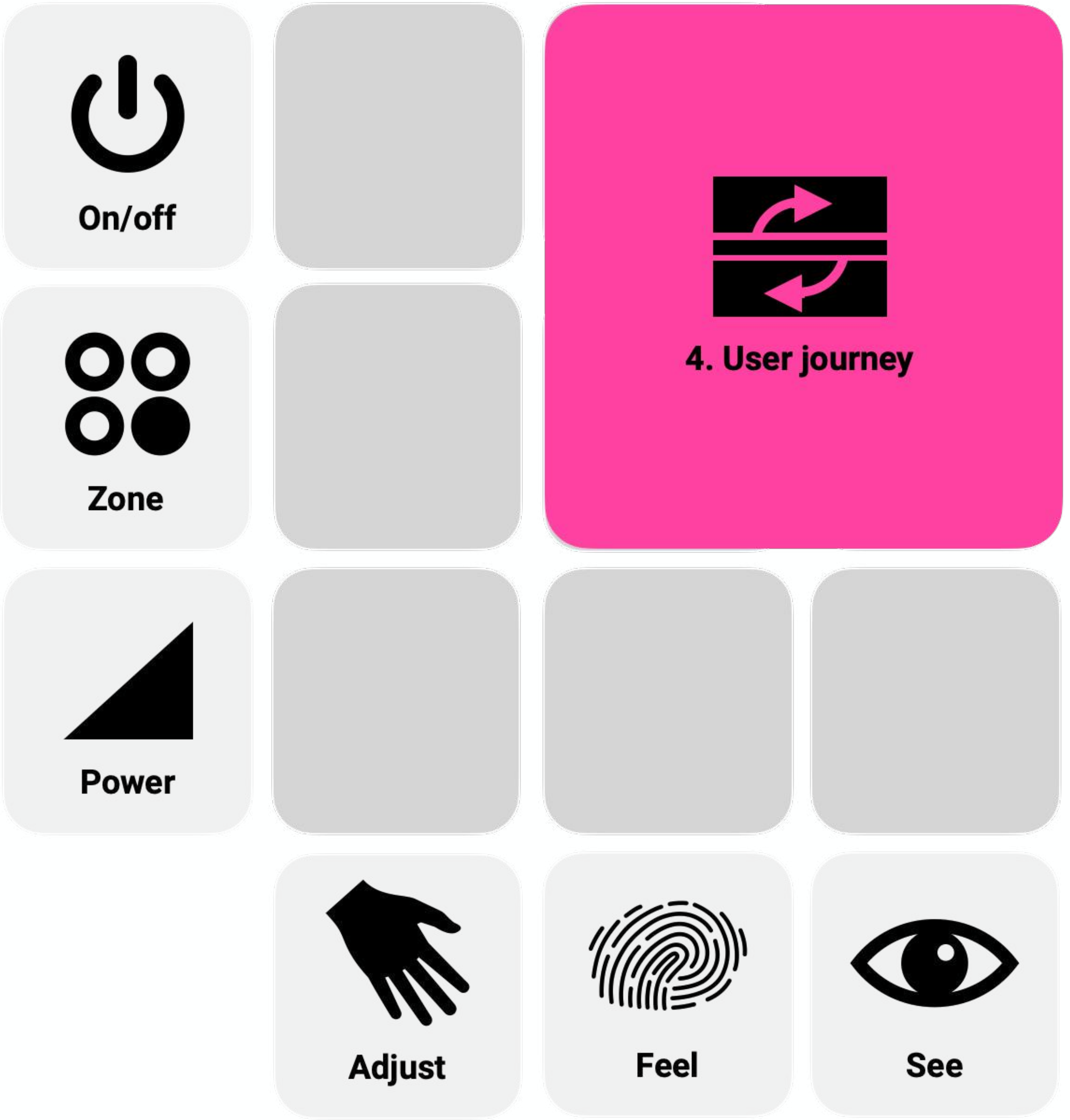
Fig 57: PTFE pad cut to match the top surface.

Fig 58: Bottom prototype 3 with bigger bearing.

User journey

Fig 60: Some quick sketches for adjusting the zone.





Now the interface, haptics and coupling have all been developed to a decent level, choices on their completion can be made as well as defining an intuitive interaction for the on/off and the zone selection of the cooktop.

Inspiration:
In the design vision I praised the Audio MMI for its simplicity. I sketched some scenarios for on/off and zone selection. Some Neff/Gaggenau cooktops use their magnetic detachable knob for adjusting the zone as well.

This is done by either moving or tilting the knob slightly towards the preferred zone. Once you select the zone, you will be notified with a beep after which the number starts to flash and a red indicator bar next to it appears.

The Lapitec Chef just as any other modern cooktops features pan detection, this too could benefit simplifying the controls. It could be beneficial to only be able to select a zone that has a pan on it, limiting options. Therefore if only one pan is placed on a zone, this one will be directly selected.

Fig 59: Neff/Gaggenau system for zone selection showing the indication.

Build-Measure-Learn 1: Intuitive controls (user test)
What do users find most intuitive in new control solutions?

I want the control solution to be truly intuitive, not worse than the current solution. By recruiting participants via a platform (Buurt Organisatie Mathenesserweg), it was possible to recruit objective participants within a large age range (20-60 years old). This is done to minimise the Hawthorne effect that normally occurs when user testing with friends and family.

Fig 61: Sketch of the control solution layout.

11/12 participants wanted to press the knob to turn it on. Turning the knob to the zone like a dial seemed most intuitive, with 5/12 participants thinking of it. Moving the knob came second with 3/12 and tilting like a joystick third with 2/12.

Learn:
Now I know that I will have to develop some kind of tap or push functionality, as almost all participants expected that. This will likely be done with capacitive touch, since this is done in the Lapitec Chef with the same kitchen worktop. Zone selection with a moving knob could be difficult as it asks for the need of additional moving parts. Both scenarios will be visually prototyped in order to testing their fluidity of use.

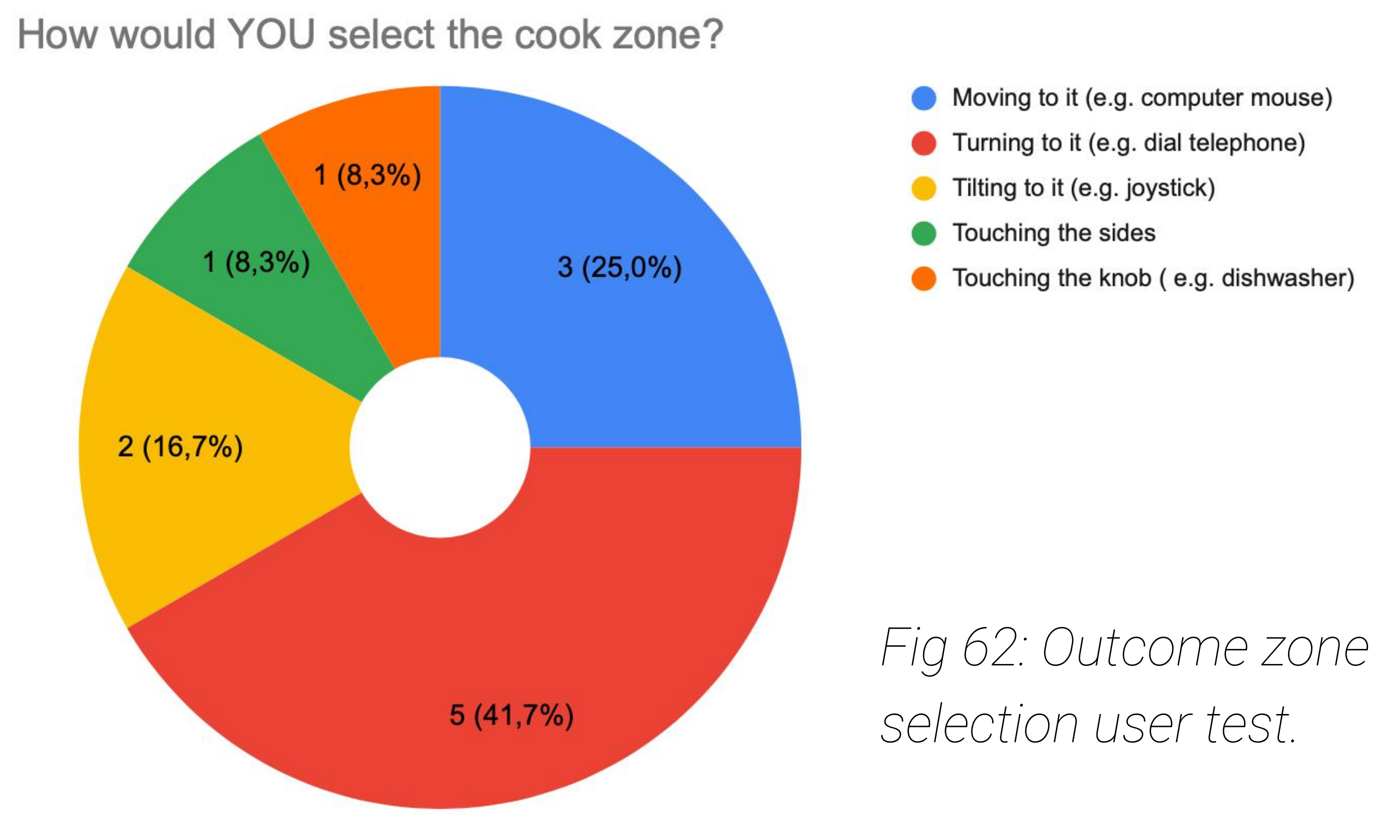


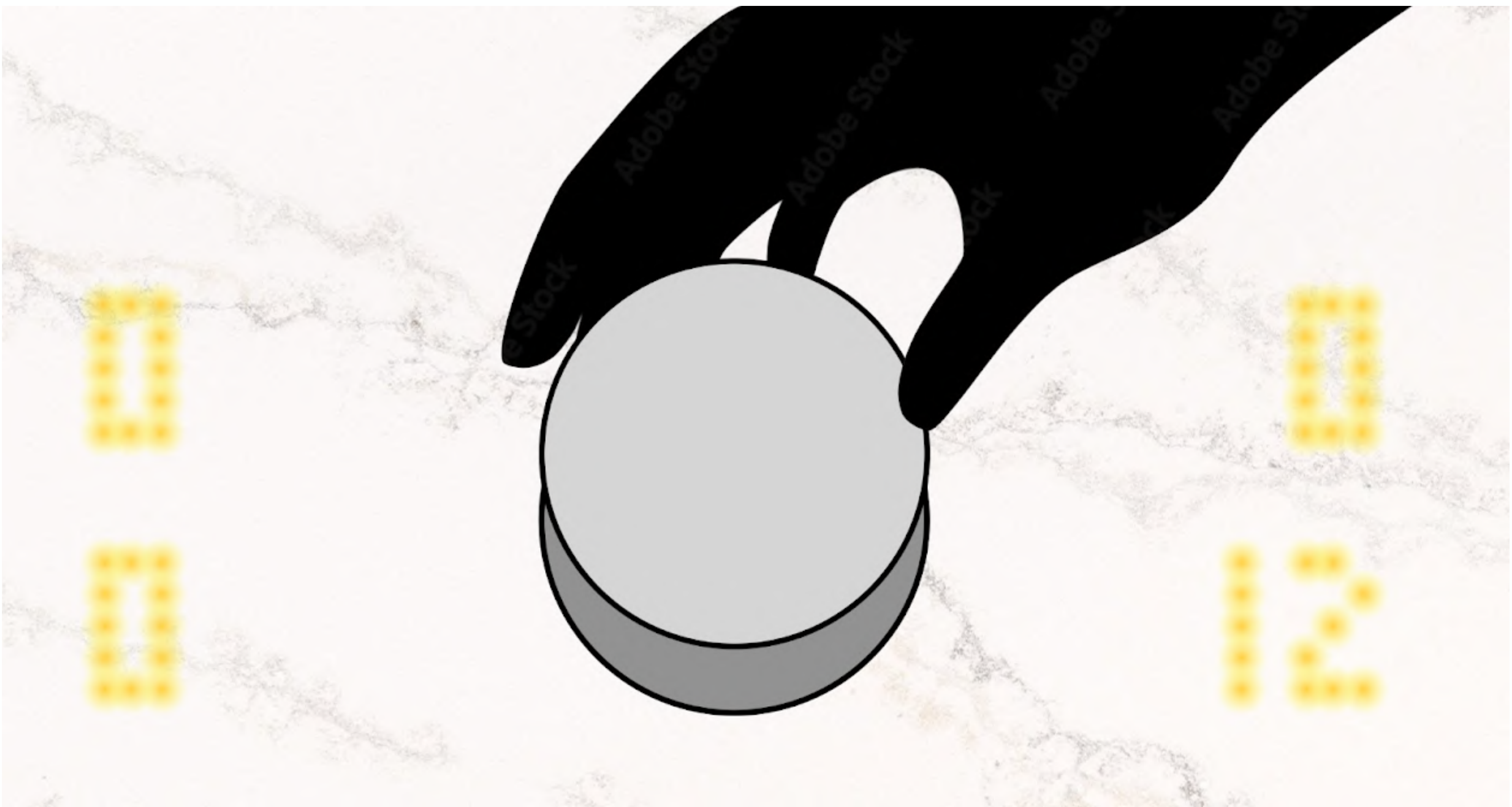
Fig 62: Outcome zone selection user test.

Build-Measure-Learn 2: User journey scenario's
Which scenario best trades-off fluidity and complexity?

Learn:
Version 3 was found to be the best trade-off between the amount of handlings and their fluidity against the added construction and haptics complexity that is needed.

Link to video showing all 3 user journey scenarios

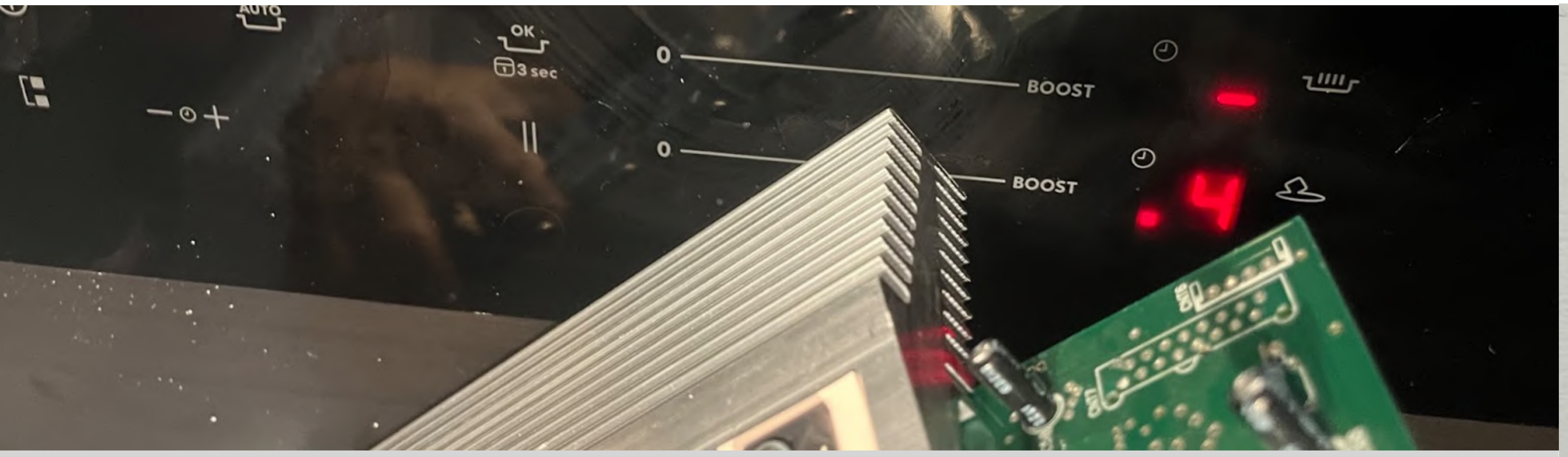
Fig 63: Screenshot of the video showing the scenarios.



Build-Measure-Learn 3: Button functionality
How can a button press be sensed through the worktop?

Learn:
Most metals seem to work well with capacitive touch sensors, leaving me with a great variety to choose from for materialisation. The cover does not need to be fully made out of this metal, an insert that touches the surface would suffice.

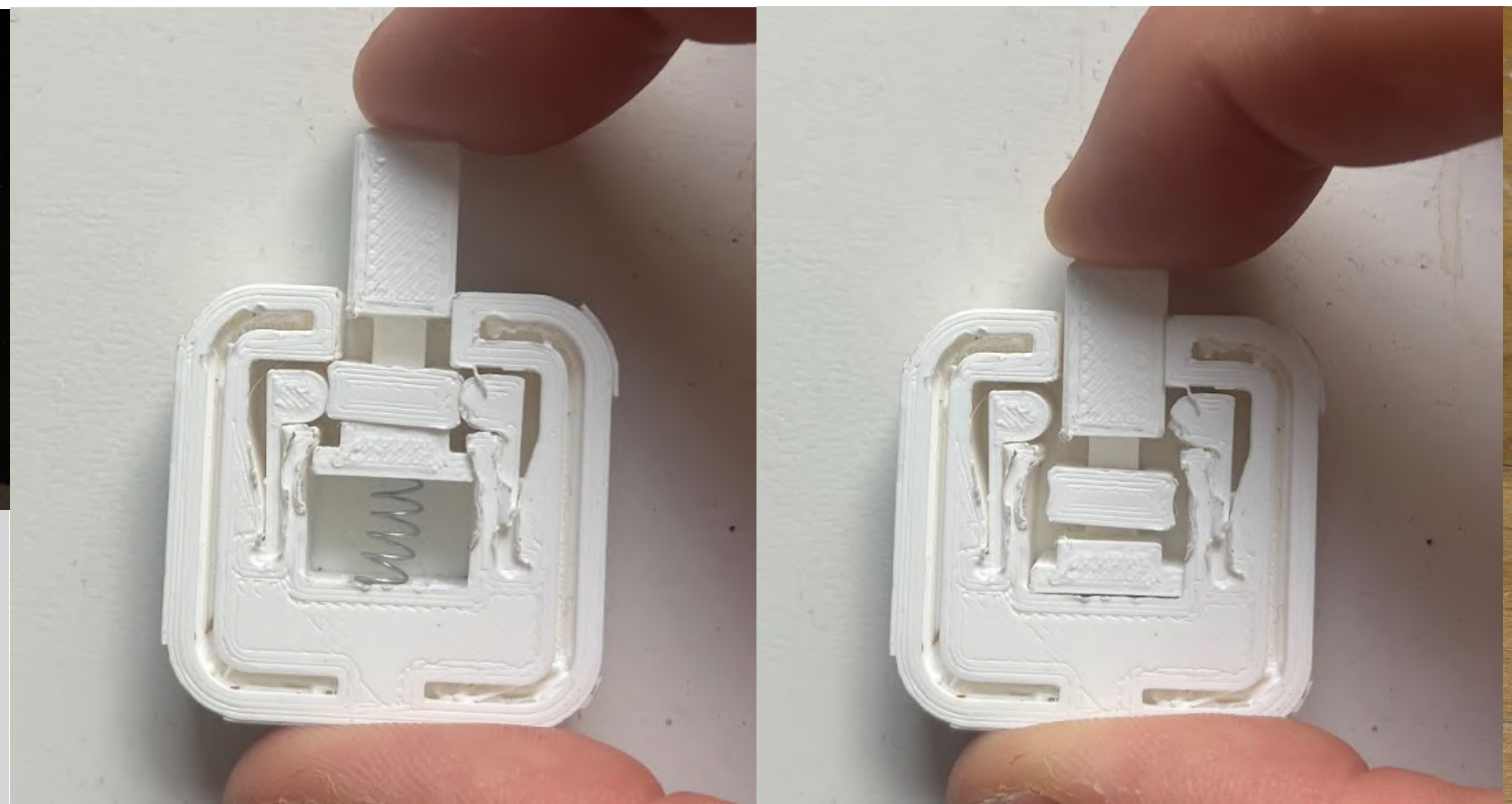
Fig 64: Testing the capacitance of an Aluminium heatsink on my induction cooktop.



Build-Measure-Learn 4: Achieving the button click
How can a tactile click be achieved mechanically?

Learn:
The knob will need to feature a kind to later be determined metal spring bellow and plastic springs on the sides to achieve the click. By varying the thickness and amount of plastic springs the sensation can be intensified.

Fig 65: Click button prototype in normal and clicked state.

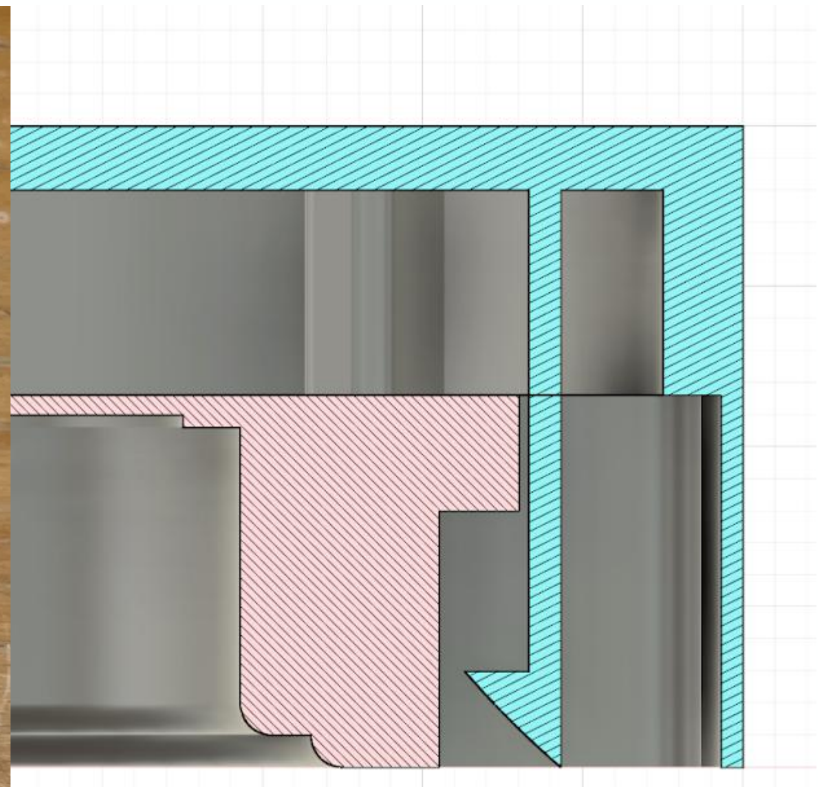


Build-Measure-Learn 5: Restrict motion of the push parts
How can the motion be constrained within the push action?

Learn:
The 4 coupling teeth did a great job of restricting the torque around the z axis and the snap fits in combination with the edge and spring allowed for a momentary push button with 5mm off travel.

Fig 66: Body showing coupling teeth of the final prototype.

Fig 67: Cross section showing the snap-fit.



Requirements

This is what is learned during the development phase.

Requirements:

- Specifications knob:
    - Diameter ~60mm
    - Height ~20-25mm
    - Weight ~200g
- Interface:
    - Works only with Lapitec Bianco Assoluto milled to 4mm thick
    - Should consist of 4 matrices of at least 3x5 5050 LEDs run at 36mA
    - Should have a pixel density of at least 7,5mm/pixel, ideally closer to 5mm/pixel
- Haptics:
    - Should consist of BLDC motor of at least 260KV with diametric magnet with 3/6PWM motor controller, ideally the TMC6300 by Trinamic controlled by ESP32 microcontroller and MT6701 in SPI mode for haptics
    - Angle between 7-14 degrees for power adjustment
    - Progressively heavier detents for power adjustment
- Coupling:
    - Should consist of two sides with 4 10 mm diameter 3 mm thick Neodymium magnets with bearings with an O.D. of 28.6mm and an I.D. of 9.6mm approximately.
    - Minimal torque transfer 0.06 Nm
    - Disconnect at 10 N perpendicular
- User journey:
    - ON/OFF should be controlled by a push, zone selection by pushing and turning and power selection by turning the control knob
    - Push functionality works by adding a tuned capacitive touch sensor under the worktop that senses a metal part in the knob touching the worktop in the pressed position
    - Control knob should restricted motion by at least 3 coupling teeth 120 degrees apart in the z-axis and an edge and reversible snap-fits for the push distance

Wishes:

- Fluid control
- Minimal learning curve
- Minimal technology
- Being a joy to use
- Being able to use it blindly
- Multiple finishes
- Recyclable

These requirements and wishes are to be applied and verified as much as possible in the embodiment part.

Embodiment

Embodiment

Introduction

In order to verify earlier findings, evaluate form and further refine the interaction another user test is done. This time an age group of 23-75 is achieved through reaching out to 12 acquaintances. Two participants in their 70s also participated who have never interacted with an electric cooktop. The embodiment focuses on all parts above the worktop, as the solution below is heavily dependent on cooktop cabinet details which are classified.

Form
Interaction
Production

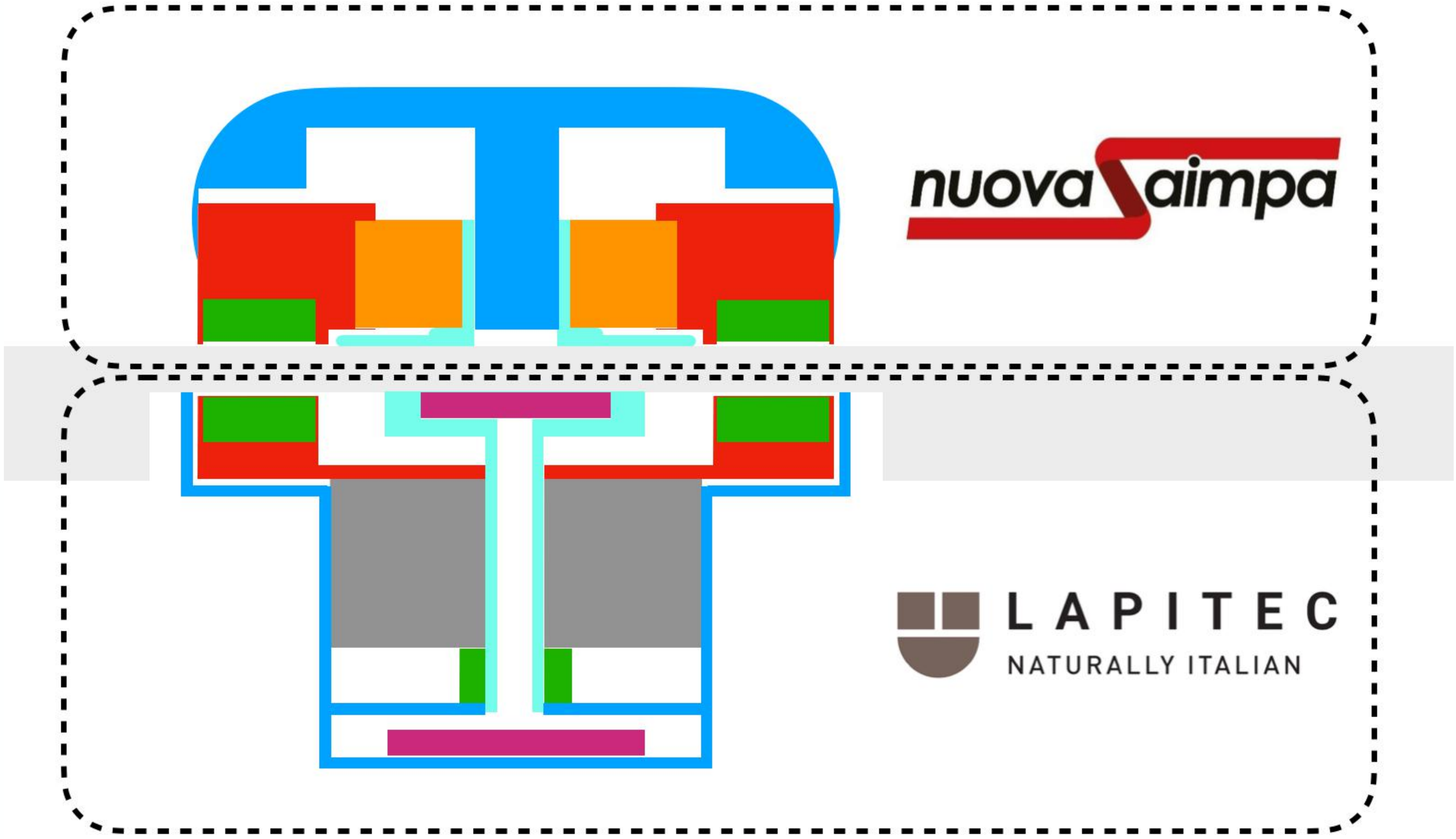


Fig 68: Showing possible production partners parts above and below the worktop.

Embodiment

Form

The point of my concept is that I want to figure out the inner workings for a better interaction while showing there is endless design freedom for the final form. There could even be could several options, as it is the only visible branded item.

My form exploration started by recollecting the rough specifications of the outlines of the knob validated by the user test, then key features of the brand Boretti are defined. These features are then combined with personal inspiration to 3 concepts that showcase the design freedom of this knob.

Rough knob specs earlier user test:

- 9/12 said weight is perfect, 3/12 weight could be little less
    - Weight (218g), so approximately 200g
- 11/12 said diameter is perfect, 1/12 could be bigger
    - Diameter 57mm, so approximately 60mm
- 9/12 said height is perfect, 3/12 height could be little less
    - Height 25 mm, so approximately 20-25mm

Boretti designer Jacco Bregonje explained the design to be modern with a classic wink, organically with a technical touch and in details inspired by vintage Italian cars. When we discussed keywords that could be used to describe the design; tough, elegant and attractive came to mind.

Fig 69: Examples of Boretti design.

Fig 70: EXTETA Roller Kitchen control knob.

During my visit at the Salone Di Mobile 2023 in Milan the control knobs for the outdoor gas grills of EXTETA and ILVE inspired me. In a search online I found several gear knobs from 60s-70s Italian sports cars that I thought would work great in terms of shape, size and finish for a control knob. More inspiration can be found in the appendix. Using both streams of inspiration I came up with 3 examples for the form of the knob. Two made out of metal (finish could have multiple options) and one made out of hard plastic.

Fig 71: 1970 Maserati Ghibli Spyder shifter.

Fig 72: Form design 1.

Fig 73: Form design 2.

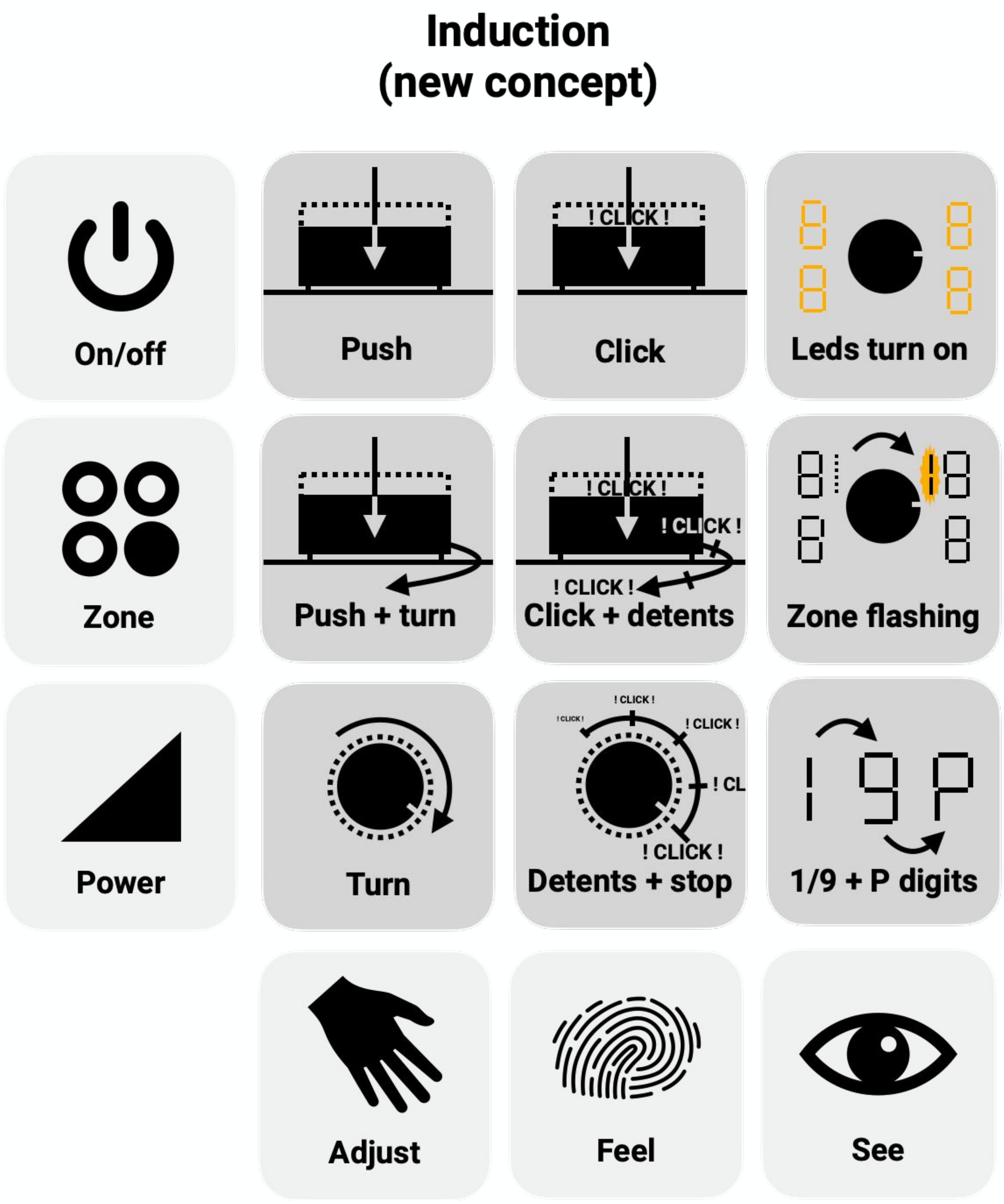
Fig 74: Form design 3.

Most (10/12) participants preferred design 1, when asked what they found important in their choice, they replied with the following. Most given answers are counted and clustered per topic in the list on the right.

4/12: a metal finish is a must (in favour of 1&2)
2/12: there should be no logo on top (in favour of 1&2)
2/12: the sides should have knurling (in favour of 1)
2/12: a simple shape is more elegant (in favour of 1)

Output:
The design should simple shaped of metal with knurled sides that contain the logo. More variants of the knob should be made, as its design is the only thing that is visible of Boretti.

Interaction



Requirements made during the development phase regarding the user journey are tested and further refined.

On/off:
In general the all interaction should be as subtle as possible. While I used the smallest gas cooktop push knob travel as a benchmark for the button and 6/12 participants thought it was perfect, the other half thought the spring was too stiff and travel could be less. After further testing I changed it from 5 to 2 mm.

The cooktop will be turned after the button is pushed all the way down, no matter for how long. The cooktop will be turned off after the button is pushed all the way down for 4 seconds without turning it (to change the zone).

Zone selection:
12/12 participants stated that they first put the pan on the cooktop before putting the zone on. All induction cooktops have pan detection meaning that if only one pan is used, no zone selection will be needed at all. When two pans are detected only a choice between the two has to be made. If there is no pan on the zone the number indicating the power level will be slightly dimmed.

The angle of 40 degrees between the detents for zone selection was perfect according to 9/12 of the participants, while 3/12 said it could be slightly less. After further testing I changed it to 20 degrees.

All participants noticed a difference between the detents of the zone and power selection, but not all were positive. 2/12 explained that the stronger detents and bigger angle in combination with the need to push made it hard to turn. As noted before the travel should be less, this together with a new angle of only 20 degrees simplified the selection a lot.

Fig 75: Alternative emblems for zone indication shown next to a zero.

2/12 participants commented that the emblem for zone selection could be confused with the number one. The emblem should thus either be changed or a flashing power number could be used to indicate the selected zone. This depends on the room the LED matrix may have in the final design, which depends on further strength testing. A flashing power number could indicate the zone with no additional space (3X5 matrix), while a small arrow shown in figure 75 will be most clear in expense of needing additional LEDs.

Power selection:
The angle of 14 degrees between the detents for power selection was perfect according to 9/12 of the participants, while 2/12 said it could be slightly less. After further testing I changed it to 10 degrees, exactly half of the zone selection and within the predefined margins of 7-14 degrees. The sensation of the haptic detents was graded by an 8.17 on scale from 1 as annoying until 10 for joyful.

Knob (dis)connecting:
8/12 thought the removal of the knob was unpleasant, either because it was too heavy or because they felt it would break the knob or its connection with the worktop. 3/12 said it was scary to connect it and 3/12 said it was awkward because of the interchanged polarity of the magnets. Luckily I found out 4 uniform magnets per side instead of 8 interchanged polarity ones would already suffice with the bigger ball bearings reducing the friction (see chapter 3 coupling build-measure-learn 5). Having only 4 magnets per side drastically decreases the 'scariness' of the (dis)connecting off the knob, while the uniform polarity removes the awkwardness that was experienced during the connecting of the knob.

These last insights are all incorporated into a short video showing all features of the user journey with voiceover.

Link to video showing final user journey scenario

Output:
The button can now intuitively turn the cooktop on and off, change zones and power levels while informing the user of this through the interface and haptics. When finished, it can be removed for proper cleaning of the worktop or use in another way.

Production

Together with Boretti's knob production partner Nuova Saimpa drawings of one of the prototypes of the knob has been discussed in order to come up with a realistic product. I explained that I ideally did not want any (permanent) fasteners and that friction fits and (reversible) snap-fits were my fastening methods of choice.

An engineer from Nuova Saimpa explained that I should make the internals out of Acetal and the outer parts out of Zamak, since it is their plastic and metal of choice for cooktop knobs because they enjoy the following benefits.

Benefits Acetal (Piedmont Plastics, 2022):

- Excellent stiffness and strength combined with durability
    - Great for snap-fits
- Self lubricating
- High heat/water/chemical/solvent resistance
- Foodsafe
- Recyclable

Benefits Zamak die-casting (Viasetti, 2020):

- Resistance to shocks, wear and corrosion
- Versatility in finishing the articles
    - Easy for plating different metal finishes
- High accuracy of the castings
- Lower cost of production than other alloys
- Less energy for production due to low melting point
- Recyclable

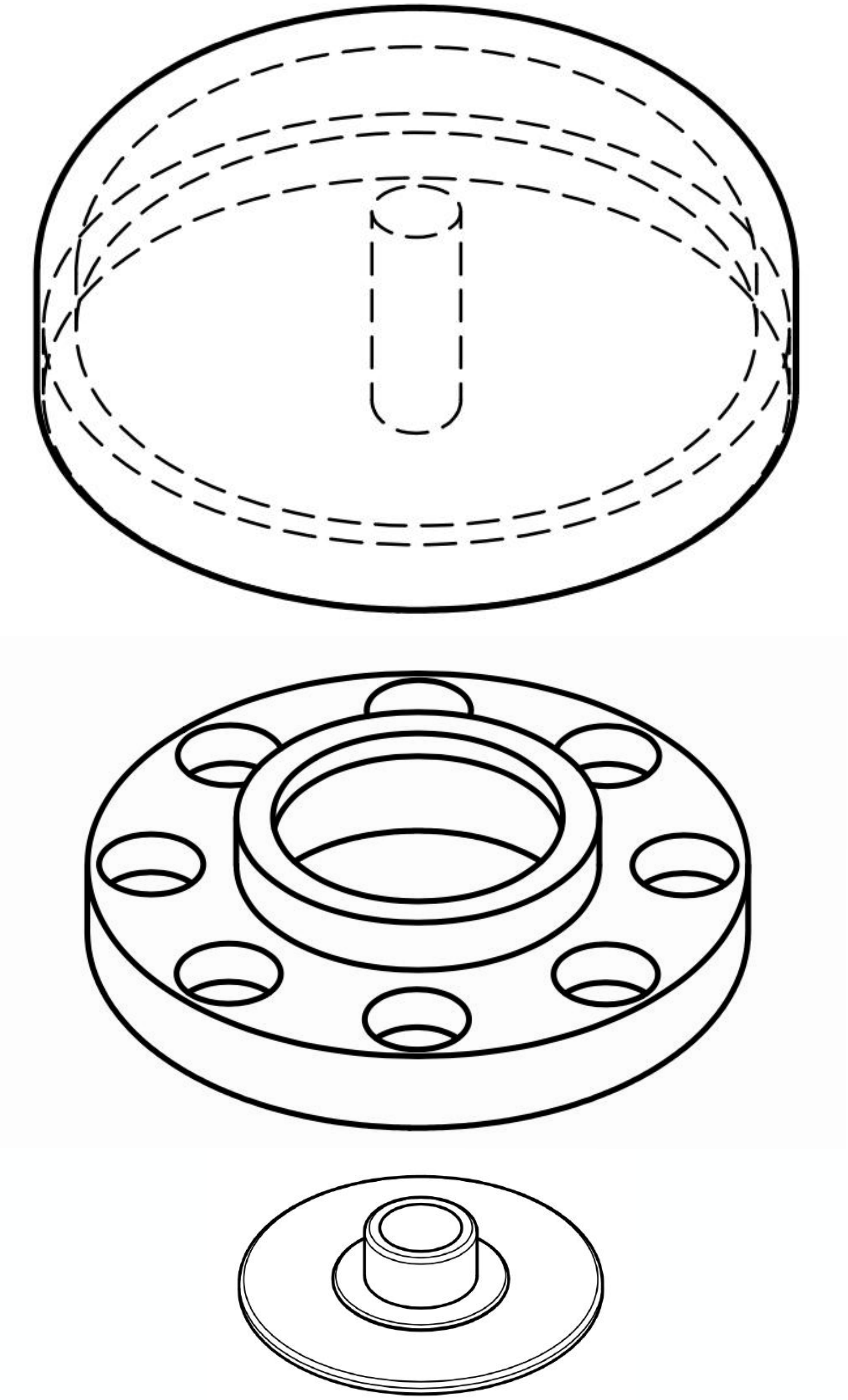
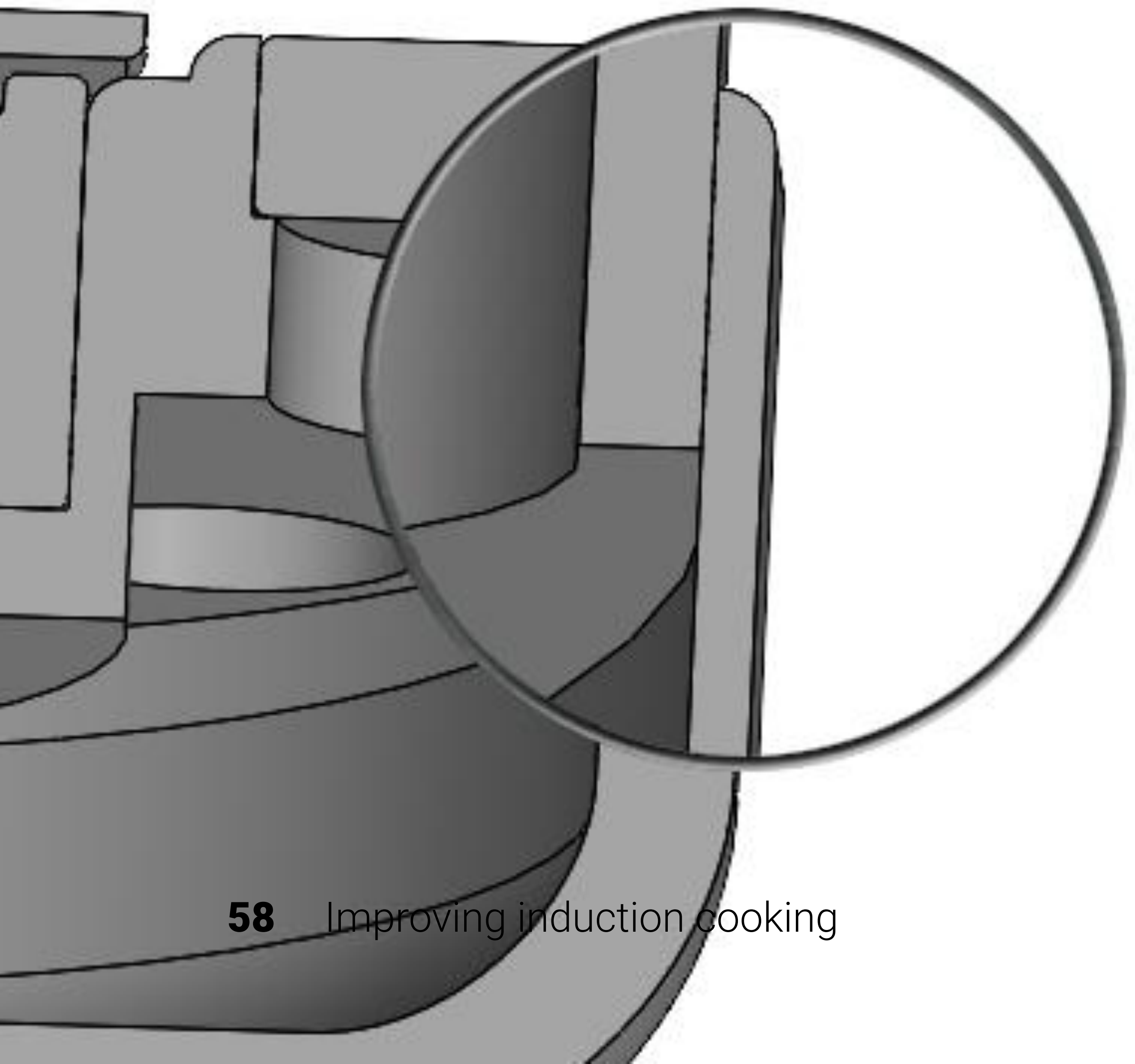


Fig 76: Isometric drawings of the Acetal feet, Acetal body and Zamak cover.

Feedback:
- Don’t make Zamak parts thinner than 1mm, they risk deformation (see figure 77)
- Avoid having sliding/rotating Zamak on Acetal parts, this makes the products lose some perceived value and come across as a Chinese toy

Fig 77: The original Zamak cover had problematic 0.5 mm sides.



The solution is to make a thin Acetal cover which can slide/rotate smoothly over the Acetal body as these both parts have self lubricating properties, which can be 0.5 mm on the sides and makes for a better feeling of the push and turn functionality. Then have a Zamak outer layer of the cover of at least 1 mm which facilitates the look, feel and perceived weight of the knob, this layer gives endless form freedom.

Rough cost estimates for parts to be made by Nuovo Saimpa (M. Saletti, personal communication, August 19, 2023):
- Zamak (€3.00/kg)
    - Outer layer: € 14,500 approx.
- Acetal (€4.00/kg)
    - Feet: €11,000 approx.
    - Body: €13,700 approx.
    - Cover: €12,000 approx.

Parts to be bought:
- Bearing
- Neodymium magnets

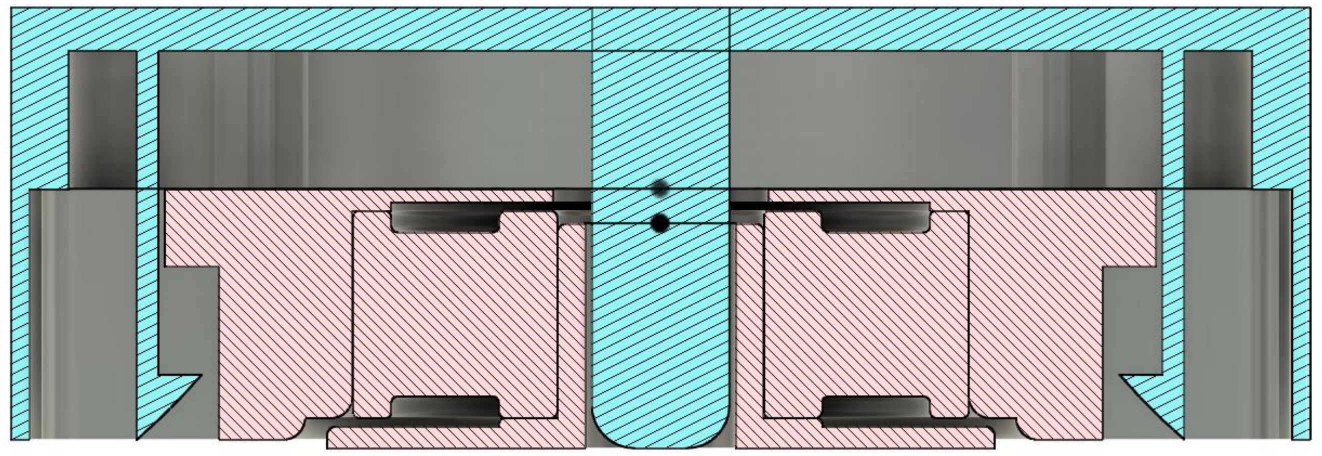


Fig 78: Cross section of the final design.

Output:
The finished knob is estimated to cost between €4.50 and €6.00 in batches of 1,000 pieces (M. Saletti, personal communication, August 19, 2023) with a combined mould cost of €76,700. The product is not production ready yet but shown to be fully feasible by the current production partner.

Assessment

Introduction

By going along the three pillars of Industrial design, namely feasibility, viability and desirability, I show once again step by step that this concept has a right to exist

Feasibility
Viability
Desirability

Assessment

Feasibility

Can we do it?

The new control solution does not introduce any new techniques, just a new integration of existing techniques. These are all plausibly made to work together in the build-measure-learn cycles of the Development chapter.

The top end of the control solution, namely the knob, has been broadly talked through with Boretti's current production partner, Nuova Saimpa. They saw no difficulties with the design. The underside of the control solution would be incorporated into an updated version of the Lapitec Chef. Although hardware and software for this certainly still needs further development, this part of the design does not introduce any extreme difficulties either.

I fully prototyped the important parts of the design, namely the interface, haptic feedback and the magnetic coupling, myself. All this shows that the design is definitely feasible.

We can do it!

Fig 79: Interface prototype.

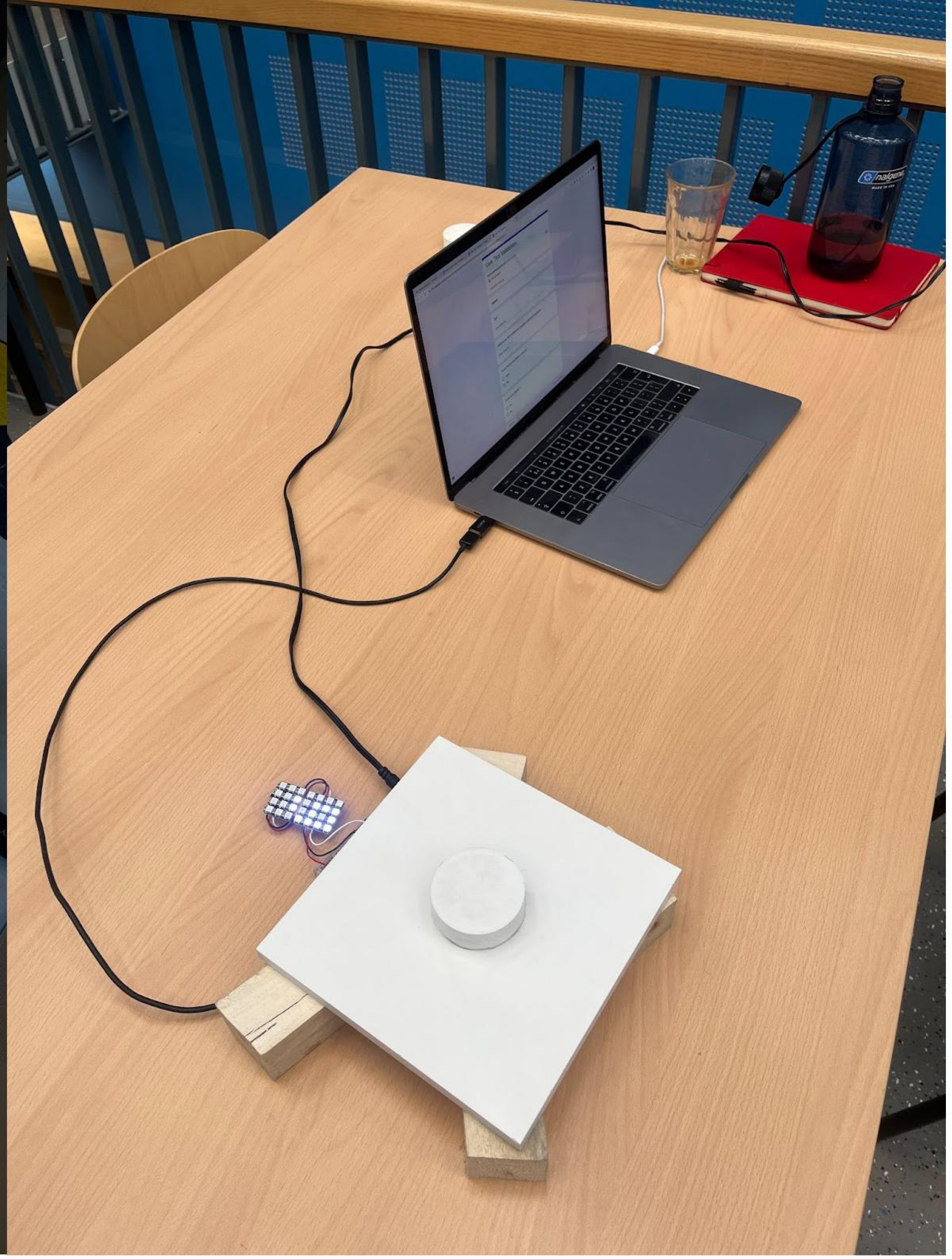


Fig 80: Knob, haptics and coupling prototype.

Desirability

Do people want it?

Past half year induction cooktops have been a conversation topic for me, even dropping the word induction cooktop sparked emotions in people. The topic resonated as almost everybody had some notable negative experience with them.

In the user test in the embodiment phase I asked the participants what they thought about induction cooktops with touch controls. These are the reactions bundled per topic:

- 7/12: touch buttons don’t work consistently
- 4/12: not intuitive
- 4/12: changing the power level is slow
- 2/12: you have to press to hard
- 1/12: zone is not clearly marked

More than half of the users complained about the controls of current induction cooktops. While the user were delighted to play around with the haptic solution that was prototyped. Together with the new wave of developments in the area of magnetic removable knobs and the premium that is paid for intuitive simple knobs I can conclude users want it.

By addressing the downside of induction cooking, its controls, it is possible to make this safer, more energy-efficient and thus objectively better way of cooking more attractive.

People want it!

Fig 81: My grandmother happy with her analog controlled induction cooktop.

Viability

Should we do it?

At Keukenloods, a shop selling low-end cooktops in Rotterdam I found out that most people found the price difference between a magnetic knob and touch controls usually not worth it.

While a sales assistant from Samsung told at the Batibouw fair in Brussels that they are incorporating the magnetic control knobs in their flagship model because there is actually demand for them. The company Bora, which was also present at this fair, was only on sale with the new physical knobs they developed for the Professional 3.0 cooktops.

When I visited Poggenpohl, a high-end kitchen designer in Rotterdam, it became clear that the demand for intuitive simple knobs for cooktops is high. The shop sold Gaggenau and Bora, among others. The sales assistant indicated that many home cooks choose Bora's 'professional' hob over the normal one because of the physical dials it has, despite a price difference of roughly 6000 euros (normal Bora induction at 2.4k and the Professional 3.0 at 8-9k)! On Bora's website, the Professional 3.0's first highlight is that it features physical knobs. Which shows the importance of this.

The Professional 3.0 is the perfect example that the high-end market is waiting for a better control solution for induction hobs and has money to spend on it. Boretti being the Alfa Romeo among cooktops could fill the gap between low and high-end cooktops with my new control solution.

We should do it!

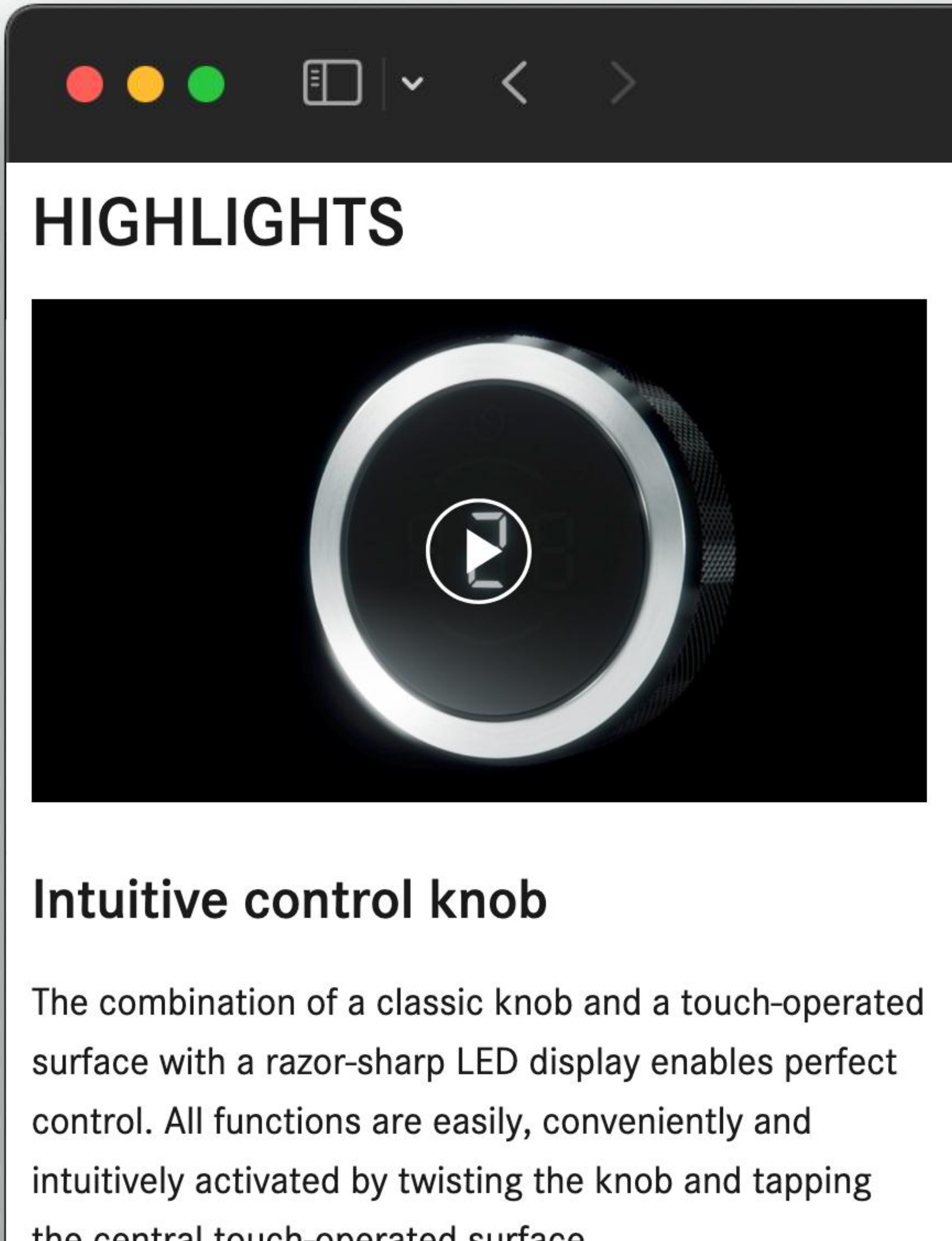


Fig 81: N°1 highlight on Bora's webpage of the Professional 3.0.

Conclusion

To conclude the project, I will talk through the project from the project brief to eventually arrive at the final deliverables

This project began not as an assignment from Boretti but as a personal frustration. Together with Jacco Bregonje (independent designer for Boretti), we looked at overlap of my frustration and ongoing projects within the company to arrive at the assignment; Design a better induction control solution that can ideally become the new standard, but can be brought to market with the 'cooking on stone' concept.

I then stated; 'I want to get to the core of the technology and redefine according to user testing what is needed for a good cooking experience, in order to humanise this technology. Ideally I would deliver a working physical prototype for the interface of the Boretti cooktop. This would be worked out and ideally proven feasible by Boretti's suppliers.'

By looking at the induction technology, the brand Boretti and the past developments of the cooking on stone concept I formulated a Project Vision. In it, I discussed the essence of hob functionality and how to measure its success, as well as a matrix for plotting current and future solutions.

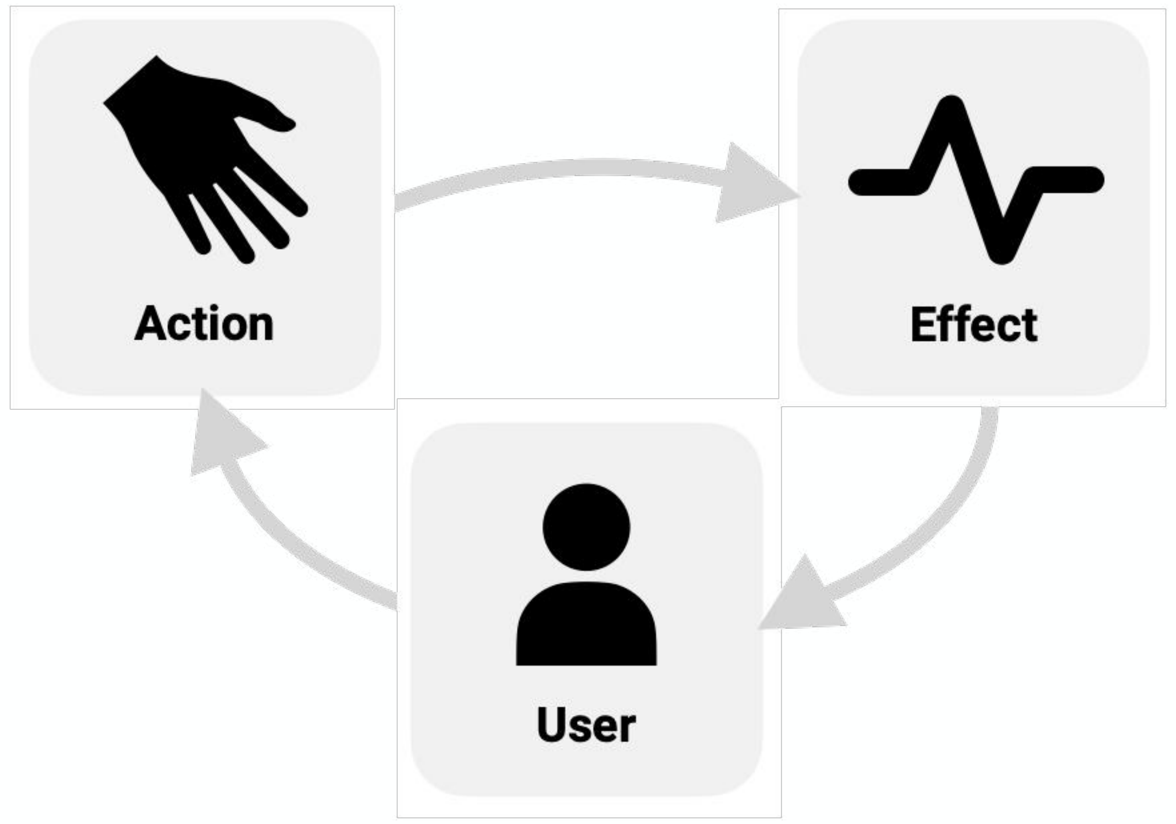


Fig 82: User action effect feedback loop

Through a broad research phase, I scoped my solution direction, outlined a design vision and categorised the biggest challenges for realising this. Here, it became apparent the control of the solution should be detachable, provide additional information through haptic feedback and all this without having electronic components above the kitchen worktop.

These were solved step by step and tested in the development phase after which the results were incorporated into a list of requirements. These formed the blueprint for elaboration in the embodiment phase of the project.

The overall assignment is fulfilled. This has been worked out into a working physical prototype that is tested to be better (in my own measurement of the user action effect feedback loop), which has been declared feasible as far as it can be by Boretti's suppliers. As the control solutions handlings are intuitive, offer multimodal feedback and are direct.

Recommendations

To bring this concept to market some recommendations are given for the next steps to be taken after the development of this graduation thesis.

More practical recommendations for the current design are:

- More mild uniform polarity magnetic coupling
- Other worktop materials on transparency
- Strength tests with milled worktop material
- Tuning capacitive touch sensor + rework bottom coupling
- Click functionality incorporated into the push button design
- Alternative for silicone placemats
- Other functionality (e.g. bridged zones, timers etc.)

The relationship with Lapitec should be bettered in order to further develop the underside of the solution, while coming up with a partnership for the stone kitchen worktops. This could turn Boretti into the Dutch supplier for cooking on stone, as few companies combine the sales of integrated induction cooktops with the sale of the worktop.In reaction to that a version of the control solution for normal ceramic glass cooktop could be developed. This would bring the popularised by the more high-end cooking on stone cooktops control solution to the general public on a lower budget.

Fig 83: Neff induction cooktop with badly photoshopped knob.

Reflection

I look back on the last six months with great pleasure. In the project letter beforehand, I indicated that I wanted to improve competences in the field of user experience and usage testing, in order to achieve the most minimalist rich interaction solution. I wanted to do this by, among other things, doing in-depth interviews and unravelling the technology behind the cooktop to ideally deliver a 1:1 prototype.

As conceived, I started with technology where online research, taking apart a cooktop and talking to the inventors of the induction cooktop led to a good background knowledge. In the following period, I talked to as many people as possible from personal and professional circles at trade fairs to get a good idea of the current situation and developments.Then I started solving design problems in short cycles, which I verified with a user test. I incorporated these solutions in my final design, which I again tested with users.

Needless to say, it was not easy to deliver a 1:1 prototype. Due to my poor programming skills and the complexity of the solution, I had to focus on the most important elements. I developed these in two separate prototypes in order to use them for testing and present them to Boretti internally.

I think I have indeed developed a solution that delivers richer interaction in a simpler way, just as I have learned a lot about getting valuable information from user testing. All this has definitely improved my competences in the field of user experience and so I can say with satisfaction that I have met my own goals.

I would like to take this opportunity to thank my supervisors Daan van Eijk and Stephanie Gieles from the human centred design department from the Delft University of Technology. Both for having periodic meetings with me in which they always managed to make me enthusiastic while providing constructive criticism of my process and result. Stephanie in particular for always being ready for a call or cup of coffee to discuss issues I was getting stuck on. Daan for successfully pulling me through the academic machine which is the university.

I would also like to thank company coach Jacco Bregonje for all his support and knowledge regarding the development of the concept. His patience and professional knowledge and contacts enabled me to take the concept to the next level while having a good time. Furthermore, I would like to thank the company as a whole Boretti including Wouter den Bruigom in particular for this opportunity and the (financial) support to make it happen.

Finally, I would like to thank all the people I have had the opportunity to interview or who have taken the time to participate in one of the user tests.

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Appendix

These are added as PDF pages after this one in order to maintain original quality. Page numbers will be compromised.

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Priester 6324
initials: F.F. given name: Floris
student number: 4661001
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): ★ IPD ◯ Dfl ◯ SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ◯ Honours Programme Master
specialisation / annotation: ◯ Medisign
◯ Tech. in Sustainable Design
◯ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: dept. / section: HCD/ AED
** mentor: Stephanie Gieles dept. / section: HCD/ DA
2nd mentor: Jacco Bregonje
organisation: Boretti
city: Amsterdam country: The Netherlands

comments (optional): I wish to include two mentors from different HCD sections, as this fits with the focus of my graduation project. Daan has been active in cooktop ergonomics, whilst Stephanie has a focus on applied aesthetics and experience.

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair ______ date 10 - 03 - 2023 signature ______

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 24 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 24 EC

List of electives obtained before the third semester without approval of the BoE

- [ ] YES all 1st year master courses passed
- [x] NO missing 1st year master courses are:

ID4070 IDE Academy (4,0)

name Robin den Braber date 13 - 03 - 2023 signature ______

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: [x] APPROVED [ ] NOT APPROVED

Procedure: [ ] APPROVED [x] NOT APPROVED

- the missing course ID4070 should be finished before the green light meeting

Remark: the planning is unclear

comments

name Monique von Morgen date 21 - 03 - 2023 signature ______

Improving the user experience of induction cooking

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 20 - 02 - 2023

12 - 08 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

CONTEXT:
Induction cooking is the most efficient way of cooking, but many people still prefer natural gas because of its lower price and better control and feedback (ETNA, 2020). Currently, more than half of the Netherlands still cooks on gas (Zonneplan, 2022). In the light of the increasingly acute climate crisis and current geopolitical conditions, the importance of independence from gas is becoming clearer than ever.

Technology occupies an ever-increasing portion of our lives. While it is usually (successfully) deployed to unburden us it sometimes introduces unnecessary complexity during and after its use phase. At the same time people have become more interested in low tech pursuits such as doing analog photography, playing vinyl or hand-pouring coffee. Surveys also show a rising demand for so-called digital detoxes (EY, 2019).

While the brand Boretti started out with selling re-branded Italian stoves, nowadays it has a big portfolio of in-house designed products that are still being produced in Italy. But instead of only bringing the love of the 'Italian Culinary Lifestyle' to the Netherlands, the company now also tries to internationalise its brand new portfolio.

STAKEHOLDERS:
- Boretti
- End users
  - Everyday
  - Elderly
  - Power users
- Manufacturers
- Resellers

OPPORTUNITIES:
- Because of political agreements no new houses will be able to get a gas connection. Therefore slowly all Dutch users will move to induction cooktops.
- Haptic technology and other ways of feedback are rapidly evolving.

LIMITATIONS:
- Induction cooktops tend to be more expensive than their gas fired counterparts.
- Electric cooking worsens grid congestions at moments of peak use.

space available for images / figures on next page

introduction (continued): space for images

image / figure 1: Integrated kitchen concept Appasionato by Boretti.

image / figure 2: Smart knob by TU graduate Jeroen van Rijnberk in its context.

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

PROBLEM DEFINITION:
While the technical properties of induction cooktops are objectively superior to alternatives (e.g. safer, better clean-ability, less energy lost & shortened cooking times), some features have added costs, learning curves and in general complexity to a simple in the 1900s patented principle. Even when looking at the best rated more expensive cooktops, reviews still indicate poor control and frustration (Amazon, 2019).

RESEARCH QUESTION:
What is the best form of control for improving the user experience of induction cooktops?

SUB QUESTIONS:
* What forms of control are useable for induction cooktops?
* What is important for the user experience of induction cooktops?

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

I want to got the core of the technology and redefine according to user testing what is needed for a good cooking experience, in order humanize this technology. Ideally I would deliver a working physical prototype for the interface of the Boretti cooktop. This would be worked out and ideally proven feasible by Boretti's suppliers.

I expect to deliver an intuitive induction cooktop control solution that is optimised for the Boretti integrated kitchen concept, but be usable for all induction cooktops. Ideally to become the new standard.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 20 - 2 - 2023

12 - 8 - 2023 end date

Half-year planning (GANTT chart):
https://docs.google.com/spreadsheets/d/15bxjF59gcMVh1JF2pfq51PE1e0pR1OzU7TYQFlYQlKo/edit?usp=sharing

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

My master's program has had a strong focus on energy. I started with an ACD assignment for PON on solar generated energy surplus in which I developed a business case for implementing local DC grids. During AED we developed a mono-material seat for Embrear's planned line of electrified planes. Last five months I did an internship at Unify.energy, a Rotterdam startup that develops and promotes market models for peer 2 peer energy distribution. All in all I have a strong interest in electrification, in which I want to be an allround expert. Whilst the PON project and internship focussed mostly on concept strategy (SPD skills) and the Embraer case was more traditional product design (IPD skills), I would like to focus this graduation project on product user interaction and obtain skills in the DFI area also.

Although I am aware of the complexity of today's problems surrounding electrification and the need for systems thinking and service solutions, I chose Integrated Product Design for its physical edge which interests me. Of all physical parts concerning electrification, I feel the most affinity for the topic of induction cooking. As my quest for its improvement is fuelled by personal frustration for the unnecessary non-user friendly design I also experience on a day to day level and my love for cooking itself.

Doing this graduation project with Jacco Bregonje as my mentor for Boretti, with him being an independent designer is something I am looking forward to. As my internship at Unify focussed on systems thinking and future solutions, this will focus on design thinking for creating tangible solutions right now. I basically want to figure out if being a product designer is something I would like to do professionally and so in what form.

Competences that I want to improve would be in the area of user experience design and user testing. Where the focus lies in finding the most minimalistic but rich feeling interaction possible for the final product. This would be combined with more in depth interviews and knowledge on all components concerning induction cooking.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Development

The four design challenges are worked out by providing literature/examples/inspiration as a starting point and Build Measure Learn iterating from those. While solving the design challenges, learnings are translated into requirements/wishes. The updated list with requirements and wishes then forms the outlines for the embodiment phase.

Assignment: Design a better induction control solution that can ideally become the new standard, but can be brought to market with the 'cooking on stone' concept.

As read here the solution would ideally become the new standard, meaning it would also need to work on ceramic glass instead of just gres porcelain. Ceramic glass for cooktops is ~3mm and transparent, so interface is not a problem. The coupling will be harder for gres as the material is a tad bit thicker (when milled) than glass at ~4mm.

Fig X: Developments needed for successful integration of the design vision.

Interface

Being able to see the state of each or the three main features through visual cues through the worktop surface.

Inspiration

When cut in thinner panels the alabaster stone has translucent properties making it usable for smaller windows. Popularised by Byzantine and later medieval churches in Italy (Schibille, 2016), the use of these translucent properties fits their culture.

At the SICAM 2018 Lapitec presented a range of 'hi-tech' uses of their material. They showed a touch interface, wireless charger and even some lights passing through the worktop. In comparison to other ceramic worktops that use printed designs the Lapitec material is homogenous to the core. So while the material is available in only 12 & 20 mm slabs, there is the possibility to mill it to a desired thickness and at a couple millimetres even let light pass through. RAK just launched their Luce line which comes at a thickness of 6mm and also has translucent properties.

Fig X: Lapitec at the SICAM 2018 showing lights passing through.

At ALCOVA during the Milan Design Week 2023 Bettina Bessinyei showcased the SHANGO concept, a marble outdoor induction cooktop. The cooktop features an interface that was developed by Sensonic Design, a Hungarian company that specialises in high tech stone solutions. The interface consisted of a led matrix combined with touch sensors.

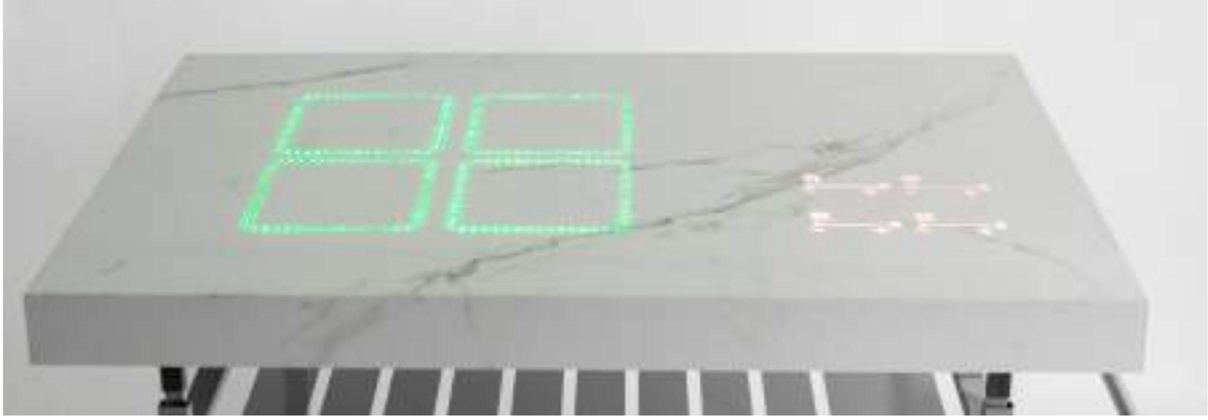


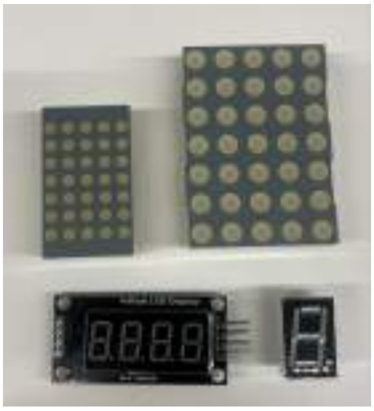
Fig X: SHANGO full marble outdoor cooktop with LED touch interface.

Build-Measure-Learn 1: Light through the worktop
Figuring out how bright a light should be for it to shine through the worktop material.

Build:
In contact with the engineers of Lapitec they explained that for smaller area's milling the materials up to ~4 mm thick is possible. They strongly advise against hollowing out the material leaving only 2–3 mm. I received some 20x20 cm 12 mm thick samples slabs from Jacco, which were too small to mount in a CNC mill. Classic Stone Rotterdam was willing to mill them by hand. An area with 60 mm diameter in the heart of the slab was milled to the thickness of 4 mm. This could then also be used for the magnet coupling.

Fig X: The Lapitec sample being milled by hand with diamond headed drill.

The grove 4-Digit display could be directly hooked up to an Arduino Uno, while the small 7 Segment display needed a limiting resistor. The manual stated that it would be the brightest at a resistor of 150Ω, this was achieved by putting two resistors in series. The KingBright display needed to run at 2V 20mA, this is achieved by using the 3.3V bus of the Arduino and putting three resistors in series.



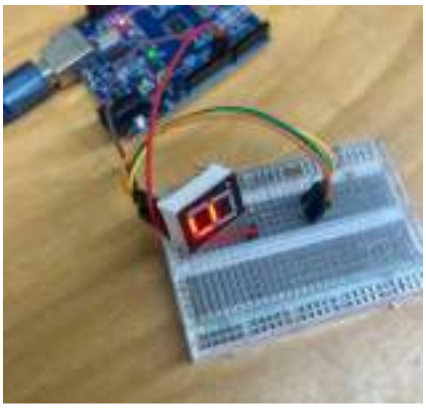


Fig X: 7 segment displays & Led matrix'. *Fig X: 3 segments at full brightness.*

Materials:

- 7 segment displays
  - Grove - 4-Digit Display
  - 0.56inch LED display 7 Segment 1 Bit Common Anode (CA)
    - 150Ω limiting resistor
      - 100Ω+47Ω
- Led matrix'
  - TA20-11EWA Kingbright Dot Matrix, CA 7 x 5 Dot Matrix Red 10 mcd 52mm

        - 2V 20mA
            - R = (V1 - V2) / I = (3.3 - 2) / 0.02) = 65Ω limiting resistor
            - 10Ω + 10Ω + 47Ω
    - TA12-11EWA Kingbright Dot Matrix, CA 7 x 5 Dot Matrix Red 14 mcd 30.5mm

Measure:
Only the 1 bit 7 segment gave a slight reading on the other side of the worktop. All others were not visible at all.

Learn:
The light source needs to be brighter in order to be visible throughout the material. Only then can I worry about the definition of the display.

Build-Measure-Learn 2: Definition of light
Figuring out how to position the LED's for making the display possible.

Build:
Brighter NeoPixel LEDs were sourced that also have RGB functionality, so also the effect of colours on visibility can be checked. Apart from visibility now we can also measure the definition. The LEDs only need to be hooked up to +5V, GND and a digital pin of an Arduino. Since NeoPixel has their own Arduino library, this choice makes wiring and coding easy.

Materials:
- Flora RGB Smart NeoPixel (version 2)
- 5 RGB Smart NeoPixel circle
- Arduino UNO

Measure:

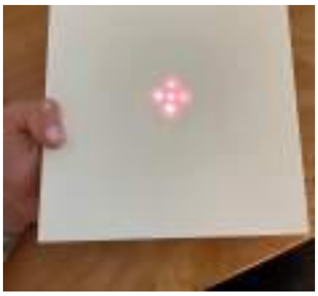


Fig X: NeoPixel circle at (255,0,0).

Fig X: NeoPixel Flora at (50,50,50).

The NeoPixel LED chips are 5x5mm and the worktop material is ~4mm thick. On maximum brightness white light (pixels.Color(255, 255, 255) or 60mA) they give a beam on the surface that is the brightest in the centre 5mm diameter, but bleeds out until 10mm diameter. On a low brightness white light (pixels.Color(50, 50, 50)) they give a beam on the surface that is evenly less bright and bleeds out until only 7mm diameter. The colour does not seem to matter as much as the brightness. The NeoPixel circle at full red (pixels.Color(255,0, 0) was despite only 1/3 of the LEDs chips being activated, plenty bright enough. Full green did also work great while full blue was barely visible.

Learn:

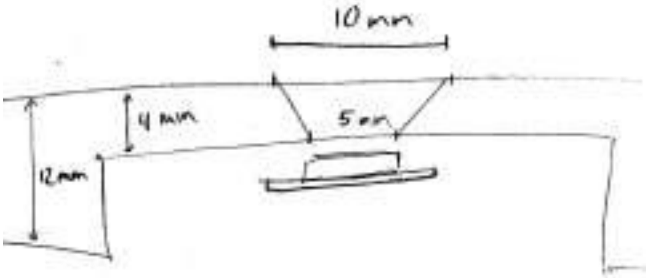
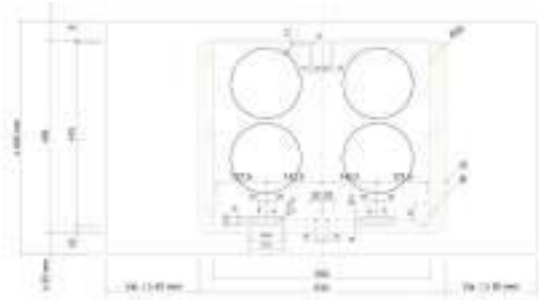


Fig: Drawing NeoPixel light projection through the worktop.

LEDs with a power handling of 60mA at 5V (0.3W) are bright enough for shining through the material. If the leds are 2mm apart the bright spots will join nicely. Combinations of colours work great as long as they are not more than 50% blue.

Build-Measure-Learn 3: Pixels needed for numbers

Figuring out what the minimal resolution is for making the display possible. Using installation drawings of the Lapitec Chef I was able to find the sizing of the controls.



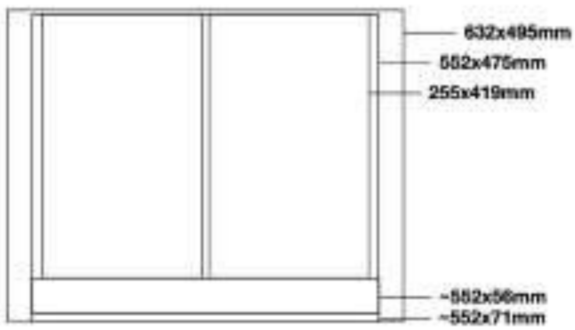


Fig X: Lapitec Chef installation drawings. Figure X: Drawing showing control size.

The compartment reserved for the Lapitec Chef control solution is 552x712mm. Ideally my feature solution would fit this perfectly, in order to lower development costs.

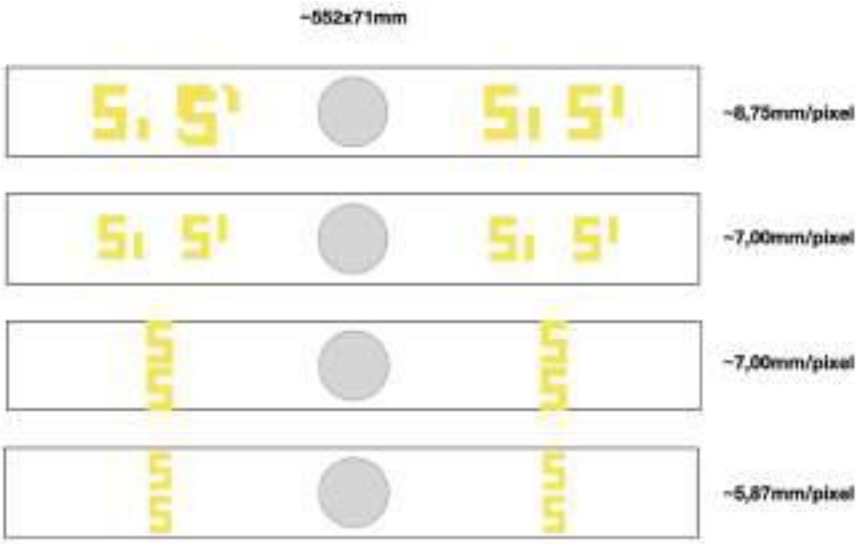


Fig X: Rough layout of the control solution with matrix' pixel density.

Build:
Now I know in which definition the light can shine through, I can look at the amount of pixels that are needed in order to showcase numbers clearly. Inspiration will be taken from online examples. Because of the numbers that have two holes (e.g. 8) a minimum of 5 pixels in height is needed. The final interface would ideally be as small as possible while being readable. While there are numerous styles to make numbers and letters in a pixel matrix, I chose the most fat/boxy style that would be most readable and a more classic approach to test their readability.

While looking in the manual of the Boretti and Lapitec cooktop I found the following archetype communication that I wanted to make sure would be readable. The stripes mean the three modes for keeping food hot after cooking, P for power, A for automatic, H for hot zone (after cooking), E for error (could be combined with a number) and C for zone misfit pan.

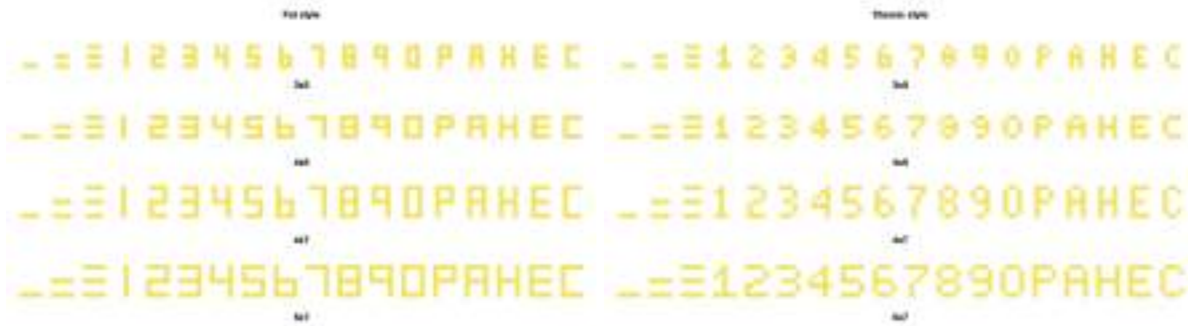


Fig X: Two styles of 3X5, 4X5, 4X7 and 5X7 essential archetype communication.

Measure:
On screen all numbers are easily readable, even when very small.

Learn:
The minimum amount of pixels in height for a number is 5, but 7 will give more detail. For width the minimum is 3, but 4-5 gives more detail. Since 5 pixels in height does not seem to be a problem, this is the size that will be experimented with more in depth.

Build-Measure-Learn 4: Preferred matrix size
Figuring out what the preferred resolution is for making the display possible.

Build:
This will need to be verified on a Neopixel matrix through the worktop material. Matrices were only available in symmetrical sizes such as 2x2, 4x4, 8x8, 16x16 etc. Since the milled part of the sample Lapitec worktop sample is only 65mm in diameter, the 8x8 matrix would not fit. Ideally the pixels would be mounted as close together as possible. This will look better as the lights join and will leave more room in the Lapitec Chef control area. The FeatherWing needed extra controllers and was too big for the milled hole in my sample.

Fig X: Pixel density of several NeoPixel Matrices.

In the available 2x2 matrices the pixels were not evenly distributed. It is therefore chosen to use two 4x4 matrices (35x35mm) of which one the top row of pixels is chopped off. They have a relatively low pixel density. This is possible since the inner wiring zig-zags through the board and only one side of the outer connections is needed for it to function. As the NeoPixels are individually addressable, the first full matrix' out pin could just be connected to the half matrix' in pin, for the whole to function as a 4x7 matrix.

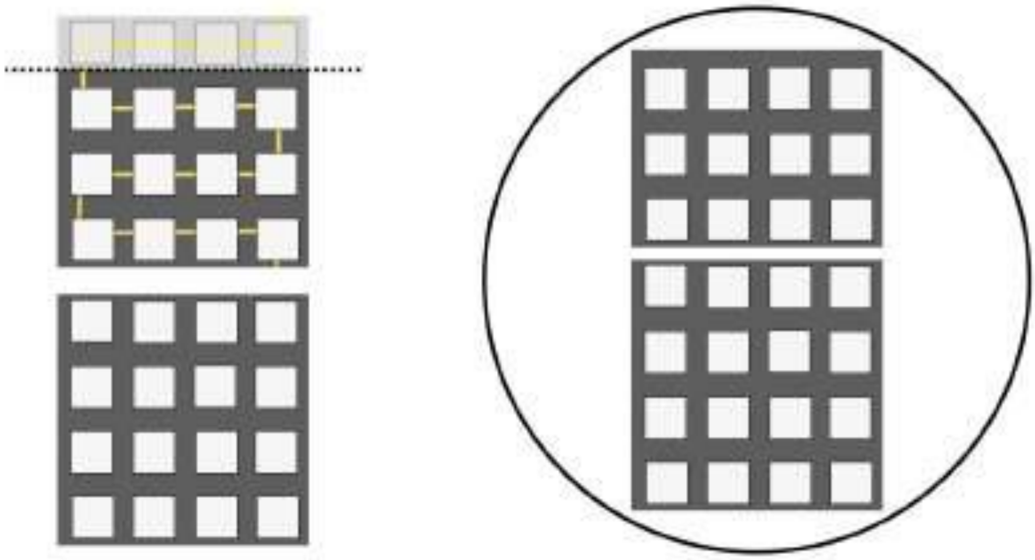


Fig x: Custom 4x7 matrix and milled hole fit example.

Buy:

- LED NeoPixel 4x4 - 16 x WS2812 5050 RGB LEDs met drivers

Now the hardware is functional, a code must be written. Using the following libraries I was able to make the matrix function like a small display. This way numbers can be easily tested in different fonts (e.g. 3X5, 5X7 etc.) without the need of addressing individual pixels.

Arduino libraries:

- Adafruit_GFX
- Adafruit_NeoMatrix
- Adafruit_NeoPixel
- robjen/GFX_fonts

Measure:

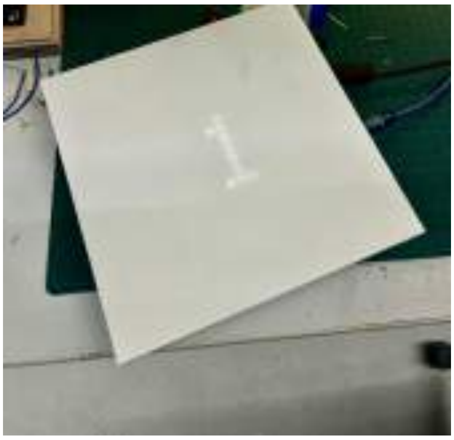


Fig X: *5X7 font (at 40% brightness).*

Fig X: 3X5 font (at 100% brightness).

The following fonts were tested:
- 3X5 (Font3x5FixedNum.h)
- 4X5 (Font4x7Fixed.h)
- 4x7 (Font5x7Fixed.h)

All fonts were clearly readable through the sample surface.

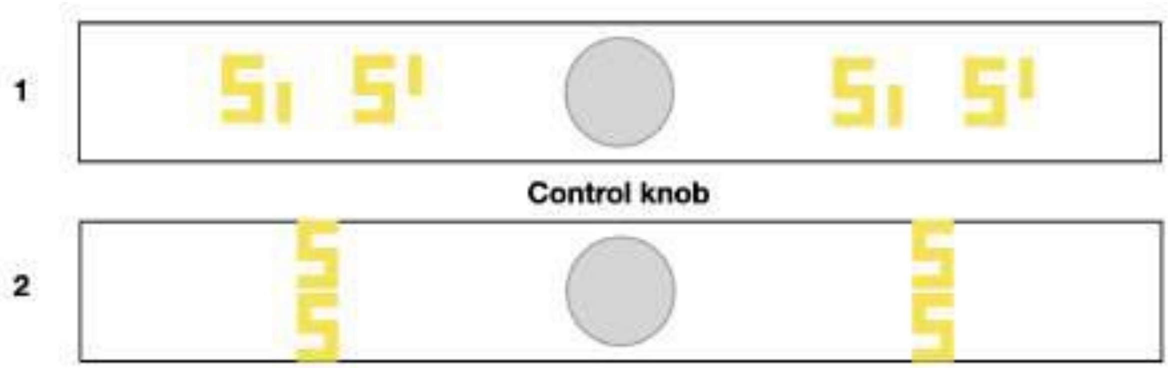


Fig x:

The participants of the user journey test of 4.4 were also asked which number style (fat/classic) and which layout they preferred. Ten out of twelve (10/12) would have them in a square (option 2), saying that first time use would greatly benefit this configuration and that the symbols can sometimes be confusing. Eight out of twelve (8/12) would prefer 'fat' style numbers, saying the style is better readable (certainly for people with bad eyesight) and is more modern as it has less MS Dos / Atari resemblance.

Learn:
I will continue with the 3X5 font as this leaves me the most room for the lay-out. This will be done in the 'Fat' font in a square configuration surrounding the control knob. For the design I will continue with the 5,87mm/pixel density of the FeatherWing 4x8 as this product proves that it is feasible.

Build-Measure-Learn 5: Different materials/settings

Lapitec is known for their bright gres worktops, but the company has more styles to offer. According to Linea Marmi the SATIN finish is most in demand, followed by Lithos Vesuvio, thicknesses 12 and 20 mm. Sales are pretty evenly distributed. For the colours, Nero Assoluto (absolute black) and Bianco Assoluto (absolute white) are the main players.
For veined colours, Bianco Vittoria is the best seller. If Nero Assoluto works with the LED interface all others will too, as this is by far the darkest composition. While currently tested in a bright indoor lab environment, the interface should work in direct sunlight as well.

Build:

Samples for linea Marci will be tested. The material will be brought down to a thickness of ~4mm. This time only a small area, just enough to fit one neopixel, around ~15mm diameter.

Measure:

The sample will first be tested in several lighting situations to see if the ambient light intensity will affect visibility. This is measured in lumens per square meter (lux), done with a smartphone app (Light Meter) and a diffuser which is calibrated for my iPhone 13 mini.

Materials:

- Sample mounted NeoPixel matrix
- Smartphone with Light Meter app
- Diffuser
- Hera DC power supply (261.305.400)

Lux measured:

- Indoor (lights on)
    - 1600 lux > easily visible
- Indoor (5 cm from fluorescent bulb)
    - 16500 lux > visible
- Shadow (50 cm from sun)
    - 1100 lux > easily visible
- Shadow (30 cm from sun)
    - 1400 lux > easily visible
- Shadow (edge)
    - 17500 lux > visible
- Direct bright sun
    - 125000 lux > not visible
- Direct bright sun (through HR+ window)
    - 60000 lux > barely visible

Fig X: 100% brightness at 1400 lux.

Fig X: 100% brightness at 125000 lux.

During the experiment all indoor and shadow situations were easily visible. After 60K lux visibility went down drastically, with it being invisible in direct bright sun. In my code the LEDs were all coloured (255,255,255) at 100% brightness. The WS2812 5050 LEDs of which my matrix is built are supposed to use a max of 60mA, which would be achieved at (255,255,255). I measured the amp draw by turning 10 LEDs on and taking the average with the built in current meter of the power supply. My amp draw was only 15.1mA at 5V. Since the spec sheet confirmed 5V is the correct voltage, I will try to up the amps in an attempt to increase visibility in bright daylight. I will use a spare matrix I bought to prevent my modified one from burning. I will increase the brightness step by step while checking the temperature of the leds.

Amp draw measured:

- (255,255,255) at 100% brightness > 15.1mA
- (255,255,255) at 110% brightness > 16.5mA
- (255,255,255) at 150% brightness > 22.1mA
- (255,255,255) at 175% brightness > 25.6mA
- (255,255,255) at 200% brightness > 29.0mA
- (255,255,255) at 250% brightness > 36.0mA
- (255,255,255) at 260% brightness > 1.7mA
- (255,255,255) at 300% brightness > 7.3mA

Increasing the brightness worked until 250% resulting in a peak of 36mA per LED. After that amp draw dropped. At 250% the LEDs were getting fairly hot in open air, but when I mounted them to the worktop sample it stayed under control. At this point I had to wear sunglasses when the LEDs were not mounted behind the sample. Using 250% brightness and 36mA per LED I will check visibility again in the most critical situations.

Fig X: 250% brightness at 125000 lux.

Fig X: 250% brightness at 60000 lux.

Lux measured:

- Direct bright sun
    - 125000 lux > barely visible
- Direct bright sun (through HR+ window)
    - 60000 lux > visible

Fig X: Samples Lapitec.

Fig X: 10 mm diamond bit.

Fig X: Endless drilling.

Fig X: Light test setup.

Other samples Lapitec:

- Nero Assoluto (Lux finish) @ 4mm: no light pass through
- Nero Assoluto (Lux finish) @ 1mm: no light pass through
- Grigio Cemento (Lux finish) @ 4mm: no light pass through
- Bianco Crema (satin finish) @ 7mm: no light pass through

Using the Flora RGB Smart NeoPixel LED (which was only ~13mm diameter), I was able to make the holes faster than for the whole matrix to fit. Since both boards use the 5050 LED chip the brightness is the same. With a hollow 10mm diamond drill bit I was able to make holes of ~20mm, this was done by using a drill press while slowly moving the tiles in a circular motion and constantly refreshing the cooling water. Nero Assoluto did not show any light pass through at 4mm, so I decided to drill it all the way to mere 1mm thickness in order to see if i could get any, without success. After drilling the Grigio Cemento the bit became dull and I was only able to drill the Bianco Crema till a depth of 7mm.

Learn:
With the highered brightness the matrix was visible and thus readable at direct sun behind a window. Now it is even barely visible while in direct sunlight, a situation which will never occur as the cooktop is developed for indoor use. The other Lapitec samples sadly gave no light pass through at all.

Haptic feedback

Being able to adjust and feel the state of each or the three main features through tactile cues. Where there is first focussed on the adjusting and feeling of the power, as this feature will be used most often.

Inspiration

Vibrating haptic feedback refers to the use of touch to communicate with users. Popularised with vibration motors in phones or game controllers this allows for an extra level of communication. When Apple made the Taptic engine, a powerful and more precise Linear Resonant Actuator (LRA), they also made some guidelines for the app developing community to use it. LRA, while great for notifying users, are not able to apply torque.

Fig X: Apple's Taptic Engine.

Apple Haptic Design Guidelines:

- Causality, for the feedback to be useful it must be clear what caused it
- Harmony, it should feel just as the same way as it looks
- Utility, add haptics that provide clear value in the experience

Haptic force feedback is used for example in racing simulator wheels. Using a motor they are able to apply torque on the wheel. This can be used to make steering heavier or making the wheel unable to turn any further, ideal for the hard endstops at a normal rotary knob for cooking.

Fig X: Scott Bezek fully customizable SmartKnob project.

Scott Bezek developed the SmartKnob which is an open-source haptic knob with software-configurable endstops and virtual detents. The knob uses a Brushless Direct Current electric (BLDC) motor that is controlled using Field Oriented Control (FOC). While FOC is normally quite complex, this project uses the Open-Source SimpleFOClibrary algorithm. Jack Eichenlaub translated this to a simplified Arduino project the FidgetKnob for this graduation. His knob too consists of a BLDC gimbal motor with built-in diametric magnet, a motor controller (TMC6300 BOB) and a magnetic encoder (MT6701) working in closed loop with an ESP32, but runs on Arduino. He built 3 prototypes of these for the IDE faculty, of which I could use one for a test.

Build-Measure-Learn 1: Testing current solutions
Figuring out if the current solutions are convincing enough for me to use.

Build:
Using Jack's FidgetKnob I could test if this system feels right and how much torque would need to be transferred through the magnetic coupling (Chapter 4.3) in order for it to work. I also was curious how much power it consumed while doing so. Jack programmed 7 modes of which I tested with the weakest and strongest detent mode as well as a mode with hard end stops in order to test max power of the motor.

Equipment:
- Haptic FidgetKnob prototype Jack
- Digital Push Pull Gauge (Model: SH-500)
- Alecto Energy Monitor (Model: EM-17)
- Callipers

Setup:
A screw is mounted on the wheel of the haptic knob at 10mm (0.01m) of the centre of the rotational axis. Then the knob is put on the corresponding modes while the newton meter is pulled along the torque vector.

Measure:
- Torque weak detent:
  - Mode = 2
  - detent_strength_unit = 0.2/1
  - Max wattage = 0.21W
  - Max newton = ~
- Torque strong detent:
  - Mode = 3
  - detent_strength_unit = 1/1
  - Max wattage = 1.62W
  - Max newton = 0.2N
  - Max torque = 0.2 * 0.01 = 0.002Nm
- Torque end stop:
  - Mode = 6
  - endstop_strength_unit = 0.7/1
  - Max wattage = 12.89W
  - Max newton = 4N
  - Max torque = 4 * 0.01 = 0.04Nm

Fig X: Testing the FidgetKnob made by Jack.

Learn:
The feeling of the FidgetKnob was convincing! The motor had almost zero cogging and the detents were strong and accurate enough to give the illusion of an analog knob, making it usable for my project. The maximum amount of torque that is transferred during operation is during the end stop. This results in a torque of 0.04Nm that corresponds to the maximum power use of ~13W, only for a couple of seconds. Making it neglectable in the shadow of the cooktop itself.

Build-Measure-Learn 2: Testing adaptation
Figuring out if there is an easier way to achieve the effect of the current solution.

Build:
Now I will replicate the core components of the FidgetKnob, in order to modify it to work best with the magnetic coupling and mounted under the kitchen worktop. Jack complained that while the motor he used had low cogging and a diametric magnet, it was not that robust. Therefore I wanted to buy more motors in order to do my own comparison and feel the differences. BLDC motors with low Kv ratings have relatively high torque (per ampere), this is desired as it makes for a convincing end stop. The TMC6300 BOB motor controller Jack used was not available in The Netherlands at the time so I opted for the SimpleFOCMini v1.0 BLDC motor controller as it was developed by the SimpleFOClibrary makers and seemed therefore be suitable as well.

Buy:
- MT6701 Magnetic encoder
- SimpleFOCMini v1.0 BLDC motor controller
- BLDC 12V 3205 3-phase Motor
    - Hollow Shaft
    - Infinite Position
    - KV value: 260KV
- BLDC 12V 2804 3-phase Motor
    - Hollow Shaft
    - Infinite Position
    - KV value: 320KV
- Arduino UNO

Fig X: The new 2804 motor (left) and the 3205 motor (right).

Measure:
When testing both motors it became clear that the new variant (2804) had noticeable cogging and lacked a diametric magnet, adding that myself seemed cumbersome. Its build quality seemed more sturdy, but this was not worth the added hassle. Also the 3PWM of the SimpleFOCMini v1.0 was difficult for me to implement in the code as it was made for 6PWM.

Learn:
Use the BLDC 12V 3205 3-phase Motor with diametric magnet. I will start to look for another way to get a hold of the TMC6300 BOB and developer ESP32, to keep as many things code wise the same, in order to simplify prototyping.

Build-Measure-Learn 3: Testing code
Figuring out how to code needs to change in order to test the wanted variables.

Build:
After calling the sold-out warehouse they told me they still had one board of the TMC6300 BOB laying around so I bought it together with an ESP32.

Buy:
- ESP32 WROOM Developer Board
- TMC6300 BOB

I printed some of the FidgetKnob enclosure parts to house the motor and magnetic encoder for some tests.

Print:
- 1x MotorAssembly - FK_AssmBasePlate-1
- 4x MotorAssembly - FK_AssmPeg-1
- 1x MotorAssembly - FK_BLDCMount-2
- 1x MotorAssembly - FK_MT6701Holder-1

Using these parts I was able to build the prototype. The MT6701 Magnetic encoder is standard in I2C mode, by bridging two pins below it is possible to configure it in SPI. This requires less parts and is well tested by the original developer.

Fig X: Printed parts.

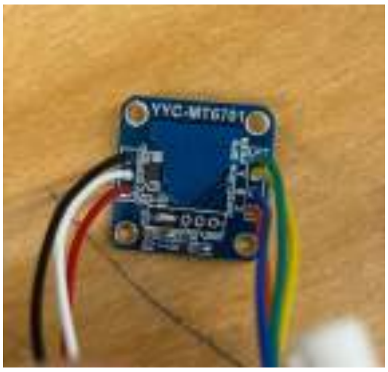


Fig X: Solder bridge MT6701.

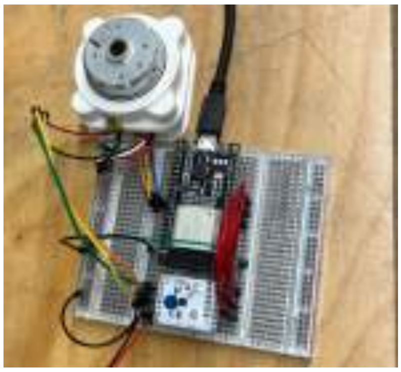


Fig X: Total assembly.

The code was originally in Python, but Jack rewrote the key elements to C for the use of Arduino. This code was able to cycle through 9 modes using a push button in order to test its use for fidgeting.

Pinout:
- MT6701:
    - VCC > 3.3V ESP32
    - OUT > GND ESP32
    - GND > GND ESP32
    - Z DIR > Pin 5 ESP32
    - B SCL > Pin 18 ESP32
    - A SDA > Pin 19 ESP32
    - GPO PUSH > GND ESP32
- TMC6300 BOB:
    - 1 VCC > 5V ESP32
    - 2 GND > GND ESP32
    - 3 UH > Pin 32 ESP32
    - 4 UL > Pin 33 ESP32
    - 5 VH > Pin 25 ESP32
    - 6 VL > Pin 26 ESP32
    - 7 WH > Pin 27 ESP32
    - 8 WL > Pin 14 ESP32
    - 9 +VBAT > 10V DC Adapter
    - 10 GND > GND DC Adapter
    - 11 GND > GND ESP32
    - 12 W (Motor Phase) > W BLDC
    - 13 V (Motor Phase) > V BLDC
    - 14 U (Motor Phase) > U BLDC

I changed the code to an even more bare bones version with only 1 mode, but now it is possible to change individual detents. This is done in order to experiment with its use for the interface. The basic mode has 11 steps, 0-9 and P.

Customizability :
- Amount of detents
- Starting detent
- Angle per detent (degrees)
- Detent strength (0-2)
- Endstop strength (0-2)
- Snap point (0-2)

By using the line 'config[3] = config[1] * 0.2', I was able to gradually build the detent strength (config[3]) by multiplying the current detent number (config[1]) by 0,2. Making sure the total detent strength never surpassed 2.

Measure:
While testing the code I found that an angle of 40 degrees per detent as standard was way too much for cooking with 10 modes. Online research was done using DINED to find the biggest flick of the wrist that could be done by all age groups.

Suggestions:
- Full power in one flick of the wrist
    - Dined (P05 Dutch Elderly 1998)
        - Pronation 90 degrees
        - Supination 50 degrees
        - Total = 140 degrees for full power

- 140/10 = 14 degrees

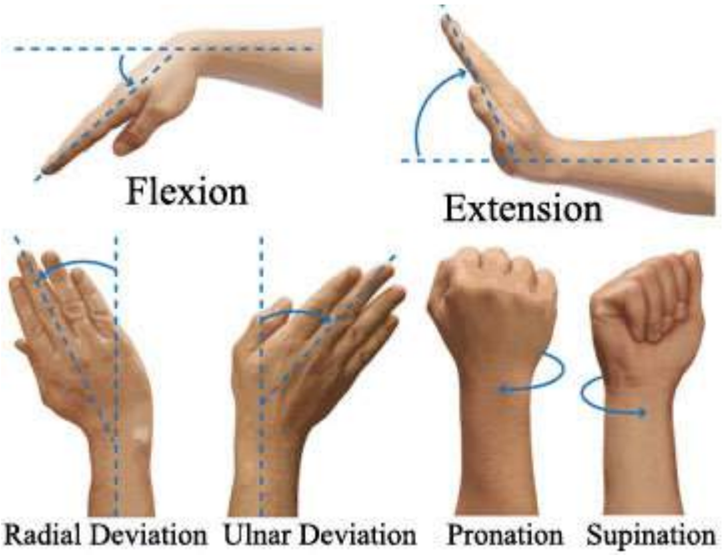


Fig X: Explainer hand movements.

The endstops of 2 instead of 1 were a big improvement in order to make the haptics come across as more sturdy. The gradual improvement of detent strength is subtle but noticeable.

Learn:
Degrees per detent should be no more than 14 degrees as that will hinder some users from putting the cooktop to full power in one fluid movement. As the motor used is quite small, changes in detent strength are quite subtle. They are still noticeable and could improve user experience in the long term.

Build-Measure-Learn 4: Influence of weight and diameter
Testing by using the motor itself as a knob made for very conficing detents. I will test if this is still the case when this sensation is transferred through the magnetic coupling to a knob that was some weight while being of a bigger diameter.

Build:

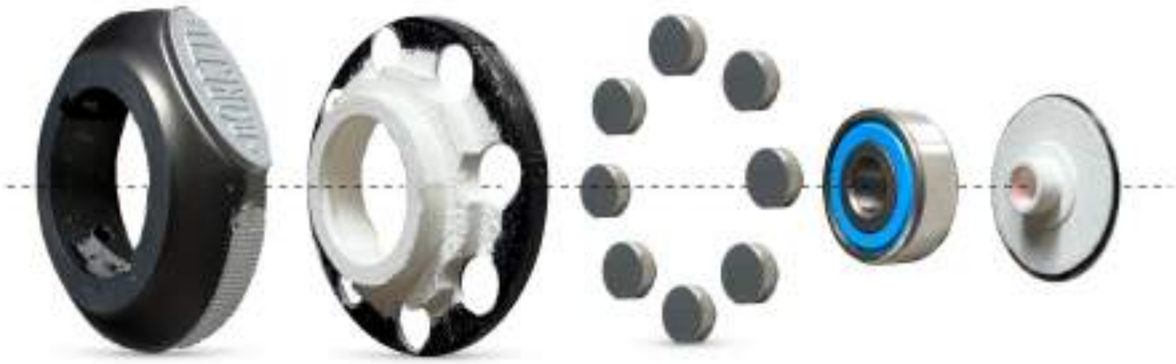


Fig X: Full size/weight prototype using parts of the Carrara knob.

Weight:
- Prototype with Carrara knob ~200G
- Fully 3D printed prototype ~100G
- Fully 3D printed prototype + glass of water ~500G

Testing in the chapter User Journey showed that users prefer a knob that has a bit of weight (around 200 gram), as it reflects quality. To verify this a prototype was built that was able to fit the Zamak part of the Carrara knob, in order to increase the weight. Later a glass of water was added to a fully 3D printed prototype to verify that weight and diameter would not be a problem for the motor driving the haptics.

Measure:

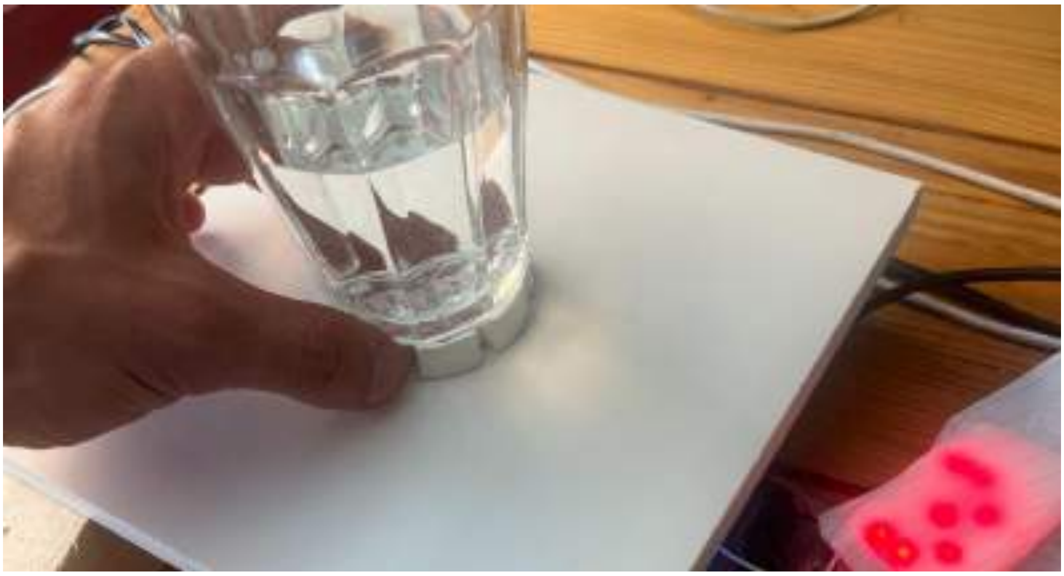


Fig X: Fully 3D printed prototype with a glass of water in order to test a high weight scenario.

The motor itself was 33mm, the Carrara knob was 57mm and the fully 3D printed prototype was 60mm diameter. There was a slight effect on the experienced torque but all were convincing. Both versions with the magnetic coupling worked great, even the detents and endstop of the one with the added weight of the glass of water was still convincing.

Learn:
A knob diameter of 60mm with a combined weight up till 500g will still give convincing detents with the 3205 3-phase 260KV motor driven at 10V.

Build-Measure-Learn 5: Definition of feedback
Testing the minimal angle for the detents.

Build:
Using the code I was able to alter the amount of degrees that is needed to change detent. Dined showed that 14 degrees was the maximal amount per detent that could be used for full power in one fluid movement.

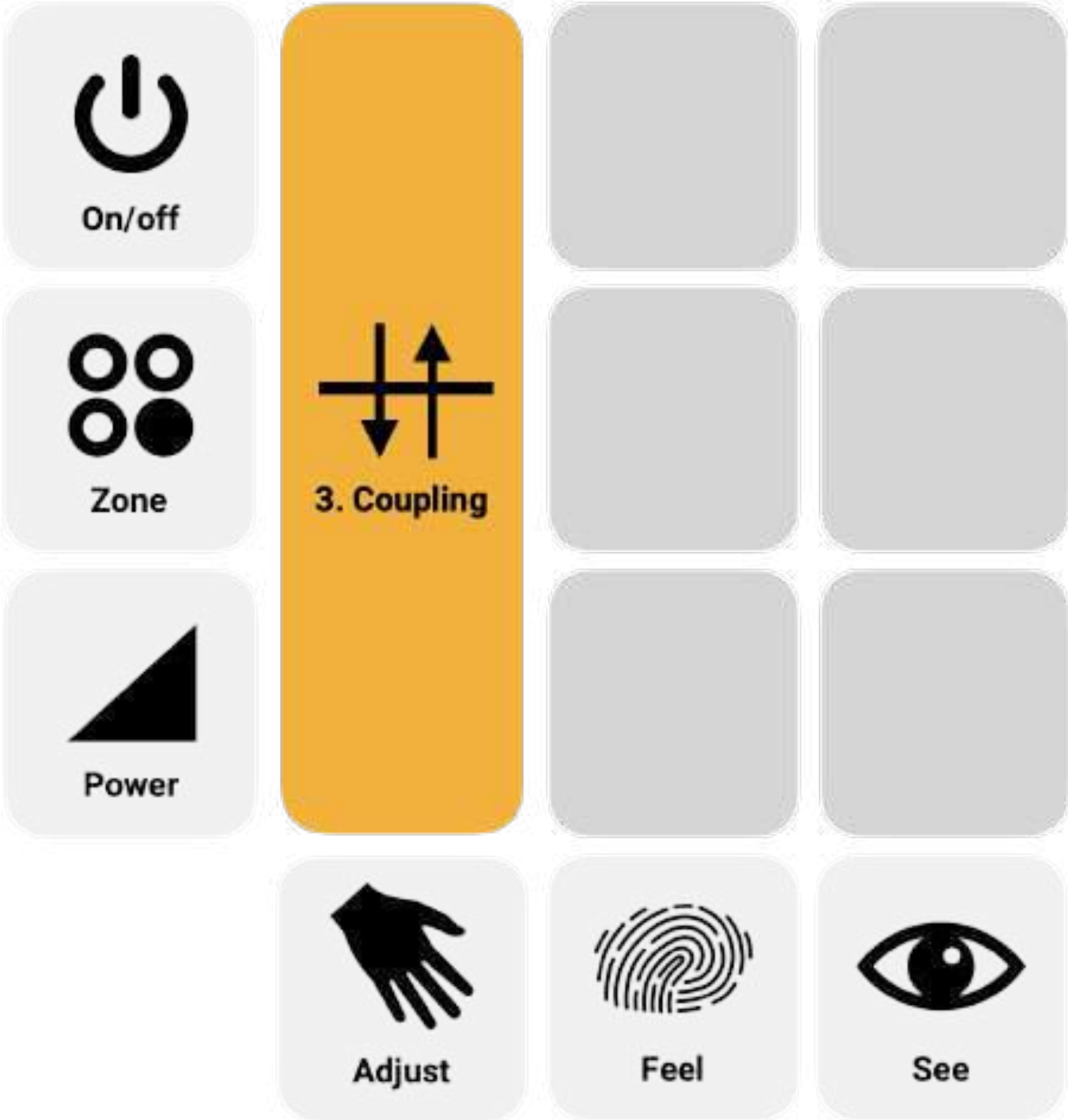
Measure:
I halved the angle per detent until I was unable to confidently change the mode in one fluid movement.

Angles per detent:
- 14 degrees > Very confident
- 7 degrees > Confident
- 3,5 degrees > Little confident
- 1,75 degrees > Hesitant

Learn:
With all angles I was able to change the mode successfully, but below 7 degrees it became a lot harder to do it in one go. As the last thing i want is to further complicate movements this will be the lower limit.

Magnetic Coupling

Being able to transfer the adjusting and feeling of the state of each of the three main features through the worktop surface.



Inspiration

Other brands that have developed magnetic control knobs, only use magnets for keeping the knob in place or sensing rotation. There is no torque transferred through under the worktop surface. This keeps the connection simple but hinders the use of any hard end stops or other haptic cues.

Fig x: Magnetic coupling posted by Markse68 on the Stargazers Lounge forum.

While looking for magnetic connection in a DIY project online I found a quick release focussing module that could be connected to a telescope for fine tuning its focus using a servo. The coupling allowed for torque transfer as well as easy dismounting but did not pass through material.

Coupling info:

- Two disk with 8 magnets each with interchanging polarity
- Magnets: Neodymium 10mm diameter
- PTFE pad to avoid friction

While looking for magnetic connections that can transfer torque through a material, I came across a water pump for an industrial espresso machine. The turbine of the pump is magnetically coupled to its electric motor, making the pump less prone to failure by having a fully closed water system.

Coupling info:

- Two disk with 4 magnets each with interchanging polarity
- Magnets: Neodymium 10mm diameter and 4mm thick
    - Circumscribed circle: 40mm
    - Inscribed circle: 20mm
- Transfers torque through 1mm RVS disk
- PTFE piece to avoid friction

Fig x: HOVE 41533100 26V water pump and its inner magnetic coupling.

Using basic physics I can tell something about the basic dimensions of the magnetic coupling and kitchen worktop. We need quite a bit of torque for a convincing end stop.

$F \propto 1/R^2$

- F = magnetic force
- R = distance between the magnets

As seen in this formula the distance is quadratic, meaning that if it doubles the magnetic force will be quartered. Therefore this distance should be as small as possible. In chapter 4.1 Lapitec told us the minimal thickness the worktop could be milled to is 4mm.

$\tau = r * F$

- T = torque transferred
- r = radius magnets
- F = magnetic force

So if the magnetic force degrades so much over distance it makes sense to use it wisely. By increasing the radius of the circumscribed circle in which the magnets are mounted as much as possible, we are able to transfer more torque without increasing the force needed to disconnect the coupling.

$F = \mu * N$

- F = friction coupling
- μ = friction coefficient
- N = normal force due to magnetic force

Lastly, the coupling should transfer torque in a smooth manner. So friction due to the magnetic force should be minimised. A ball bearing or material like PTFE which has a low friction coefficient and is heat resistant could be used for this.

Build-Measure-Learn 1: Coupling strength

At first I was not sure if the coupling would even hold through thicker material that was used in the water pump (1mm). Using perspex and the coupling from the pump I was able to see what strength of holding would suffice to later adjust the coupling, since this is faster then changing the kind and amount of magnets.

Build:

Two disks out of the pumps were extracted in order to test their strength and have a baseline for development. The effect of the thickness of the worktop and its effect on the strength of the coupling, the dislodging force and torque transfer were tested. As I had one prototype at the time this was the most simple way to find the preferred coupling strength.

Prototype is 65mm from the table to the top of the magnet coupling. Two wooden blocks were added in order to have a 'kitchen top' surface at the same height. Now different materials can be tested. I used perspex as it was widely available in multiple thicknesses.

Measure:

- 1mm thick perspex:
  - Parallel disconnect force = 13.4N
  - Perpendicular disconnect force = 13.2N
- 2mm thick perspex:
  - Parallel disconnect force = 10.6N
  - Perpendicular disconnect force = 10.2N
- 3mm thick perspex:
  - Parallel disconnect force = 5.6N
  - Perpendicular disconnect force = 8.3N
- 4mm thick perspex:
  - Parallel disconnect force = 5.3N
  - Perpendicular disconnect force = 6.6N
- 8mm thick perspex:
  - Parallel disconnect force = 2.1N
  - Perpendicular disconnect force = 2.7N

Fig X: Measuring perpendicular disconnect force with a digital newton meter.

Learn:

2-3 mm were best for parallel disconnect force and perpendicular disconnect force. As the material of the worktop can never be of this thickness, the coupling will need to be stronger. This can either be done by choosing magnets of a higher magnetisation grade or by adding more of them. Torque transfer was hindered due to the friction created by the magnets rubbing against the perspex. Next version will need a bearing in order to prevent this friction from occurring.

Build-Measure-Learn 2: Smooth torque transfer
Figuring out if torque transferred could be more smooth using a ball bearing to help mitigate the friction caused by the magnets. As the material will be thicker than the 2-3mm perspex from Build-Measure-Learn 1, I will need to add magnets. I will try if 3D printing the coupling and friction fitting the magnets and bearing will work.

Build:
Using a small bearing that fit the magnetic coupling from the waterpump I was able to compare them.


Fig x & x: Showing the magnetic coupling from the water pump with teflon and bearing respectively.

Using the outer diameter of the Boretti Carrara knob (58 diameter) as a starting point, I made the two sides of the coupling. Using a bearing holder piece, I lifted the assembly 0.4mm from the kitchen top. This is done in order to minimise friction

Fig x: First 3D printed magnetic coupling.

Measure:
The ball bearing made for significant smoother operation. The 6 magnet knob was now able to transfer enough torque, but it was hard to mount the bottom side without the use of a bearing. The magnetic force hindered correctly spacing a gap, causing unnecessary friction.

Learn:
Future couplings will all make use of ball bearing for at least the worktop side of the coupling. The next generation will need a bearing on the bottom side as well or a better way of spacing.

Build-Measure-Learn 3: Torque transfer through material
Now I know the coupling will hold, the next step is for it to actually transfer torque. Using bearings I am hoping to lose as little torque as possible due to friction with the pass through surfaces. When measuring the haptic system I noticed it could produce up to 0.04Nm of torque at the endstops. You want to be able to experience this hard stop without the coupling becoming undone. Therefore, the knob should be able to hold that torque plus a safety factor of ~50%, say 0.06Nm total. Here I will test if I am still able to achieve that toque while covering the magnets (slightly).

Build:
A 3D printed version is made using the same magnets as before. Each side now has 6 neodymium magnets in interchanging polarity. For testing purposes both under and top side are equipped with a bearing.


Fig x: Bottom coupling mounted on sample.


Fig x: Top coupling mounted on sample.

Parts:
- 12x neodymium magnet 10mm diameter and 4mm thick
- 2x steel bearing 13mm diameter and 5mm thick

Measure:
I measured the amount of torque the coupling could transfer without disconnecting. Three scenarios were tested; magnets directly mounted, a small edge of filament spacing the magnet (0.15mm) and a full layer of filament between the magnets and the mounting surface.

6 magnets:
- direct magnets: 6.5 N
- 6.5*0.02 = 0.13 Nm (0.065 Nm comfortable)
- Layer filament with hole: 5.5N
- 5.5*0.02 = 0.11 Nm (0.055 Nm comfortable)
- Layer filament:: 4.5N
- 4.5*0.02 = 0.09 Nm (0.045 Nm comfortable)

Learn:
The coupling's smoothness improved greatly from adding a bearing on the bottom side. In order to achieve the torque that is needed for convincing end stops (0.06Nm), more magnets need to be added if I want them to be slightly covered for production. As the coupling would ideally be 50% loaded, just before failing the control gets wobbly and awkward.

Build-Measure-Learn 4: Polarity and amount of magnets
While interchanging polarity seems to improve torque transfer, it can be a tad bit awkward when connecting the coupling and when over torquing it to failure. Testing both options I will weigh for the best option. There needs to be enough torque transferred for convincing end stops without disconnecting while ideally having as little friction caused by magnetic force as possible.

Build:
A new 3D printed prototype is made that has the same diameter and bearing position as 1, but now has the option to mount 8 or 4 magnets.

Fig x: Bottom prototype 2 for 4-8 magnets.

Fig x: Top prototype 2 for 4-8 magnets.

Using prototype 1 with 6 magnets and prototype 2 with the option of 4/8 magnets all situations are tested with uniform and interchanging polarity.

Measure:
- 4 magnets
  - Uniform: 3 N
  - 3*0.02 = 0.06 Nm (0.03 Nm comfortable)
  - Interchanging: 3 N
  - 3*0.02 = 0.06 Nm (0.03 Nm comfortable)
- 6 magnets
  - Uniform: 4.5 N
  - 4.5*0.02 = 0.9 Nm (0.045 Nm comfortable)
  - Interchanging: 6.5 N
  - 6.5*0.02 = 0.13 Nm (0.065 Nm comfortable, thus enough)
- 8 magnets
  - Uniform: 5 N
  - 5*0.02 = 0.1 Nm (0.05 Nm comfortable)
  - Interchanging: 7.5 N
  - 7.5*0.02 = 0.15 Nm (0.075 Nm comfortable, thus enough)

During these tests there is checked if enough torque is transferred and what happens when one side of the coupling is forced. 4 magnets did not seem to be enough for transferring torque, while both 6 and 8 were. When forcing one side the coupling just skipped one magnetic position at the uniform polarity.

Learn:
8 magnets in interchanging polarity seem perfect if they want to be covered later.

Build-Measure-Learn 5: Variables friction
The coupling still had some unnecessary friction from touching the worktop. I will try if a more sturdy bearing or heightened bearing holder will prevent this. Also I will try mounting PTFE film on areas that might still rub on the worktop.

Build:
A new prototype was built that consisted of 8 magnets with interchanging polarity that could be used for fine tuning the last decisions concerning friction in the magnetic coupling. The new bearing had an outer diameter (O.D.) of 28.6mm and an inner diameter (I.D.) of 9.6mm.

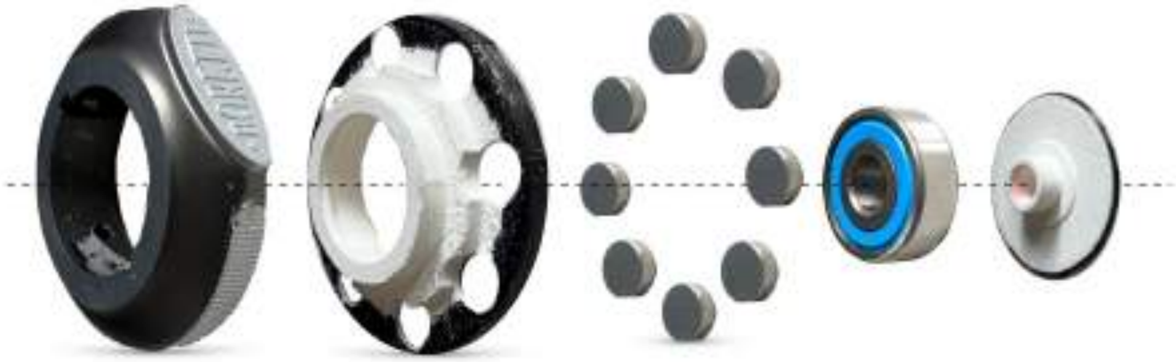


Fig: Prototype 3 using 8 magnets and bigger bearing.

New bearing holders for that top and bottom side were printed with 0.8mm gap between the surface, instead of 0.4mm. To see what kind of effect this has on the friction.

Fig: 3D printed bearing holder, 0.8mm gap left and 0.4mm gap

Fig X: PTFE pad cut to match the surface that was experiencing friction.

Also another underside of the magnetic coupling will be made that will feature the same enlarged ball bearing of the topside to see if this has any effect on the friction of the coupling.

Measure:
Changing the 0.4mm to 0.8mm gap to the surface worsened the friction as the coupling had more tendency to bend over to one of the sides. The PTFE pad slightly improved some of the friction. Changing the bottom bearing to the larger one that was already used in the top coupling immensely lowered the friction in the coupling. Apparently the lower coupling had been rubbing against the underside of the worktop tile, the increased sturdiness of the bigger bearing greatly improved the situation.

As this worked so much better I even tried removing magnets, to see if that would still suffice for the torque transfer that was needed. Even 4 magnets on each side with uniform polarity was enough, which was not nearly enough in build measure learn 3.

Fig X: Bottom and top coupling featuring the larger ball bearing.

Learn:
Having a big ball bearing on the bottom side of the coupling greatly improved the torque transfer, even with just 4 magnets uniformly mounted!

User journey

Now the visual interface, haptic feedback and magnetic coupling have all been developed to a decent level, choices on their completion can be made as well as defining an intuitive interaction for the on/off and the zone selection of the cooktop.

Inspiration

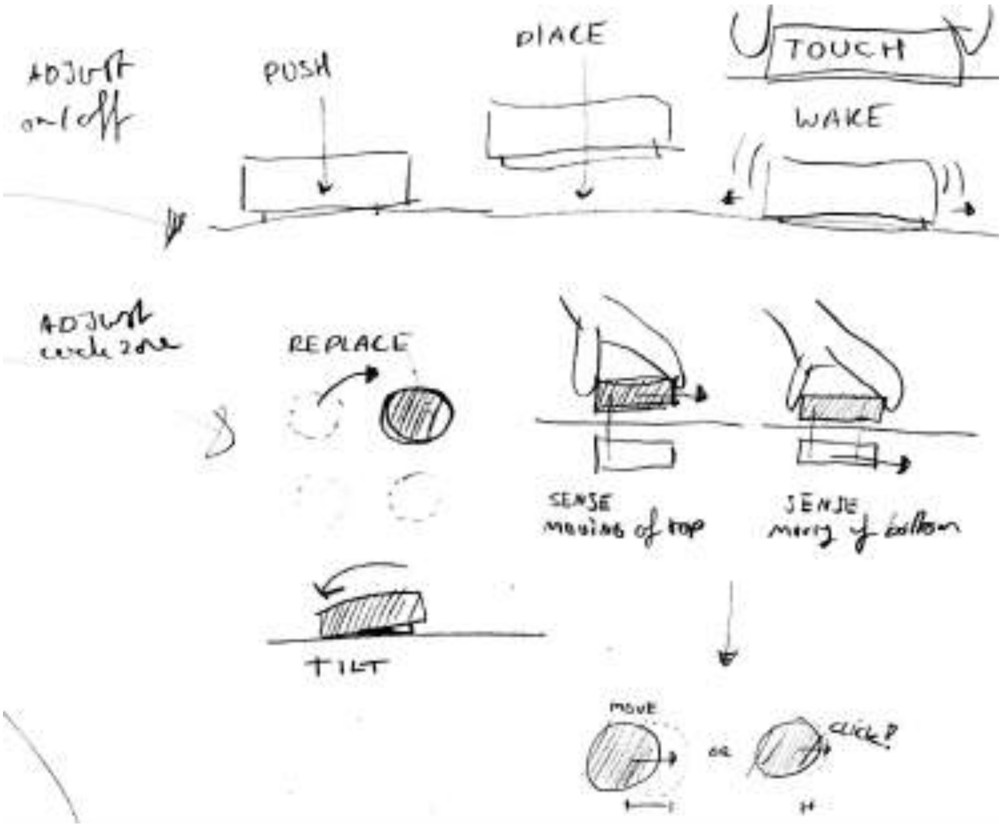


Fig x: Some quick sketches for adjusting on/off and selecting the zone.

In the design vision I praised the Audio MMI for its simplicity. I sketched several scenarios for both on/off and the selecting of the zone.

Fig x: Neff/Gaggenau system for zone selection showing the indication.

Some Neff/Gaggenau cooktops use their magnetic detachable knob for adjusting the zone as well. This is done by either moving or tilting the knob slightly towards the preferred zone. Once you select the zone, you will be notified with a beep after which the number starts to flash and a red indicator bar next to it appears.

The Lapitec Chef just as any other modern cooktops features pan detection, this too could benefit simplifying the controls. It could be beneficial to only be able to select a zone that has a pan on it, limiting options. Therefore if only one pan is placed on a zone, this one will be directly selected.

Build-Measure-Learn 1: What is intuitive?

I wanted to ask participants which one they would prefer, but then realised explaining how each of mine scenarios would work would hinder their first intuitive response. I want the control solution to be truly intuitive, not worse than the current solution.

Build:

Using a visual and physical mockup of the design I was able to roughly show how the control knob and the induction cooktop would look.

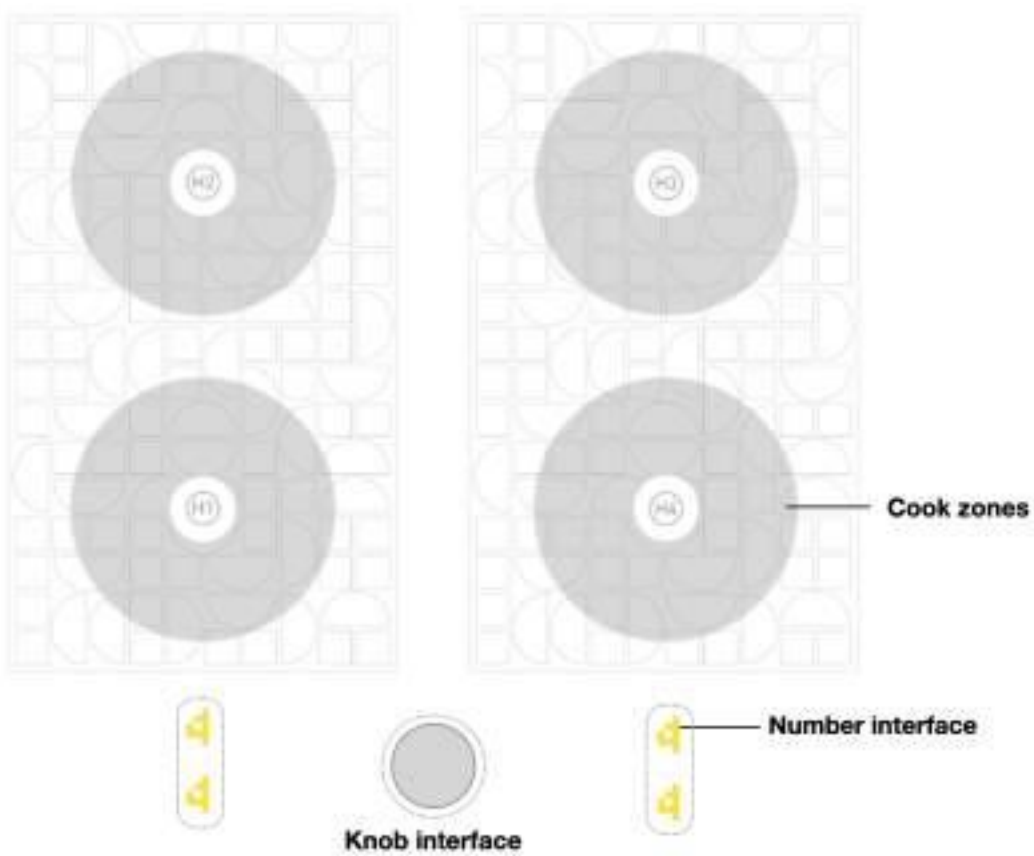
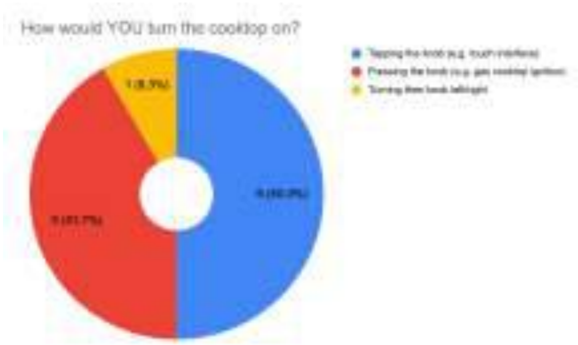


Fig X: Visual prototype of the induction cooktop and control solution layout.

Measure:

Because of this I asked open questions like; 'If you saw this cooktop at a friend's place, how would you turn it on using this knob?'. Then I asked with what machine they knew they could compare the expected interaction.

By recruiting participants via a neighbourhood platform (Buurt Organisatie Mathenesserweg) so they did not know me, it was possible to recruit objective participants within a large age range (20-60 years old). This is done to minimise the Hawthorne effect that normally occurs when asking friends and family.



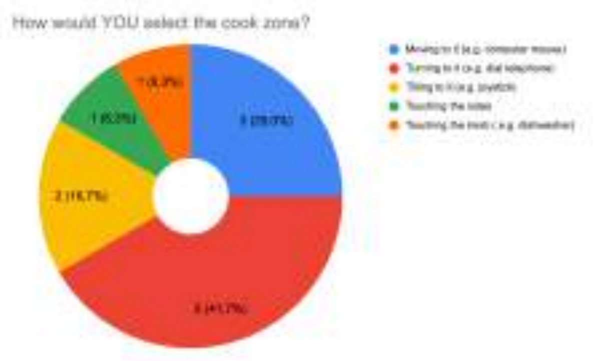


Fig x: Outcome ON/OFF.

Fig x: Outcome zone selection.

11/12 participants wanted to tap or press the knob to turn it on. For selecting the zone, turning the knob to the zone like a dial seemed most intuitive with 5/12 participants thinking of it. Moving to it like a mouse came second with 3/12 and tilting like a joystick third with 2/12.

Suggestions:

- Keep the ridges on the side
- Should be less tall to resemble BMW media control knob
- Make sure that it does not move
- Make clear which zone is selected! > emblem better than flashing?
- Make sure that there is clear click, otherwise (old) users might push to hard/soft
    - The clicks should feel like confiture cap click
    - If the whole knob should be pushable, a clear gap should be visible between the knob and worktop to explain that.

Learn:
Now I know that I will have to develop some kind of tap or press functionality as almost all participants expected that. This will likely be done with capacitive touch, as Lapitec has this functionality in their Lapitec Chef with customised sensors already. zone selection with moving could be quite difficult as it asks for the need of additional moving parts, so both scenarios will be sketched testing elegance.

Build-Measure-Learn 2: Scenario's
Now I know which ways of turning the cooktop ON/OFF and selecting the zones users would find intuitive, I can put them into context by sketching scenario's. Using these scenarios I will be able to find the one that is most fluent and requires the least handlings while weighing this off with added product complexity.

Build:
Using Keynote for Mac I will design visual mockups of the scenarios and then animate them. I will not differentiate between pushing and tapping the button as their functionality will be the same. I will give two options for the dial zone control, as this is more complex in interaction.

Scenario's:

- Version 1
  - ON/OFF: PUSH/TAP
  - ZONE: MOUSE
  - INDICATION: BLINKING Nº
- Version 2
  - ON/OFF: PUSH/TAP
  - ZONE: PUSH/TAP & DIAL
  - INDICATION: BLINKING Nº
- Version 3
  - ON/OFF: PUSH/TAP
  - ZONE: HOLD & DIAL
  - INDICATION: BLINKING EMBLEM

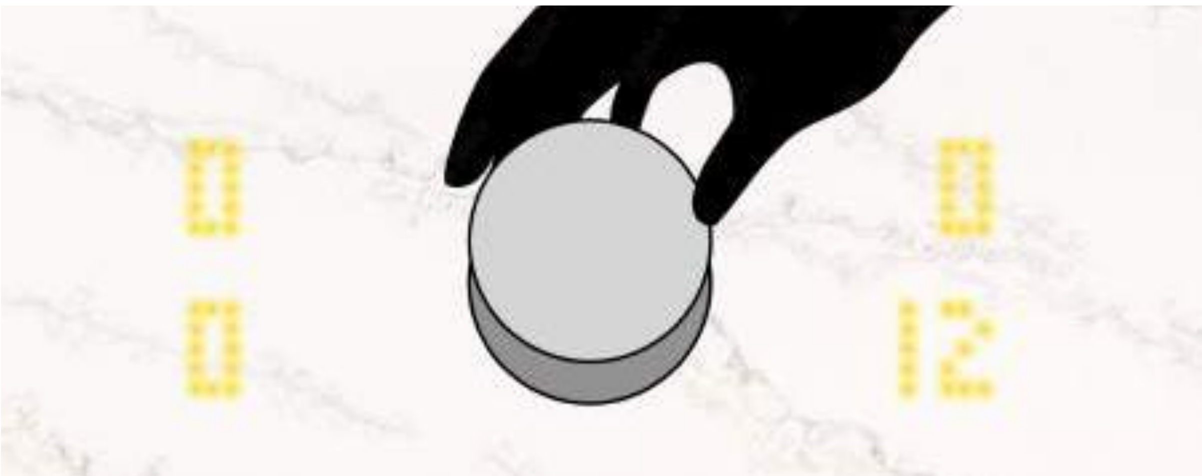


Fig X: Screenshot

Link video all 3 scenarios > https://vimeo.com/843248262?share=copy (password: keynote)

Measure:

Scenario’s:

- Version 1
    - ZONE: (2 handling)
        - Swipe to the zone
        - Swipe back
    - Sensor:
        - Push/tap
        - Movement
    - Interface:
        - Clear
    - Haptics:
        - Figure out something new
    - Construction complexity:
        - New moving parts
- Version 2
    - ZONE: (3-4 handlings)
        - Push/tap to initiate
        - Dial to the next zone
        - (Dial to the next zone)
        - Push/tap to confirm
    - Interface:
        - Confusing
    - Sensor:
        - Push/tap
    - Haptics:
        - Works with existing tech
    - Construction complexity:
        - No added parts
- Version 3
    - ZONE: (2-3 handlings)
        - Push, hold and dial to the next zone
        - (hold and dial to the next zone)
        - Let go
    - Interface:
        - Clear
    - Sensor:
        - Push/tap
    - Haptics:
        - Works with existing tech
    - Construction complexity:
        - No added parts

Learn:
After sketching the three scenarios and showing them to friends I found out version 3 was the best weight off between the amount of handlings and their fluidity and construction and haptics complexity.

Build-Measure-Learn 3: Button functionality through worktop
Lapitec has developed a capacitive touch sensor that is able to function through the worktop material. I want to use this to sense the pushed-in state of my control knob. I will try to find out which material works with capacitive touch.

Build:
For this test I will use my own induction cooktop as I know it too has capacitive touch controls. I have collected some objects that are made out of different kinds of metals in order to verify their workings with the sensor.

Measure:
Now all objects will be used to try and control the cooktop. I will note if a material gets recognised by the cooktops capacitive touch sensor and how well.

Materials:
- Carbon steel (frying pan) > works well
- Zinc coated iron (piece of a warehouse closet) > work swell
- Stainless steel (callipers) > works well
- Brass (key) > does not work
- Aluminium (heatsink) > works
- Zamak (Boretti Carrara knob) > works well

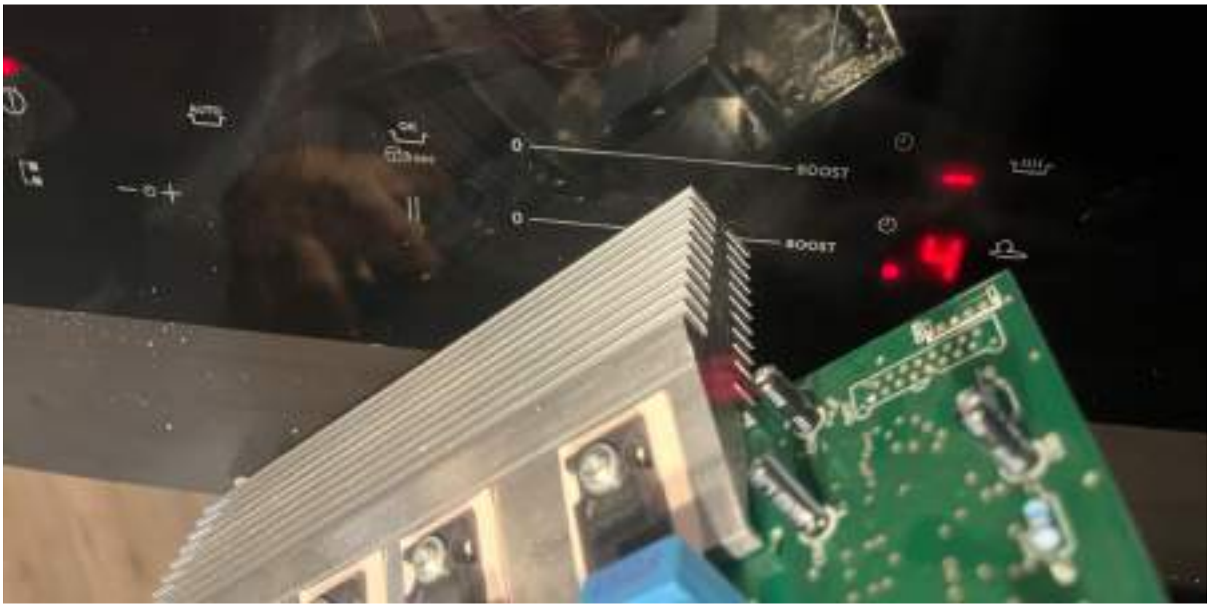


Fig X: Testing the capacitance of an Aluminium heatsink on my induction cooktop.

Learn:
Most metals seem to work well with capacitive touch sensors, leaving me with a great variety to choose from for materialising the knob. The top half does not need to be fully made out of this metal, just an insert that touches the worktop surface would suffice.

Build-Measure-Learn 4: Achieving the button click
As stated in the Project Vision i want all notifications to be multi modal, therefore the pushing of the button will have to be confirmed by a tactile click. I will explore options for achieving this mechanically.

Build:
The click will need to happen when the button is at its lowest position and thus makes contact with the worktop surface and is recognised by the capacitive touch sensor. I found the ‘Mechanical Switch Fidget Click’ by @Kriswillcode on Printables that achieves just that. The design features a ‘slider’ piece which is guided by the ‘button’, that is kept in place by two side springs. When the button is pushed until its lowest position the slider is forced out of the side springs, creating a satisfying click. The spring below pushes the assembly back up afterwards, creating another click when reaching its initial position within the side springs.

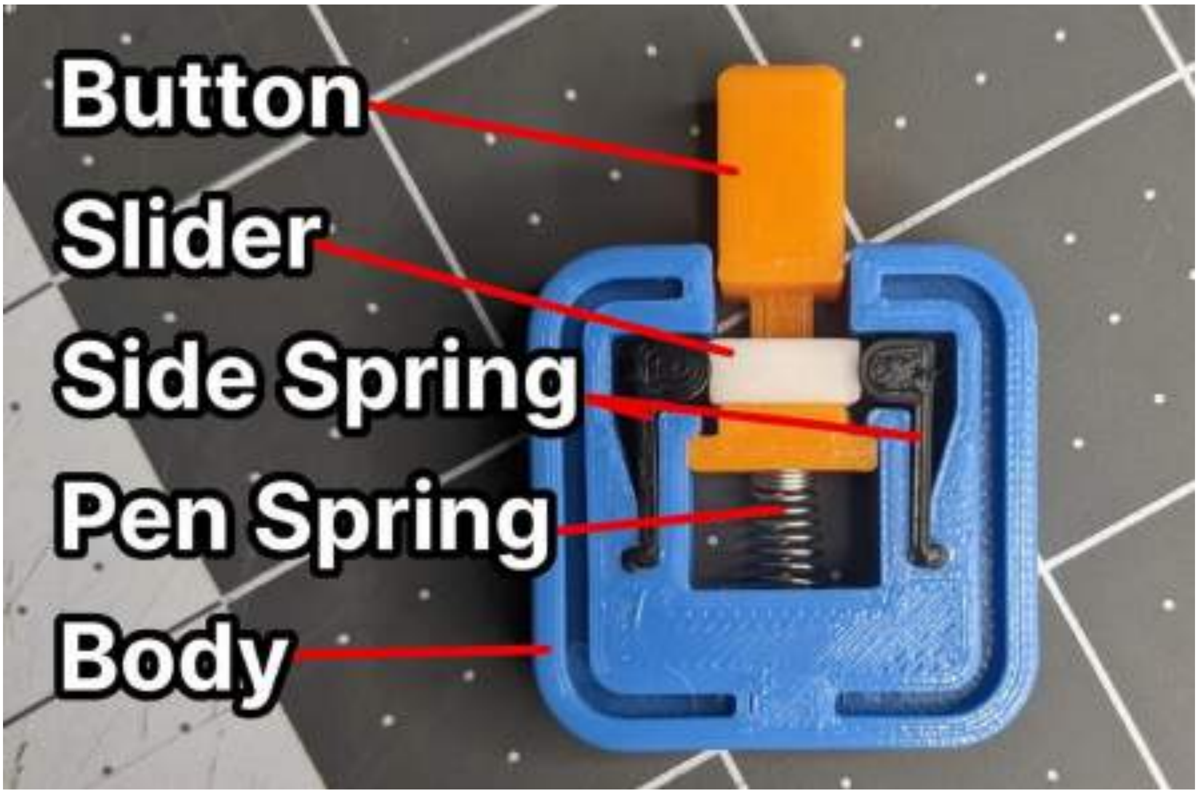


Fig X: Kriswillcodes explanation of his click button.


Fig x: Click button parts.


Fig x: Normal state.


Fig x: Clicked state.

Measure:

By adjusting the stiffness of the side springs the clickiness can be adjusted, I explored this by poking toothpicks between the side springs and the outer body. The click feels great and is easily achieved.

Learn:
The knob will need to feature some kind of spring and side springs to achieve the click sensation.

Build-Measure-Learn 5: Restrict motion of the push components
The top part of the knob needs to be pushable, but also needs to be able to transfer the torque of the haptic system and therefore the magnetic coupling. As the pushable top needs to be able to freely move along the body's Z axis, a solution needs to be found to transfer torque. Apart from that the pushable parts should not become undone.

Build:
In contact with Nuova Saimpa they advised to have at least 3 coupling teeth (spaced 120 degrees apart) with corresponding grooves/collars. These could either be in the central column or in the outer ring. As the central column currently only is 6.4 mm in diameter the outer ring will suit better. For the 3D printed prototype I will use 0.3mm tolerances for all sliding parts.

I measured the depth of which the buttons of three gas cooktops I like can be pushed in for its ignition, to have a benchmark of the depth of my button.

Push depth control knobs gas cooktops:

- SMEG: 5 mm
- Hendi (professional): 9 mm
- ATAG: 6 mm

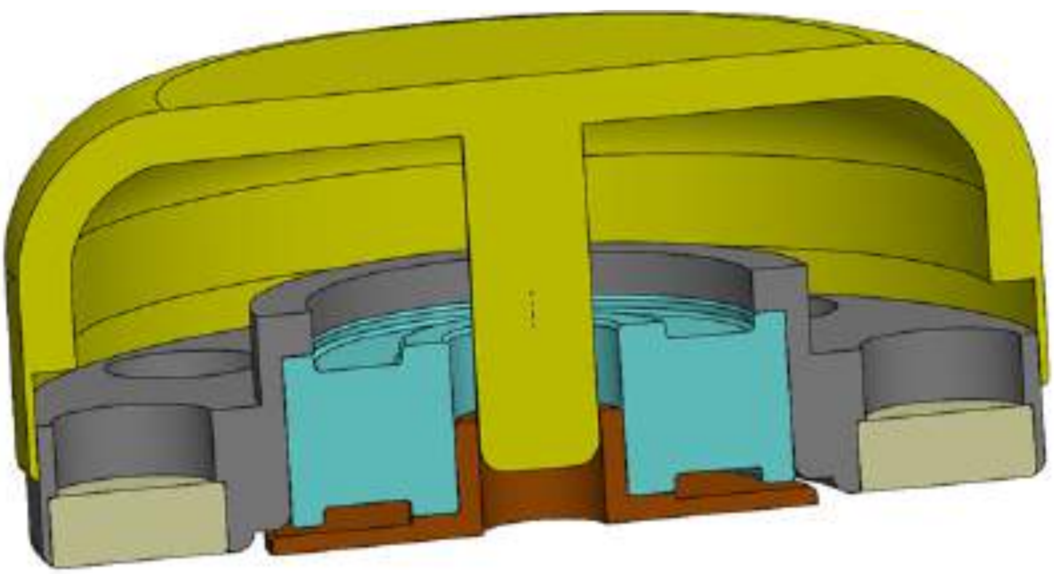


Fig x: Cross section of a prototype showing the pushable parts in yellow.

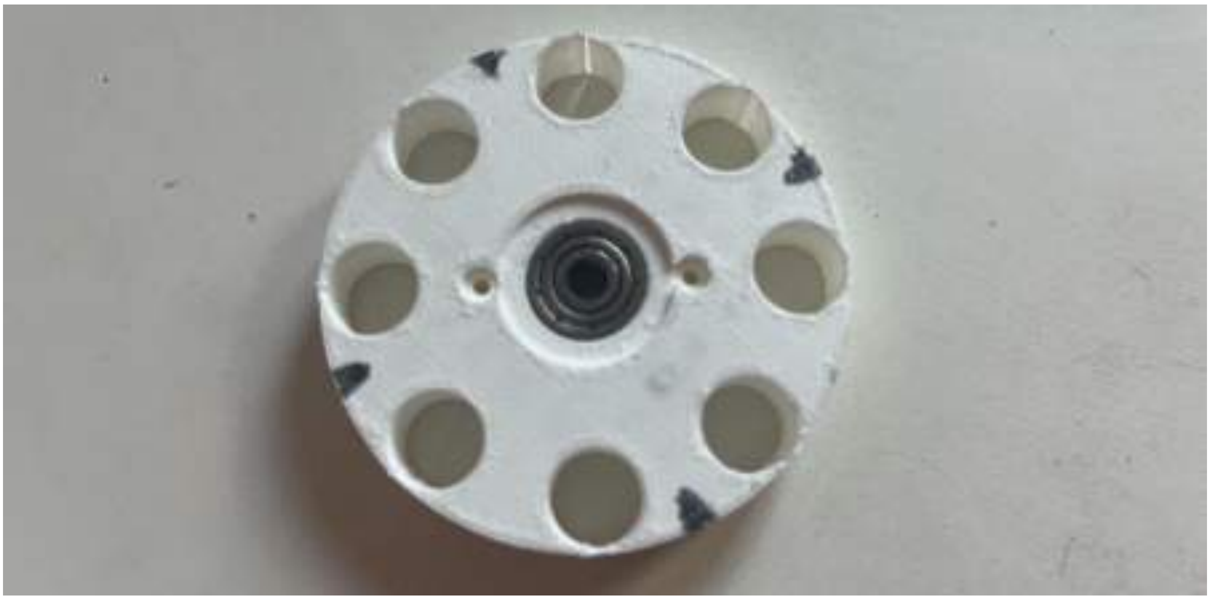


Fig x: The body shows room for coupling teeth between the magnets with pencil marks.

Using an edge with a smaller diameter than the inner body the pushable parts can be restricted from going further down. I will make up a 4 reversible cantilever snap-fit to prevent the part from going back up and thus allow it 5 mm of movement.

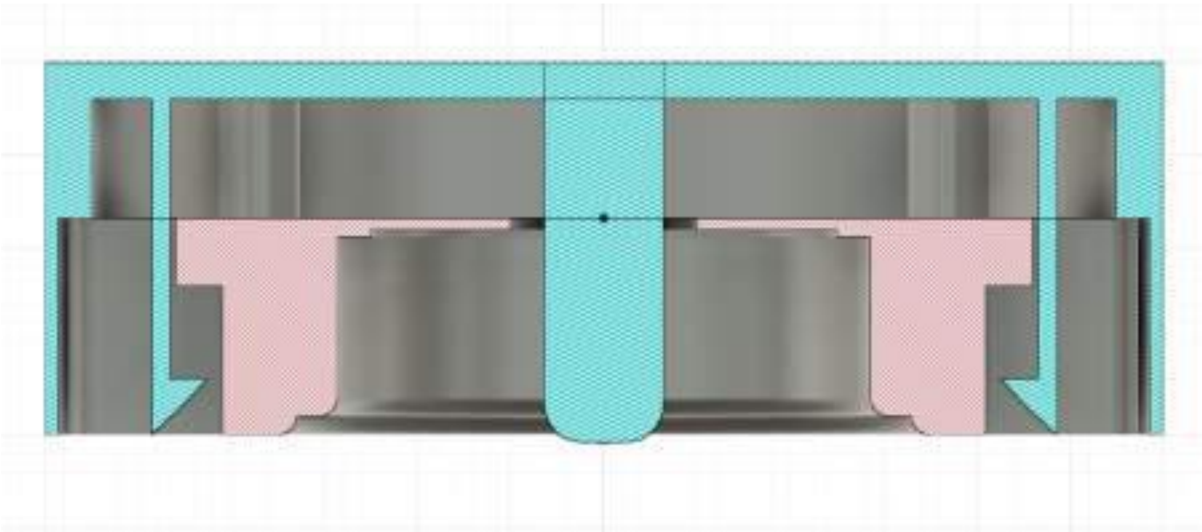


Fig x: Cross section of the main body (red) with the pushable top (blue) showing the snap-fit.

Measure:
After printing all the parts and sourcing a spring (1.0 x 20 x 7mm), the assembly was successfully able to click together with the snap-fits. The spring was able to accommodate the 5mm of travel while being able to be compressed to 1.4mm in the pressed position.

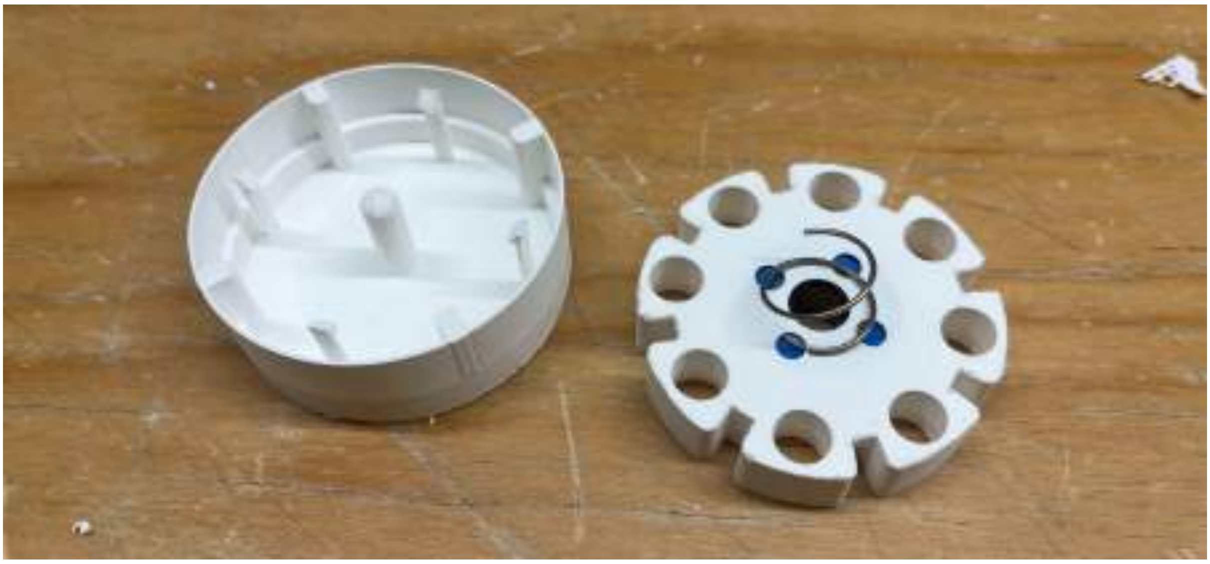


Fig x: All parts for the knob of the final prototype.

Learn:
The 4 coupling teeth did a great job of restricting the torque around the z axis and the snap fits in combination with the edge and spring allowed for a momentary push button with 5mm of travel.

Requirements and wishes

This is what I learned from the development phase.

Requirements:

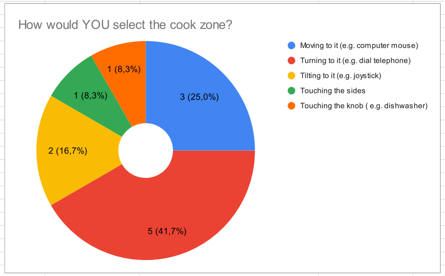
- Specifications knob:
    - Diameter ~60mm
    - Height ~20-25mm
    - Weight ~200g
- Interface:
    - Works only with Lapitec Bianco Assoluto milled to 4mm thick
    - Should consist of 4 matrices of at least 3x5 5050 LEDs run at 36mA
    - Should have a pixel density of at least 7,5mm/pixel, ideally closer to 5mm/pixel
- Haptic feedback:
    - Should consist of BLDC motor of at least 260KV with diametric magnet with 3/6PWM motor controller, ideally the TMC6300 by Trinamic controlled by ESP32 microcontroller and MT6701 in SPI mode for haptics
    - Angle between 7-14 degrees for power adjustment
    - Progressively heavier detents for power adjustment
- Magnetic Coupling:
    - Should consist of two sides with 4 10 mm diameter 3 mm thick Neodymium magnets with bearings with an O.D. of 28.6mm and an I.D. of 9.6mm approximately.
    - Minimal torque transfer 0.06 Nm
    - Disconnect at 10 N perpendicular
- User journey:
    - ON/OFF should be controlled by a push, zone selection by pushing and turning and power selection by turning the control knob
    - Push functionality works by adding a tuned capacitive touch sensor under the worktop that senses a metal part in the knob touching the worktop in the pressed position
    - Control knob should restricted motion by at least 3 coupling teeth 120 degrees apart in the z-axis and an edge and reversible snap-fits for the push distance

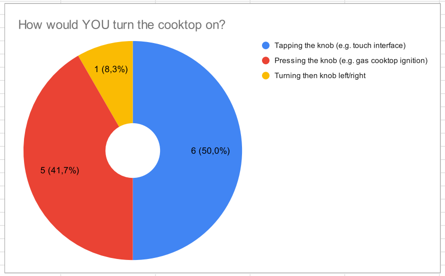
Wishes:

- Fluid control
- Minimal learning curve
- Minimal technology
- Being a joy to use
- Being able to use it blindly
- Multiple finishes
- Recyclable

These requirements and wishes are to be applied and verified as much as possible in the embodiment part.

Tijdstempel	Using the example knob, I Can you explain it using tl	What is your age?	How would YOU turn the	How would YOU select the cook zone?	How would you prefer the	Why?	Which style of power leve	Why?	What do you notice about	Weight of the knob	Diameter of the knob	Height of the knob	Any suggestions
25-6-2023 10:57:54	tapping and moving to the	59	Tapping the knob (e.g. tou	Moving to it (e.g. computer mouse)	Relative to their correspor	mimics real position	Classic	better readable	Getting heavier with end s	Feels good	Feels good	Feels good	
25-6-2023 11:11:31	I would expect there to be	24	Tapping the knob (e.g. tou	Turning to it (e.g. dial telephone)	Relative to their correspor	more clear	Fat	more serious, classic look	progressively heavier with	Feels good	Feels good	Feels good	
25-6-2023 11:25:18	Push the knob and turn it	56	Pressing the knob (e.g. ga	Tilting to it (e.g. joystick)	2: Above each other (relat	More intuitive	Fat	Better readable! Certainly	Progressively heavier anc	Too heavy	Feels good	Feels good	How do you know which cook zone is selected?
27-6-2023 12:50:27	on/off clicking or tapping c	52	Tapping the knob (e.g. tou	Tilting to it (e.g. joystick)	1: In a row with a symbol	I think it is most important	Fat	more clear and less mess	turning right is hot. You ha	Feels good	Feels good	Feels good	I like the smooth motion and ribbed sides. But I would prefer the logo to be on the side instead of the top!
27-6-2023 17:24:28	For on/off induwen, a light	44	Tapping the knob (e.g. tou	Turning to it (e.g. dial telephone)	2: Above each other (relat	intuitiver, more logical	Fat	Easier to read while being	clicks are well defined. De	Feels good	Feels good	Too tall	Less tall, so it feels more like the BMW media control knob
27-6-2023 17:44:38	for on/off pressing it. For c	34	Pressing the knob (e.g. ga	Touching the sides	2: Above each other (relat	2 is more intuitive. 1 looks	Classic	Fat look like a robot font, (	At first I didn't notice the e	Feels good	Feels good	Feels good	The weight helps with quality. Diameter is good and that is even with my small hands.
4-7-2023 14:44:43	on/off: touch slightly one t select: like a dishwasher,	39	Tapping the knob (e.g. tou	Touching the knob (e.g. dishwasher)	2: Above each other (relat	for the first use this would	Classic	Since this is standard, wh	for power selection the de	Feels good	Too small	Feels good	it is the control of something important and should be treated like that. It should be fully closed in order for it not het greasy. One flick of the wrist should be full power.
4-7-2023 17:21:27	on/off: pressing lightly, not cookzone: dial, though the	20	Pressing the knob (e.g. ga	Turning to it (e.g. dial telephone)	2: Above each other (relat	the symbols can be confu	Fat	more clear	-	Feels good	Feels good	Feels good	make sure that it can not move!
4-7-2023 17:29:38	on/off: pressing it couple r cookzone: dial	23	Pressing the knob (e.g. ga	Turning to it (e.g. dial telephone)	2: Above each other (relat	more logical, the other on	Fat	Fat looks more chique the	-	Feels good	Feels good	Feels good	Kitchens can be intimidating because of the amount of options. the knob is heavier than expected, but that makes it feel durable. bigger would be unpractical
4-7-2023 17:37:33	on/off: pushing it slightly, b Cookzone: like a joystick,	24	Pressing the knob (e.g. ga	Moving to it (e.g. computer mouse)	2: Above each other (relat	Since it would work better	Fat	classic looks oldschool, nc	-	Feels good	Feels good	Feels good	The weight feels good, than it is less likely to move on the worktop
5-7-2023 19:13:11	on/off: twisting it left/right t cookzone: like a joystick t	28	Turning then knob left/righ	Moving to it (e.g. computer mouse)	2: Above each other (relat	easier / more streamlined	Fat	better to read for people v	-	Too heavy	Feels good	Too tall	you want to feel quality but don't want it to be to heavy. The grip helps.
5-7-2023 19:19:49	on/off: tapping on the cookzone: like joystick	24	Tapping the knob (e.g. tou	Turning to it (e.g. dial telephone)	1: In a row with a symbol	It seems more clear.	Classic	Looks better	-	Too heavy	Feels good	Too tall	I would rather have it a bit lighter. Can be a tad bit shorter.





Tijdstempel	Age	What do you think of indu	Do you first put the power	Do you know Boretti?	Amount of travel of the bu	Cookzone selection: Ang	Power selection: Angle tu	Difference between cookz	Can you remove the butto	Can you connect the butto	What do you think of the h	Which design do you pref	Which design would fit Bo	Comments
17-8-2023 15:01:51	22	I hate it because sometim	Pan	No	Just right	Just right	Smaller angle per zone	It is harder to turn for cool	Yes	Easy	8	2	2	The top edge should be soft!
17-8-2023 15:17:49	57	Not to intuitive. No direct l	Pan	Yes	To much travel	Smaller angle per zone	Just right	Pushing and turning is an	Is pretty heavy	is annoying because of th	9	1	1	Push should travel less and angle for cookzone should be less. (dis)connecting is not intuitive!
17-8-2023 15:30:51	25	The buttons are too 2 dim	Pan	No	Just right	Smaller angle per zone	Just right	The difference is too mucl	it is a little hard.	it is quite tight a little loose	8	1	1	I would question plastic finishes near hot cookzones. And i like that the logo is not on top!
17-8-2023 15:43:04	23	they are convenient, since	Pan	No	Just right	Just right	Just right	The power selection is mo	it is a bit strong	The magnets are quite str	8	1	1	1/2 feel more premium. The knurling seems nice with slippery cooking environment
17-8-2023 15:53:24	22	you have to press quite ha	Pan	No	Spring should be less stiff	Just right	Just right	Because of pushing it is a	okay	bit awkward because of th	8	1	1	metal is more elegant. I like simple precise lines, so 1
17-8-2023 16:07:26	25	Hard, moisture hinders us	Pan	Yes	to much, about 2/3 of the	Just right	Bigger angle per zone	for power 180 would be ni	connection could be less :	While pushing it is quite e	9	1	2	bit less travel for pushing
17-8-2023 16:39:24	24	some are non responsive,	Pan	No	To much travel	Just right	Just right	Sizing, but for the cookzoi	intuitive approach is to gra	the detent make it a bit ha	8	1	1	i would prefer 1 because of the straight sides and knurling
20-8-2023 12:02:14	75	Nee	Pan	No	Just right	Just right	Just right	More space between click	Heavy magnets, sliding is	also hard	8	1	1	(dis)connecting is hard
20-8-2023 12:14:27	74	No	Pan	Yes	Just right	Just right	Just right	distance between clicks	Disconnecting is to heavy	Connecting is scary	7	1	1	Magnets are too strong!
20-8-2023 12:53:50	56	Can be difficult to deal wit	Pan	Yes	Just right	Just right	Just right	Heavier clicks and bigger	First time is really hard, bu	easy	8	1	2	2 would fit Boretti as it can be quite chique and the details would fit it best. The emblem is confusing as it looks like one! I would rather have the number that represents the cookzone to
20-8-2023 13:13:19	59	Controls can be unclear, t	Pan	Yes	Spring should be softer! D	Smaller angle per zone	Smaller angle per zone	Clicks are lighter	Way to heavy! Should be	Unpleasant as it connect t	9	3	1	All interactions should be as subtle as possible. E.g. the pushing of the button, the angle between the click and the removal of the control knob. I like 3 best as its playfullness fits the ch
20-8-2023 15:27:44	56	It was complicated. I takes	Pan	Yes	Travel seems right, but co	Just right	Just right	Cookzone selection feels	It feels scary as you need	okay if it is clearly marked	8	1	3	1 is more chique. 3 would fit boretti best as it comes across as very manly

23 February - Terry Malarkey

Engineer atWestinghouse Electric Company
1970 - 1974 · 4 jr

CT2 Westinghouse
Bill Moreland and Terry Malarkey

CT2 had four "burners" of about 1,600 watts each. The surface was a Pyroceram ceramic sheet surrounded by a stainless-steel bezel, upon which four magnetic sliders adjusted four corresponding potentiometers below. That design, using no through-holes, made the range impervious to spills. The electronics section was made of four identical modules cooled by a single quiet, low-speed, high-torque fan.

Touch control was not invented in the 70s.

Do you have anything about the CT2 development? Photo’s or files?
Yes I will send you a picture!

What made you focus on no through holes?
It had to be cleanable and save with the huge current.

How did you come up with the control? Sliders instead of rotational knobs?
Pot meter with rack to slide.

What safety features did the cooktops have?

How did people react on the cooktop?
It was cool but too expensive. It was losing money on the long term. We had spare parts in a warehouse to make a complete cooktop. This is the one from bill Moreland.

Raymond Baxter Tomorrow's World episode on BBC showing the CT2 with a slab of ice?

Check out:

- Inertial navigation, they used it in submarines before satellites. It measures the acceleration in all axes. Integrating that would give distance
- SEMS
- Reference design refers to a technical blueprint of a system that is intended for others to copy.

- https://www.microchip.com

Text folder CT2:

induction range cited for excellence

The Westinghouse CT-2 Induction Range is a platform model which can be inserted in a standard kitchen counter. The perimeter of the exterior portion of the range is a decorative stainless steel trim. The four controls for the heating units are located in this trim, which also serves as the frame to support the glass-ceramic cook-top. Four electronic power modules are mounted in a steel box directly beneath the trim and are used to generate the needed high frequency current for the four induction coils. The coils are located directlv below the four cooking areas defined on the cook-top surface. With cooking vessels of proper materials and thicknesses, sufficiently high currents can be induced in the bottom of such vessels to generate up to the 1.5 Kw needed for conventional cooking. To cool the electronics, forced convection is needed. The air is drawn in through a grill attached to the front of the base cabinet and expelled by a fan out through a grill located near the floor in the kick-space. In order to optimize the performance of the range, special consideration had to be given to the operating frequency selected and the properties of available cooking utensil materials. To make the range inaudible, an opeating frequency above 20 KHz is necessarv. Since the switching losses in semiconductor electronics increase with frequency, an operating frequency below 50 KHz is desired to keep these losses to an acceptable level. For operation in the band of 20 to 50 KHz. iron and steel properties provide the most efficient induction heating. Extensive tests were run to verify this by testing numerous metal alloys and various laminates. The most efficient of these combinations tested was a composite of 304 stainless (approximately 8 mils thick) bonded to a 1010 carbon steel. However, by proper electronic circuit feedback control, the power supplies were designed to operate reasonably well with most steels commonly used in the manufacture of cookware. Triply (300 series cold carbon steel) and porcelain enameled steel vessels perform excellently. Solid 400 series stainless vessels and cast iron perform almost as well but at somewhat reduced power levels. However, solid non-magnetic stainless steels such as the 300 series do not perform satisfactorily, nor do solid copper or aluminum vessels. In fact, even steel vessels with copper or aluminum bottoms do not perform satisfactorily either.

"

Another unusual application of steel was utilized in the design of the controls. Linear controls were desired to be in keeping with the novel design of the range itself. However, the slot required in the trim panel to transmit this motion was unsightly. The slot also presented an almost insurmountable sealing problem to prevent the leakage of spilled liquids from entering the range.

To circumvent these problems, a magnetic coupling system was developed utilizing two permanent magnets with multiple poles. One magnet is located in the decorative control knob which is placed in a depressed channel on the top surface of the trim. This channel limits the travel of the knob to rectilinear motion. The second magnet is located on the bottom side of the trim surface and is polarized to be attracted to the knob magnet. Consequently, the lower magnet follows the movement of the knob on the upper surface. This motion is transmitted mechanically to switch on power to the various electronic modules and to vary their power output. The knobs can he lifted from the control surface for cleaning and, be-

6 March - Jan-Kees

Wat doe je precies voor de echoput
Restaurant van de familie, eerst opa toen ouders en nu ik en mijn broer

Waarom?
Minder afhankelijk zijn van fossiel. Eerst in 2020 over op een warmtepomp. Hotel was in 2007 geopend.

Wat hadden jullie eerst?
Oud fornuis ~1980.

Ervaring inductie:
Ik heb het idee dat mensen het verschil tussen keramisch/elektrisch en inductie niet weten. Met inductie is het veel gelijkmatiger. Geen hitte recht boven de vlam maar de hele pan heet. Inductie is top! Je moet gevoeligheid creëren voor de hitte. Aan het begin bij normaal koken gooi je hem vol open en bij inductie is dat direct. Aan het begin lieten de koks dingen aan branden, na een paar weken ging dat weg. Ik ben opgegroeid als inductie fan, vooral de gelijkmatige verdeling van de hitte is super. Je haalt tacid knowledge weg in je kookproces. Met gas koken is in die zin een ervaringsvak. Met inductie kan je er van uitgaan dat elk stukje even hard gaart.

Verbetering:
- Communiceer inductie
- Communiceer de hitte

Waar hebben jullie op gelet bij aanschaf:
Via Van Gestel (de keukenboer van de Hanos) kijk je wat je nog kan gebruiken en nieuw kan halen. Warmte brug en warme borden kast hadden we nog en een salamander hadden we nieuw moeten koken. We hebben het niet over merk en features gehad. We hebben het over de pitten en verplaatsbaarheid gehad. Wat top is dat er een sensor in zit zodat hij alleen aan staat met een pan erop. Vroeger stond de waakvlam altijd aan, dit scheelt heel veel. In de keuken heb je een koude en warme kant. Koud doet desserts en warm voor en hoofdgerechten. De hitte in de keuken is veel minder, dus comfort in de keuken is veel beter.

Wat voor knoppen heeft hij:
Draaiknoppen aan de voorzijden en lampje dat aangeeft of er een pan opzit. We laten hem eigenlijk altijd aanstaan zodat hij meteen werkt als er een pan op staat. De bediening gebruiken we dus ook weinig.

Prijs:
Je investeert echt in de toekomst en niet op korte termijn terugverdien tijd. Je moet echt zelf motivatie hebben. Je kan subsidie krijgen als horeca gelegenheid voor inductie.

geïntegreerde inductie koken:
24 kitchen Angelique Schmeink heeft een geïntegreerde inductie koken

We overweegde dit voor de kookschool. Het was sowieso niet voor de echoput, we hebben daar genoeg ruimte en het was duurder. Voor losse keukens zou dit wel ideal.

10 March - Christopher Galarza

Christopher Galarza
Culinary Sustainability Consultant / Owner at Forward dining solutions

First and only firm in America to focus exclusively on developing and implementing commercial electric kitchens

What made you focus on sustainability in kitchens?
I started as a young cook, then to cooking school.

From suis chef to executive chef.
The executive chef at Chatham University Eden hall Campus.
The decided to do the kitchen electric and I figured it out.
There were daily meetings for energy and water usage.
The kitchen there reused the heat for heating the building.

I love induction. I thought gas was the best. I also mistaken induction with old ceramics.

The have gone from small to google and Microsoft to working with the us department of energy.
We are going to do a bigger study on the health effects of gas cooking.

Cooktops:

- **What kind of cooktops do you recommend?**
  - Depends on what they want. Some prefer US made some want specific features.
  - You would also have to think about the growth
- **What features do these cooktops have?**
  - Power indication bar (like signal bars on cellphone)
  - Temperature dial
  - I prefer the dial and that chefs learn by feel
  - What looks like what the have always done; just a mail!
- **Still have cooktops with touch interface?**
  - Not in commercial
- **Do the cooktops make sounds?**
  - No, not at all. Not even if there is not a pan
  - Sometimes it will make a whining
  - You don’t really hear the cooling fans
- **Downsides too electrification? Grid problems / power outage?**

    - It can be costly to add electric groups

Commercial chef needs power and ease of use!
Difference between light and heavy cooking

Things that look like they already know will help them through the transistion.

In china they have automated induction woks

If people want autenicity go to coal wood. This kind of gas has been just for 100 years

- **Do you have studies you recommend that show benefits health/ environment of electric kitchen**
    - The have gone from small to google and Microsoft to working with the us department of energy.
    - We are going to do a bigger study on the health effects of gas cooking.

Home systems:

What do you think are interesting developments in induction cooking?
- Small tv screens
    - They give step by step instructions
    - Has build in recepes

Do you know cooktops that have detachable knobs?
- I feel that people are going to lose it
- KISS
    - Keep it simple, stupid

What kind of system do you have at home?

What home cooktop would you recommend and why?

Nicolas Tesla switch, cool

Hestan Cue
- https://shop.hestancue.eu/en