IMO - MILLENNIUM SERIES

GRADUATION REPORT

Design of a smart, household, audio mixing console

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PERSONAL MOTIVATION

This is a product idea I had a handful of years ago, while I was struggling with my own set of speakers and my multiple audio sources. Back then and even until this day, there is no device in the market, similar to the one portrayed in the pages to follow. The absence of such a product brings many issues to an elaborate audio set-up; issues that I know first-hand, and I am very committed to fix, by bringing this product to life.

I am personally very interested in audio and music related products as music plays a huge role in my life. I aspire to have a career in the industry. Designing speakers, amplifiers, mixers, and so on. I have learned a lot about sound reproduction during my AED (Advanced Embodiment Design) project with the glass speaker Ammos. My next goal is to learn more about sound signals and how they should be treated, something I hope to achieve during this project.

While working on Ammos, I also became aware of the complex architecture that a highly repairable product carries. As challenging as it may be, I am very much interested in diving deeper into circular product design and design for repair. I have tried refurbishing many electronics in the past, enough to be able to appreciate a user friendly product architecture. One that is self explanatory and allows for multiple repairs over time.

D. Seleridis

This is me, doing my best to make a glass speaker diaphragm sounds good. Anechoic chamber of TU Delft, June 2020

Summary

IMO - Millennium is a smart, modular audio mixing system. It is designed to cater to the music routing needs of a modern household. High fidelity, uncompromising, analogue audio pathways mixed with digital controls. Aesthetics that compliment music equipment of any era, and materials that will last for ever. Starting off with two audio inputs and one output, it can also expand, with the installation of additional audio modules, in order to accommodate more audio sources. Moreover, with extension plug-ins, it can support music protocols other than a raw audio signal, in order to keep up with new technologies. Those form fitted blocks can introduce Bluetooth, AirPlay, Optical, or even Phono Pre-amplification functionalities and so on. Wi-Fi connectivity enables remote control of the console's motorised volume knobs, through a mobile application. IR receivers and transmitters, hidden out of sight, can identify pattern signals of traditional remote controls and replicate them, gaining this way control of other devices in the room. Each audio channel is also equipped with a customisable button and its function can be programmed to the users liking.

Sustainable design, with minimised environmental impact and great repairability. IMO is using a short bill of materials, most of which are either already recycled or great for recycling at end of life. Reversible fasteners are dominating the structure, without the use of any destructive adhesives. The simple assembly of the housing and the electronics, make repairs easy and essentially fool-proof. A single HEX key (Allen key), is needed to fully dismantle the entire product. Common, off-the-shelf electronics, that are easy to understand and identify, are used for the internal circuits. Internal circuitry communications are handled by connectors widely available to the public, making repairs even more manageable.

IMO - Millennium, as a modular system, adjusts according to configuration. The starter pack includes the Smart Master Output and two individual Audio Input Channels. A kit that is referred to as the IMO-2000. Expanding with another channel also upgrades to what is called an IMO-3000.

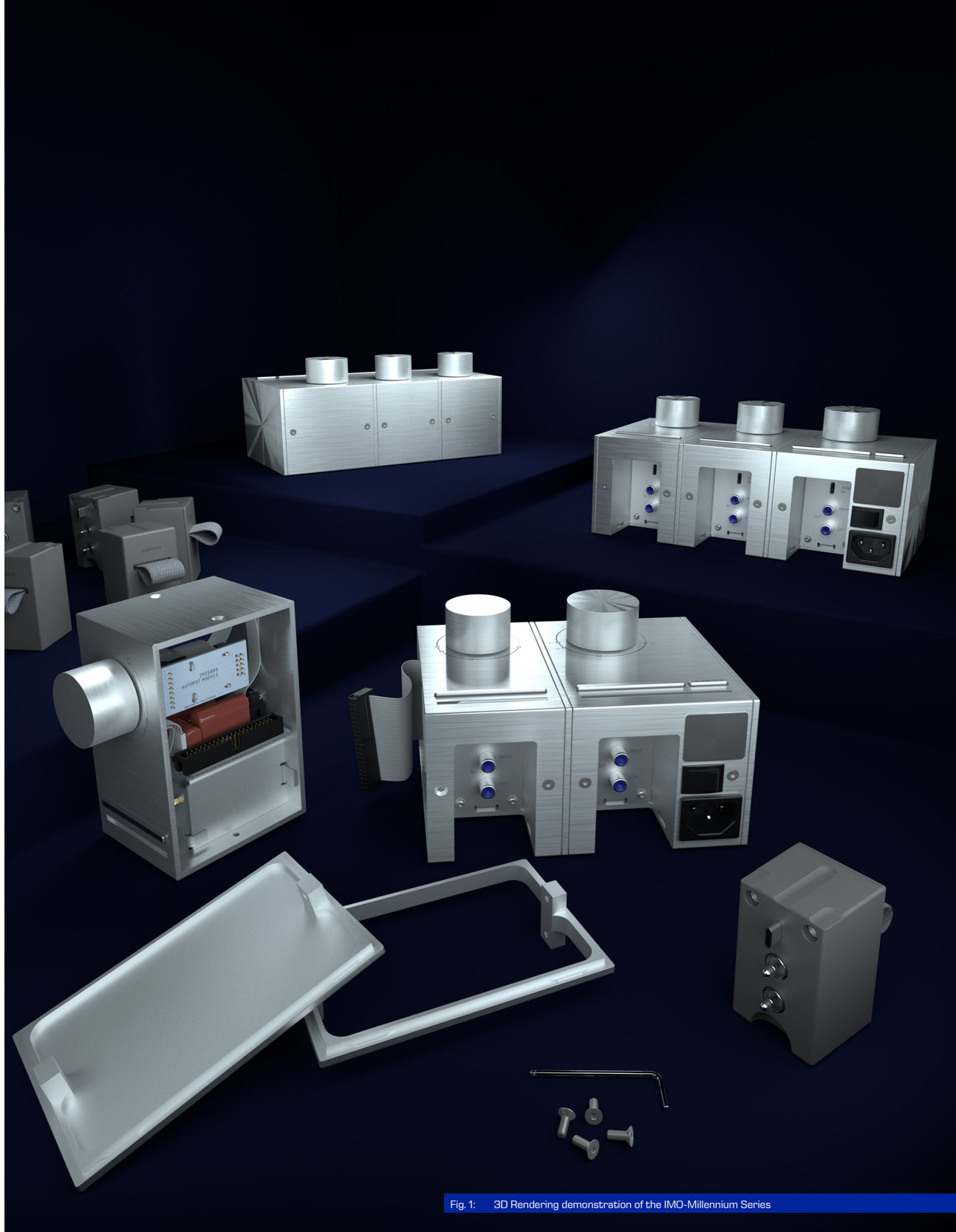


Fig. 1: 3D Rendering demonstration of the IMO-Millennium Series

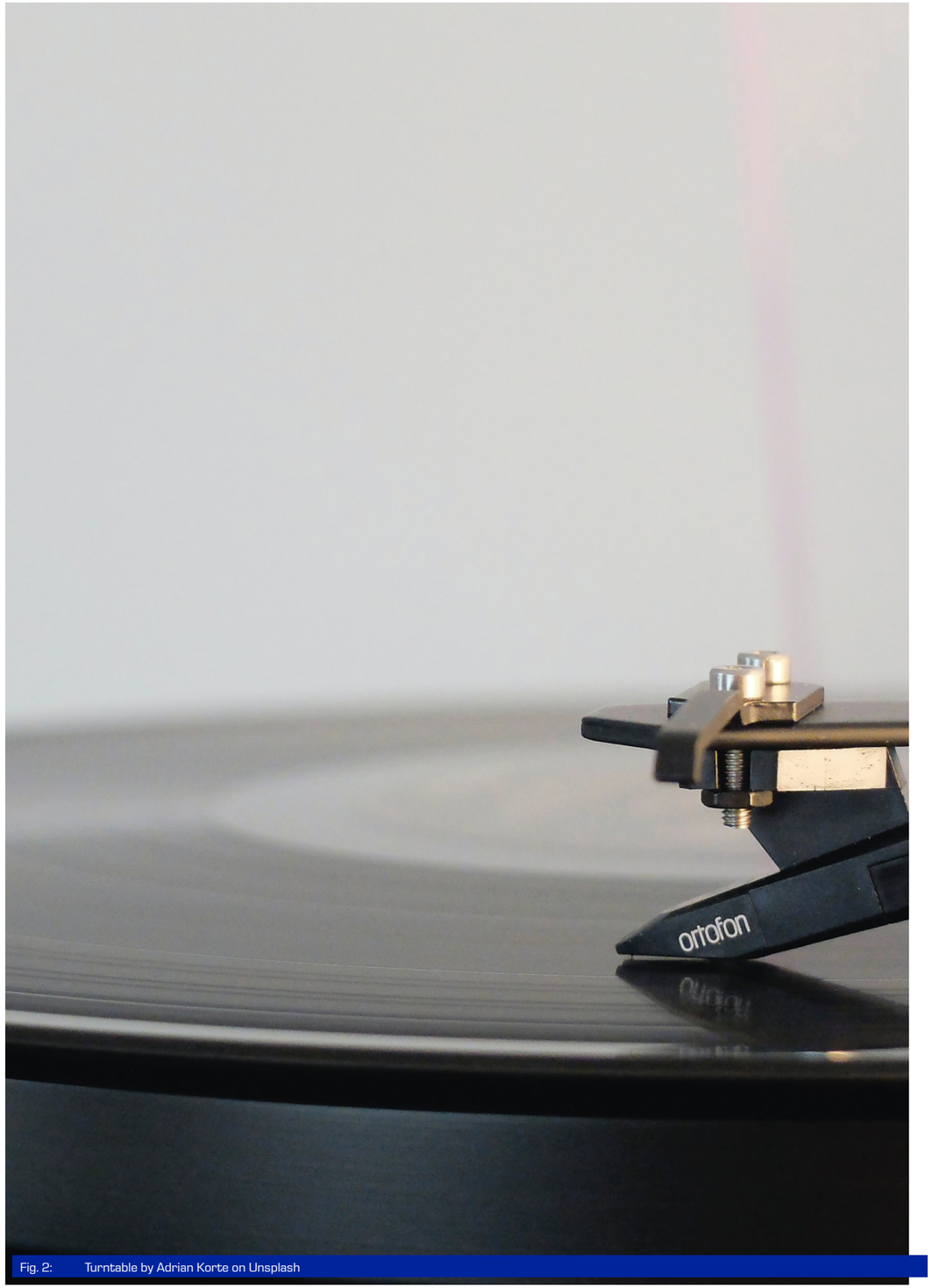


Fig. 2: Turntable by Adrian Korte on Unsplash

1. INTRODUCTION

The diverse and inclusive audio market

The primary way we consume music is through speakers. Whether that is a bookshelf loudspeaker or a set of headphones, the working principle remains the same. A moving diaphragm, powered by electromagnetic energy, produces sound pressure waves of variable frequencies, leading to what we interpret as sound, or better yet, music. This technology finds its roots around a century ago, when the first patents for coil based loudspeakers were filled (M.W. & Normandin, 2014). Of course since then, many things have changed and speaker technology has progressed drastically, with speaker drivers becoming ever so small, while being more accurate and faithful in the way they reproduce audio.

There is one thing though, that despite the technological progress, remained the same. That is the source signal. Loudspeakers have always relied on an analogue, waveform, electric signal, in order to move in a linear & rhythmic manner. It is because of this that we can actually still use equipment that was build decades ago, paired with modern devices. Stereo amplifiers from the 80s can still drive speakers of the 21st century, and in many cases with exceptional results. This unique characteristic of the audio industry is the driving force of this very project.

Modern households often carry a galore of electronic devices dedicated to music reproduction. From stereo amplifiers, to wireless speakers, all the way to turntables, everything works with analogue audio signals to some extend. Older equipment is usually purely analogue, but even modern smart speakers absolutely need to use a DAC (Digital to Analogue Converter). This is great for users because they have the freedom to mix and match to a degree rarely possible.

But as great as such a diverse ecosystem may be, it very often ends up being messy and cluttered. Each device has a certain connection protocol and its own power demands, making cabling management a nightmare. In addition, even though most devices share the same or similar source signal properties, very rarely these devices can actually communicate with one another for anything other than audio.

That is in a way, half of this projects goal. To unify the audio ecosystem of the modern household by bridging the gap of audio, but also the gap of communication between devices.

Furthermore, the audio equipment landscape is one that traditionally has cared very little over sustainability and its environmental impact. Loudspeakers are full of composite materials, older stereo amplifiers are power hungry beasts and modern smart speakers are filled with silicon and adhesives. None of the above help reduce the environmental impact our love for music has (George & McKay, 2019). If there is one thing green about this industry, it is that it remains inclusive while evolving. It is therefore vital that any new member of this ecosystem lives a long and green life, while being agile enough to adapt to technological changes.

2. ANALYSIS

2.1. Existing solutions

The music and audio electronics market is a highly saturated one. For any given music related task, there are probably more than ten different, readily available options, accessible through a handful of clicks.

Music mixers are no different. A quick search can reveal hundreds of options, from industry leading brands, all the way to cheap knock-offs. Audio mixing can be divided in three main feature categories.

- DJ Mixers
- Live Performance Mixers
- Music Production Studio Mixers

DJ Mixers are used, as the name suggests, for live DJ events. Their main task is to mix two or more individual sources of audio into one, while offering individual adjustments for each channel. They usually support turntable connections and feature microphone and headphone connections. In many ways, a DJ mixer can be a useful piece of equipment for a house music set-up but at the same time, features like microphone support are of no use.

From an aesthetic point of view, DJ mixers are certainly not a household item. They are designed to be used in between turntables and CD players, embedded in a travel case. Their overall aesthetic approach does not fit that of a living room.

Live performance mixers on the other hand, are often slightly more stylish. As they are not meant to be encased in any way, they sometimes feature refined bodies that could potentially look decent in a living room. That is until one starts plugging-in devices, and cables are sticking out of everywhere.

Live performance mixers are used by bands while performing on stage. Naturally, easy cable access is a key selling feature. Of course, the mixing needs of a band while on stage are far different from those of a household, rendering live performance mixers an unsuitable choice.

Music Production Studio Mixers are used while recording and mastering music tracks. They are traditionally bigger in size and

Fig. 3: Rane MP2015 DJ mixing console, from the official rane.com webpage

highly technical. As they are tailored for their intended task, they are obviously unfit to serve a household.

In short, the product under development is unique in this category. It is still of great value to take a look at similar products and try to learn from them. The next best thing in terms of offered features is DJ mixers. As expected, the most important factor that makes a mixer great, is audio quality and performance. Of course, when we speak of high end audio gear, there is no doubt that the build quality should be up to par with the audio quality.

2.2. Literature Analysis

Defining Fidelity

Probably the most important piece of information for the proper execution of the project was the definition of fidelity in audio. Important for both proper communication but also effective research.

Sound is a matter of physics and it is very much objective. On the other hand, music is an art-form, and art is always subjective. It is because of this cross-over that reliable information, when it comes to audio and music, is scattered and hard to find. From a physics point of view, all that matters is how sound waves behave. From an artistic point of view it is all about how sound makes you feel. This last part of how we feel because of music is the reason the internet is filled with falsehoods and conspiracy theories around audio.

Till this day, there is an ongoing debate on whether analogue audio is still superior to digital. Research has proved that people actually prefer digital over analogue when performing blind tests (Geringer & Dunnigan, 2000) but also that digital is a more reliable medium with repeated results (Frosch , 2017). Yet, there are strong supporters of the claim that analogue audio feels different and is in fact better, without having any sort of scientific evidence to prove it.

In this chaotic world of audio misinformation, there is one man, determined to set the record straight. In his book “The Audio Expert”, Winer (2012) tries to differentiate audio-philia from audio-foolery by debunking common myths while stating scientific facts. In his work, audio fidelity is defined by 4 pillars:

- Noise
- Frequency Response
- Distortion
- Time-Based Errors

When talking about an audio mixer, fidelity refers to the output signal in relation to the input source. A perfect audio circuit is a transparent one. That means that regardless of whether the mixer is actually part of the audio circuit or not, the signal remains the same.

In more detail, Noise, is the introduction of new artefacts in the audio signal that were not present on the input source. For example, this can be the common 50Hz noise caused from the AC power-line connection.

Frequency response refers to the output level of each given frequency of sound. Humans can perceive sound roughly in the range of 20Hz, all the way to 20 KHz. A transparent mixer would have a flat response through out the entire audible spectrum. This means that no frequency is amplified or attenuated in any way, leaving the input signal untouched.

Similar to Noise, Distortion deals with unwanted artefacts in the output source. Distortion occurs when the input signal is altered in terms of structure but not altitude. This means that a sound may still sound as loud as it did before and there are no new elements introduced, but it sounds different. That would be a distorted signal. It usually affects the waveform of the signal but sometimes it deals with the introduction of harmonics.

Time based errors can occur when the signal is being edited heavily or being run through long circuits, thus creating a delay between input and output. In the context of this project, such errors are of minor importance as a home set-up is not that sensitive to signal delays.

All of the above theoretical pillars of fidelity can be very easily measured with a good audio interface by performing loop-back null tests and frequency sweeps. Such tests were carried throughout this project in order to determine the performance of different components or designs. In order to achieve trustworthy results, a professional grade audio interface was used (Focusrite Scarlett 2i2), with very low levels

Fig. 4: Scarlett 3rd Gen Product line, from the official focusrite.com webpage

or distortion and a virtually flat frequency response. Software used for the tests included REW (Room Equalisation Wizard) and Adobe Audition.

2.3. User Research

Music Gear Survey

This project was initiated and fuelled by personal interest in a product such as the one in development. It was based on the assumption that more people have similar needs and desires. As a result, one of the very first steps of this project was a user survey, aiming to validate previous assumptions, but also to gather more information about the users. Distributed online via popular forums and through direct, personal contact with potential users, a total of 50 individuals participated. The survey collected information around demographics, purchasing habits, product end-of-life management, but most importantly, it mapped out the audio setup of those users and helped in understanding what equipment they use for music listening.

As expected, the results of the survey mostly validated earlier assumptions but also raised attention around the topic of sustainability. It was clear that audio related devices are mostly passed on and they only get thrown away when broken beyond repair. Sadly, none of the participants cared to recycle a discarded, broken device.

It is also worth mentioning that for the targeted user group, performance, features and build quality, are all of great importance, when purchasing a new audio related device.

Results worth mentioning:

- Users utilize an average of 3.4 input sources, with a maximum entry of 19.
- 34% of participants connect their TV to their audio system.
- 40% of participants use a Turntable but only 30% of those use a standalone Phono Pre-Amp.

It is also worth mentioning that a few participants still use equipment that is 40 and 60 years old. In most cases, that is either an audio Amplifier or a Turntable. The more recent additions to their configurations, in many cases, are wireless receivers or devices that also include smart capabilities.

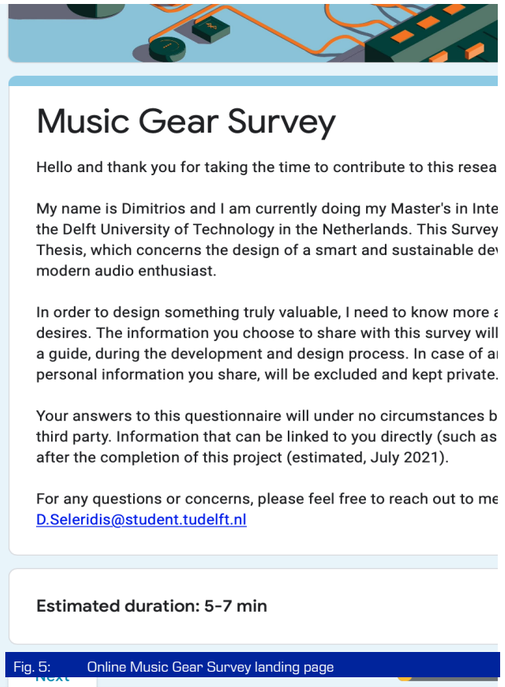


Fig. 5: Online Music Gear Survey landing page

Rotary versus Linear

As it became clear during the design and aesthetics research, any music related, consumer electronics device, needs to have some form of mechanical volume control. Such controls can be split into two main categories. Rotary and Linear. Both of these would create design challenges and since it is impossible to create a design that works with both options well enough, it was important to know what users actually prefer.

By deploying Instagram Story Polls, a total of 188 answers were collected, during the story lifespan of 24 hours. A looping 3D animation of both control options in use was posted by 3 different accounts, prompting users to pick one or the other (Fig. 5). After the 24 hour lifespan of each story, all answers were collected in a spreadsheet, marked with the Instagram handle of each user and a manually assigned gender label. This helped filter out potentially double answers and provided more information on the reliability of the collected data. Out of all 188 entries, 96 were by females. 67.2% of all participants were in favour of “Rotary” volume controls (Fig. 6).

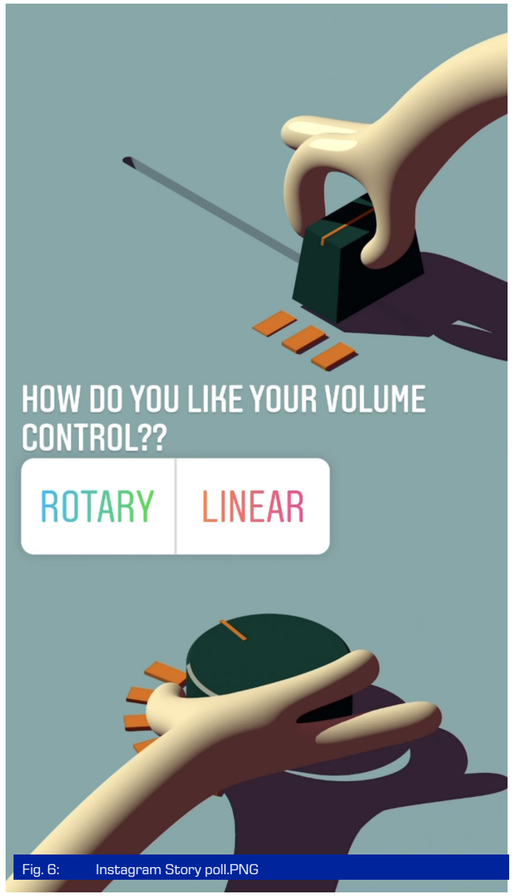


Fig. 6: Instagram Story poll.PNG

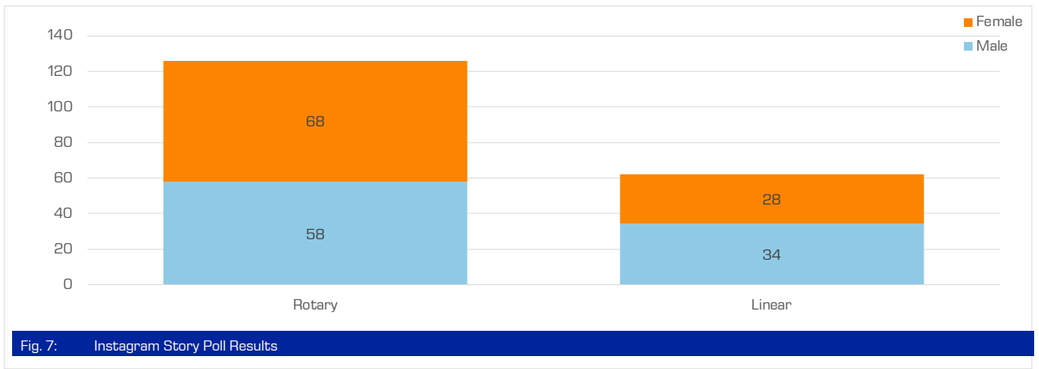


Fig. 7: Instagram Story Poll Results

Potentiometer versus Encoder

Once the linear control was taken out of the equation, it was also important to choose the preferred behaviour of a rotary knob. Rotary knobs, because of their circular design, have the unique characteristic of being able to rotate towards both directions for an unlimited number of turns. This means that there is no physical beginning or ending to their range of motion. Such controls are run by electronic components called rotary pulse encoders. Their precision varies and they can often have snapping points, rotating thus in small increments. Rotary pulse encoders are digital drivers. When tempered with, they provide a digital signal to a micro-controller which acts accordingly.

On the contrary, the more traditional approach is the one of a potentiometer. Potentiometers have a limited range of motion, usually around 300 degrees of rotation. A potentiometer is a resistor of variable value. A passive component that limits the amplitude of any signal passing through it.

In a way, this debate is a battle between analogue and digital signal processing.

In practice and from an electronics point of view, both components can be used and we can find many examples around us, using either or. The key difference is that a rotary pulse encoder would require additional components, such as an LED array or a display, in order to provide feedback to the user. On the other hand, a potentiometer, being a passive component, can clearly provide visual feedback with its position.

In order to determine whether potentiometers are preferred over rotary encoders, a somewhat functioning prototype was put together. The box featured a regular potentiometer with clear indications of position and a rotary encoder, coupled with an array of

Fig. 8: Preliminary testing prototype made out of cardboard, 3D printed parts and Arduino based electronics

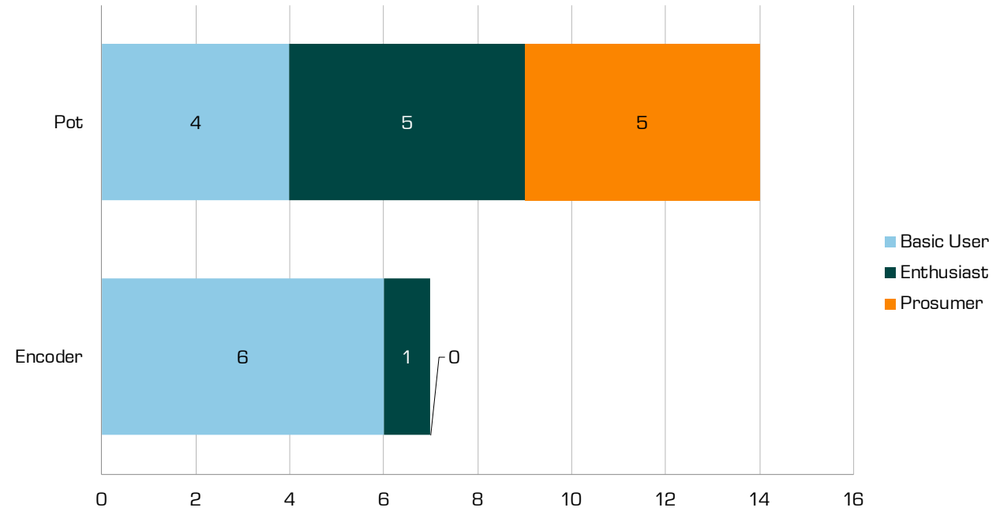


Fig. 9: Potentiometer versus Rotary Pulse Encoder survey results

LEDs that light up progressively while users twist the knob. User's were asked which of the 2 approaches they prefer. It was also explained that the LEDs are just an example of how such a system could work, but in reality this luminous volume indication could come in the form of a display or something similar.

Due to the complexity of the question, users were surveyed through conversations. Individually or in groups, users were presented with the preliminary prototype and had the chance to explore it while asking questions. It was also communicated to them that this concerns the design of a music related device.

With a total of 21 users participating, 66% showed a preference for the potentiometer. It is also worth mentioning that more advanced users, almost exclusively preferred the potentiometer over the encoder. Some participants also mentioned that even though the rotary encoder feels more fun, due to the tactile feedback while rotating, it also feels less premium, as it is usually something one finds in a car's infotainment system.

Deciding on whether the device should work with a potentiometer or an encoder was one of the most time consuming processing of the entire project. Many factors were taken into account. One of the most important ones was sustainability. As shown in a later section (Component Feasibility Testing), using a digital encoder proved to be a potentially more environmentally friendly option for this use case. Regardless, it is more important to design a product that fulfils the real needs and desires of users, because an environmentally sustainable product that doesn't sell, is not sustainable from a business standpoint.

2.4. Case study

Rotary Knob Size

Along with the question of “Potentiometer versus Encoder”, potential users were presented with a collection of volume knob size options. Various rolls of tape were used to imitate volume knobs of different sizes (Fig. 9). Users were asked to inspect each one of them in terms of size, and then choose the one they find the most comfortable to use as a volume knob. User’s that participated online were asked to do the same, but with cylindrical objects of their surrounding. The objects used during the in-person tests ranged from 25mm to 60mm in diameter. The average preferred diameter for a volume knob, for this specific context, was calculated at 40,5 mm.

Fig. 10: Tape rolls used to test different sizes of knobs

While it was important to understand how fidelity is defined and measured, it was equally important to fully understand how an audio mixer really works. To satisfy this need, Behringer NOX101, an off-the-shelf DJ mixer, was purchased as a testing subject.

First and foremost, to study the circuit and to try to understand its functionality. In addition, to learn more about the product architecture and means of assembly. Finally to test its overall performance.

NOX101 is one of the cheapest but branded options in the current market, with a retail price at just 80 Euros at the time of this project. A DJ mixer was used as it has features that come very close to the needs of a household system.

While disassembling, the very first observation one can make is that the actual volume of the electronics is only a fraction of the available volume. This is common in the professional audio industry, as products try to maintain a relatively standardized height, to be flush with one another and create a continuous surface when placed in series. In this case, NOX101, being a DJ mixer, would sit between two turntables or CD players.

The entire circuit is based on digital micro-controllers and chips, driven by analogue potentiometer. Even though potentiometers can actually handle audio signals on their own, in this case they are only used as an input source that drives a digital potentiometer. A total of 3 integrated circuit boards sits inside the steel chassis, fixed in place with Phillips screws and HEX standoffs. Phono inputs are fixed with low pass

Fig. 11: Behringer NOX101 faceplate and main circuit board

filter, presumably to cut out the unwanted “hiss” noises from records. Line inputs on the other hand have high-pass filters, cutting off the very low frequencies of sound that can actually cause damages on the circuitry when left untreated. Such a filter doesn't exist on the Phono inputs as the RIAA Phono equalisation protocol attenuates low frequencies to begin with.

RIAA pre-amplification and equalisation is being handled by dedicated amplifier chips sitting right next to the RCA Phono Inputs.

One of the most interesting observations relates to the power supply. The mixer works with an external AC to AC power converter and further AC to DC conversion takes place inside the mixer and alongside the audio signal inputs. The reasoning behind this design choice remains unclear.

The entire chassis in made out of steel sheet metal. A bent box that houses the I/O ports and a thicker, flat, faceplate that features the majority of controls. Everything

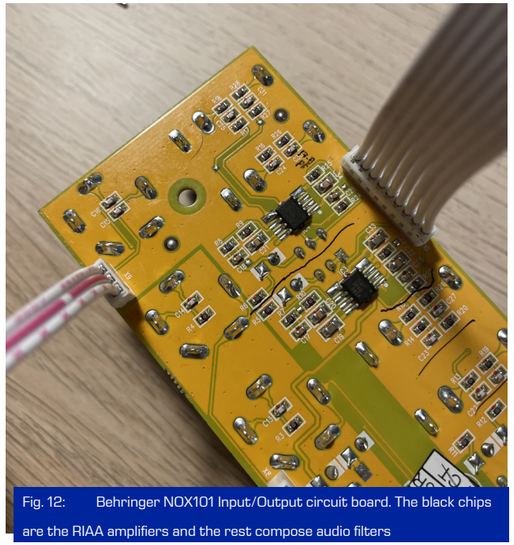


Fig. 12: Behringer NOX101 Input/Output circuit board. The black chips are the RIAA amplifiers and the rest compose audio filters

is fixed in place with screws of various sizes and designs, but all of them use a Phillips head. Ribbon cables with snap connectors are used to connect the individual boards internally. Hot-glue is used to secure the connectors.

In regards to performance, a simple mu-

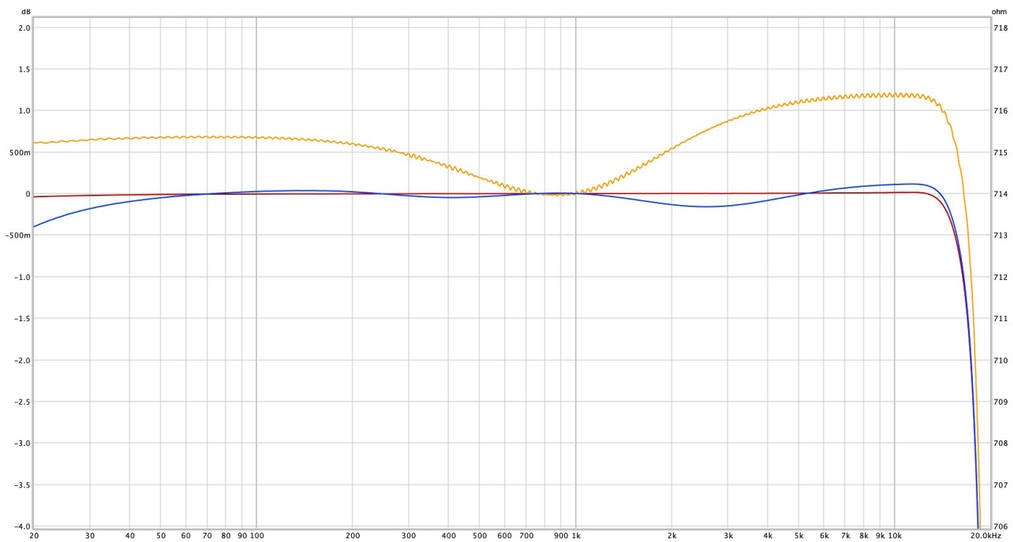


Fig. 13: Frequency Response Graph. Red, Focusrite Scarlett Audio Interface. Yellow, Behringer NOX101. Blue, Allen & Heath Xone.23

sic test and the mixer sounds decent to the average listener. Although, with a more careful listen, the mixer is audibly bad. While playing a frequency sweep, loudness alterations are very prominent, even for untrained ears. Running actual tests on it proved that it is even worse than perceived. When compared to a community praised competitive product (Allen & Heath Xone:23), the NOX101 presented up to 5 times (1,25dB) as much deviation in frequency response as the Xone:23 (0,25dB), across the audible frequency range of 20Hz-20kHz.

2.5. Component Feasibility Testing

The current landscape of audio consumer electronics is as diverse as it gets. In this overly saturated market, in more recent years more than ever, and especially within the audiophile community, there is an ongoing debate. Online forums and blogs are filled with opinions and argumentations on whether Digital Audio is better than Analogue and vice versa.

Since analogue audio has been around for decades already, it is well proven that great sounding devices are very much possible. In retrospective, based on what we know today, great analogue performance comes at higher costs. For example, the sublime performance a Class A amplifier can have, comes with incredibly high power consumption, coupled with low efficiency of as much as 25%, and high heat production. But when it comes to mixing audio, analogue can have the exact opposite performance. Mixing audio with analogue components can be done with a passive circuit, thus consuming no additional electricity. But it is not as simple as that.

Digital circuitry on the other hand is proving daily that it can get unbelievably small and efficient. Smartphones are the living proof of that. To put things in perspective, a Class-D audio amplifier can be as efficient as 90%. Although the actual amplification is an analogue process, it is the digital advancements that enable their efficiency. Unfortunately, audio mixing is not as energy efficient as analogue can be. Digital circuitry will always require energy in order to operate. That being said, modern chips can in fact operate with very minimal power needs when in idle, maintaining a competitive position against analogue circuits.

In a nutshell, there is no clear winner for every scenario. As Ethan Winer explains, when done right, Digital can have many advantages over Analogue. But it is also very easy to design a digital circuit that performs significantly poorer when compared to an analogue one.

Circuit Design Proposal Testing

The following is a proposal for three different options, using the minimum required electronics in order to handle audio signal attenuation (Fig. 13). Since the device has to be “smart”, sound pressure levels should be controlled remotely as well as physically. For this reason, all of the following three

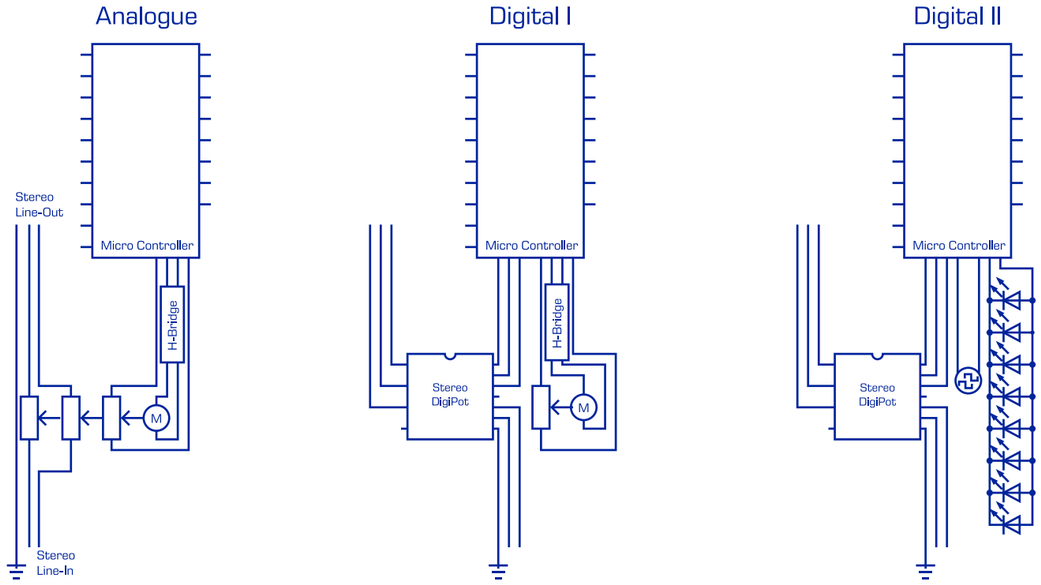


Fig. 14: Electronics proposals based on readily available electronic components

proposals are assumed to be taking advantage of a micro-controller, offering wireless control.

In more detail, “Analogue”, features a 3-gauge potentiometer as the core of its system. Two channels are used as the stereo audio signal gateway, and one is used by the micro-controller in order to read the potentiometer’s position at any moment without introducing audible artefacts on any of the other two channels. The entire 3-gauge potentiometer is connected to a motor that can change its position on command, with the help of a driving chip, the H-Bridge.

“Digital I”, similarly to “Analogue”, features a motorised potentiometer but just with a single channel. The micro-controller constantly monitors the position of the potentiometer. The reading value is then used by the micro-controller to program a digital potentiometer. This digital potentiometer features two channels that handle the stereo audio signal. Similarly to Analogue, this proposal also requires a motorised potentiometer with an H-Bridge. Essentially, Digital I, utilises analogue controls in order to manipulate a digital audio circuit.

“Digital II” is the fully digital proposal. Driven by a Rotary Encoder that can spin indefinitely, this design requires no motorised parts. The encoder manipulates a digital value on the micro-controller which is then used to program the stereo digital potentiometer. Since the encoder has no indication of position, LEDs are also incorporated as the actual level indication. In practice, altering the volume, physically or wirelessly, would be indicated by a change in the LED illumination state. The LEDs are in this case, the most basic option but they could be easily replaced by something like a screen.

In order to get answers based on facts, the

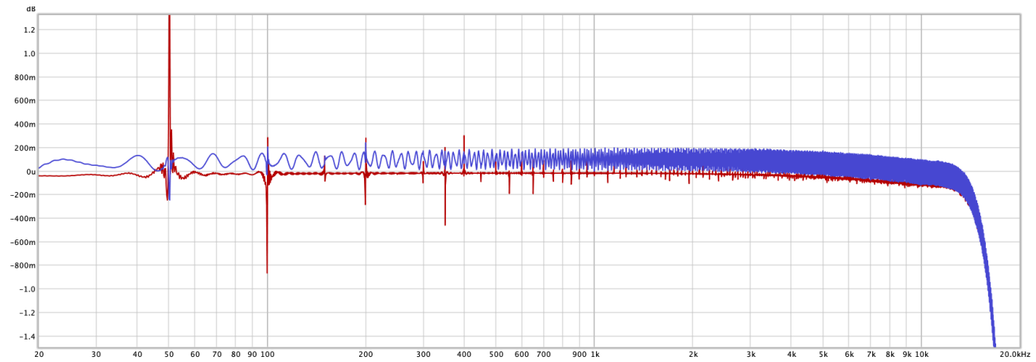


Fig. 15: Frequency Response Graph. Red, Alps Analogue Stereo Rotary Potentiometer. Blue, Microchip Digital Stereo Potentiometer

core audio components of the proposal have been put to the test in terms of fidelity and overall performance.

A high-end, analogue, stereo logarithmic potentiometer with a DC motor was compared to a high efficiency digital stereo potentiometer (Table 1). Both devices can be used to control the sound pressure levels, or simply put, the audio volume.

When put to the test, both components presented minor losses and distortion in the audible frequency range (Fig. 14). Those non-linearities in performance are in both cases so minor, that cannot act as decisive factors on the digital versus analogue debate.

In addition to the negligible fidelity evaluation results, components have been evaluated from a sustainability standpoint. The main components of all three proposals have been assessed through Life Cycle Analysis (LCA). In order to evaluate them in a more realistic way and given the small size of many on them, all components have been assessed as part of a complete assembly, based on an early concept, including a micro-controller (ESP32). The analysis was based on the assumption that the device is shipped via Air from Amsterdam to New York City. Energy use was evaluated based on the hypothetical scenario of 8 hours per day, 200 days per year for a total of 20 years.

In particular, the electronic components shown in "Table 1" have been analysed and assessed alongside an aluminium body, for a device of two input and one output channels.

Part Number	Part Description
MCP42010-I/P	Microchip Stereo Digital Pot
RK27112MC-LOG10K	Alps Stereo Pot w/ Motor
STEC12E07	Alps Digital Encoder
L293D	Texas Instruments Quadruple Half-H Drivers

Table 1: ELECTRONIC COMPONENTS ASSESSED THOUGH LCA

Looking at the initial evaluation results, it is very obvious that both digital and analogue components have their own pitfalls. Manufacturing a digital potentiometer is a very

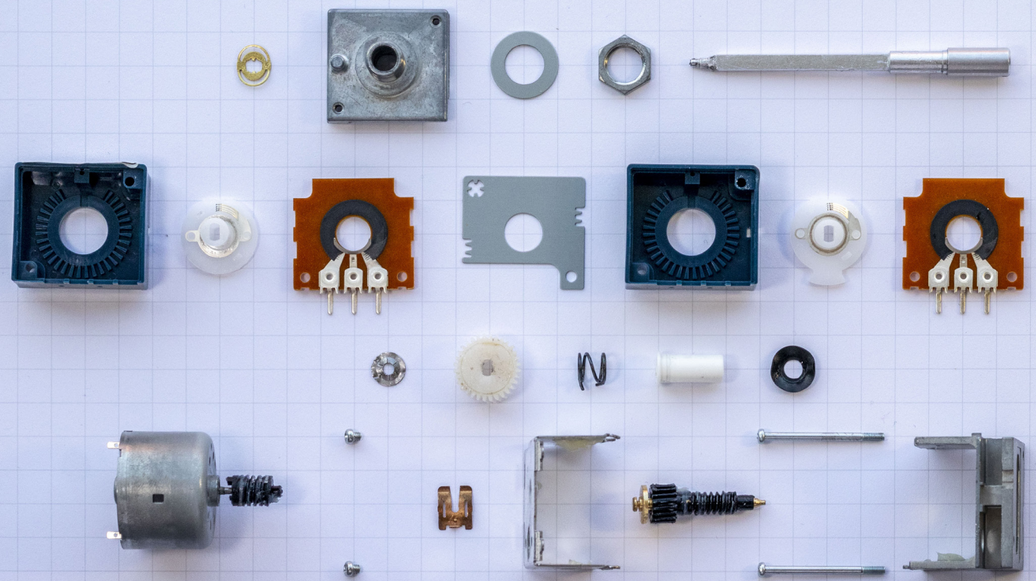


Fig. 16: Top view of all the components of an Alps Stereo Motorised Potentiometer

environmentally costly process and so is the power consumption and manufacturing of the motor's H-Bridge. Therefore, proposal number two, "Digital I", is disqualified as it essentially uses the worst of both elements of the other two.

While comparing the remaining two, Analogue, even though heavier, is seemingly friendlier towards the environment, due to the simpler manufacturing processes. On the other hand, the costly digital potentiometer is so efficient that consumes very little energy when in use. In contrast, the H-Bridge uses significantly larger amounts of energy.

As seen earlier, during the User Research, it was determined that users have a preference towards traditional potentiometers, at least for a device of this context. Regardless, the results of the LCA are still valuable as they point towards areas that require more attention during future development (Fig. 17). The motor's H-Bridge is clearly a highly energy consuming component that needs improvement (Fig. 16). Admittedly, the tested H-Bridge chip, L293D, is a rather old and inexpensive design that is popular among the DIY community for its ease of use and availability. It is likely that newer chips of vastly improved performance can be used instead, thus improving the energy consumption by a lot.

During early stages, LCA data was drawn from the Ecolizer 2.0. Due to limited data resources, further analysis was based on the Ecoinvent database. The disassembled parts were weighted with a scale of 0.01g Graduation. The full LCA spreadsheets can be found in the Appendix.

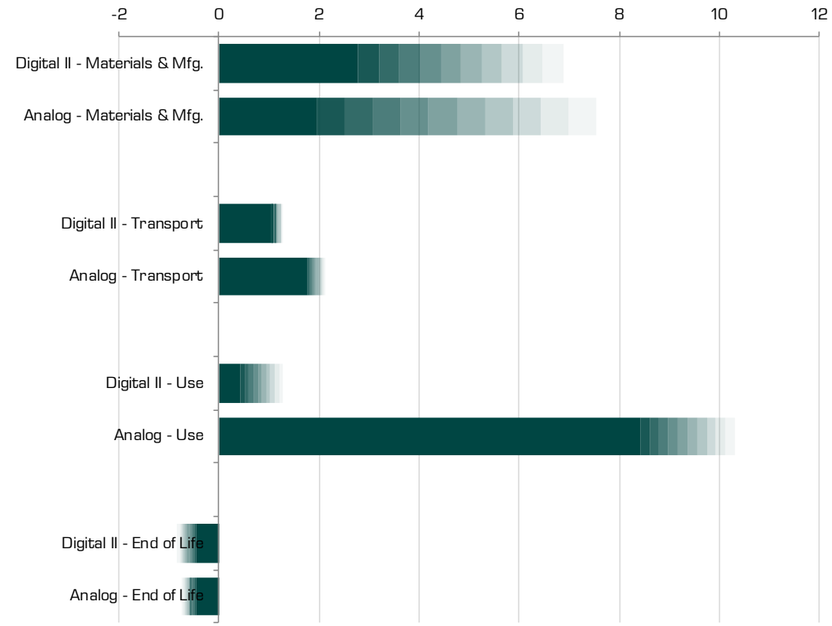


Fig. 18: Impact Comparison by Life Cycle Stage

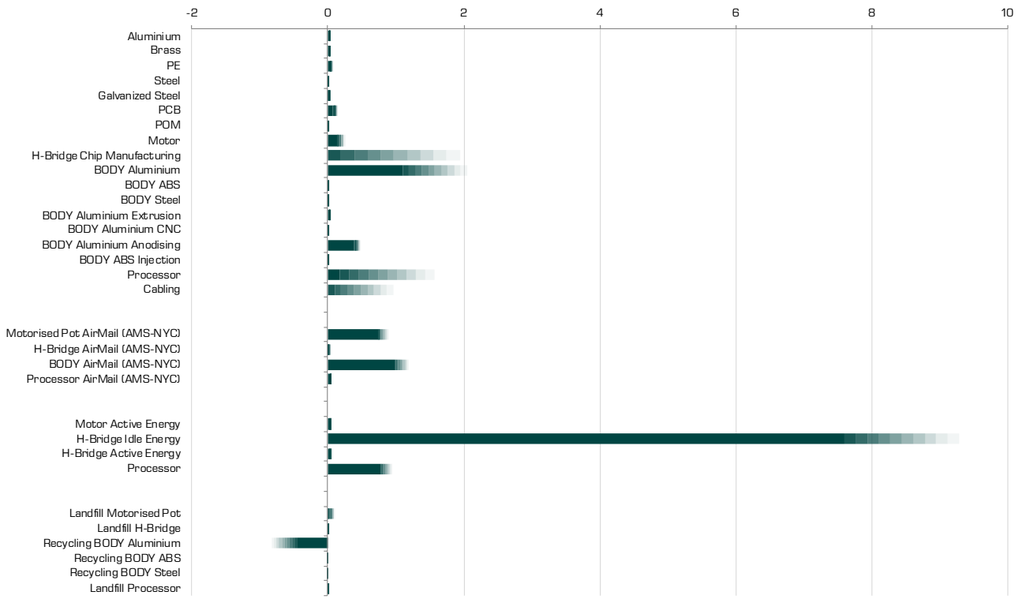


Fig. 17: "Analogue" Impact by component

2.6. Aesthetics & Design Language

The product under development is intended to act as a control hub for many other devices. It is therefore crucial that, from an aesthetics point of view, the complete system looks concise and uniform. Furthermore, it would need to clearly and intuitively communicate its intended use.

Audio consumer electronics have their own design language. This is something that was established even since the 80s, the golden era on audio consumer electronics. The general approach is relatively unchanged since then. Only in recent years, with smart devices becoming more popular, we start to see a change in body shapes and user interface designs. Traditionally, controls were based on knobs, buttons and switches. In more recent years we see more and more the appearance of touch surfaces and “invisible” touch controls. But even when a modern touch interface is present, it is designed to resemble a conservative gesture. For example, a circular gesture in order to increase the volume, mimicking the rotary motion of a volume knob.

By studying many designs, both marketed products as well as concepts, the following key points can be made.

Clean and boxy geometric shapes. The main body of the majority of devices is either one of the primitive shapes or a combination of no more than two or three. Speakers, especially in the more recent years, are a bit more adventurous, with cylindrical and spherical designs. Amplifiers, media players, and turntables seem to stay true to their heritage. Bulky, rectangular boxes of low gravitational centre. They evoke strength and durability.

Form fitted parts and controls. Parts that come together tend to complete one another’s form. Buttons and switches are often found submerged in the pain body, filling in the gaps.

Textured but flat surfaces. Surface finishing is taken seriously but it remains subtle. Most surfaces remain flat and three dimensional patterns are reserved for when mechanical properties are needed. For example, the grill of a speaker front or a ventilation opening. Most metallic parts are either brushed of blasted, and shiny metals are only used for detailing, such as chrome trims. Plastics can be found in many variations, from solid to opaque and from hard to soft. Plastics, especially in the more premium products, are used for their properties and not for their offered aesthetics. In most cases they are used in small functional parts and bigger parts are primarily metallic. Wood is also a premium material we often see. Usually as a decorative piece within the whole assembly, like wood panels end-plates on an expensive amplifier.

Size and placement of controls, translates to importance. Especially in more complex devices where extensive control is possible, we see size being used to communicate hierarchy. The most important and regular controls are always bigger and more easily accessible than those used once in a while. The master volume knob, in the majority of designs, is the biggest knob of them all, and is usually positioned on the very right end of the device

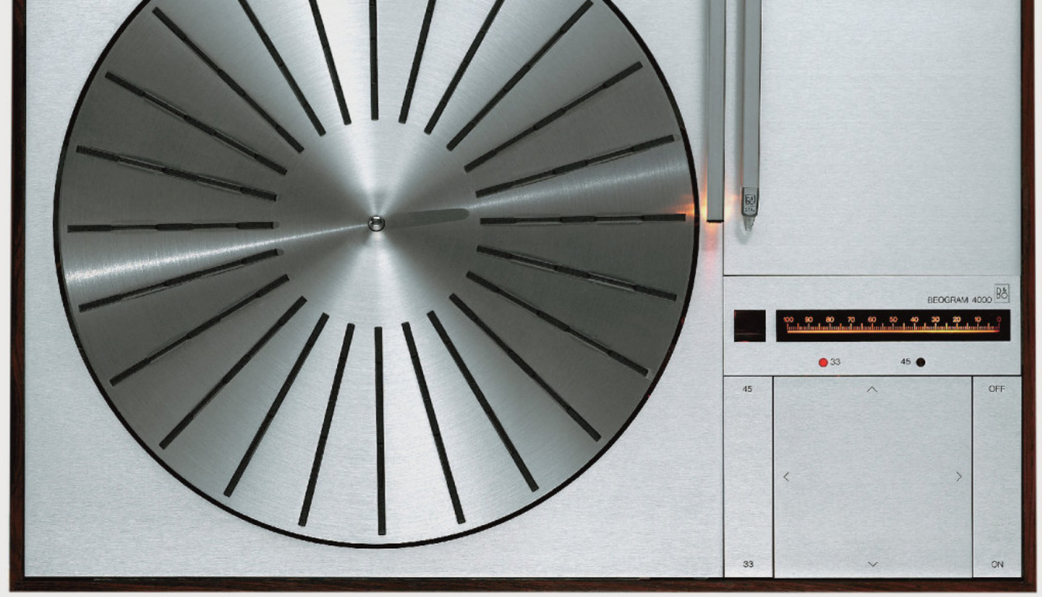


Fig. 19: Beogram 4000 Record Player, from 95 Years of Magic at bang-olufsen.com

Fig. 22: Teenage Engineering OP-Z, from musictech.net

Fig. 21: Beosound Balance Wireless Speaker, from headphones.sg

Fig. 20: Braun TG 60 Reel to Reel player, from dasprogramm.co.uk

2.7. Product Requirements

Audio Module

The following requirements concern the core console. That includes the master channel and the audio expansion modules.

Area	ID	REQ/ WISH	Requirement	Focus Area
1. Performance	0101	**REQ**	The console is plugged into a 220V Socket	Function
	0102	**REQ**	The console is plugged into a 110V Socket	Function
	0103	**REQ**	The console is controlled by a Smartphone via Wi-Fi	Function
	0104	**REQ**	The console has power ports for each expansion plug-in	Function
	0105	WISH	The console should have USB power ports for 3rd party accessories	Function
	0106	**REQ**	The console connects to speakers via RCA	Function
	0107	WISH	The console should be audibly transparent between 20Hz-20kHz	Function
	0108	**REQ**	The console has a hard ON/OFF switch	Function
What main functions does the product need to fulfil? What functional properties should it have (speed, power, strength, precision, capacity, etc.)?	0109	**REQ**	The power consumption of the console is negligible while in passive use	Function
	0110	**REQ**	The console has a master volume control	Function
	0111	**REQ**	Each audio channel has one user customizable button	Function
	0112	**REQ**	The console starts with 2 stereo audio inputs (Starter pack, IMO-M2000, Master & 2 Channels)	Function
	0113	**REQ**	The console can be expanded with additional audio inputs	Function
	0114	WISH	The console should be able to learn the IR commands of other devices	Sustainability
	0115	WISH	The console should replicate the IR signal and control other devices	Sustainability
2. Environment	0201	**REQ**	The console can withstand the heat generated by old generation, A class amplifiers and devices of similar or greater heat generation	Safety
What kind of environmental influences does the product need to withstand during production, transport and use (temperature, vibrations, moisture, etcetera)? What effects of the product to the environment should be avoided?	0202	**REQ**	The console does not slide easily on its resting surface	Safety
	0203	**REQ**	The console doesn't rattle at loud audio playback volumes	Experience
3. Life in Service	3001	**REQ**	The console can work for at least 32000 Hours (8x200x20)	Function
With what intensity will the product be used and how long should it last?	3002	**REQ**	All connections are made of corrosion resistant materials	Function
4. Maintenance	0401	WISH	The main electronics should be accessible within as little steps as possible	Sustainability
	0402	**REQ**	HEX screws are used for fixations	Sustainability
	0403	WISH	Assembly should be made easy by using Poka-Yoke principles, so every component only has one definitive way of montage	Sustainability
Is maintenance necessary and possible? What parts need to be accessible?	0404	WISH	Any parts that require occasional conditioning should be easy to reach	Sustainability
	0405	WISH	Glued connections should be disregarded in favour of re-usable connections like fasteners	Sustainability
	0406	WISH	The materials used should be resistant to cleaning chemicals	Experience
	0407	WISH	Cracks and grooves that can collect debris should be avoided	Sustainability
	0408	**REQ**	HEX/Allen keys are provided with the console	Sustainability
5. Cost	0501	**REQ**	The total cost of the console (IMO-M2000) Does not exceed 200 Euros	Cost
What is a realistic price for the product, considering similar products? What margin does it need to deliver?	0502	WISH	The total cost of the console should be as low as possible	Cost
6. Transport	0601	**REQ**	The packaging shape allows for easy stacked shipping	Sustainability
	0602	**REQ**	The shipping package is smaller than 0.01 M^3	Sustainability
What requirements are set by transport of the product during production and to the location of usage?	0603	WISH	The "starter kit" (IMO-M2000) Should be packed in a single box	Sustainability
	0604	**REQ**	Channel extension blocks are packed individually	Sustainability
7. Size and weight	0701	**REQ**	The console does not exceed 340 Mm in width	Function
	0702	**REQ**	The console does not exceed 2 kilograms in weight	Function
Are there boundaries to the size and weight of the product due to production, transport or use?	0703	WISH	The console should weigh a minimum of 0,5 kilograms	Function
	0704	WISH	The packaged console should be light enough to transport via Air Mail	Function

8. Aesthetic, Appearance and finish	0801	WISH	The console should offer a timeless appeal in materiality	Sustainability
	0802	WISH	The console should offer a premium touch and feel	Experience
Which preferences do buyers and users have? Should the product fit a house style?	0803	**REQ**	The console brand logo must be readable from 1 m away, while looking at it perpendicularly	Experience
	0804	WISH	The console should obviously resemble an audio product	Experience
	0805	WISH	The console should communicate its main function through interaction elements	Interaction
9. Materials	0901	**REQ**	The console uses 80% Of recycled or easy to recycle materials considering its mass	Sustainability
	0902	WISH	The console should use thermoplastics like PP or PE without reinforcement for hard-plastics parts	Sustainability
	0903	WISH	The console should consist of as much recyclable material as possible	Sustainability
Should certain materials (not) be used (because of safety or environmental reasons)?	0904	WISH	Bio-(degradable)materials should be used for dampening and seals if they perform same or better, compared to their traditional alternatives	Sustainability
	0905	WISH	The materials used should maintain their look and finish throughout the console's lifespan	Experience
	0906	**REQ**	Recyclable or biodegradable packaging is used	Sustainability
10. Ergonomics	1001	WISH	The console is movable by using two hands at shoulder width by adult users within the 90 Percentile of shoulder widths	Interaction
	1002	**REQ**	Connection ports are marked on the backside	Interaction
	1003	**REQ**	The power connection is situated on the backside or the bottom of the console	Interaction
	1004	WISH	The power connection should be hidden in the bottom of the console	Interaction
What requirements results from observing, understanding, handling, operating, etc. the product?	1005	WISH	Moving parts should not present the potential of hurting users	Safety
	1006	WISH	The ports should be communicated in a way that the user can use them within one minute	Interaction
	1007	**REQ**	The volume knobs have a diameter of approximately 40 Mm	Interaction
	1008	**REQ**	Spacing between knobs is at least half of the knobs diameter (40/2=20 Mm)	Interaction
	1009	WISH	Auxiliary connections should be easily handled by adult hands in the 90 Percentile	Interaction
11. Safety	1101	**REQ**	High current wires are under no circumstances touching the main frame	Safety
	1102	**REQ**	All wires are enclosed inside the housing	Safety
	1103	**REQ**	Modular connections do not carry high current / voltage electricity	Safety
Should specific precautions be taken with regards to the safety of users and non-users?	1104	**REQ**	The main frame is grounded	Safety
	1105	**REQ**	The console is tight against spraying water (IP63)	Safety
	1106	**REQ**	Modular fixations cannot be undone unintentionally	Safety

12. Assembly, Installation and Initiation of Use	1201	WISH	The console should be easy to disassemble	Sustainability
	1202	**REQ**	The console is assembled by using a maximum of 3 different HEX head sizes	Sustainability
What requirements result from assembly outside the factory, installation, connecting to other systems and learning how to handle and operate the product?	1203	**REQ**	The console is using a maximum of two destructive fixtures	Sustainability
	1204	**REQ**	The console needs a maximum of 3 steps to assemble each expansion block	Experience
	1205	**REQ**	Non smart features can work right after assembly	Experience
	1206	**REQ**	All smart features are set-up through a mobile application	
13. Reuse, Recycling	1301	**REQ**	The console uses 80% Of recycled or easy to recycle material considering its mass	Sustainability
	1302	**REQ**	The console uses standardized connectors that can be repurposed at the end-of-life (RCA, USB, etc.)	Sustainability
	1303	WISH	The console should be easy to separate and collect all different components	Sustainability
Can the material cycle be extended by reuse of parts and materials? Are parts and materials easy to separate for recycling or waste processing?	1304	WISH	Multi-material combinations that are difficult to take apart should be prevented	Sustainability
	1305	WISH	Sturdy materials should be used to provide longevity and long lasting surface finishing	Sustainability
	1306	WISH	The housing should be made out of a single material that allows for recycling without requiring disassembly	Sustainability
14. Standards, Rules and Regulations	1401	**REQ**	Apply with the CE standards	Safety
	1402	**REQ**	Apply with ISO 10377: 2013 - consumer product safety	Safety
	1403	**REQ**	Apply with ISO 10393: 2013 - consumer product recall	Safety
What standards, rules and regulations (nationally and internationally) apply to the product and to the production process? Should standardisation within the company or within the industry be taken into account?	1404	**REQ**	ISO/IEC Guide 37 - Instructions for use of products by consumers	Safety
	1405	**REQ**	ISO Guide 50 - safety aspects - Guidelines for child safety in standards and other specifications	Safety
	1406	**REQ**	ISO Guide 51 - Guidelines for their inclusion in standards	Safety
	1407	**REQ**	ISO Guide 71 - Guide for addressing accessibility in standards	Safety
	1408	**REQ**	ISO Guide 74 - Graphical symbols - Technical guidelines for the consideration of consumers' needs	Safety

Expansion Plug-in

Part of a successful and sustainable design is longevity. Physical longevity can be achieved with good engineering, but in the fast paced environment of technology, it is harder to keep up. An effective way to make such a device future proof, is to make it as upgradable as possible. This way not only it can quickly keep up with its competitors, but it can also be more easily repaired if needed. The core console, with its expandable audio modules, only handles analogue audio signals and the smart features are limited to remote control through Wi-Fi. For additional support, plug-in extensions can be attached to every channel, offering more diverse connectivity options.

Area	ID	REQ/ WISH	Plug-in Requirements	Focus Area
1. Performance	PL 0101	**REQ**	The plug-in can receive audio via Wi-Fi (AirPlay)	Function
	PL 0102	**REQ**	The plug-in can receive audio via Bluetooth	Function
	PL 0103	**REQ**	The plug-in can amplify Turntable signal (RIAA Equalisation)	Function
What main functions does the product need to fulfil? What functional properties should it have (speed, power, strength, precision, capacity, etc.)?	PL 0104	**REQ**	The plug-in can receive audio via Optical	Function
	PL 0105	**REQ**	The plug-in can output audio via Bluetooth	Function
	PL 0106	**REQ**	The plug-in can connect to speakers via Balanced Jack Plugs	Function
	PL 0107	**REQ**	The plug-in is receiving power from the console	Function
2. Environment	PL 0201	**REQ**	The plug-in can withstand the heat generated by old generation, A class amplifiers and devices of similar or greater heat generation	Safety
What kind of environmental influences does the product need to withstand during production, transport and use (temperature, vibrations, moisture, etcetera)? What effects of the product to the environment should be avoided?	PL 0202	**REQ**	The plug-in doesn't rattle at loud audio playback volumes	Experience
3. Life in Service	PL 0301	**REQ**	The plug-in can work for at least 32000 Hours (8x200x20)	Function
With what intensity will the product be used and how long should it last?	PL 0302	**REQ**	All connections are made of corrosion resistant materials	Function
4. Maintenance	PL 0401	**REQ**	HEX screws are used for assembly	Sustainability
	PL 0402	WISH	Any parts that require occasional conditioning should be easy to reach	Sustainability
Is maintenance necessary and possible? What parts need to be accessible?	PL 0403	WISH	Glued connections should be disregarded in favour of loosen-able connections	Sustainability
	PL 0404	WISH	The materials used should be resistant to cleaning chemicals	Sustainability
	PL 0405	WISH	Cracks and grooves that can collect debris should be avoided	Sustainability
5. Cost	PL 0501	**REQ**	The total cost of each plug-in does not exceed 80 Euros	Cost
What is a realistic price for the product, considering similar products? What margin does it need to deliver?	PL 0502	WISH	The total cost of each plug-in should be as low as possible	Cost
6. Transport	PL 0601	**REQ**	Plug-ins are packed individually	Sustainability
What requirements are set by transport of the product during production and to the location of usage?	PL 0602	**REQ**	The packaging shape allows for easy stacked shipping	Sustainability
7. Size and weight	PL 0701	**REQ**	The plug-in can fit discreetly at the back, underneath or inside the console	Function

8. Aesthetic, Appearance and finish	PL 0801	**REQ**	The plug-in's design should match and compliment the console	Experience
9. Materials	PL 0901	**REQ**	The plug-in is made by radio-wave transparent materials	Function
Should certain materials (not) be used (because of safety or environmental reasons)?	PL 0902	**REQ**	The plug-in uses 80% Of recycled or easy to recycle material considering its mass	Sustainability
10. Ergonomics	PL 1001	**REQ**	The plug-in offers good grip for detaching it from the console	Interaction
11. Safety	PL 1101	**REQ**	The plug-in carries low current power	Safety
Should specific precautions be taken with regards to the safety of users and non-users?	PL 1102	**REQ**	The body of the plug-on is not conductive	Safety
12. Assembly, Installation and Initiation of Use	PL 1201	**REQ**	Attaching the plug-in can be done without adjusting the position of the console	Experience
What requirements result from assembly outside the factory, installation, connecting to other systems and learning how to handle and operate the product?	PL 1202	**REQ**	The plug-in is held in place by it's plugs/connectors	Experience
13. Reuse, Recycling	PL 1301	**REQ**	The plug-in uses 80% Of recycled or easy to recycle material considering its mass	Sustainability
	PL 1302	**REQ**	The plug-in uses standardized connectors that can be repurposed at the end-of-life (RCA, USB, etc.)	Sustainability
Can the material cycle be extended by reuse of parts and materials? Are parts and materials easy to separate for recycling or waste processing?	PL 1303	WISH	The plug-in should be easy to disassemble	Sustainability
	PL 1304	WISH	Commercially available electronics should be used anywhere possible	Sustainability
14. Standards, Rules and Regulations	PL 1401	**REQ**	Apply with the CE standards	Safety
	PL 1402	**REQ**	Apply with ISO 10377: 2013 - consumer product safety	Safety
	PL 1403	**REQ**	Apply with ISO 10393: 2013 - consumer product recall	Safety
What standards, rules and regulations (nationally and internationally) apply to the product and to the production process? Should standardisation within the company or within the industry be taken into account?	PL 1404	**REQ**	ISO/IEC Guide 37 - Instructions for use of products by consumers	Safety
	PL 1405	**REQ**	ISO Guide 50 - safety aspects - Guidelines for child safety in standards and other specifications	Safety
	PL 1406	**REQ**	ISO Guide 51 - Guidelines for their inclusion in standards	Safety
	PL 1407	**REQ**	ISO Guide 71 - Guide for addressing accessibility in standards	Safety
	PL 1408	**REQ**	ISO Guide 74 - Graphical symbols - Technical guidelines for the consideration of consumers' needs	Safety

3. Ideation & development

Fig. 23: Rendering of early plug-in concept

3.1. User Body Shape Evaluation

User input was of significant importance throughout the project. Through surveying or just simple one-on-one conversations useful user insights and feedback was gathered. A key moment while developing the final design was when users were presented with a collection of numbered body iterations (Figure 23). Users, already aware of the context, were asked to choose their favourite shapes and in some cases they even provided more elaborate comments on their motivation. The majority seemed to favour the simpler designs with straight angles (Fig. 24). A vertical approach seemed to be of little to no interest.

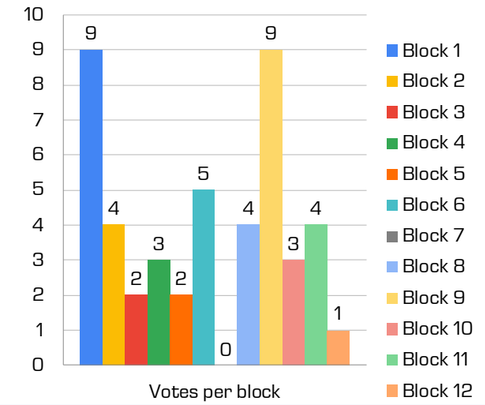


Fig. 25: Body shape user vote graph

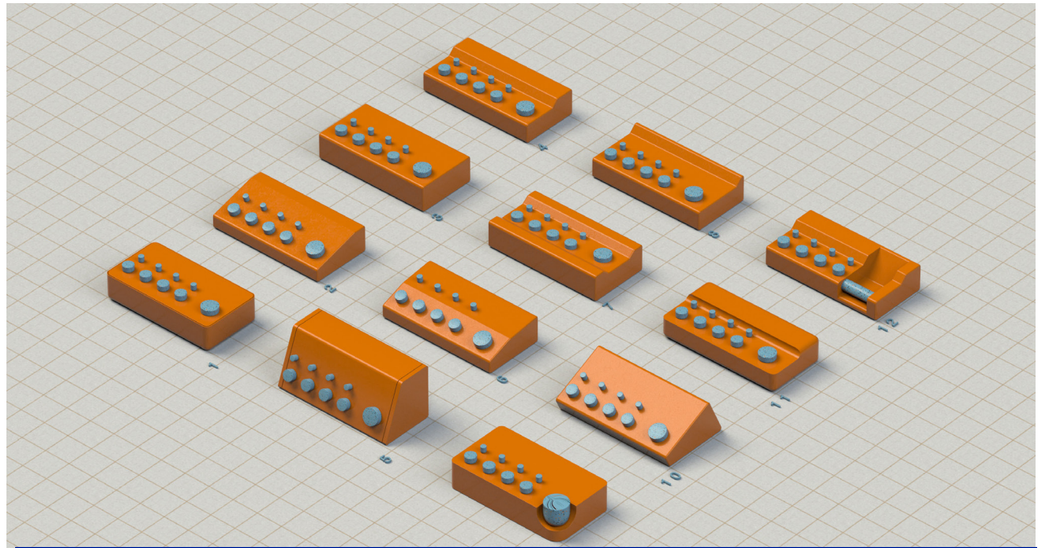


Fig. 24: Rendering of body shape design iterations for user feedback

3.2. Concept Evolution

Early ideation

While looking at the results from the very first user survey, what was really intriguing was the range of number of inputs people use. On an average, users use 3.5 individual input sources of audio but in some cases that number was as high as 19 individual inputs. Accommodating everyone's needs would have been tricky. Maintaining a balance between size, price, number of inputs and ease of use would be a real challenge. This is when the idea of a modular system came to existence. Even though this was early in the exploration process, it played a key role on how ideas evolved.

In the earlier stages of conceptualisation, when engineering was still out of the picture, designs were relatively big and most ideas revolved around a dual-channel design. In parallel to the concept evolution, research and development of the internal electronics sparked new light. It started to seem like a better idea to dissect each dual-channel audio module to a single channel, making expansion more approachable for the user and easier to handle in terms of manufacturing. Based on the electronics and the user input on the body shape preferences, designs started to get progressively smaller and more geometric, more thought was put into the engineering and manufacturing processes and concepts started to resemble real products. Sustainability and repairability were also taken into account while designing. Most design ideas, even from a conceptual level, were put together in a way

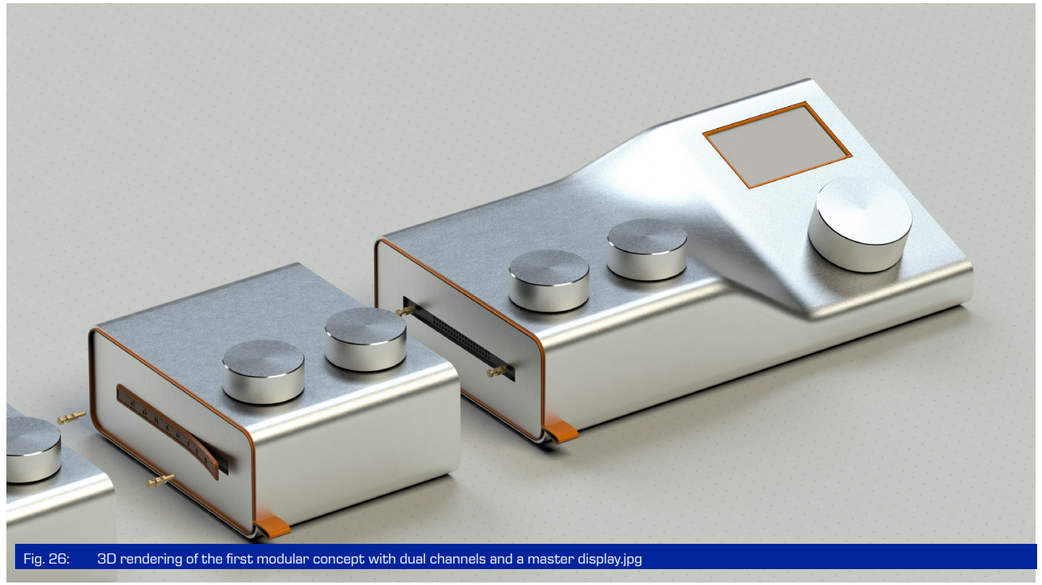
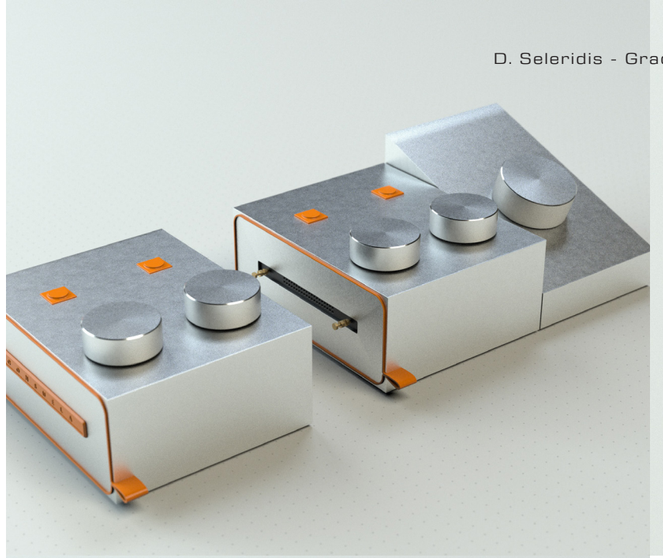
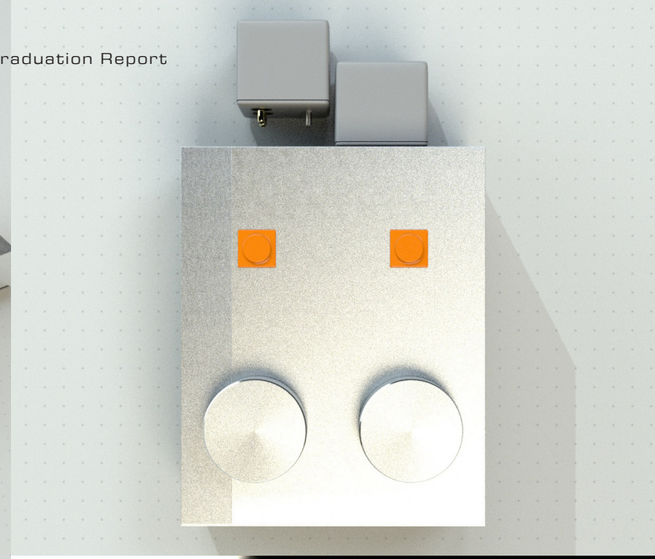
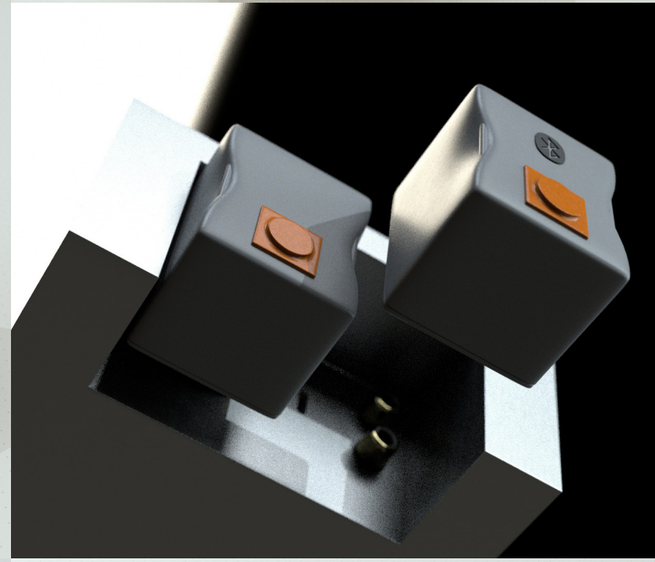
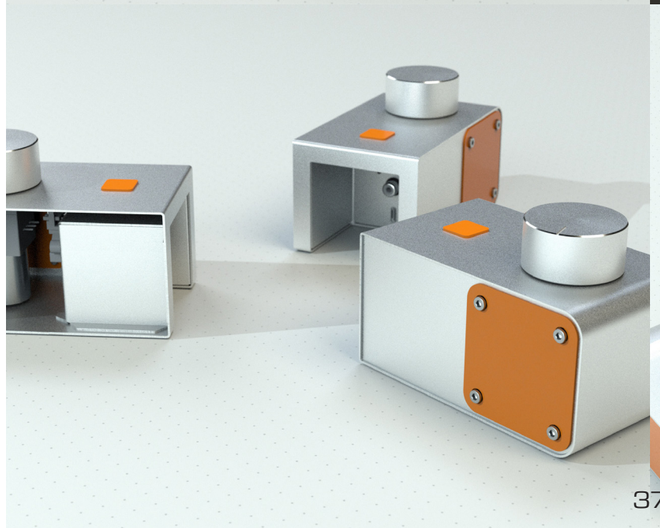


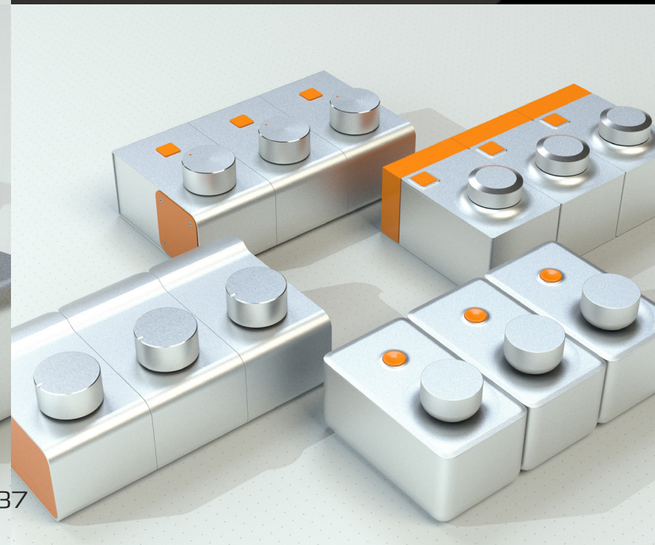
Fig. 26: 3D rendering of the first modular concept with dual channels and a master display.jpg











that rendered them manufacturable while keeping in mind that they should be easy to repair too. Most ideas revolved around sheet metal bending or extrusion profiles, in combination with milling.

Somewhere along the way and with a handful of different design options, a look back at the aesthetic goal revealed that design was taking the wrong direction. The clean lines that were originally the aesthetic goal, somehow, got more complex along the way. Even though the conceptual designs looked boxy as a whole, smaller details introduced curves that distorted the intended look.

Design Freeze

With a recently refreshed perspective and an empty page, a new concept was formed. Combining the good aspects of previous ideas, while staying true to the intended aesthetic character, ultimately resulted in the concept design freeze. Primitive shapes make up the entire design. The body is shrunk down to the volume that the electronics dictate, in combination with sensible ergonomics. From a manufacturing standpoint, most body parts are machined aluminium extrusion profiles, folded sheet metal or machined pieces from solid metal. The main assembly uses screws with the exception of some permanently welded parts.

As a system, the “starter pack” consists of a wider module that serves as the Master channel and two smaller, identical modules. The latter are just regular audio channels that function as inputs whereas the master controls the smart features of the entire system, but also the master audio volume.

This design was also the starting point for further development around manufacturing, electronics and of course, sustainability.

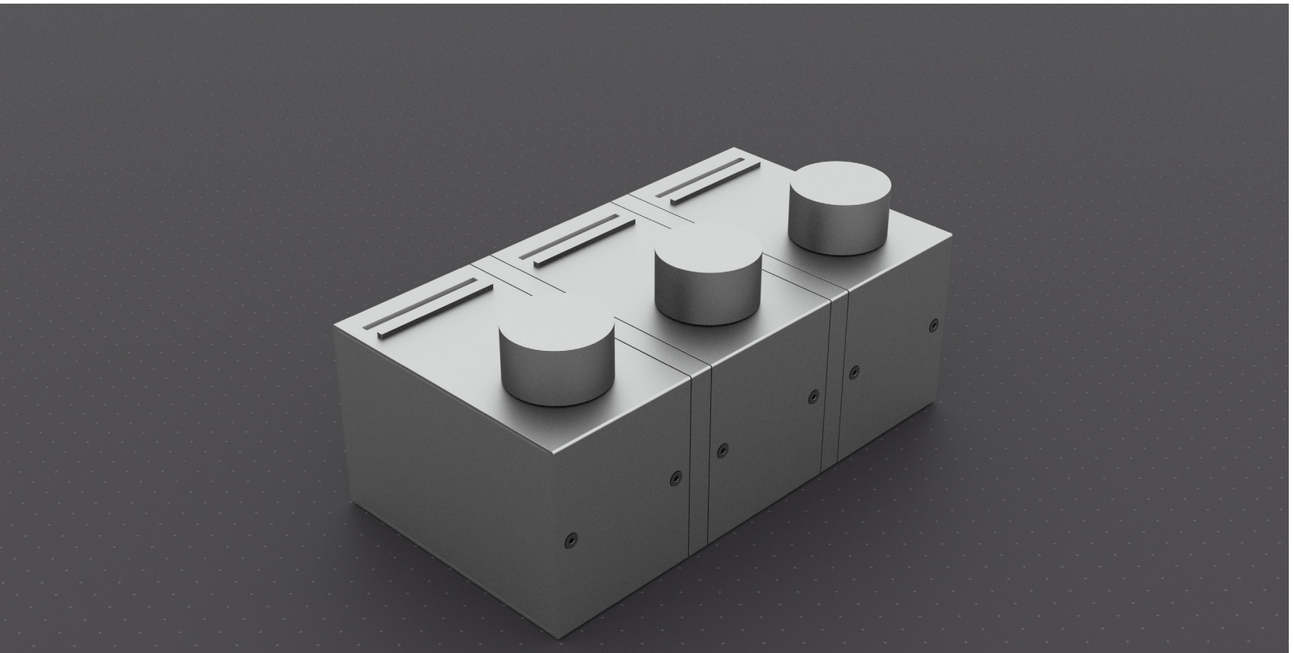


Fig. 27: Concept rendering, full assembly during design freeze

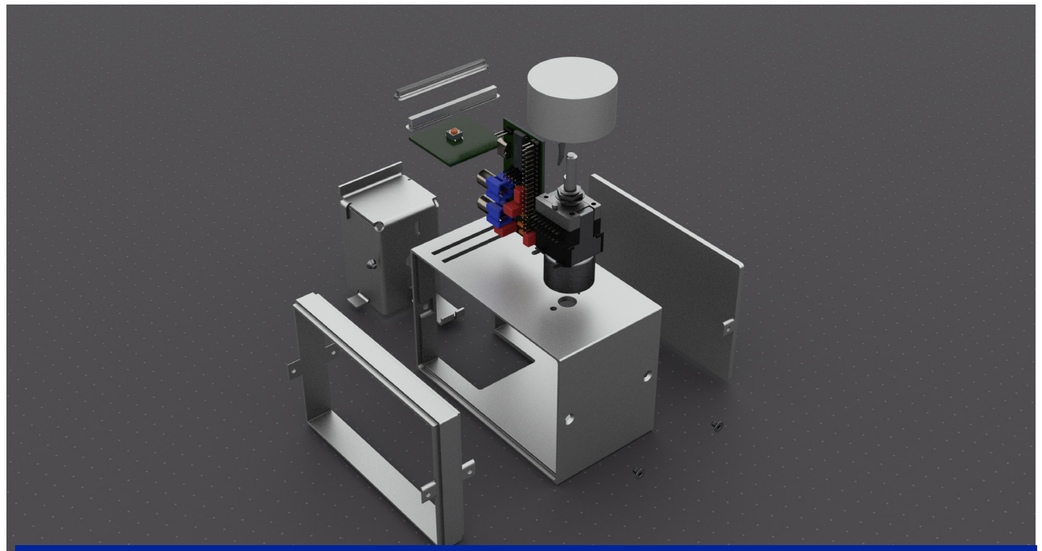


Fig. 28: Concept rendering, exploded view of a single audio module during design freeze

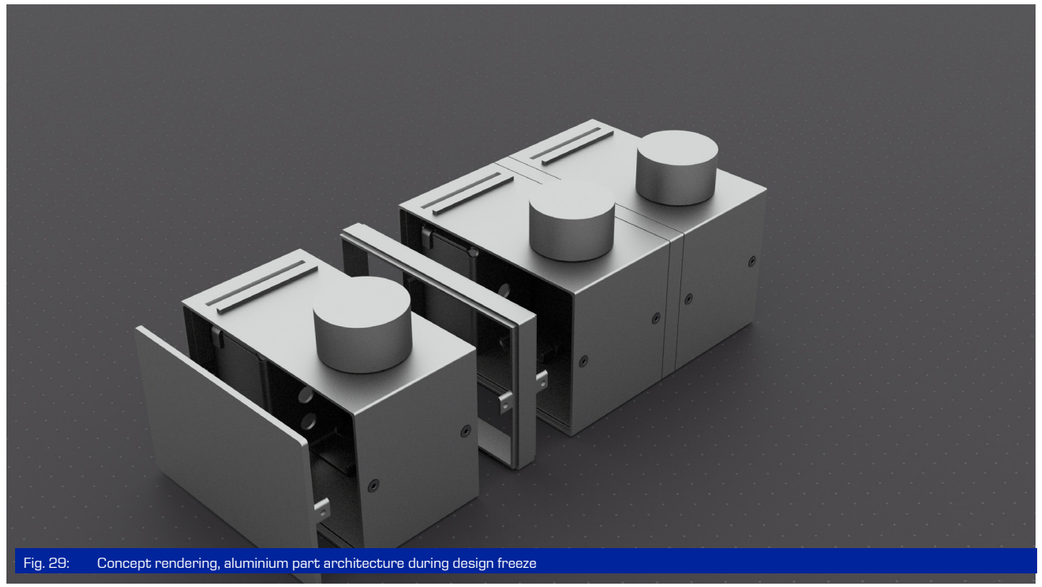


Fig. 29: Concept rendering, aluminium part architecture during design freeze

3.3. Sustainability development

Design for manufacturing

The concept carried over from the design freeze is one with very limited engineering input. Upon close inspection, certain areas seem too frail and certain parts are too complicated to easily produce. In addition, other parts are unnecessarily large, increasing environmental impact without offering anything in return. More specifically, the main body features four machined slots that also carry holes for countersunk screws. With a material thickness of just 3 mm, the material left is not sufficient for the purpose of securing the entire assembly. Moreover, those slots introduce an extra milling axis, increasing the chances of error while machining.

Similar issues appear to the connecting part. The end plates, as well as the modular connection links, feature “wings'' that align with the previously mentioned slots. These wings carry threaded holes for the already mentioned countersunk screws. The thickness of those wings is just under 1,5 mm. Considering the use of M3 screws, the 1,5 mm thickness is inadequate.

Furthermore, the modular link that connects audio modules to one another, is approximately 10mm in thickness, excluding the wings. Part of this thickness is utilised by a lip, around the profile, that properly positions the link between the modules. This configuration leaves a wide strip of material exposed to the exterior. While this characteristic has nothing to offer, it also complicates the aesthetic of the entire design.

Thanks to those observations a new revised

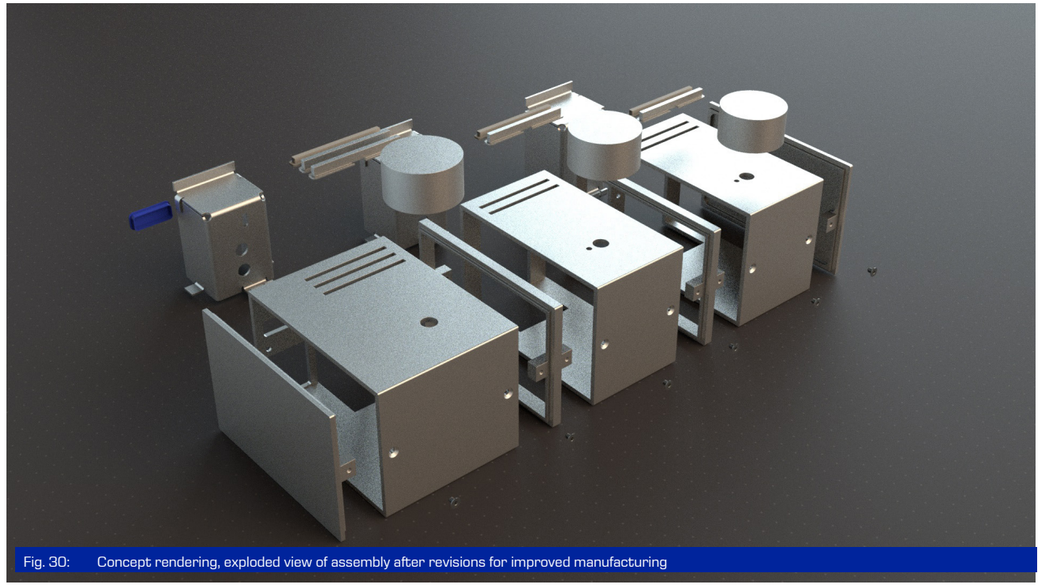


Fig. 30: Concept rendering, exploded view of assembly after revisions for improved manufacturing

design was developed. Optimised for manufacturability and strength. The new and improved design was compared to the original one in terms of environmental footprint. The results of this LCA showed that despite the increased material volume, the impact increase was minor.

Material & Manufacturing Process Selection

Market as well as aesthetic research, showed that most similar products that fall in the premium category, use metals as their main material. Most commonly stainless steel or aluminium. Similarly, the final concept was based on an aluminium frame of 3 mm in thickness. Since this was an unjustified choice, based purely on aesthetics, it was deemed necessary to explore alternatives. Given the big amount of metal that the design would require, options were limited to aluminium and stainless steel, as anything else would drastically increase the environmental footprint.

Finite element analysis was used to determine the right thickness of a stainless steel body that would perform similarly to an aluminium one of 3mm. Multiple thickness’s were analysed until 1,5 mm Stainless Steel eventually yielded results similar to 3mm Aluminium. In fact, Aluminium outperformed the thinner stainless steel but both options were close enough to compare in approximation.(Fig. 31)

An appropriately modified design, made out of stainless steel, was analysed and compared to the one made out of partially recycled aluminium. The LCA results revealed that the stainless steel option, while being inferior in strength when compared to the aluminium one, was also less sustainable. It should be taken into account that the level of uncertainty, as illustrated by the gradients of the graphs, is too high, in order to properly assess the two. Nevertheless, stainless

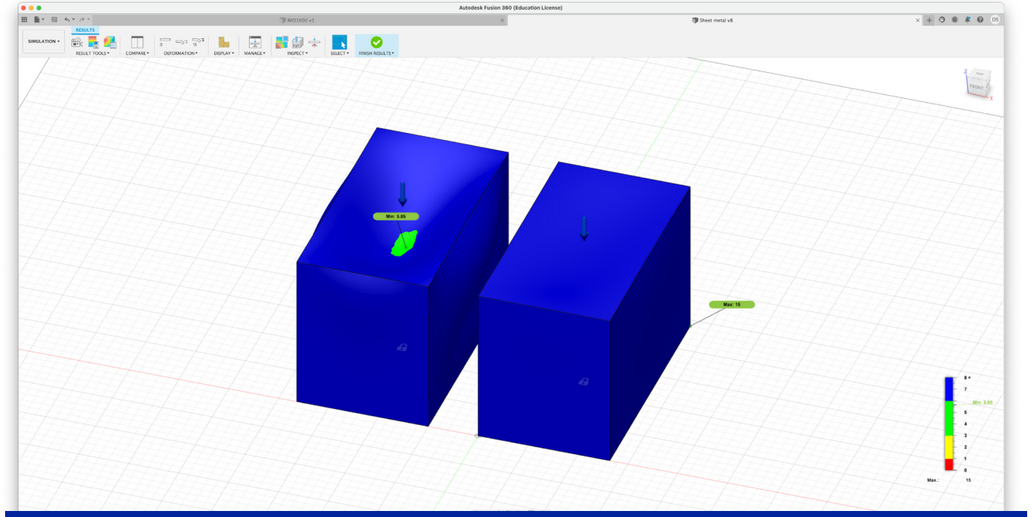


Fig. 31: FEM of a Stainless Steel body of 1.5 mm in thickness (left) and an Aluminium body of 3 mm in thickness with a linear load of 500 N

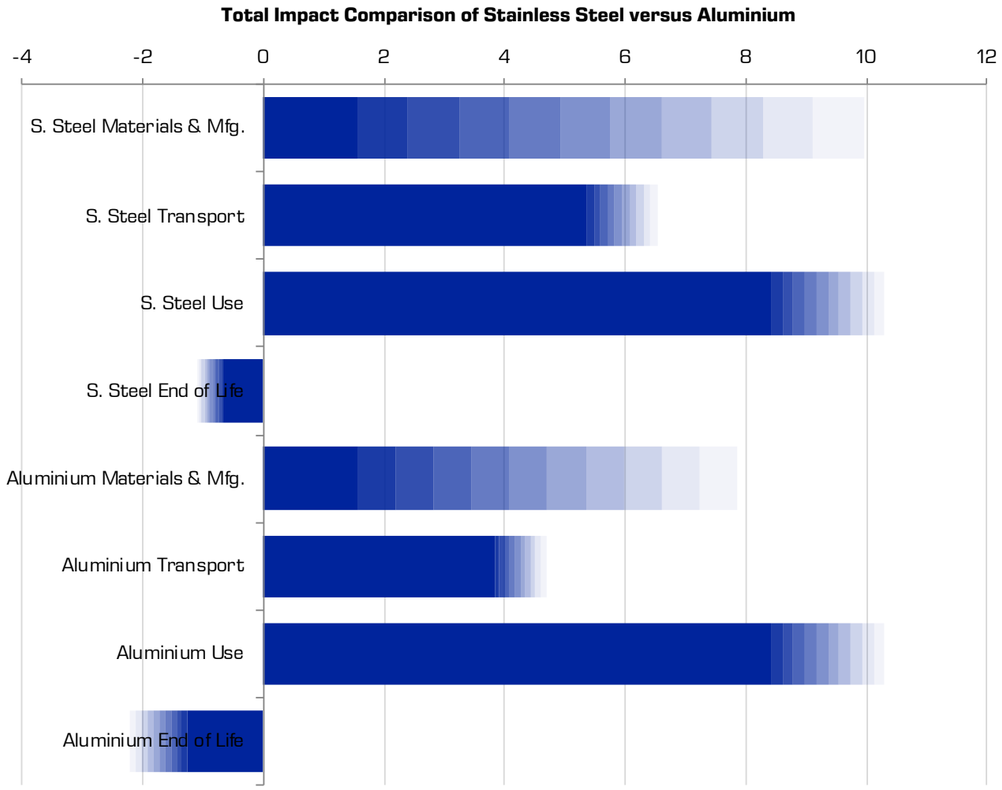


Fig. 32: LCA comparison of Stainless Steel and Aluminium, presented by life cycle stage.

steel does not present significant benefits so as to replace aluminium as the primary material choice.

Life cycle analysis was also useful in determining the ideal manufacturing processes. In particular, the complicated design of the volume knob that needed to fit a D shaped shaft. Such shafts are usually fitted with plastic knobs that are easy to mould through injection moulding. In some other cases, where metal knobs are required, a grub screw is used to secure the knob against the flat side of the D shaft. Another variation, more commonly found on kitchen stoves, is the leaf spring approach. With this design, a leaf spring is fitted between the shaft and the knob, securing the two as one, while offering easy disassembly. This last design was the most favourable option as it can be executed with aluminium and steel and the locking mechanism remains hidden, unlike the visible grub screw.

Determining the manufacturing process was a matter of comparing the impact of the sensible options. Examples from other consumer electronics products, like kitchen stoves, make use of casting for metallic knobs. Casting though, is a very energy consuming process because is requires that the metal is in a liquid state. As an alternative option, machining was compared with the use of an LCA (Fig. 33). Analysing the two, revealed that machining of such a part is less costly for the environment and that does not even take into account the additional treatment a cast part requires.

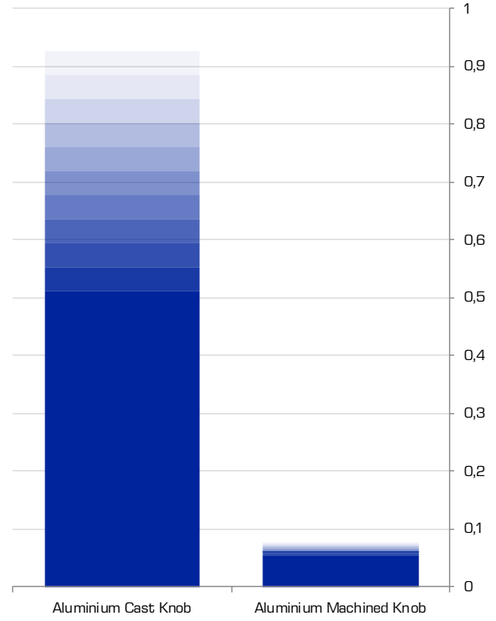


Fig. 33: LCA comparison of aluminium cast and machined knob

Reversible Assembly

An important aspect for a repairable design is the means of assembly. From early on, the use of adhesives was rendered unacceptable. Screws were clearly one of the best options as they are re-usable fasteners. Many available screw types are available in the market and many more can be developed, but proprietary fasteners are to be avoid, in order to make a more repairable product (Flipsen, 2016). Choosing what that screw head should be, can be a decision based on facts. The European Commission as well as academic studies (Park, 2019), are listing Slot, Philips and HEX screw heads as highly repairable options. Out of the three, HEX was preferred because of its elevated aesthetics in combination with ease of use when compared to the other two. In addition to readily available screws, a good practice is limiting the amount of screw heads in one design.

3.4. Electronics

Audio Filters

As seen in previous chapters (Case study), inside audio consumer electronics, it is common to find audio filters embedded in the circuit. This is a way to fight unwanted signal travelling through the circuit, causing interference or even damage. Especially low frequency signals, when powerful, can cause damage to sensitive components. Since each channel is designed to receive both a line or a phono signal, a band-pass filter seemed like the ideal choice. Band-pass filters combine the benefits of both High and Low pass filter, ultimately allowing a certain band of frequencies to pass through.

There are many different designs for a band pass filter and based on the components used they can function in the desired frequency range. Most of those designs are active filters, meaning that they require power to properly function. Such a design would

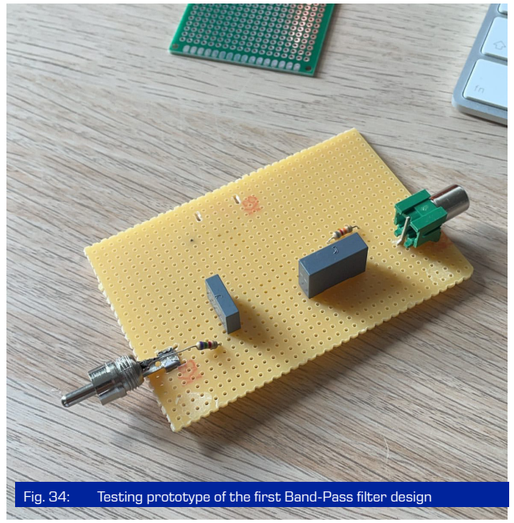


Fig. 34: Testing prototype of the first Band-Pass filter design

greatly affect sustainability. Luckily there are also simpler filter designs that are fully passive, requiring no energy at all.

The desired band, or frequency range, would be 20Hz to 20kHz. Based on the following equations we can calculate the required resistors and capacitors.

The first filter design was based on components of high resistance, in an attempt to keep capacitance low. This was a decision based on ignorance that proved to be problematic. Even though the filter operated as expected, the high resistance elements lead to severe attenuation. At the same time, since the slope of the filter design is very smooth by definition, a wide range of frequencies close to the cut-off points was also attenuated by a lot, leading to a much narrower band of available frequencies. Based on these observations and learnings, updated versions of the filter were designed.

The new filter was designed around resistors of small value, aiming towards a modest source signal attenuation. This obviously affected the capacitance needed, which lead to big capacitor bodies.

Wi-Fi enabled Micro-controller

The desired smart features of the final design require the availability of Wi-Fi connectivity. In addition to wireless connectivity, a processing unit would be needed to control all the possible aspects of the console. The final product will most likely feature a custom developed circuit that features its own micro-controller on board. For the sake of prototyping, an ESP-32 has been acquired and put to the test. The ESP-32 prototyping board supports Wi-Fi connectivity right out of the box and it can be coupled with the Blynk mobile application. This way, custom UI elements on any phone with the Blynk application can be linked to the Wi-Fi enabled micro-controller, thus emulating a fully developed smart device.

Display

During the research and development of this product, there seemed to be a need for the integration of some sort of digital display. Throughout conceptual phase, designs included a "master" display but also smaller screens for each channel in some cases. These could be regular LCD displays, OLED and so on. Unfortunately, analysing the best option in terms of sustainability is nearly impossible in this projects scope, as cre-

Fig. 35: Electronic components used for testing and prototyping

ating a bill of materials for such a complex and small scale component, requires special resources and information not available.

As an alternative to a quantitative analysis like an LCA, there is research available comparing the different options. Multiple studies compare the environmental impact of various display technologies. More specifically, in a study comparing LCDs and OLEDs in terms or raw materials used and their toxicity at an end-of-life state, OLED displays present significantly higher risks because of their high concentration in precious or hazardous metals (Ji-Min Yeom, 2018). At the same time, it should also be considered that OLED is still a new technology in the broad market. Demand for OLED panels is significantly lower when compared to LCD. LCDs are cheap to produce and their raw materials easy to source. The industry has evolved over the years, in order to cater to the increasing demands of the market, as LCDs found their way in virtually every new device. (Antti Lääperi, 2009)

On the other hand, when comparing LCDs to e-Ink displays, the environmental impact of e-Ink panels is rendered negligible over time. Considering that e-Ink displays only require small bursts of electricity when refreshing frames, their long term energy consumption is remarkably lower than both LCD and OLED technologies. In some cases e-Ink is even more sustainable than actual printed paper. (Åsa Moberg, 2009)

Considering that this is a smart and connected device, any other device with wireless capabilities and a display, could be used as an intermediate control point. A smartphone with its prominent and advanced display can be used to adjust complex settings on the smart mixer. This way a display on the mixer could be avoided, improving the overall aesthetic, making it less cluttered. This way, the product could also look less intrusive and more like a discreet device with a “smart secret”. On top of the aesthetic gain, avoiding a display would also benefit sustainability by a great deal.

4. Final Design

IMO - Millennium Series

4.1. Aesthetics

Console

The final design is a homage to the golden era of music gear. An 80s inspired body, with a 21st century soul.

From first glance, IMO - Millennium, stands out for its dominant aesthetics. Strictly straight design lines are running across its entire length. The unidirectional pattern is honoured by the placement of all elements but also the texture finishing of most parts. Buttons, illumination strips and screws are all following the same principal.

It is only when linearities would create unorthodox continuity that we see a change in pattern. Disrupting the grain of the main frame, friendlier circular elements appear on the volume knobs as well as smaller details around the whole body. The volume knobs are undoubtedly cylindrical, with a circularly brushed surface. The screws holding everything together, even through positioned in a straight continuous line across the frame, feature HEX heads, appearing as concentric circles from a far. Rounded edges on milled openings match the radius of screws, creating a uniform look. But probably the boldest break in pattern comes from the end plates. Rectangular in shape but brushed with a mesmerising concentric circular pattern. The surface finishing of the main body assembly, without the volume knobs, resembles the visual patterns of a rectangular slab of wood. A concentric pattern, extruded along the length on the entire body.

The majority of parts are made out of anodised aluminium, with the exception of plastic parts when certain mechanical characteristics are required. In addition, stainless steel is used for the screws holding everything together. All tactile buttons have a plastic sleeve around them, reducing friction, thus making them easier to press while preserving their surface finishing. Above the buttons, the illuminating strips, made out of milky white plastic, scatter light from the inside out evenly, while keeping the interior components hidden out of site. Plastics can also be spotted at the back of the Master module, covering the Wi-Fi antenna without blocking signal.

Visual indications of the sound volume level are engraved on the anodised aluminium surface. A scientific dB scale is used instead of percentages, aiming to spark the curiosity of unsuspecting users but also please the enthusiastic audiophiles. The actual numbers only appear on the Master module, which works as a reference for all individual channels that only feature markings along the rotational travel of the knob. In addition to the volume control, laser engraved text indicates the use of each port at the back side of each module.

Fig. 36: Knob control close-up with attenuating dB scale.

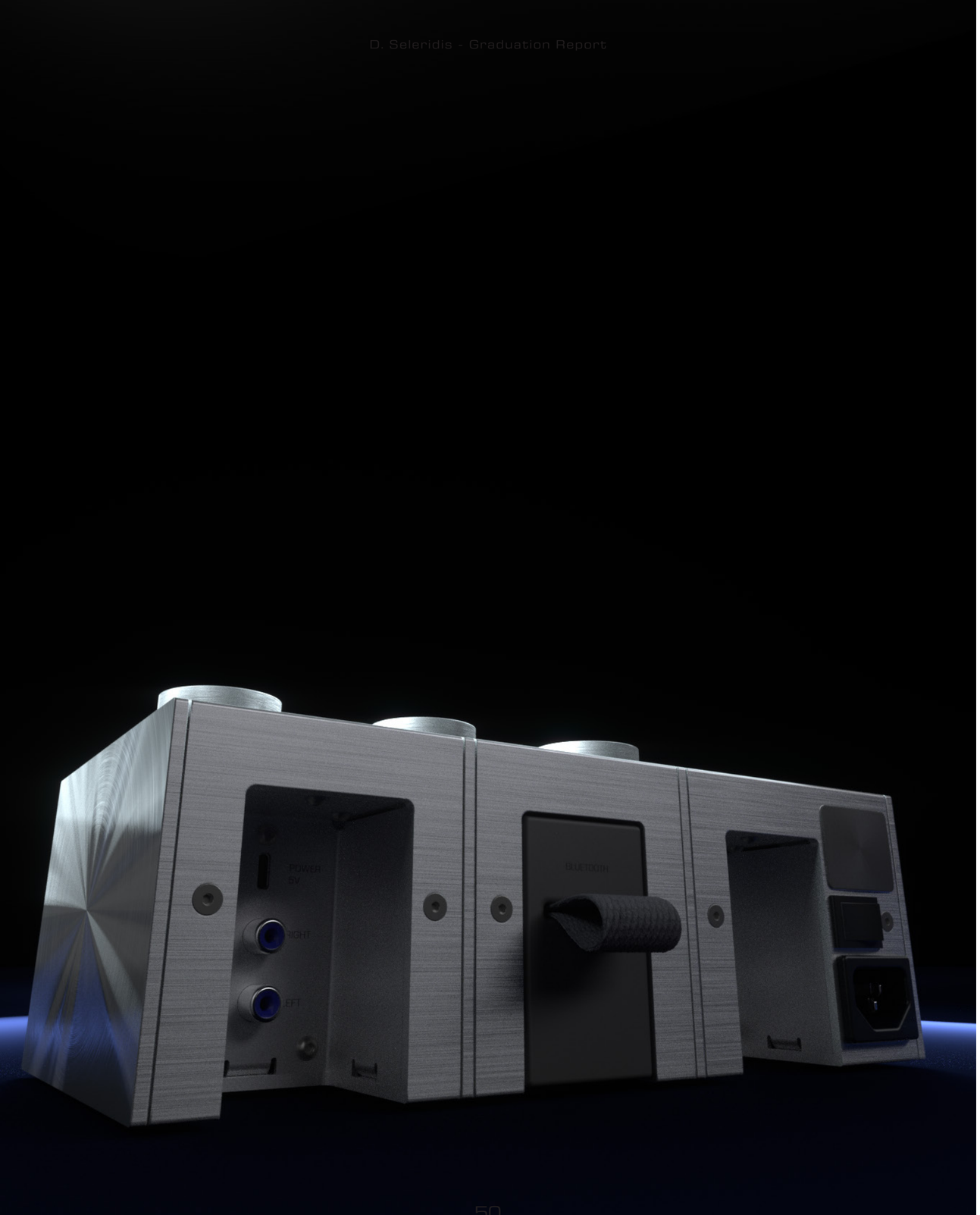


Fig. 37: Rear view, showcasing the Input/Output interface and the Bluetooth plug-in with the webbing pull tag, connected to the console.

Plug-in Blocks

The plug-in blocks are designed to seamlessly integrate with the rest of the system. They can just slide in place, completing the shape of the console, and all connections are being handled. They are made our of plastic because many of them need to be able to receive and transmit radio signals that would otherwise be of limited range. For easier use, each plug-in has a loop of webbing. This loop works as a pull-out tag for easier disassembly but it also assists in cable management. Cables can run through the loop, neatly, next to each other.

Fig. 38: Plug-in connectors

Modular Design

As dictated by the product requirements, the final design is modular. The console can be expanded in terms of audio inputs, but it can also expand in terms of features. Adding bluetooth or AirPlay capabilities is as easy as pushing a plastic block in the rear cavity of an audio channel.

Expanding the console in terms of audio channels requires a few more steps, but it is still extremely easy. By loosening two of the HEX screws, the end plate of a side can be removed. The place of the end plate takes a modular link piece. Next to the modular link, the new audio channel can be attached with a set of the familiar HEX screws. Before fixing it in place, a ribbon cable needs to be attached between the 2 audio channels. Once the ribbon cable is attached, the audio channel can be screwed in place and the end plate screwed on to it. This is a process that can be repeat, towards both directions. The master channel module can be oriented either on the left or the right of the entire assembly.

This is the very reason the design is called the “Millennium Series”. As a design that can take many forms, it is important to be able to differentiate one from the other. Each audio block/channel, is adding 1000 “points” to the system. For example, the starter console that features 2 audio inputs, is appropriately referred to as IMO-2000. Expanding this system with two additional audio channels, would also add up to its name, making it IMO-4000.

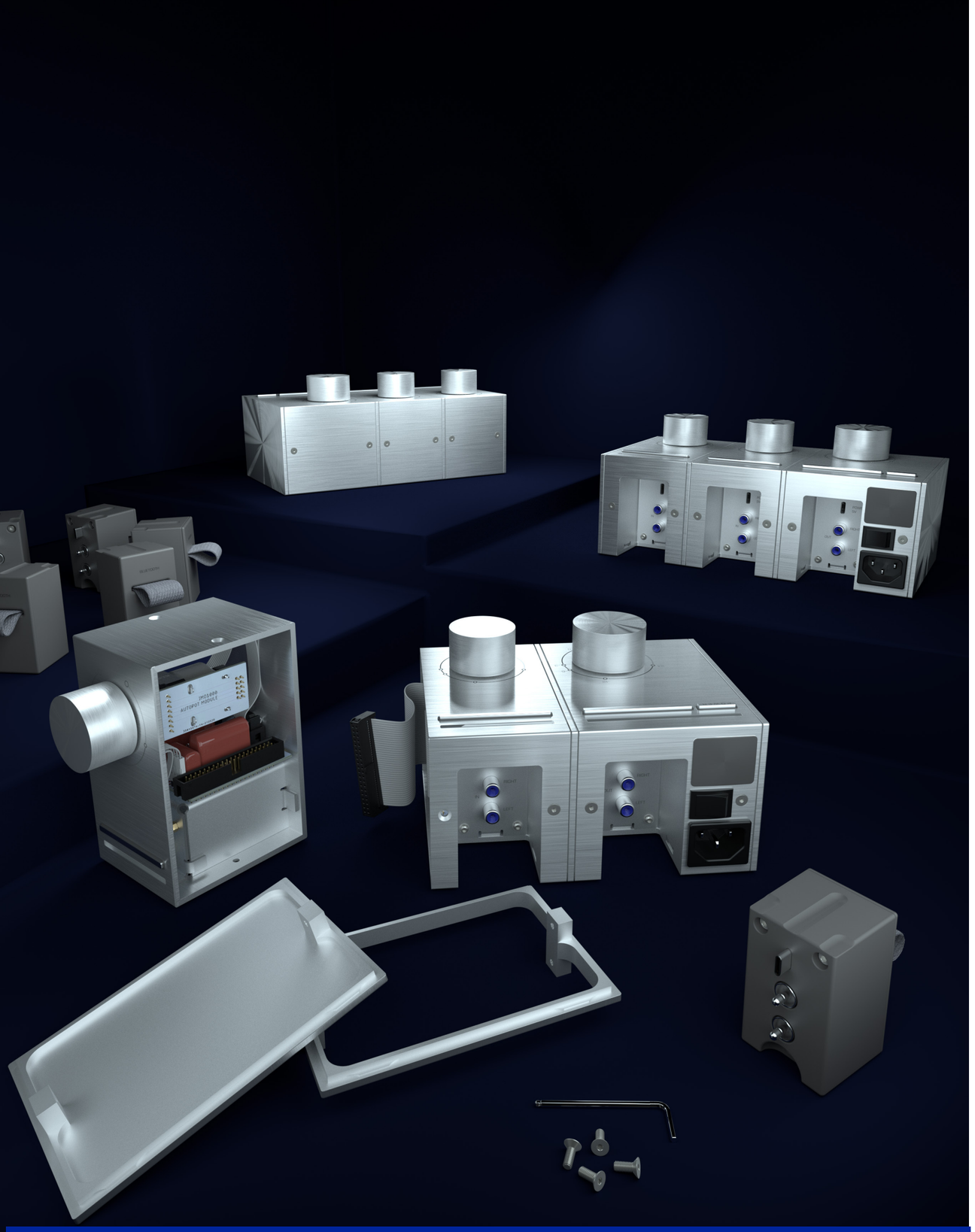


Fig. 39: Disassembled console showcasing the modular design.

4.2. Mechanical Engineering

Console

As a product driven by sustainability and design, the biggest challenge of engineering was creating a visually appealing product with the minimum impact possible. As a result, aluminium dominated the architecture of the design.

The main body is made out of machined aluminium profile extrusions of 3 mm in thickness across the perimeter. The rectangular, extruded piece, is cut to size and then milled from four individual sides. Machining included the opening of slotted holes for the buttons but also the removal of bigger areas, such as the back input/output cavity.

The Input/Output (I/O) plate is made out of aluminium sheet metal. Aluminium of 1,5 mm in thickness is first laser cut to shape and then bent to form. Once formed properly, the bent sheet metal is spot welded to the machines aluminium frame, in 5 spots, securing it permanently.

The modular links are also made out of aluminium extrusions. A profile similar to the one used for the main frame, but thicker and with some additional details is used for the modular connection links. The process is more or less the same as the main frame with the exception of the tapped M3 holes.

Similarly, the end plates are machined from extrusion profiles and feature tapped M3 holes. Furthermore, both the end plates as well as the modular links, have small notches of material left behind while machining. Those 4 notches around the perimeter act as precise spacers for the entire assembly. They ensure that only a small gap of consistent thickness is visible around each body-to-body connection. This tight fit, also creates an assembly that feels like a single, solid piece.

The rest of the aluminium components, the buttons and the volume knobs, are machined from solid aluminium pieces. In particular, the volume knob, is machined from a cylindrical piece. The exterior of this part seems rather simple but underneath the surface things are a bit more complicated. The potentiometers used inside the device operate with a D shaped shaft. For that very reason, besides a circular hole, a thin slot is machined, in order to fit in a steel leaf spring. This way the knob is tightly secured around the potentiometer shaft without requiring composite material solutions.

Aluminium parts, once manufactured, undergo surface treatment. As explained in the previous section (Aesthetics), all parts are receiving a brushed surface finishing. In most parts that is a unidirectional brushed finish but it other, a circular one. This process not only creates a nice look, but also replaces the machined sharp edges with dull, rounded edges of micro-radii.

Most plastic parts are injection moulded out of either ABS or Nylon and secured in place with snap fitted wings.

Plug-in Blocks

In the case of the plug-in, the biggest plastic part, the main assembly is using three screws, instead of snap fits. This way each

plug-in can be disassembled without fear of breaking the snap fit wings. The screws used are self-tapping HEX head screws, for plastic. The same HEX size as the rest of the console is used for these screws as well. As mentioned earlier, plastic parts are injection moulded and in this case, out of Nylon (PA). Each plug-in is comprised by at least 2 pieces, the main body and the cap. The main body is more of less a rectangular container that features the connectors as well as the recessed screws. The entire piece has a draft of 1 degree all around, for proper injection moulding.

The cap, similarly to the rest of the plug-in body, is made out of Nylon. Nylon was chosen because it can also be used to produce webbings. Having the same source material for both the cap of the body and the webbing loop, allows the two to be welded together permanently sonically.

Smart Features

Any product made in the year 2021 is expected to offer smart features and IMO should be no different. But aside from being controllable remotely, IMO is armed with Infrared light communication capabilities. This way, it can act as smart remote for older devices that would otherwise be operated by a remote. Utilising an IR receiver, the master module can “learn” the light pattern any remote is using and map it on to either one of its smart buttons or a virtual button on the mobile application. For example, an older CD player that has its own remote with pre-programmed functions. IMO can read the signal from this remote and replicate it. This way, the user can use the console as a smart and connected remote for older, “dump” devices.

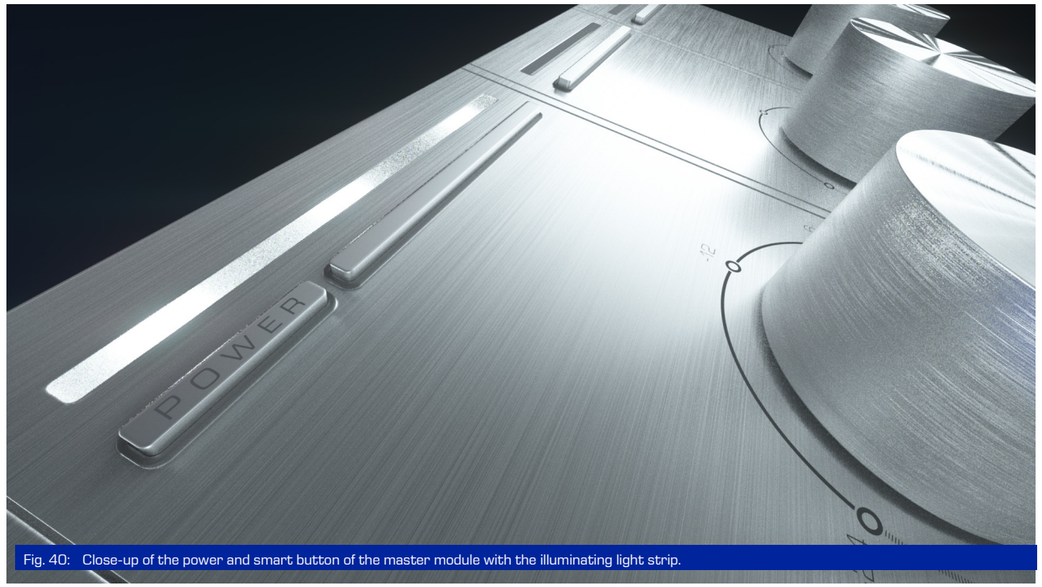


Fig. 40: Close-up of the power and smart button of the master module with the illuminating light strip.

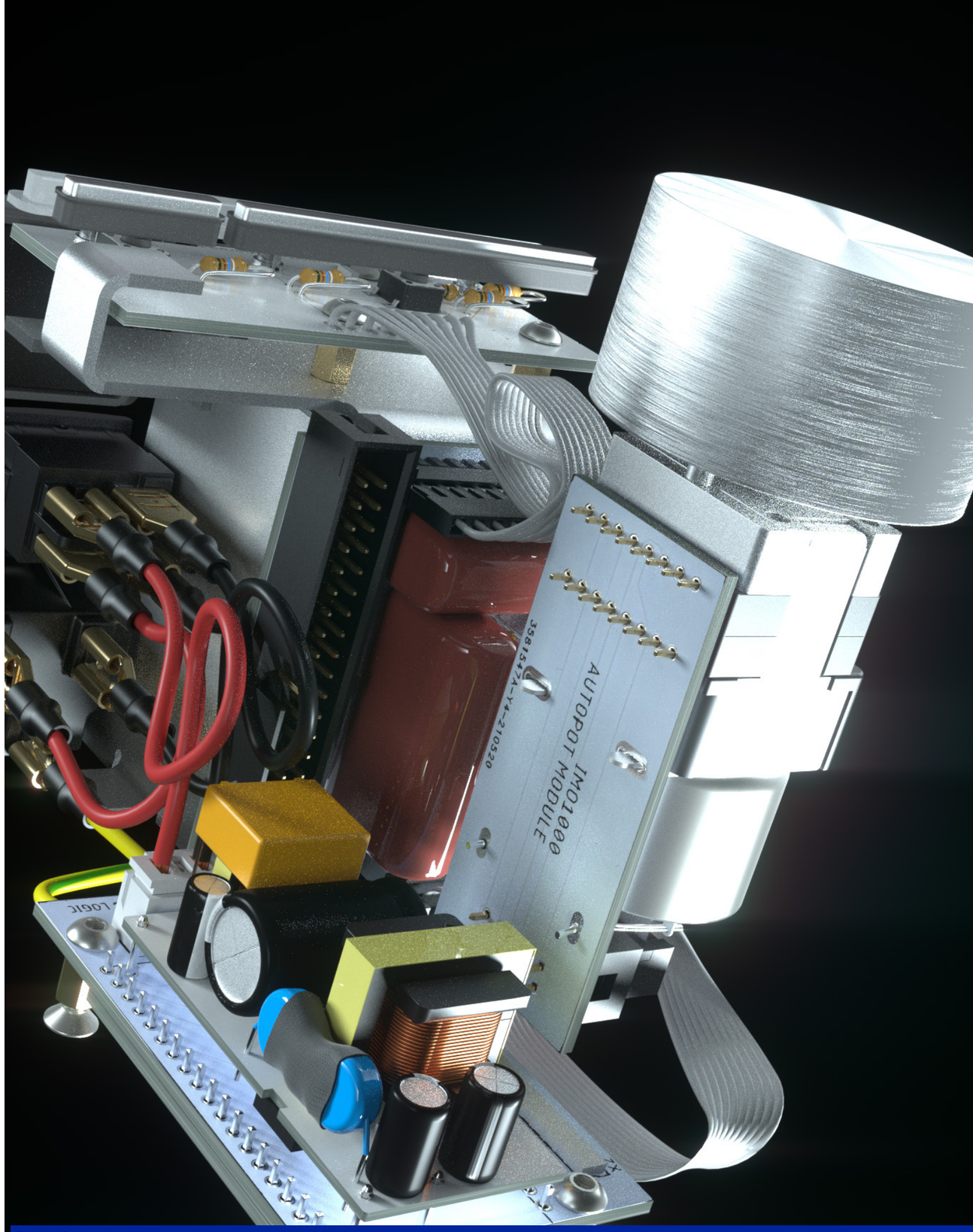


Fig. 41: Floating view of the complete electronics assembly of the Master module.

4.3. Electronics

Circuit Design

The circuit of the console is a hybrid of digital and analogue design. While audio remains an analogue signal throughout, digital signal is dominating operational controls.

As part of the final design and based on decisions and conclusions of earlier stages, custom PCBs have been designed and manufactured for this project.

In total, 4 individual PCB design were developed and manufactured based on specific readily available electronic components.

AUDIO I/O

This board serves as the main input/output for each audio module. It is designed to be the core of each channel, handling audio signal, as well as power, digital button and motor signals. It features RCA connectors as audio input/output and a band-pass filter that eliminates signal beyond the audible frequency range. A USB-C port provides power to any peripherals and extensions. On this board we can also locate the H-Bridge chip that operates the motor of the potentiometer. Finally, it features the modular connection shrouded 40-pin headers, for module to module communication, as well as the potentiometer's shrouded 10-pin header. The board is attached to the body with 6 screws and 3 standoffs.

This was the very first board designed for this project and has seen the most versions out of all boards. Originally, the board featured horizontal RCA connectors. This meant that the orientation of the board would be parallel to the longest side of the module. This soon caused space and orientation issues in relation to the rest of the electronics. In addition, it made tethering harder and raised issues of solder failures due to excessive forces on the horizontally positioned RCA connectors.

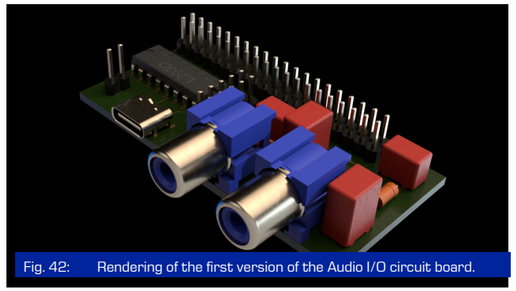


Fig. 42: Rendering of the first version of the Audio I/O circuit board.

AUTOPOT MODULE

This rather simple board ensures proper connection between the potentiometer assembly and the pin headers. As the potentiometer has multiple pins that cannot properly connect to any regular connector reliably, it was best to have the entire assembly soldered on a circuit board. Apart from the motorised potentiometer, the board features a 10-pin shrouded header. The board is only attached to the potentiometer through soldering and the entire soldered assembly is kept in place by the threaded neck and nut of the potentiometer.

CONTROL PCB

This board sits right under the smart button of each channel. It features the feedback LEDs and a tactile switch. It is tethered similarly to the Audio I/O board, with 3 standoffs and 6 screws, 3 on each side. On the mas-

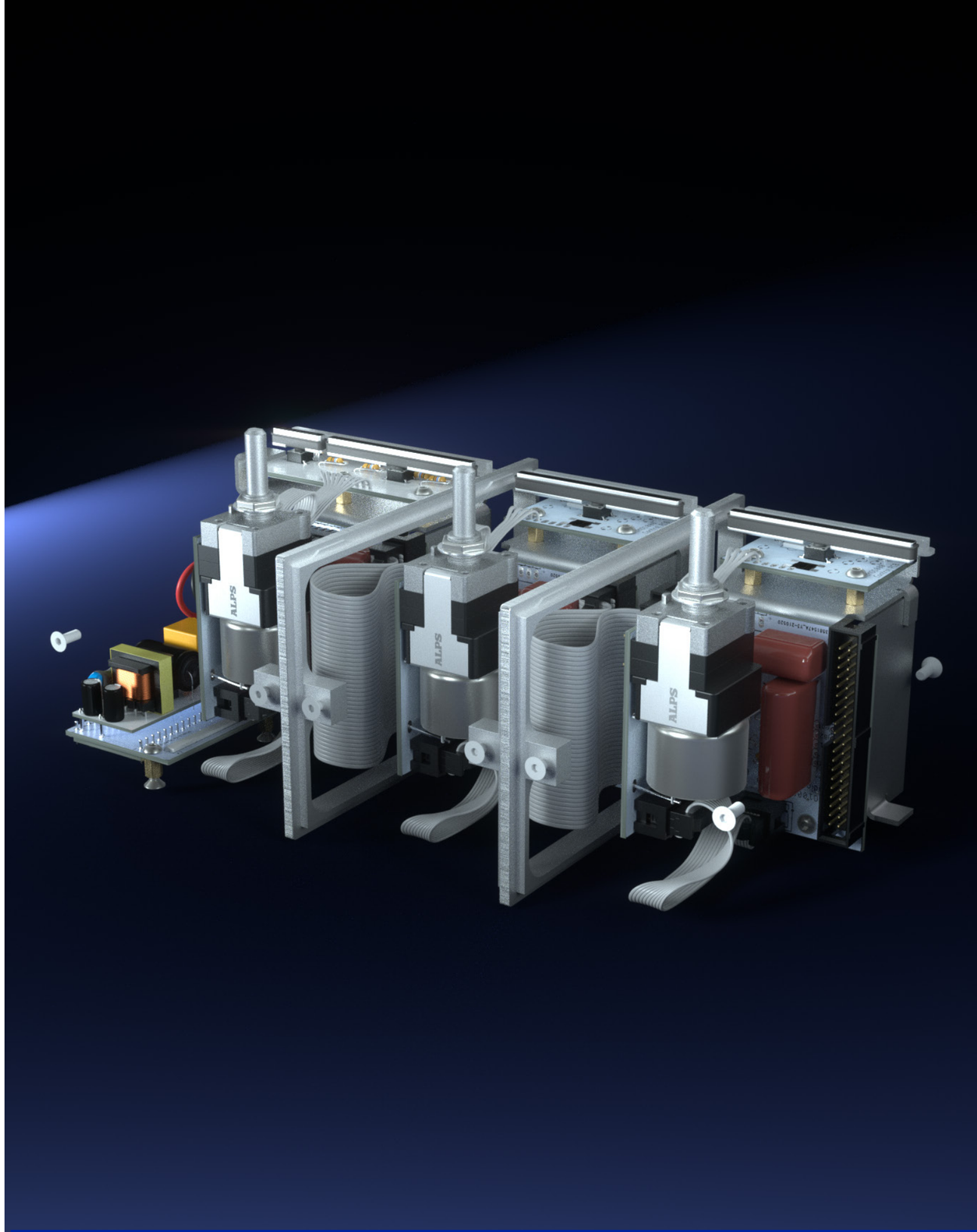


Fig. 43: Full "naked" assembly of IMO-2000, showcasing the internal electronics and connections.

ter channel, this board is slightly altered. It is longer in size, as to accommodate for the power button and an additional LED, for uniform light on the longer strip. All the more, it features 3 Infrared LEDs for remote control of 3rd party devices as well as an Infrared receiver.

POWER & LOGIC

This board is only used in the master module. It supports the AC/DC power converter as well as the ESP32 micro-controller. Secured to the main body with 6 screws and 3 standoffs.

BOARD TO BOARD CONNECTIONS

The connection between each audio channel module runs through a 40-core ribbon cable with insulation-displacement contact ends (IDC). The shrouded pin header of each board, in combination with the IDCs, prevent false connections and make assembly intuitive and fast. In the case of a broken cable, all parts are broadly available and very easy to repair at home without the use of any tools.

The Control PCB features a ribbon cable of 4 cores, soldered directly to the board. The cable plugs on the Audio I/O board via a pin connector. The additional components on the Master Control PCB require more communication connections so an 8-core ribbon cable is used instead.

Power Delivery is handled by an industry standard C13 connector. Internally, cables run by a hard switch and then connect to the Power & Logic PCB with a JST connector for easy and safe disassembly. None of the power cables is soldered to other components. Instead, spade connectors are used for all AC power connections, ensuring easy and fast disassembly. It should also be noted that the “Earth” cable of the C13 plug is connected to the housing of the console, something often required, in order to eliminate audible noise.

4.4. Sustainability in design

As mentioned in the previous section of Mechanical Engineering, the vast majority of parts are made out of aluminium. Aluminium was chosen for aesthetic reasons at first, but through evaluation was also proven to be a great option in terms of sustainability, especially when not virgin. Recycled aluminium of a minimum of 70% post-consumer scrap is used for the manufacturing of all aluminium components.

To further reduce the environmental impact, the majority of parts start off from aluminium profile extrusions. This way, the aluminium removed with machining is drastically reduced, minimizing energy use and wasted raw materials.

In terms of electronics, components of older technologies have been favoured for the simple reason of being easier to understand by a wider audience. The targeted audience is known for their hands-on approach and their will to repair when needed. By using components that are readily available to regular consumers while being manageable in size, the repairability of the entire circuit is improved. If not users themselves, regular technicians of a local repair shop can very easily pin-point issues and replace parts when needed.

Easily replacing the electronics would not be possible without the favourable means of assembly. As all parts are put together with screws, and more specifically, screws of the same head size, the only tool required for disassembly is a HEX screwdriver or a simple Allen key. Although two different types of screw heads are used, a flat and a countersunk head, the holes for each screw make it easy to visually differentiate the two. Conical holes receive countersunk screws, while flat holes receive flat head screws.

When two different parts require permanent fixation that is not possible with screws, creative solutions maintain the high level of sustainability. For example, the I/O sheet metal is spot welded to the rest of the frame. This way no new materials are introduced to the permanently fixed assembly. This way, the entire assembly of two parts can be directly recycled as a single aluminium piece. Furthermore, the webbing pull tag of the plug-ins is welded sonically to the plastic body. Ultrasonic welding is a great option as both pieces, even though drastically different in texture, are made out of the same raw material. Once again, recycling would not require separation.

In regards to plastics, while used in moderation, coloured plastics are favoured over black, so as to make identification easier and recycling more efficient. Unfortunately, black plastics are still being used on components of the electronic circuit. This is due to limited colour options of components from the manufacturer’s side.

4.5. Product Requirements Fulfilment Review

A retrospective evaluation of the final design shows that in most areas, the proposed design fulfils the product requirements. In total, two wishes can be marked as not fulfilled and a couple more that cannot be properly evaluated still.

It was stated that the device should offer some additional USB-C ports, so that users can plug in external devices for charging (Requirement no. 0105). Even though USB-C ports are implemented for the powering of the plug-ins, no additional ports have been implemented. This was mostly because of the complexity these ports would introduce to the overall assembly. Placing ports at the back would be easy, since there are already circuit boards mounted in that area, but that would offer limited usability due to awkward positioning for daily use. Placing ports in a more prominent position would most likely require additional PCBs and additional screws for fixation. This would increase complexity on the design and the screws would reduce the aesthetic appeal.

Furthermore, the rubber pads located at the bottom surface of each audio module are now made out of synthetic rubber foam. As a wish (Requirement no. 0904), those pads should have been made out of a biodegradable material. The decision to use regular foam rubber materials was based on the limited time available. Sourcing and testing more sustainable alternatives required time that was simply not available during this

project, as more crucial elements were of higher priority. Using synthetic foam rubber is a compromise and with further improvement, a better alternative can be used.

Finally, many industry safety standards are stated in the product requirements. Proper evaluation of their fulfilment is not possible as the designed device did not undergo any inspection.

4.6. Prototyping

Console

PCB Manufacturing & Assembly

Knowledge acquired during the analysis stages and while testing and prototyping with electronics, was ultimately combined in a complete circuit design. Using Autodesk's EAGLE, circuit schematics were turned into PCB designs. The designs were specifically build around components previously tested. This was an important step in making sure the components actually fit on the board but also helped develop the product architecture. By building component based circuit boards, it was also possible to visualise those PCBs in CAD software, making sure that the manufactured parts can fit and coexist with one another.

Gerber files of the PCBs were exported and delivered to JLC for manufacturing. The professionally manufactured PCBs were delivered from China and manually assembled with the pre-selected electrical components.

Fig. 44: Custom design circuit boards, ordered online, manufactured and shipped by JLC, in China.

Part manufacturing

The goal of the final prototyping process was to build a prototype as close to the real thing as possible. The design was developed to be as easy to manufacture as possible and this favoured prototyping to a great degree. Raw aluminium parts were used to create the final prototype. For the main frame pieces, extrusion profiles of the correct dimensions could be obtained but for the rest of the parts that required more complex shapes to begin with, solid blocks of aluminium were used as the starting point.

Based on milling-friendly technical drawings of the parts, each piece was manually machined, one by one. Despite being manually milled, the aluminium parts came as close as ±0,01 mm to the original design.

In the case of the volume knobs, a compromise had to be made due to the complex structure of small scale, required for the D shaped shaft. Instead of the original design, the prototyped knobs only have a flat bottom hole, fitted with 3D printed inserts that properly wrap around the potentiometer's shaft.

The I/O plate was cut to shape with a water-jet cutter. The cut pieces were engraved with the use of a specialised laser machine. Once cut and engraved, the pieces were folded manually to their final form. The small scale of the prototype made spot welding impossible with the available resources. Instead, the pieces were fitted on the main frame with epoxy resin.

The light strips were laser cut from a 3 mm sheet of semi-opaque, white acrylic. Unlike Injection moulding, laser cutting could not produce the needed wings and notches needed to snap fit the parts in place. As a

Fig. 45: Close-up of the fresh milled slots for the smart button and the light strip.

Fig. 46: Front view of the assembled IMO - 2000 prototype.

compromise, despite the tight fit, epoxy resin was used once again to ensure the light strips would not fall out of place.

The rest of the plastic parts of the audio modules were produced by SLA 3D printing. With proper post-printing treatment, the parts were fitted tightly between the main body and the aluminium buttons. Small amounts of epoxy resin were used here as well to counteract the fragility of the thin 3D prints.

When all the aluminium piece were properly machined, the entire assembly, as a whole, was given a surface finish. With all internal surfaces individually treated against stains and sharp edges, all the parts (apart from the knobs and buttons) were fitted together with screws, as intended. The whole assembly was then dragged against sanding papers of various grit. This resulted in an even and continuous surface and by pro-

Fig. 47: Early experimental assembly of a single audio module.

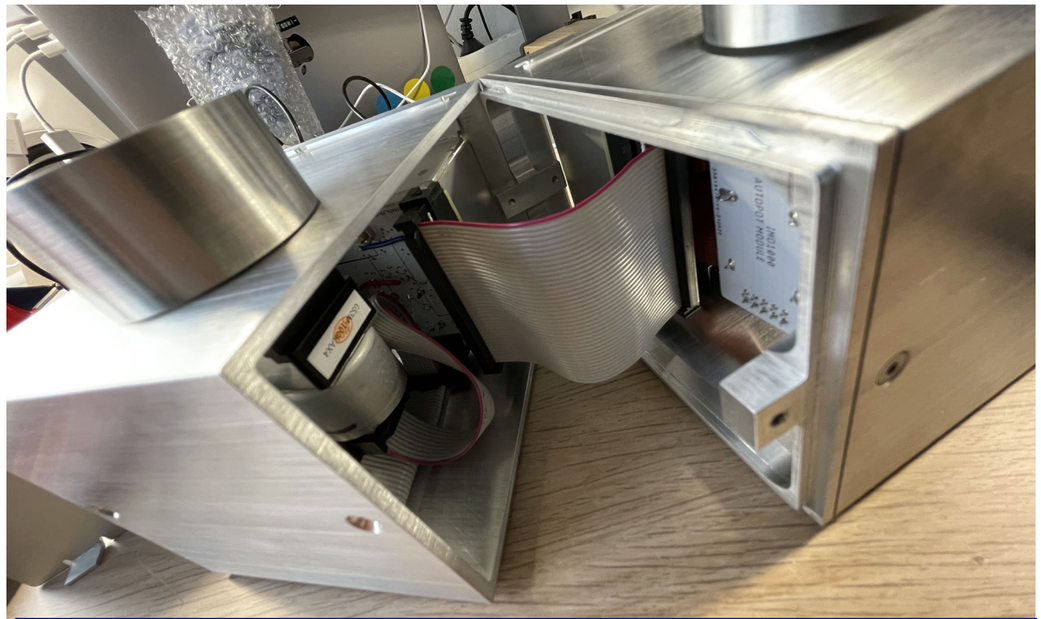


Fig. 48: Two audio modules wired together and about to be secured with each other with the help of the modular link.

Fig. 49: Aerial view of the IMO - 2000 prototype, in its "natural habitat".

gressively increasing the grit size, the body reached its final surface finish with a fine brushed look.

The circular brushed finish of the end plates and the knobs was done with the help of an industrial lathe machine. With the use of custom 3D printed toolings (see later section) the pieces were fitted to the lathe. While spinning, the parts were sanded with progressively increasing grit sizes, thus achieving the same surface finish as the rest of the parts but in a concentric pattern, instead of a linear.

Fig. 50: 3D printed and painted parts of the Bluetooth plug-in.

Bluetooth Plug-in

In addition to the main console and for proper demonstration purposed, a single plug-in was produced. The plastic body was printed out of PLA instead of the intended Nylon. The printed parts underwent multiple rounds of sanding while being covered in polyester putty. Once a clean and even surface was achieved, the parts received multiple layers or grey spray paint. A final layer of paint was sprayed from an unconventionally long distance. This helped create a surface grain similar to what is possible when using injection moulding.

Given that ultrasonic welding was not an available mean of assembly, a piece of webbing was screwed on the plastic piece that was fitted with M3 threaded brass inserts.

The two plastic parts making up the housing come together with self tapping screws made for plastic. The original design called for HEX screws with a head size identical to the one used by the console but such screws are hard to find in small batches. Instead, three self tapping Philips screws were used.

The electronics fitted inside the plug-in were less elaborate than those of the console. The connectors used, RCA and USB-C, were fixed on the plastic body by screwing and gluing respectively. The audio is produced by a bluetooth receiver of an older pair of headphones (Yamaha EPH-W32). The PCB of the headphones is connected to the USB and RCA connectors with soldered wires. The PCB is fitted with a lithium battery but it is essentially powered by the console, though the USB connection, because given the age of the PCB, the battery is unable to hold a charge for more than a couple of minutes.

Custom tooling Development

To make surface treatment precise and less time consuming, custom toolings were developed, allowing the fixation of the aluminium parts on a lathe machine. An expanding arbour designed to work in combination

with an M5 screw was used as a tight fitted axis for the volume knobs. With the arbour fitted tightly in the flat bottom hole of each knob, botch parts as a whole were fitted in the lathe, enabling easy and fast sanding.

Furthermore, a T shaped pieces was developed and printed for the proper fixation of the end plates on the lathe. With an M12 screw as the axis of rotation, the 3D printed part allowed the end plates to be secured safely, with the use of two M3 screws on the pre-threaded holes.

Finally, sheet metal bending dies were developed and 3D printed. Ultimately they were not used because better options were available, requiring less DIY trickery.

Fig. 51: Aerial view of the IMO - 2000 prototype, showcasing the Bluetooth plug-in and the webbing loop, used for cable management.

5. Reflection

5.1. Design for Manufacturing

Building a prototype as elaborate as the one detailed above was a very insightful process. The design was intended to be easy to manufacture and ultimately it was. Nevertheless, design flaws were uncovered through the process. Probably the most obvious one was the plastic inserts between the frame and the buttons. The wings intended for snap fitted placement, made the parts too brittle. Of course the fragility of a 3D printed part is much greater than that of an injection moulded part, but in any case, it is something that requires improvement. The way the plastic inserts are fitted in the slots, allows them to take advantage of the elasticity of the plastic. A design were the part only has small notches that grip around the frame, instead of entire wings, could very well function much better, as the aluminium button is essentially keeping the plastic insert relatively fixed.

Further improvement is also needed in the overall manufacturing tolerances. Most parts were too hard to actually fit together, mostly because of the low tolerances of the commercially available extrusion profiles. The main frame was build out of aluminium extrusion profiles that did not have a consistent or accurate size. Small variations of as little as 0,1 mm can make the parts incompatible. Even though that can be fixed on a prototyping level, it is not something acceptable for a streamlined production line. Alterations would have to be made either on the sitting tolerance of the milled parts, or the main frame would need to be milled to more precise dimensions.

5.2. Improvement suggestions

Electronics

As much as I wish I could say that everything if perfect, it is not. A lot of effort was put into creating a holistic design. From manufacturing, to user interface, all the way to circuit board design. Areas of expertise vastly different from one another. Naturally, the depth of knowledge cannot be equal on all of them. In particular, the area of electronics and circuit design, was probably the weakest.

The circuit boards designed for this project might work on a prototyping level, but it is rather obvious that they not in fact flawless. Lack of knowledge on the topic makes proper evaluation impossible. It is common sense that a trained professional should evaluate and develop the electronics further.

That being said, there are some aspect that can be pointed out as problematic, both from an electronics point of view, but also from a user's standpoint. First and foremost, the circuit that was designed and embodied in the PCB has a fatal flaw. While controlling the volume of a single channel works just fine, as soon as a second audio input is implemented in the circuit, the 2 channels

start to interfere with one another. Altering the volume on, say, channel no. 2, ultimately affects the loudness of channel no.1 as well. This is obviously not intended and most importantly, it is not acceptable.

Furthermore, the motorised potentiometers used in the design do not offer the best experience. The motors are rather slow and adjusting the volume wirelessly is not as instant as one would hope. In addition, the logarithmic scale they use is not matched in the digital space of a smartphone, creating a misaligned interface.

Another pretty obvious remark is the use of an ESP-32 micro-controller. As great as they are for prototyping, they are not reliable enough to be included in a commercial product. Especially a smart, Wi-Fi reliant product.

Mechanical engineering & Aesthetics

Speaking of aesthetics, one can say that the design in never finished. The same applies to this design. As said before, immense effort was put into this project over the span of the 20 weeks, but it was still not enough to explore all possibilities, especially when considering the capacity of a single person.

A possibly valuable idea concerns the overall assembly. Removing the screws from the front face of the device all together and simply relying on a different fastening method, could improve aesthetics as well as ease of assembly and disassembly. In more detail, an alternative design could utilise a fitted notch a the front of each aluminium piece and a self tightening mechanism at the back. This would reduce the amount of screws to half of what is currently used and could potentially improve aesthetics.

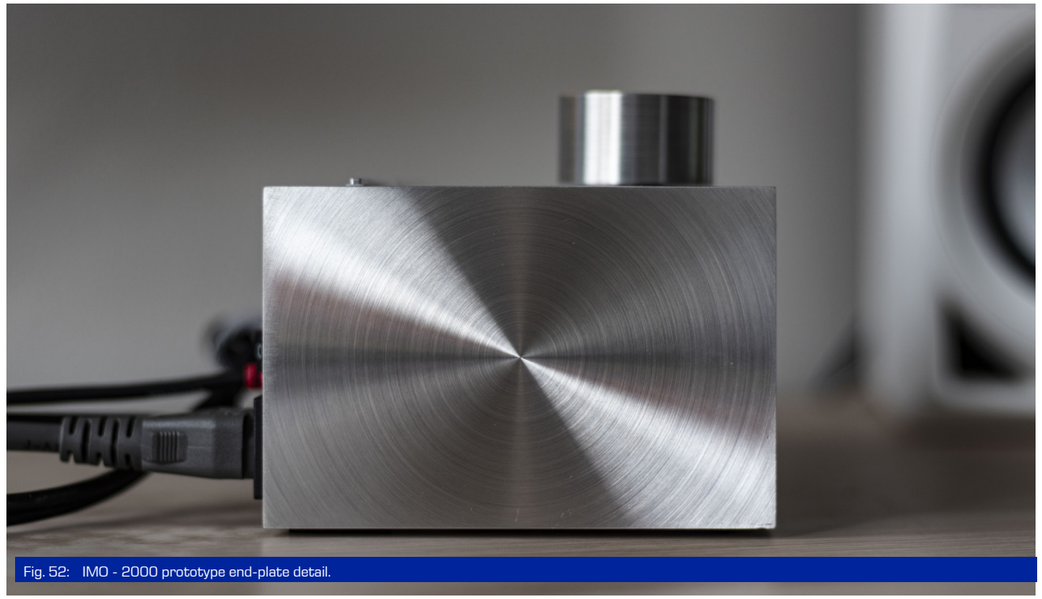


Fig. 52: IMO - 2000 prototype end-plate detail.

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7. Appendix

Music Gear Survey

Hello and thank you for taking the time to contribute to this research.

My name is Dimitrios and I am currently doing my Master's in Integrated Product Design, at the Delft University of Technology in the Netherlands. This Survey will contribute to my Thesis, which concerns the design of a smart and sustainable device, for the household of a modern audio enthusiast.

In order to design something truly valuable, I need to know more about your needs and desires. The information you choose to share with this survey will be used anonymously, as a guide, during the development and design process. In case of any future publications, any personal information you share, will be excluded and kept private.

Your answers to this questionnaire will under no circumstances be sold or shared with a third party. Information that can be linked to you directly (such as email), will be deleted after the completion of thi project (estimated, July 2021).

For any questions or concerns, please feel free to reach out to me at D.Seleridis@student.tudelft.nl

* Required

Estimated duration: 5-7 min

Let's talk demographics

1. What age group do you belong to? *

Mark only one oval.

- ◯ Under 12 years old
- ◯ 12-17 years old
- ◯ 18-24 years old
- ◯ 25-34 years old
- ◯ 35-44 years old
- ◯ 45-54 years old
- ◯ 55-64 years old
- ◯ 65-74 years old
- ◯ 75 years or older

2. What gender do you identify as? *

Mark only one oval.

- ◯ Female
- ◯ Male
- ◯ Other

3. What is your level of education? *

Mark only one oval.

- ◯ No schooling completed
- ◯ Nursery school to 8th grade
- ◯ Some high school, no diploma
- ◯ High school graduate, diploma or the equivalent (for example: GED)
- ◯ Some college credit, no degree
- ◯ Trade/technical/vocational training
- ◯ Associate degree
- ◯ Bachelor's degree
- ◯ Master's degree
- ◯ Professional degree
- ◯ Doctorate degree

Skip to question 4

What's your connection with audio?

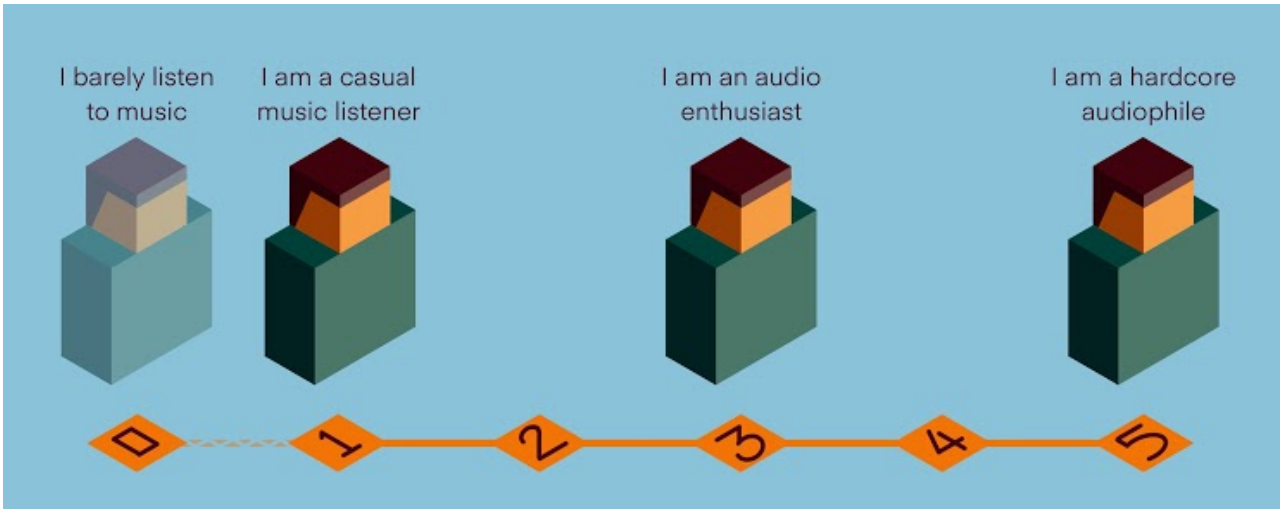
In order to properly evaluate your input, I need to know where you fall in the expertise spectrum.

A Casual music listener is someone that enjoys music but is not picky about music equipment. A loud laptop speaker will do just fine.

An audio enthusiast is someone that has certain opinions about their equipment and they can distinguish good quality systems. They like good sound quality but they don't care about the technical details.

A hardcore audiophile is someone that is so knowledgable and opinionated about music equipment that they end up making their own.

4. Which category fits you best? *



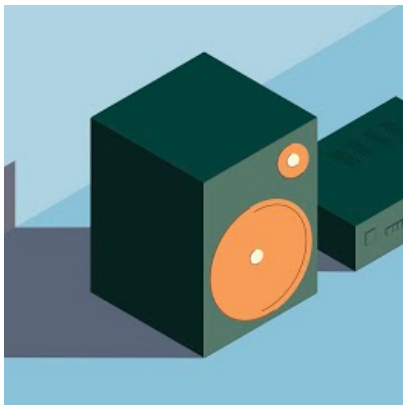
Mark only one oval.

- 0. I barely listen to music *Skip to question 30*
- 1. Casual Music Listening
- 2.
- 3. Audio Enthusiast
- 4.
- 5. Hardcore Audiophile

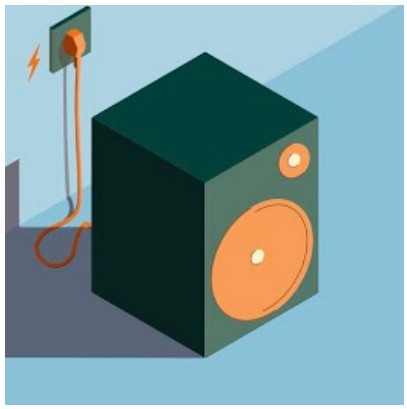
Let's talk about your music setup!

5. What is your primary, music listening speaker? *

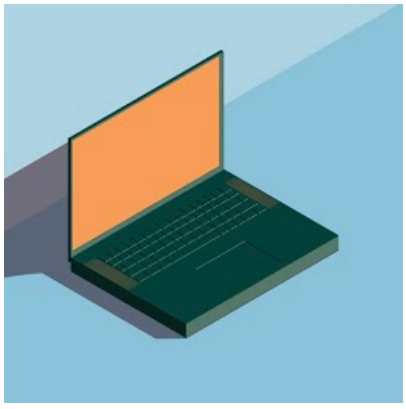
Mark only one oval.



Passive Speaker set (additional Amplifier required)



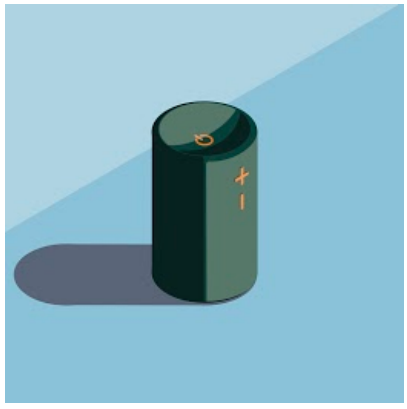
Active Speaker set (self-Amplified)



Laptop / PC / Smartphone Integrated Speakers

Headphones

Tethered Wireless Speaker (Possibly smart)



Portable Wireless Speaker (Possibly smart)

6. What is the estimated value of the speaker system you use? *

Preferably in Euros (€). If the system was passed on to you free of charge (gift, giveaway, etc.), please try to estimate value.

_____

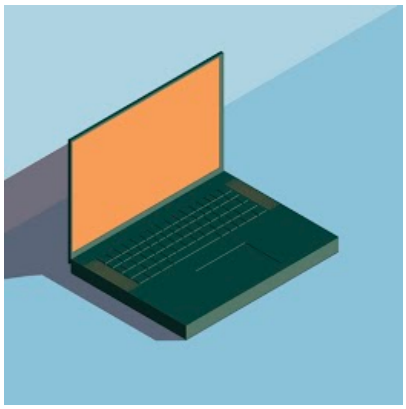
7. How old is the speaker system you use? *

Please indicate in years. (Approximately)

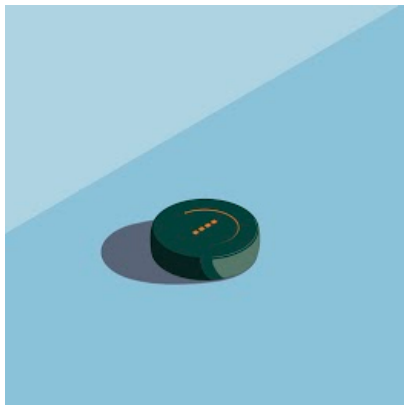
_____

8. Select all additional devices that have an active role in your current setup. *

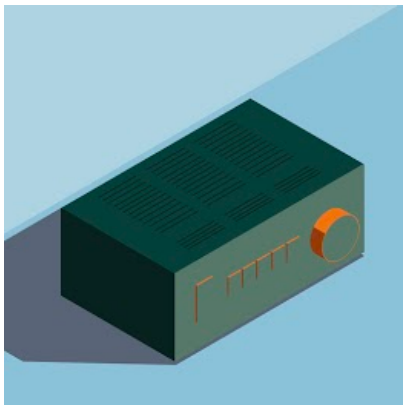
Check all that apply.



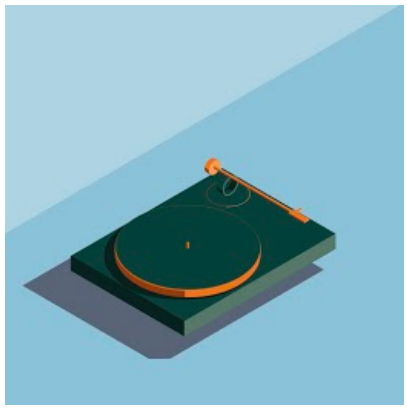
☐ Laptop / PC / Smartphone / iPod



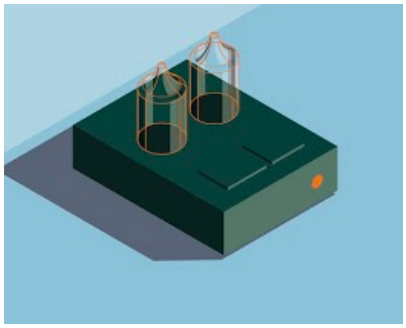
☐ Virtual Assistant Hub (e.g. Amazon Echo Input)

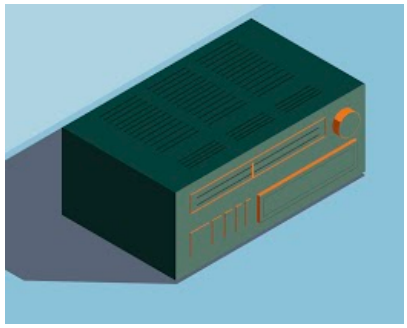


☐ Amplifier



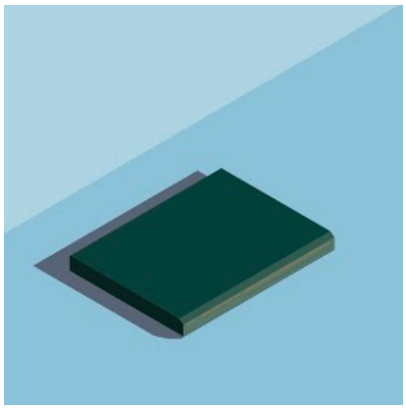
☐ Turntable

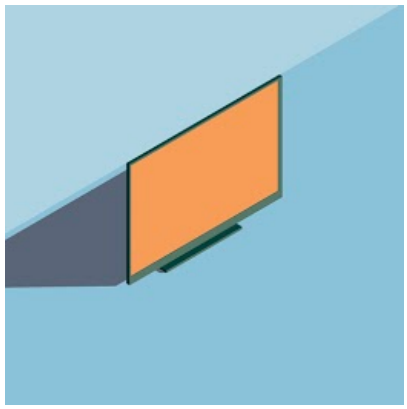




☐ Phono Pre-Amp (Stand alone, not integrated in the Turntable or Amplifier)

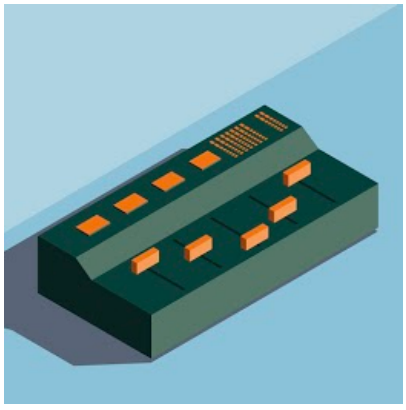
☐ Radio, CD, Cassette Player

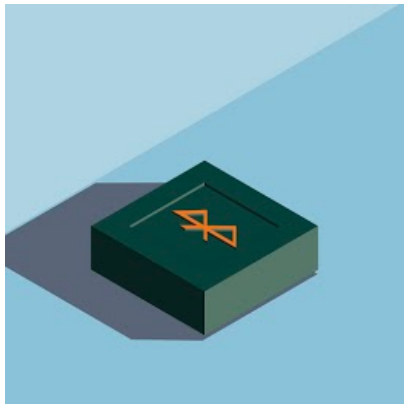




☐ Home Cinema, DVD, BluRay

☐ TV





☐ Audio Mixer

☐ Wireless Receiver (e.g. Bluetooth, AirPlay)

Other: ☐ _____

9. In total, how many individual devices do you use as audio sources? *

For example, if you use a Laptop, a Turntable and a Bluetooth receiver, the correct response would be 3 (three).

_____

10. What is the oldest piece of equipment in your setup? *

_____

11. How old is the oldest piece of equipment in your setup? (rough estimation in years) *

_____

12. What is the newest piece of equipment in your setup? *

_____

13. How old is the newest piece of equipment in your setup? (rough estimation in years) *

_____

Cables and Input Ports

14. How do you connect all of your inputs to your speakers? *

Mark only one oval.

- ◯ I use an audio mixer *Skip to question 15*
- ◯ I use cable splitters to create more input ports *Skip to question 19*
- ◯ I switch input cables every time *Skip to question 19*
- ◯ My speaker/Amp has enough inputs to support all of my sources *Skip to question 19*
- ◯ Wirelessly (e.g. Bluetooth) *Skip to question 19*
- ◯ Other: _____

Music Mixers

15. What kind of music mixer do you use? *

Mark only one oval.

- ◯ DJ Mixer
- ◯ Music Production Mixer
- ◯ Live Performance Mixer (Support for Mic and Instruments)
- ◯ Passive Audio Hub
- ◯ Other: _____

16. If possible, Please indicate the model of your mixer: *

_____

17. How many inputs does your mixer support? *

_____

18. What is the estimated market value of your mixer? *

Preferably in Euros (€). If the mixer was passed on to you free of charge (gift, giveaway, etc.), please try to estimate value.

_____

Turntable

19. Do you use a turntable? *

Mark only one oval.

- ◯ Yes *Skip to question 20*
- ◯ No *Skip to question 22*

Phono Stage

Any Turntable requires a phono stage / phone pre-amplifier. I would like to know more about yours!

20. What kind of Phono Stage do you use? *

Mark only one oval.

- ◯ Stand alone
- ◯ Integrated (in a Mixer or Amplifier)
- ◯ Integrated (in the Turntable itself)
- ◯ I don't know
- ◯ Other: _____

21. What is the estimated value of your Phono Stage? *

Preferably in Euros (€). If the Phono Stage was passed on to you free of charge (gift, giveaway, etc.), please try to estimate its value. If you use an integrated one, please enter 0 (zero).

_____

Purchasing habits

22. When purchasing a new music related device, please rate the importance of the different aspects below. *

Mark only one oval per row.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Brand Name	◯	◯	◯	◯	◯
Features	◯	◯	◯	◯	◯
Performance	◯	◯	◯	◯	◯
Design / Aesthetic	◯	◯	◯	◯	◯
Build Quality	◯	◯	◯	◯	◯
Price	◯	◯	◯	◯	◯

Getting rid of devices.

23. Have you ever had to get rid of music gear? *

For example dispose, sell or giveaway an audio related device.

Mark only one oval.

◯ Yes *Skip to question 24*

◯ No *Skip to question 27*

Let's talk device after life!

24. What kind of device did you get rid of? *

Feel free to enter multiple devices.

_____

25. What did you do with your device? *

Mark only one oval.

- ◯ Disposed it in the trash
- ◯ Disposed it at a recycling point
- ◯ Sold it to a reselling/refurbishing store
- ◯ Sold it to an individual
- ◯ Gave it away for free
- ◯ Up-cycled it and/or used it for spare parts
- ◯ Other: _____

26. What was the reason you got rid of it? *

Mark only one oval.

- ◯ I needed the money
- ◯ It was broken
- ◯ It was taking too much space
- ◯ I had no use for it in my set-up
- ◯ I got a better replacement/upgrade

Thank you for taking part in this survey

Developing a product is a time consuming process that requires constant rounds of feedback from futur users and experts. As you can imagine, doing such work during a pandemic brings along great challenge and there is always the possibility that more questions come up in the future. If you think you may be available to answer more questions or maybe even have an informal interview/chat, please be so kind and share your contact details below.

27. Name

Just your First Name is enough!

_____

28. Email address

29. This is your last chance to share any thought you may have on the topic.

Thank you for taking part in this survey

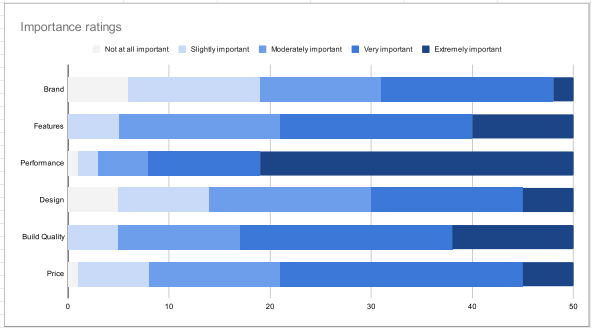
It looks like we already have enough responses from people like you! Nevertheless, thank you for partaking.

30. If there is anything you wish to share with us, feel free to do so :)

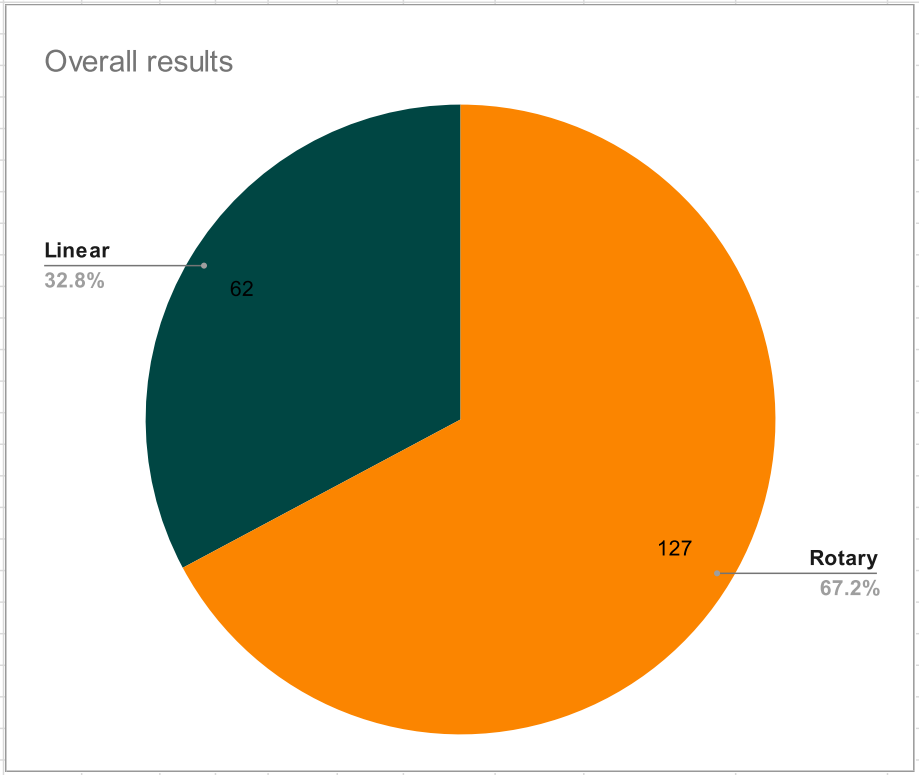
Timestamp	What age group do you be	What gender do you identi	What is your level of educ	What is your country of re	Which category fits you bi	What is your primary, music listening sp	What is the estimated value of the speaker	How old is the speaker sy	Select all additional devices that have an active role in your current setup.
2/18/2021 14:14:47	25-34 years old	Male	Master's degree	Netherlands	3	Active Speaker set (self-Amplified)	€160	3	Laptop / PC / Smartphone / iPod, Turntable, Audio Mixer, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/18/2021 14:48:41	25-34 years old	Male	Master's degree	Belgium	1	Headphones	€200	2	Laptop / PC / Smartphone / iPod
2/18/2021 15:02:45	25-34 years old	Male	Some high school, no dip	Greece	3	Active Speaker set (self-Amplified)	€500	7	Laptop / PC / Smartphone / iPod, Turntable, Radio, CD, Cassette Player, Audio Mixer
2/18/2021 15:05:30	25-34 years old	Male	Master's degree	Greece	3	Active Speaker set (self-Amplified)	€360	4	Laptop / PC / Smartphone / iPod, Turntable, Audio Mixer
2/18/2021 15:34:05	18-24 years old	Male	Bachelor's degree	Netherlands	4	Headphones	€400	3	Laptop / PC / Smartphone / iPod, Virtual Assistant Hub (e.g. Amazon Echo Input), Wireless Receiver (e.g. Bluetooth, AirPlay)
2/18/2021 15:40:57	25-34 years old	Female	Bachelor's degree	Greece	1	Active Speaker set (self-Amplified)	€250	4	Laptop / PC / Smartphone / iPod, TV
2/18/2021 15:43:13	35-44 years old	Male	Bachelor's degree	Japan	3	Passive Speaker set (additional Amplifi	€500	5	Amplifier, Radio, CD, Cassette Player
2/18/2021 15:53:45	12-17 years old	Male	High school graduate, dip	Sweden	3	Headphones	€100	3	Laptop / PC / Smartphone / iPod
2/18/2021 15:53:46	45-54 years old	Male	Bachelor's degree	United States	3	Active Speaker set (self-Amplified)	€35	1	Laptop / PC / Smartphone / iPod, Amplifier, TV
2/18/2021 15:58:45	25-34 years old	Female	Master's degree	Greece	3	Headphones	€150	3	Laptop / PC / Smartphone / iPod, TV, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/18/2021 16:11:51	25-34 years old	Male	Some college credit, no d	Japan	4	Passive Speaker set (additional Amplifi	€500	1	Laptop / PC / Smartphone / iPod, Amplifier, Radio, CD, Cassette Player, Audio Mixer, DACs
2/18/2021 16:12:01	45-54 years old	Male	Professional degree	India	3	Passive Speaker set (additional Amplifi	€900	0.5	Laptop / PC / Smartphone / iPod, Virtual Assistant Hub (e.g. Amazon Echo Input), Radio, CD, Cassette Player, Home Cinema, DVD, BluRay, TV, Wireless Receiver (e.g. Bluetooth, AirPlay), AVR
2/18/2021 16:17:10	25-34 years old	Male	Bachelor's degree	Netherlands	4	Passive Speaker set (additional Amplifi	€600	4	Amplifier, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/18/2021 16:19:23	25-34 years old	Male	Bachelor's degree	Malaysia	4	Active Speaker set (self-Amplified)	€2,000	2	Laptop / PC / Smartphone / iPod
2/18/2021 16:20:53	18-24 years old	Female	Bachelor's degree	Netherlands	2	Tethered Wireless Speaker (Possibly s	€150	2	Laptop / PC / Smartphone / iPod
2/18/2021 16:26:29	25-34 years old	Male	Master's degree	Belgium	4	Passive Speaker set (additional Amplifi	€2	35	Amplifier, Turntable, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/18/2021 16:31:21	25-34 years old	Male	Professional degree	Canada	5	Passive Speaker set (additional Amplifi	€5,000	15	Amplifier, Turntable, Phono Pre-Amp (Stand alone, not integrated in the Turntable or Amplifier), Radio, CD, Cassette Player, TV, Wireless Receiver (e.g. Bluetooth, AirPlay), Power conditioner; subwoofers
2/18/2021 16:38:46	65-74 years old	Male	Associate degree	United States	3	Passive Speaker set (additional Amplifi	€580	4	Virtual Assistant Hub (e.g. Amazon Echo Input), Amplifier, Radio, CD, Cassette Player, Home Cinema, DVD, BluRay, TV
2/18/2021 16:45:27	25-34 years old	Male	Some college credit, no d	Netherlands	4	Passive Speaker set (additional Amplifi	€2,500	8	Amplifier, Turntable, Radio, CD, Cassette Player
2/18/2021 16:49:27	25-34 years old	Male	Some college credit, no d	Mexico	4	Active Speaker set (self-Amplified)	€100	1	Turntable, Audio Interface
2/18/2021 16:49:54	18-24 years old	Male	High school graduate, dip	United Arab Emirates	4	Passive Speaker set (additional Amplifi	€1,600	6	Amplifier, Turntable, Radio, CD, Cassette Player, Home Cinema, DVD, BluRay, TV
2/18/2021 16:58:31	25-34 years old	Male	Master's degree	Netherlands	3	Passive Speaker set (additional Amplifi	€1,000	42	Laptop / PC / Smartphone / iPod, Amplifier, Turntable, Radio, CD, Cassette Player, TV, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/18/2021 17:10:05	35-44 years old	Male	Master's degree	United States	2	Passive Speaker set (additional Amplifi	€500	1	Laptop / PC / Smartphone / iPod, Amplifier, Turntable, Phono Pre-Amp (Stand alone, not integrated in the Turntable or Amplifier), Home Cinema, DVD, BluRay, TV
2/18/2021 17:10:11	35-44 years old	Male	Bachelor's degree	United States	4	Passive Speaker set (additional Amplifi	€497	1	Laptop / PC / Smartphone / iPod, Amplifier, Radio, CD, Cassette Player, Home Cinema, DVD, BluRay, TV, DAC
2/18/2021 17:18:07	12-17 years old	Male	Some high school, no dip	United States	3	Headphones	€50	0.5	Laptop / PC / Smartphone / iPod
2/18/2021 17:32:39	45-54 years old	Male	Bachelor's degree	Canada	4	Passive Speaker set (additional Amplifi	€1,000	20	Amplifier, Turntable, Phono Pre-Amp (Stand alone, not integrated in the Turntable or Amplifier), Radio, CD, Cassette Player
2/18/2021 17:37:11	45-54 years old	Male	Bachelor's degree	Estonia	3	Passive Speaker set (additional Amplifi	€12,000	3	Laptop / PC / Smartphone / iPod, Virtual Assistant Hub (e.g. Amazon Echo Input), Amplifier, TV, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/18/2021 17:41:32	45-54 years old	Male	Doctorate degree	United States	4	Passive Speaker set (additional Amplifi	€800	2	Laptop / PC / Smartphone / iPod, Amplifier
2/18/2021 17:54:53	25-34 years old	Male	Bachelor's degree	United States	3	Passive Speaker set (additional Amplifier required)		3	Amplifier, TV
2/18/2021 18:14:10	45-54 years old	Male	Bachelor's degree	United States	4	Passive Speaker set (additional Amplifi	€900	31	Turntable, Radio, CD, Cassette Player, TV, Xbox
2/18/2021 18:46:56	55-64 years old	Male	Trade/technical/vocationa	South Africa	3	Headphones	€150	2	Laptop / PC / Smartphone / iPod, Amplifier, Turntable, Radio, CD, Cassette Player, Reel-to-Reel Tape Player
2/18/2021 21:31:16	45-54 years old	Male	Master's degree	France	4	Passive Speaker set (additional Amplifi	€8,000	6	Laptop / PC / Smartphone / iPod, Devialet 220 (integrated renderer/DAC/preamp and amplifier)
2/18/2021 22:11:07	25-34 years old	Female	Master's degree	Netherlands	1	Laptop / PC / Smartphone Integrated S	€2,000	1.5	Laptop / PC / Smartphone / iPod, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/18/2021 22:19:55	35-44 years old	Male	Master's degree	Germany	3	Headphones	€600	6	Laptop / PC / Smartphone / iPod, Virtual Assistant Hub (e.g. Amazon Echo Input), Amplifier, TV
2/18/2021 23:17:13	45-54 years old	Male	Master's degree	Norway	3	Passive Speaker set (additional Amplifi	€400	20	Amplifier, Turntable, Radio, CD, Cassette Player
2/19/2021 12:42:47	45-54 years old	Male	Master's degree	Netherlands	3	Passive Speaker set (additional Amplifi	€750	18	Laptop / PC / Smartphone / iPod, Amplifier, Turntable, Phono Pre-Amp (Stand alone, not integrated in the Turntable or Amplifier), Home Cinema, DVD, BluRay, TV, Wireless Internet Radio's, Raspberry Pi's, Smartphones/tablets
2/19/2021 13:35:36	35-44 years old	Male	Master's degree	Greece	4	Passive Speaker set (additional Amplifi	€1,500	10	Amplifier, Turntable, Phono Pre-Amp (Stand alone, not integrated in the Turntable or Amplifier), TV, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/19/2021 13:40:06	25-34 years old	Male	Master's degree	Greece	5	Passive Speaker set (additional Amplifi	€500	1	Phono Pre-Amp (Stand alone, not integrated in the Turntable or Amplifier)
2/19/2021 13:47:58	35-44 years old	Male	Bachelor's degree	Greece	3	Headphones	€140	1	Laptop / PC / Smartphone / iPod
2/20/2021 5:15:21	25-34 years old	Male	Some college credit, no d	United States	3	Headphones	€550	4	Laptop / PC / Smartphone / iPod
2/21/2021 14:53:03	25-34 years old	Female	Master's degree	Greece	2	Headphones	€50	0.2	Laptop / PC / Smartphone / iPod, Radio, CD, Cassette Player, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/22/2021 10:56:13	25-34 years old	Male	Master's degree	Netherlands	4	Active Speaker set (self-Amplified)	€550	5	Laptop / PC / Smartphone / iPod, Turntable, TV, Audio Mixer, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/22/2021 16:26:01	25-34 years old	Male	Bachelor's degree	Greece	5	Active Speaker set (self-Amplified)	€800	5	interface, pc, preamplifiers, compressors, headphones preamp.
2/22/2021 19:29:17	25-34 years old	Male	Master's degree	Netherlands	3	Active Speaker set (self-Amplified)	€500	2	Laptop / PC / Smartphone / iPod, Turntable, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/22/2021 19:39:42	25-34 years old	Male	Master's degree	Italy	3	Headphones	€100	0	Laptop / PC / Smartphone / iPod
2/23/2021 10:38:41	25-34 years old	Male	Master's degree	Italy	3	Tethered Wireless Speaker (Possibly s	€600	2	Laptop / PC / Smartphone / iPod, Wireless Receiver (e.g. Bluetooth, AirPlay)
2/23/2021 11:08:29	25-34 years old	Male	High school graduate, dip	Italy	5	Active Speaker set (self-Amplified)	€500	10	Laptop / PC / Smartphone / iPod, Turntable, Radio, CD, Cassette Player, Audio Mixer
2/23/2021 11:16:42	25-34 years old	Male	High school graduate, dip	Italy	3	Active Speaker set (self-Amplified)	€40	5	Laptop / PC / Smartphone / iPod
2/23/2021 12:44:11	25-34 years old	Male	Master's degree	Italy	4	Portable Wireless Speaker (Possibly s	€100	1	Laptop / PC / Smartphone / iPod
3/2/2021 19:22:13	25-34 years old	Male	Bachelor's degree	United States	4	Headphones	€300	5	Laptop / PC / Smartphone / iPod, Amplifier, Audio Mixer
5/15/2021 8:38:28	55-64 years old	Male	Bachelor's degree	United States	3. Audio Enthusiast	Active Speaker set (self-Amplified)	91 euros	1	Laptop / PC / Smartphone / iPod, Wireless Receiver (e.g. Bluetooth, AirPlay)
							€1,050		
							1005.088095		Average of target audience
								TV	34.00%
								Turntable	40.00%
								External preamo	0.3

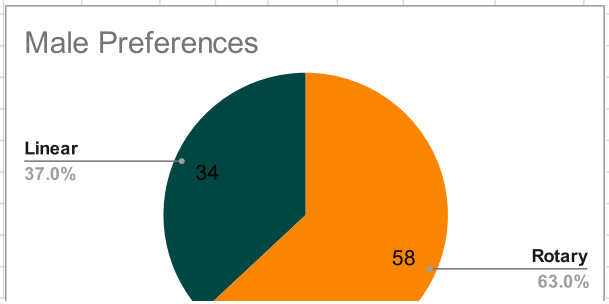
In total, how many individ	What is the oldest piece of	How old is the oldest piec	What is the newest piece of equipm	How old is the newest pie	How do you connect all of	What kind of music mixer	If possible, Please indicat	How many inputs does you	What is the estimated mar	Do you use a turntable?	What kind of Phono Stage	What is the estimated valu	When purchasing a new music re	When purchasing a new r	When purchasing a new r	When purchasing a new r	When purchasing a new r	When purchasing a new r
3	40		2		I use an audio mixer	DJ Mixer	Allen & Heath Xone 23	4	260	Yes	Integrated (in a Mixer or A	0	Extremely important	Extremely important	Extremely important	Very important	Very important	Very important
5	desktop speakers	10	sony airpods	0.4	I switch input cables every time					No			Slightly important	Extremely important	Extremely important	Very important	Very important	Very important
4	cassette player	45	laptop	1	I use an audio mixer	DJ Mixer	Native Instruments Trakto	4	500	Yes	Integrated (in a Mixer or A	0	Slightly important	Very important	Extremely important	Very important	Very important	Very important
2	turntable	5	audio mixer	1	I use an audio mixer	DJ Mixer	Numark	2	100	Yes	Integrated (in the Turntabl	0	Very important	Moderately important	Very important	Moderately important	Moderately important	Extremely important
3	Headphones	4	Google home max	2	I switch input cables every time					No			Very important	Moderately important	Extremely important	Very important	Very important	Slightly important
2	laptop	8	Active Speaker set (self-Amplified)	4	bluetooth					No			Very important	Moderately important	Very important	Very important	Slightly important	Very important
2	amp	5	iphone	1	My speaker/Amp has enough	inputs to support all of my sources				No			Moderately important	Very important	Very important	Extremely important	Extremely important	Very important
2	Headphones	3	PC	1	Wirelessly (e.g. Bluetooth)					No			Very important	Slightly important	Extremely important	Very important	Moderately important	Very important
5	Macbook	5	Speaker	1	My speaker/Amp has enough	inputs to support all of my sources				No			Slightly important	Moderately important	Slightly important	Moderately important	Moderately important	Very important
4	Headphones	3	laptop	1	I switch input cables every time					No			Very important	Moderately important	Very important	Extremely important	Moderately important	Very important
4	Amp	1	PC	0.1	I use an audio mixer	Passive Audio Hub	Generic RCA	8	15	No			Slightly important	Moderately important	Moderately important	Not at all important	Slightly important	Slightly important
3	STB	3	Speakers	0.5	My speaker/Amp has enough	inputs to support all of my sources				No			Moderately important	Very important	Extremely important	Moderately important	Very important	Slightly important
1	Chromecast audio	5	q acoustic 3030i	1	My speaker/Amp has enough	inputs to support all of my sources				No			Slightly important	Very important	Extremely important	Moderately important	Very important	Very important
1	Sennheiser Hd 598	5	Singxer SU-6	1	My speaker/Amp has enough	inputs to support all of my sources				No			Not at all important	Moderately important	Moderately important	Slightly important	Moderately important	Moderately important
2	speakers	2	laptop	1	Wirelessly (e.g. Bluetooth)					No			Moderately important	Very important	Very important	Very important	Moderately important	Very important
6	speakers	35	Player/streamer	1	My speaker/Amp has enough	inputs to support all of my sources				Yes	Integrated (in a Mixer or A	0	Very important	Moderately important	Very important	Very important	Extremely important	Very important
2	Power conditioner	30	Raspberry Pi	2	My speaker/Amp has enough	inputs to support all of my sources				Yes	Stand alone	200	Very important	Slightly important	Extremely important	Moderately important	Extremely important	Slightly important
5	25	25	1	1	My speaker/Amp has enough	inputs to support all of my sources				No			Very important	Extremely important	Extremely important	Very important	Very important	Moderately important
3	Amp	10	Turntable	7	My speaker/Amp has enough	inputs to support all of my sources				Yes	Integrated (in a Mixer or A	0	Moderately important	Very important	Extremely important	Moderately important	Extremely important	Moderately important
2	My PC	3	My interface	0.25	My speaker/Amp has enough	inputs to support all of my sources				Yes	Integrated (in the Turntabl	0	Moderately important	Moderately important	Extremely important	Not at all important	Very important	Extremely important
5	Book shelf Speaker	12	Av receiver	1	My speaker/Amp has enough	inputs to support all of my sources				Yes	Integrated (in a Mixer or A	250	Very important	Extremely important	Extremely important	Very important	Extremely important	Moderately important
4	amplifier	42	DAC	1	My speaker/Amp has enough	inputs to support all of my sources				Yes	Integrated (in a Mixer or A	0	Slightly important	Moderately important	Extremely important	Very important	Very important	Very important
3	TV	10	AVR	1	My speaker/Amp has enough	inputs to support all of my sources				Yes	Stand alone	150	Moderately important	Very important	Very important	Moderately important	Very important	Moderately important
3	TCL Roku TV	2	Audiolab 6000CDT	0	DAC has switchable inputs, and amplifier has additional input analog input for future turntable.					No			Slightly important	Moderately important	Extremely important	Slightly important	Very important	Very important
2	My headphones	0.5	The phone I listen to	0.2	My speaker/Amp has enough	inputs to support all of my sources				No			Slightly important	Moderately important	Moderately important	Slightly important	Slightly important	Moderately important
2	Turntable (1979)	40	Phone pre-amp	3	My speaker/Amp has enough	inputs to support all of my sources				Yes	Stand alone	600	Slightly important	Moderately important	Extremely important	Moderately important	Very important	Very important
4	Amplifier	6	Pi-streamer	1	My speaker/Amp has enough	inputs to support all of my sources				No			Not at all important	Extremely important	Extremely important	Slightly important	Very important	Very important
2	valve amp	60	Speakers	2	My speaker/Amp has enough	inputs to support all of my sources				No			Moderately important	Extremely important	Extremely important	Moderately important	Extremely important	Extremely important
3	Amplifier	4	Center Channel	1	My speaker/Amp has enough	inputs to support all of my sources				No			Very important	Very important	Extremely important	Very important	Very important	Moderately important
3	Turntable 1986	35	TV	2	My speaker/Amp has enough	inputs to support all of my sources				Yes	Integrated (in a Mixer or A	0	Very important	Very important	Slightly important	Extremely important	Very important	Very important
6	Turntable	36	PC	2	My speaker/Amp has enough	inputs to support all of my sources				Yes	Integrated (in a Mixer or A	0	Moderately important	Extremely important	Extremely important	Extremely important	Extremely important	Moderately important
2	Devialet	7	Speakers	6	Network					No			Not at all important	Very important	Extremely important	Moderately important	Very important	Moderately important
2	Laptop	1.5	bluetooth speaker	1	Wirelessly (e.g. Bluetooth)					No			Slightly important	Slightly important	Not at all important	Moderately important	Slightly important	Not at all important
4	TV	10	Android TV set-top box	5	My speaker/Amp has enough	inputs to support all of my sources				No			Slightly important	Very important	Very important	Slightly important	Very important	Very important
1	LP-player	44	Amplifier	4	My speaker/Amp has enough	inputs to support all of my sources				Yes	Integrated (in a Mixer or A	0	Very important	Very important	Extremely important	Slightly important	Very important	Very important
19	Amplifier	25	RaspberryPi + DAC configured as a	5	My speaker/Amp has enough	inputs to support all of my sources				Yes	Both integrated in amplifie	150	Slightly important	Extremely important	Moderately important	Not at all important	Moderately important	Very important
3	amplifier	15	bluetooth	3	My speaker/Amp has enough	inputs to support all of my sources				Yes	Stand alone	250	Moderately important	Very important	Extremely important	Very important	Very important	Very important
2	A cable	15	speakers	1	My speaker/Amp has enough	inputs to support all of my sources				No			Moderately important	Very important	Extremely important	Moderately important	Extremely important	Moderately important
3	Laptop	3	Headphones	1	I switch input cables every time					No			Very important	Very important	Very important	Moderately important	Moderately important	Very important
2	sennheiser hd 600	6	cambridge audio DACmagic plus	3	my receiver has enough	inputs				No			Not at all important	Moderately important	Extremely important	Moderately important	Extremely important	Slightly important
5	Radio/ Cd player	20	Headphones	1	Wirelessly (e.g. Bluetooth)					No			Very important	Very important	Extremely important	Very important	Very important	Extremely important
4	Turntable	40	Speakers	4	I use an audio mixer	DJ Mixer	Numark	4	80	Yes	Integrated (in a Mixer or A	0	Moderately important	Moderately important	Extremely important	Extremely important	Very important	Moderately important
3	An analog synthesizer that i	40	My interface	1	I use an interface					No			Extremely important	Extremely important	Extremely important	Slightly important	Extremely important	Moderately important
3	Laptop	3	Bluetooth	1	I switch input cables every time					Yes	Integrated (in the Turntabl	0	Slightly important	Very important	Extremely important	Moderately important	Moderately important	Very important
3	Pc	2	Headphones	0	Wirelessly (e.g. Bluetooth)					No			Not at all important	Moderately important	Moderately important	Slightly important	Moderately important	Slightly important
2	Smartphone	3	Laptop	1	Wirelessly (e.g. Bluetooth)					No			Very important	Very important	Very important	Very important	Very important	Very important
6	Technics 1200	20	Cdj2000nxs	6	I use an audio mixer	DJ Mixer	Pioonerdjm900nxs	4	1000	Yes	Integrated (in a Mixer or A	0	Not at all important	Slightly important	Slightly important	Not at all important	Slightly important	Slightly important
2	Bas	5	None	7	I switch input cables every time					No			Very important	Slightly important	Extremely important	Extremely important	Extremely important	Extremely important
2	computer	1	speaker	0	Wirelessly (e.g. Bluetooth)					No			Very important	Very important	Extremely important	Moderately important	Moderately important	Moderately important
2	Headphones	5	Equalizer	0	My speaker/Amp has enough	inputs to support all of my sources				No			Moderately important	Extremely important	Extremely important	Not at all important	Moderately important	Very important
1	laptop	2	speakers	1	Wirelessly (e.g. Bluetooth)					No			Moderately important	Very important	Extremely important	Slightly important	Moderately important	Very important

3.36		Brand	Features	Performance	Design	Build Quality	Price
3.40	Not at all important	6	0	1	5	0	1
	Slightly important	13	5	2	9	5	7
	Moderately important	12	16	5	16	12	13
	Very important	17	19	11	15	21	24
	Extremely important	2	10	31	5	12	5

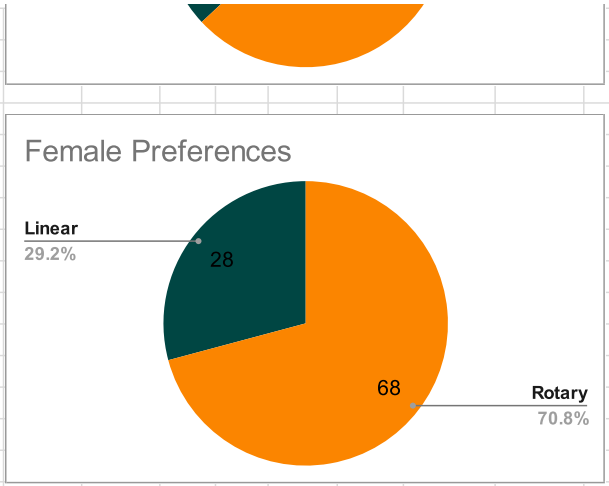


01/03/2021	Voted on	Username		Vote				Total	Rotary	Linear	Rotary %	Linear %
	selernet	aingeal_lim	F	Rotary		48.94%	M	92	58	34	63%	37%
	selernet	lexmoon	F	Rotary		51.06%	F	96	68	28	71%	29%
	selernet	marianthurn	F	Rotary			SUM	188				
	selernet	maria.falara	F	Rotary								
	selernet	ferrybot	F	Rotary								
	selernet	kdeperi	M	Rotary								
	selernet	dickeseinhorn	F	Rotary								
	selernet	iamfrancescosirianni	M	Linear								
	selernet	kostas.siam89	M	Rotary								
	selernet	sissy.str	F	Rotary								
	selernet	meliqsetian	M	Rotary								
	selernet	jaspervlaar	M	Rotary								
	selernet	irene_bour	F	Rotary								
	selernet	mariebeljaars	F	Rotary								
	selernet	afroditi_kp	F	Rotary								
	selernet	theo__st	M	Rotary								
	selernet	umorfex	F	Rotary								
	selernet	a.dim7	M	Rotary								
	selernet	charlestruijk	F	Rotary								
	selernet	ioannidoy__	F	Rotary								
	selernet	anthonyperakis_	M	Rotary								
	selernet	orfeas_krns	M	Rotary								
	selernet	roxsk	F	Rotary								
	selernet	margotellen	F	Rotary								
	selernet	nickziemer	M	Rotary								
	selernet	_true_lee	F	Rotary								
	selernet	mavidou_maria	F	Rotary								
	selernet	pasxalis_agapitos	M	Rotary								
	selernet	eva_soro12	F	Rotary								
	selernet	martinsteffner	M	Rotary								
	selernet	yami.guup_	M	Rotary								
	selernet	thanosf	M	Rotary								
	selernet	despinaalafouzou	F	Rotary								
	selernet	elisavet_stavropoulou	F	Rotary								
	selernet	tasosparaskeuas	M	Rotary								
	selernet	dimitrakar_	F	Rotary								
	selernet	y.skoulidas	M	Rotary								
	selernet	nikooah_	F	Rotary								
	selernet	kevinbrucewayne	M	Rotary								
	selernet	annagre	F	Rotary								
	selernet	emilio.dejonghe	M	Rotary								





	selernet	nicole.g.s	F	Rotary
	selernet	krrrrrrrristinnnna	F	Rotary
	selernet	nottodayjewelry	F	Rotary
	selernet	duchessevdoxia	F	Rotary
	selernet	anna.deli	F	Linear
	selernet	jordan_x_grossand	M	Linear
	selernet	sugarenia_k	F	Linear
	selernet	antissat	F	Linear
	selernet	r.robinson	M	Linear
	selernet	atmoula	F	Linear
	selernet	fitsi1987	M	Linear
	selernet	morefoudplease	M	Linear
	selernet	ajindal9	M	Linear
	selernet	mersiliaaa	F	Linear
	selernet	raniavr	F	Linear
	selernet	antzelsofia	F	Linear
	selernet	anemolbak	F	Linear
	selernet	rms1953	F	Linear
	selernet	nansykas	F	Linear
	selernet	nappybramy	M	Linear
	selernet	sadsad_mba	M	Linear
	selernet	v.siorovigkas	M	Linear
	selernet	mariaterol	F	Linear
	selernet	eselaar	M	Linear
	roxsk	varvara.batsiou	F	Rotary
	roxsk	geo.ski	M	Rotary
	roxsk	manolis.str	M	Rotary
	roxsk	pharlez	M	Rotary
	roxsk	papanikge	M	Rotary
	roxsk	j_karaiskos	M	Rotary
	roxsk	quiqui.ti	F	Rotary
	roxsk	nikos.nikolaou	M	Rotary
	roxsk	andrefilipp	M	Rotary
	roxsk	thodwrhs.xnts	M	Rotary
	roxsk	vagkalampalikis	M	Rotary
	roxsk	marianthi.rs	F	Rotary
	roxsk	mgkiox	F	Rotary
	roxsk	natalia.radulea	F	Rotary
	roxsk	steliosnikt	M	Rotary
	roxsk	eftychiamarr	F	Rotary
	roxsk	amaliamantz	F	Rotary
	roxsk	elen.rs	F	Rotary



	roxsk	sourotiris	M	Rotary											
	roxsk	jteach83	F	Linear											
	roxsk	mikebabounis	M	Linear											
	roxsk	peterbenos	M	Linear											
	roxsk	mindzblack	M	Linear											
	roxsk	xanthehrono	M	Linear											
	roxsk	kanel.io	M	Linear											
	roxsk	savvaskarr	M	Linear											
	roxsk	kostpl	M	Linear											
	roxsk	stefanos_kostoglou	M	Linear											
	roxsk	demian.theta	M	Linear											
	roxsk	nena_konst	F	Linear											
	roxsk	angelie_vsl	F	Linear											
	_true_lee	nansushi_	F	Rotary											
	_true_lee	nikos_mavrakis	M	Rotary											
	_true_lee	asparagus_plumosa	F	Rotary											
	_true_lee	anelis.asdf	F	Rotary											
	_true_lee	eleftherizaki	F	Rotary											
	_true_lee	maree.ya	F	Rotary											
	_true_lee	titosraptis	M	Rotary											
	_true_lee	okay__captain		Rotary											
	_true_lee	_sofia_ps	F	Rotary											
	_true_lee	chris.still.gazin	M	Rotary											
	_true_lee	maria.lyk	F	Rotary											
	_true_lee	xry_4022	F	Rotary											
	_true_lee	sophia_gagavouzidi	F	Rotary											
	_true_lee	hraklis_peiratis	M	Rotary											
	_true_lee	gr_demi	F	Rotary											
	_true_lee	tsarouca	M	Rotary											
	_true_lee	bengoab2	M	Rotary											
	_true_lee	mwvel	F	Rotary											
	_true_lee	aristotelis_manoudakis	M	Linear											
	_true_lee	irie_athina_	F	Linear											
	_true_lee	fani_limphaini	F	Linear											
	_true_lee	chrisa_grg	F	Linear											
	_true_lee	eirhnhsalm93	F	Linear											
	_true_lee	sofmartini	F	Linear											
	eva_soro12	eleana_houiris	F	Rotary											
	eva_soro12	annamaraki__	F	Rotary											
	eva_soro12	penny_sap	F	Rotary											
	eva_soro12	katsara.maria	F	Rotary											
	eva_soro12	iwanniskaravolias	M	Rotary											

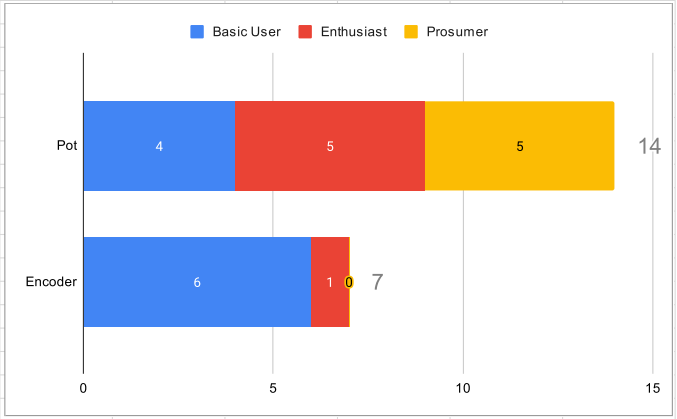
	eva_soro12	filippostriantafillou	M	Rotary											
	eva_soro12	nikos.efthimiou	M	Rotary											
	eva_soro12	sofiagamvrinou	F	Rotary											
	eva_soro12	yasmine_mioumpi	F	Rotary											
	eva_soro12	evegolf192	F	Rotary											
	eva_soro12	panagiotismanousakis	M	Rotary											
	eva_soro12	panagouv	M	Rotary											
	eva_soro12	tsakman94	M	Rotary											
	eva_soro12	stavroulast	F	Rotary											
	eva_soro12	johnpapa757	M	Rotary											
	eva_soro12	thecostagiacomo	M	Rotary											
	eva_soro12	eirinoulid	F	Rotary											
	eva_soro12	billniagkos	M	Rotary											
	eva_soro12	d_mitrogiannis	M	Rotary											
	eva_soro12	nasia_ppm	F	Rotary											
	eva_soro12	_ipapamen	F	Rotary											
	eva_soro12	youradvocate	M	Rotary											
	eva_soro12	marina_magik.bean_tr	F	Rotary											
	eva_soro12	el_greco28	M	Rotary											
	eva_soro12	kourkoumpini	M	Rotary											
	eva_soro12	spyros__gian	M	Rotary											
	eva_soro12	nikivamvakouri	F	Rotary											
	eva_soro12	e.neep	F	Rotary											
	eva_soro12	k_angelakis	F	Rotary											
	eva_soro12	witenblak	M	Rotary											
	eva_soro12	kostiana_theo	F	Rotary											
	eva_soro12	_nikossid	M	Rotary											
	eva_soro12	teoriganas	M	Rotary											
	eva_soro12	sotosblackeye	M	Rotary											
	eva_soro12	evrofeli	F	Rotary											
	eva_soro12	eleni.m	F	Rotary											
	eva_soro12	dimeloper_	M	Rotary											
	eva_soro12	maria_hasapi	F	Rotary											
	eva_soro12	spbofy	M	Rotary											
	eva_soro12	billtsaklidis	M	Rotary											
	eva_soro12	diamantis_flg	M	Rotary											
	eva_soro12	selernet	M	Rotary											
	eva_soro12	xristina_ec	F	Rotary											
	eva_soro12	mxioannidis	F	Rotary											
	eva_soro12	annakiakou	F	Rotary											
	eva_soro12	michalis.arch	M	Rotary											
	eva_soro12	spirosfubu	M	Linear											

	eva_soro12	nikos_seitis	M	Linear											
	eva_soro12	christostsavas	M	Linear											
	eva_soro12	christiana_plati	F	Linear											
	eva_soro12	nikos_sid	M	Linear											
	eva_soro12	gab_el_pi	M	Linear											
	eva_soro12	anastako	M	Linear											
	eva_soro12	aliciaki	F	Linear											
	eva_soro12	georginatser	F	Linear											
	eva_soro12	enri.60	M	Linear											
	eva_soro12	theodriva	M	Linear											
	eva_soro12	natygeo	F	Linear											
	eva_soro12	sir_achil	M	Linear											
	eva_soro12	loukas_lp	M	Linear											
	eva_soro12	dida_aggeliki	F	Linear											
	eva_soro12	georgekordatsakis	M	Linear											
	eva_soro12	anmaypsilantis	F	Linear											
	eva_soro12	stergos_lamprianos	M	Linear											
	eva_soro12	victor_benetatos	M	Linear											
	eva_soro12	george_papakis	M	Linear											
	eva_soro12	eveberyl	F	Linear											
	eva_soro12	areboulaki	F	Linear											
	eva_soro12	dimitra_kobothekla	F	Linear											

Have you ever had to get	What kind of device did yc	What did you do with your	What was the reason you	Name	Email address	This is your last chance to	If there is anything you wish to share with us, feel free to do so :)
Yes	Mixer	Sold it to an individual	I got a better replacement	Giorgis			
Yes	Headphones, earphones,	Disposed it in the trash	It was broken	Emilio			
No				Andreas			
No							
Yes	Headphones	Disposed it in the trash	It was broken	Thor		Go nuts, I support you	
Yes	radio/cd player	Disposed it at a recycling	I got a better replacement	K.		Loved the graphics in this survey!	
Yes	all	Sold it to a reselling/refurt	I needed the money				
No				I.			
No							
Yes	bluetooth speaker, headpl	Gave it away for free	I got a better replacement	D.			
Yes	Turntables, amps, headpl	Donated to charities	I had no use for it in my sa	J.		I got rid of all my old stuff because I moved home, but aside from that, good survey	
Yes	Amplifier	Gave it away for free	I got a better replacement	R.			
No				M.			
No							
Yes	Headphones	Disposed it in the trash	It was broken				
Yes	headphones	Sold it to an individual	I got a better replacement	Y.			
Yes	Multiple items	Sold it to an individual	I got a better replacement	J.		Thanks; good luck!	
Yes	One of everything.	Gave it away for free	I got a better replacement	O.			
No							
No				A.		Audio isn't about social status, it's about selecting the best sounding equipment for your budget. Many "audiophile" brands focus most in the first than the latter.	
No							
Yes	amp, cassetterecorder, tu	Sold it to an individual	I got a better replacement/upgrade				
Yes	Home theater in a box sys	Sold it to an individual	I got a better replacement	N.			
Yes	speakers, receiver	Sold it to an individual	I needed the money	P.		i think another good question is "what is your primary source device for playing music?"	
No							
Yes	Speakers	Sold it to an individual	I got a better replacement	C.		The survey should consider that many of us have more than one set up, or that we continually swap out items depending on how we want our set up to sound at any given time. Related to that, the space that pe	
Yes	Headphones	Gave it away for free	I got a better replacement	N.		Bits are bits.	
No							
Yes	Bookshelf Speakers, 2-Ch	Sold it to an individual	I got a better replacement/upgrade				
Yes	Receiver	Disposed it in the trash	It was broken	R.			
No				N.		First the Music, then the Technology	
No				J. M.		Good luck for your studies	
Yes	earphones	Disposed it in the trash	It was broken	P.			
Yes	Stereo amp, DIY speaker	Gave it away for free	I got a better replacement	D.			
Yes	Every equipment possible	Sold it to an individual	I got a better replacement	T.			
Yes	Turntable, Squeezebox de	Sold it to an individual	I got a better replacement	P.		For several questions it should be possible to choose more options instead of one. In several questions Dutch words are shown (I am Dutch, feel free to contact me).	
Yes	cd player	Sold it to an individual	I had no use for it in my sa	P.			
No				G.			
No				J.			
Yes	usb dac	Disposed it in the trash	It was broken				
Yes	Cd player	Disposed it in the trash	It was broken	F.		kali tixi	
Yes	Speakers	Disposed it at a recycling	I got a better replacement/upgrade				
No				M.			
No				C.		Love you Professor!! Nail it, I will be the first buyer for sure!!!	
Yes	Headphones, amplifier	Disposed it at a recycling	It was broken	T.			
No				T.			
Yes	All my equipment	Stolen	I got a better replacement	F.			
No				G.		Bye	
Yes	drum machine	Sold it to an individual	I got a better replacement	S.			
Yes	Surround Sound Headphc	Disposed it in the trash	It was broken	R.		Personally, I think 5.1 surround sound was the best audio setup, but the industry seems to be moving away from that. Also, when is Dobly going to figure out that humans can't discern if sounds come form above	
Yes	turntable	Gave it away for free	I had no use for it in my sa	P.			

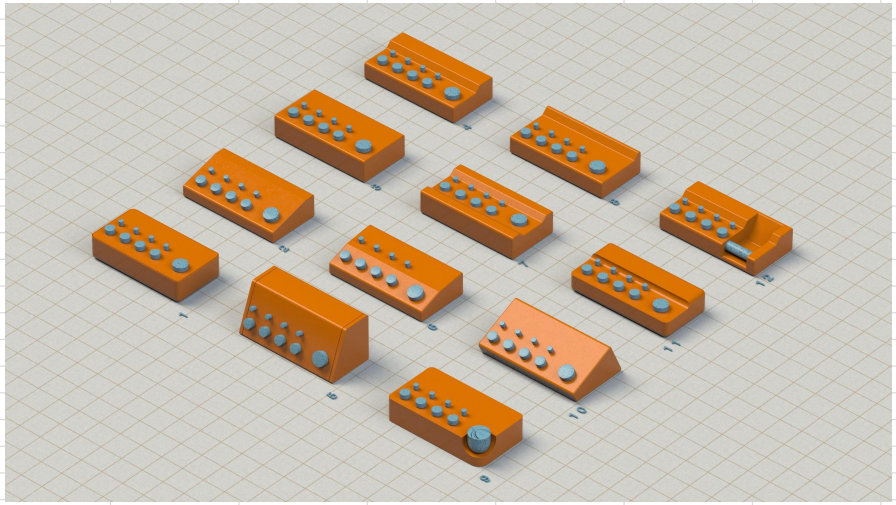
	31.7				81.875	40.5
Name	Age	Gender	Proficiency	Preference	Added value of smart	Prefered size
Maria	24	F	1	Encoder	100	35
Thor	24	M	3	Pot	MAX	60
George	30	M	3	Pot	100	38
Chiara	30	F	1	Encoder	20	
Jenny	28	F	2	Pot	20	40
Claudio	30	M	2	Pot	100	
Falara M.	34	F	2	Pot	100	40
Andrew	31	M	3	Pot	120	
Falaras V.	32	M	3	Pot	150	
Orfeas	26	M	3	Pot	50	
Ntafi	64	M	1	Pot	0	
Pepi	54	F	1	Pot	0	
Nansy	28	F	2	Encoder	100	
Romosiou	30	F	1	Encoder	100	
Karagiannakou	28	F	2	Pot	90	
Niki	28	F	1	Pot	200	40
Valentina	29	F	1	Encoder	MAX	35
Martin	29	M	1	Encoder	MAX	35
Emilio	27	M	2	Pot	MAX	47
Tim	28	M	1	Pot	MAX	
Antoniadou	28	F	1	Encoder	60	35

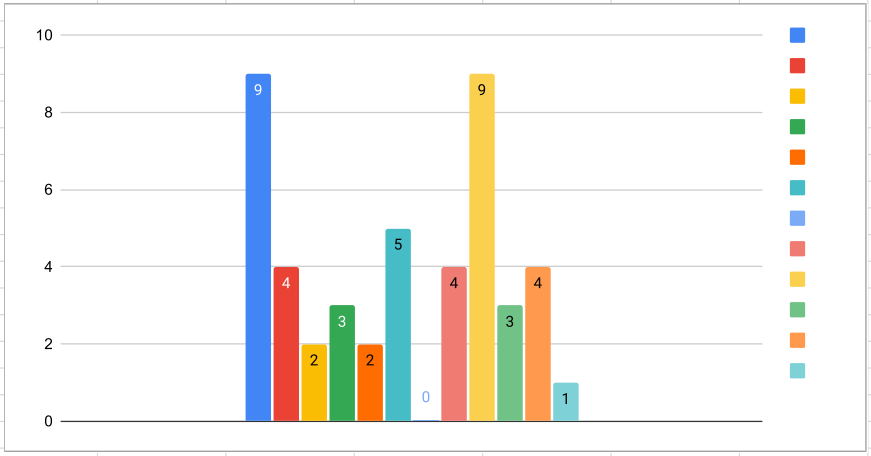
		Basic User	Enthusiast	Prosumer
Pot	14	4	5	5
Encoder	7	6	1	0



Top Selling TV Model Series						
Maker	Series	Analog Out	Digital Out	Wireless	No. Models	106
LG	CX	3.5mm	Optical	Bluetooth 5	4	
LG	BX	3.5mm	Optical	Bluetooth 5	3	
LG	GX	3.5mm	Optical	Bluetooth 5	3	
Samsung	QLED Q90T		Optical	Bluetooth 4.2	3	
LG	Nano86	3.5mm	Optical	Bluetooth 5	3	
Samsung	QLED Q95T		Optical	Bluetooth 4.2	4	
Sony	XH90/92	3.5mm	Optical	Bluetooth 4.2	10	
LG	LM6300		Optical	Bluetooth 5	2	
Sony	X70	3.5mm	Optical		8	
Philips	OLED935 Series	3.5mm	Optical	Bluetooth 4.2	3	
Philips	OLED805 Series	3.5mm	Optical	Bluetooth 4.2	2	
LG	C1	3.5mm	Optical	Bluetooth 5	4	
Sony	KD A9	3.5mm	Optical	Bluetooth 4.2	1	
Salora	UHL2800	3.5mm			4	
Samsung	QLED Q80T		Optical	Bluetooth 4.2	6	
LG	OLED C9	3.5mm	Optical	Bluetooth 5	5	
Samsung	The Frame		Optical	Bluetooth 4.2	6	
LG	Nano81	3.5mm	Optical	Bluetooth 5	3	
Samsung	The Sero		Optical	Bluetooth 4.2	1	
LG	Nano80	3.5mm	Optical	Bluetooth 5	3	
Xiaomi	Mi TV 4S	3.5mm	Optical	Bluetooth 4.2	3	
Samsung	TU7020		Optical		6	
LG	UN71		Optical	Bluetooth 4.2	7	
Sony	XH95	3.5mm	Optical	Bluetooth 4.2	5	
Samsung	QLED Q60T		Optical	Bluetooth 4.2	7	
		64%	96%	88%	64	
		60%	96%	83%		
https://tweakers.net/televisies/vergelijken/#filter:q1bKSazMLy3xzU9JVbJSKijKTyINLilWqgUA						

16	9	4	2	3	2	5	0	4	9	3	4	1
	1	2	3	4	5	6	7	8	9	10	11	12
Siel		1		1		1						
Niki	1			1	1			1	1	1		
Afro	1								1			
Despoina									1			
Trouli	1							1	1			
Nansy									1		1	
Karagiannakou						1						
Falara	1					1			1		1	
Andrew	1		1	1				1	1			1
Orpheus												
Emilio		1										
Marie	1								1		1	
Pavlidis		1				1						
Martin	1					1		1				
Tim	1	1	1						1	1		
Claudio	1				1					1	1	





Purpose: Concept Development Impact comparison
Boundaries:
Functional unit: g
Impact unit: Eco-cost

Use Scenario	Idle	Active
Years	20	20
Days per Year	200	200
Hours Per Day	8	0,1
Total Use (sec)	115200000,00	1440000

Uncertainty rubric: 10% for database perfect match, 30% for plausible substitution, 100% for wild guess

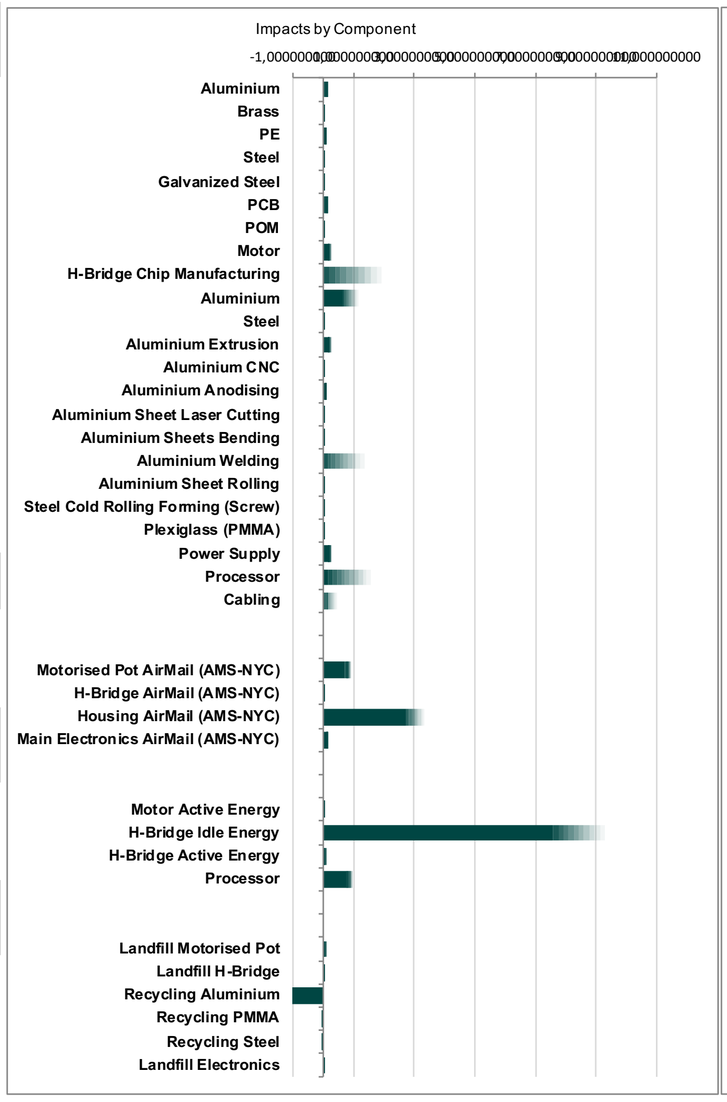
Design option:
Version One

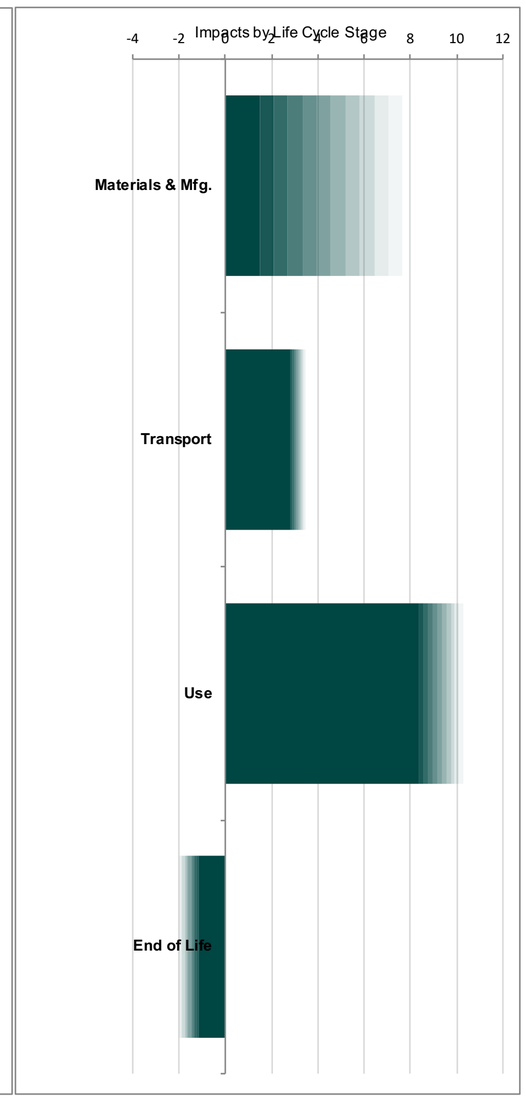
Manufacturing	Eco-intensity (impacts/g)	Mass per item (g)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Aluminium	0,00092	37,050	3,00	30%	Potentiometer	0,102701068
Brass	0,00532	1,320	3,00	30%	Potentiometer	0,021071656
PE	0,00118	11,720	3,00	30%	Potentiometer	0,041433685
Steel	0,00051	4,490	3,00	30%	Potentiometer	0,006925258
Galvanized Steel	0,00051	8,230	3,00	50%	Potentiometer	0,012693735
PCB	0,00785	4,400	3,00	30%	Potentiometer	0,103630209
POM	0,00041	5,160	3,00	30%	Potentiometer	0,006362314
Motor	0,00224	28,000	3,00	30%	Potentiometer	0,188507800
H-Bridge Chip Manufacturing	0,34	0,960	3,00	100%	Potentiometer	0,970690066
Aluminium	0,00092	327,66246	3,00	30%	Housing	0,908266795
Steel	0,00051	2,51160	3,00	30%	Housing	0,003873826
Aluminium Extrusion	0,00014	459,32232	3,00	30%	Housing	0,188387154
Aluminium CNC	0,00001	135,19304	3,00	10%	Housing	0,004675622
Aluminium Anodising	0,00001	1099,12159	3,00	10%	Housing	0,046699267
Aluminium Sheet Laser Cutting	0,02866	0,00926	3,00	10%	Housing	0,000795844
Aluminium Sheets Bending	0,00001	23,40000	3,00	100%	Housing	0,000745884
Aluminium Welding	0,04490	5,000	3,00	100%	Housing	0,673569499
Aluminium Sheet Rolling	0,00001	63,252	3,00	100%	Housing	0,002187560
Steel Cold Rolling Forming (Screw	0,00008	0,31395	3,00	100%	Housing	0,000071029
Plexiglass (PMMA)	0,00209	0,65914	3,00	50%	Housing	0,004123928
Power Supply	0,00658	29,7	1	30%	Electronics	0,195529944
Processor	0,08843	9,90000	1,00	80%	Electronics	0,875503952
Cabling	0,00536	20,00000	2,00	100%	Electronics	0,214552858

Transport	Eco-Intensity (impacts/ ton-km)	Distance per item (km)	Total Weight (g)	Uncertainty %	Items	Calculated Impact
Motorised Pot AirMail (AMS-NYC)	0,52	5862,2	88,39	10%	3,00	0,81455
H-Bridge AirMail (AMS-NYC)	0,52	5862,2	0,96	10%	3,00	0,00885
Housing AirMail (AMS-NYC)	0,52	5862,2	328,64	10%	3,00	3,02867
Main Electronics AirMail (AMS-NYC	0,52	5862,2	39,60	10%	1,00	0,12165
						0

Use	Eco-Intensity (impacts/MJ or other)	Amount per item (MJ or other)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Motor Active Energy	0,02544	1,08	1	10%		0,0274754993
H-Bridge Idle Energy	0,02544	110,592	3	10%		8,4404733861
H-Bridge Active Energy	0,02544	1,3824	1	50%		0,0351686391
Processor	0,02544	33,59232	1	10%		0,8545979303
						0

End of Life	Eco-Intensity (impacts/g)	Mass per item (g)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Landfill Motorised Pot	0,0001	124,370	3,00	100%		0,043277775
Landfill H-Bridge	0,0001	0,960	1,00	100%		0,000111352
Recycling Aluminium	-0,00165	327,662	3,00	30%		-1,624722394
Recycling PMMA	-0,00104	0,659	3,00	30%		-0,002049604
Recycling Steel	-0,00025	2,512	3,00	50%		-0,001863487
Landfill Electronics	0,00005	140,930	1,00	100%		0,006594447





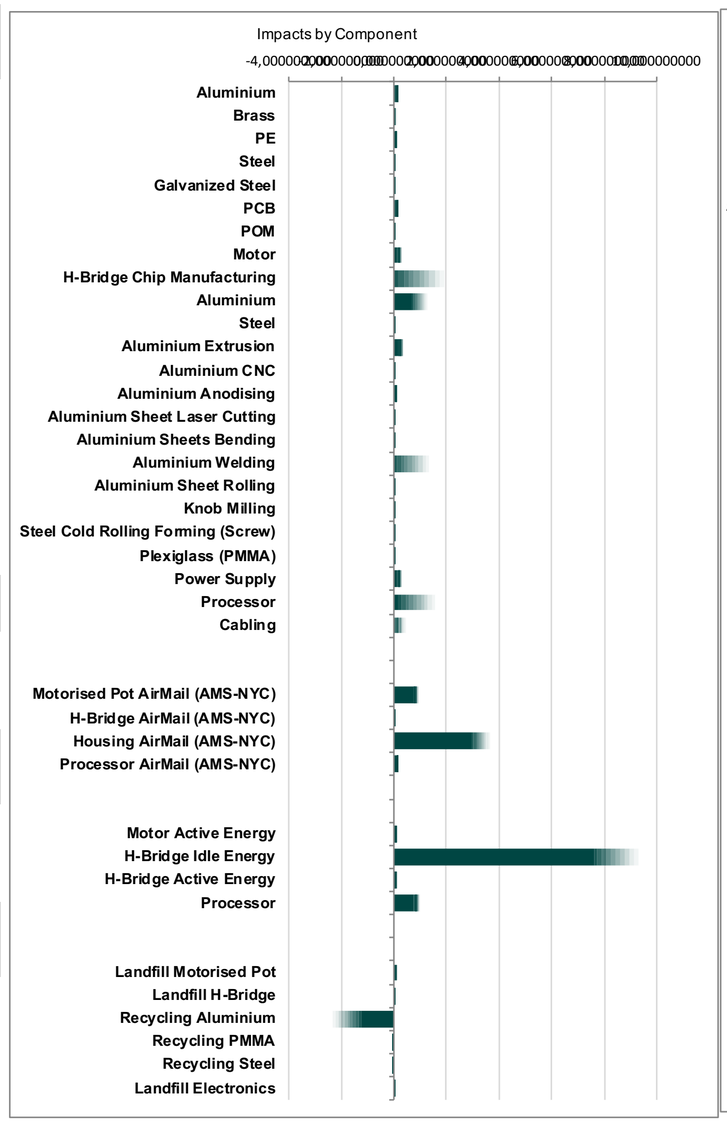
Design option:
Improved Manufacturing

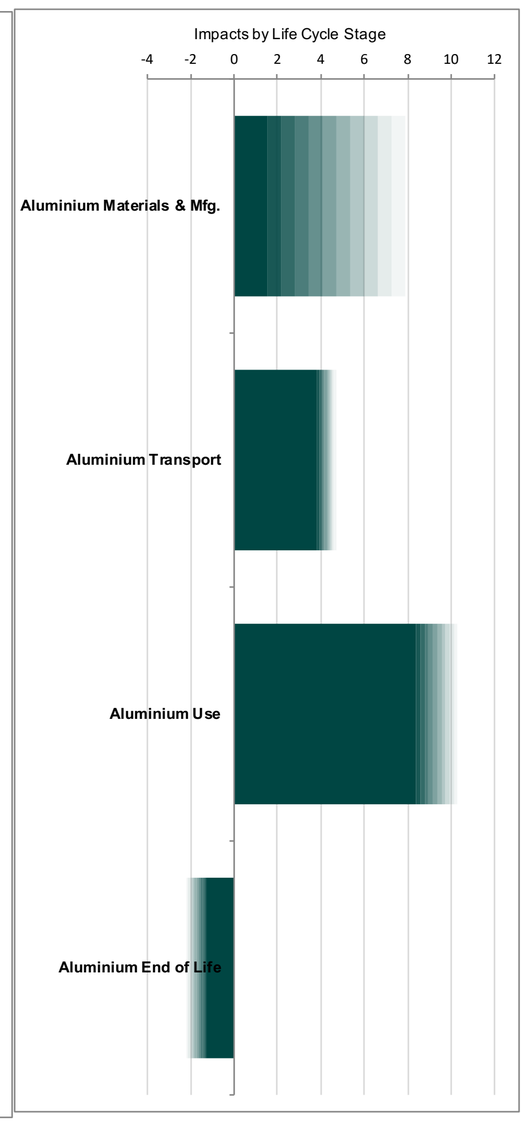
Manufacturing	Eco-intensity (impacts/g)	Mass per item (g)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Aluminium	0,000924	37,050	3,00	30%		0,10270107
Brass	0,005321	1,320	3,00	30%		0,02107166
PE	0,001178	11,720	3,00	30%		0,04143369
Steel	0,000514	4,490	3,00	30%		0,00692526
Galvanized Steel	0,000514	8,230	3,00	50%		0,01269373
PCB	0,007851	4,400	3,00	30%		0,10363021
POM	0,000411	5,160	3,00	30%		0,00636231
Motor	0,002244	28,000	3,00	30%		0,18850780
H-Bridge Chip Manufacturing	0,337045	0,960	3,00	100%		0,97069007
Aluminium	0,000924	357,631	3,00	30%	Housing	0,99133943
Steel	0,000514	2,512	3,00	30%	Housing	0,00387383
Aluminium Extrusion	0,000137	595,398	3,00	30%	Housing	0,24419726
Aluminium CNC	0,000012	135,193	3,00	10%	Housing	0,00467562
Aluminium Anodising	0,000014	1117,427	3,00	10%	Housing	0,04747700
Aluminium Sheet Laser Cutting	0,028664	0,009	3,00	10%	Housing	0,00076833
Aluminium Sheets Bending	0,000011	23,40000	3,00	100%	Housing	0,00074588
Aluminium Welding	0,044905	5,000	3,00	100%	Housing	0,67356950
Aluminium Sheet Rolling	0,000012	53,978	3,00	100%	Housing	0,00186680
Knob Milling	0,000012	61,914	3,00	10%	%	0,00214127
Steel Cold Rolling Forming (Screw	0,000075	0,314	3,00	100%	Housing	0,00007103
Plexiglass (PMMA)	0,002086	0,659	3,00	50%	Housing	0,00412393
Power Supply	0,006583	29,7	1	30%	Electronics	0,19552994
Processor	0,088435	9,90000	1,00	80%	Electronics	0,87550395
Cabling	0,005364	20,000	2,00	100%	Electronics	0,21455286

Transport	Eco-Intensity (impacts/ ton-km)	Distance per item (km)	Total Weight (g)	Uncertainty %	Items	Calculated Impact
Motorised Pot AirMail (AMS-NYC)	0,52	5862,2	88,39	10%	3,00	0,814545428
H-Bridge AirMail (AMS-NYC)	0,52	5862,2	0,96	10%	3,00	0,008847243
Housing AirMail (AMS-NYC)	0,52	5862,2	359,38	10%	3,00	3,311973298
Processor AirMail (AMS-NYC)	0,52	5862,2	39,60	10%	1,00	0,121649597

Use	Eco-Intensity (impacts/MJ or other)	Amount per item (MJ or other)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Motor Active Energy	0,02544	1,08	1	10%		0,027475499
H-Bridge Idle Energy	0,02544	110,592	3	10%		8,440473386
H-Bridge Active Energy	0,02544	1,3824	1	50%		0,035168639
Processor	0,025440277	33,59232	1	10%		0,85459793

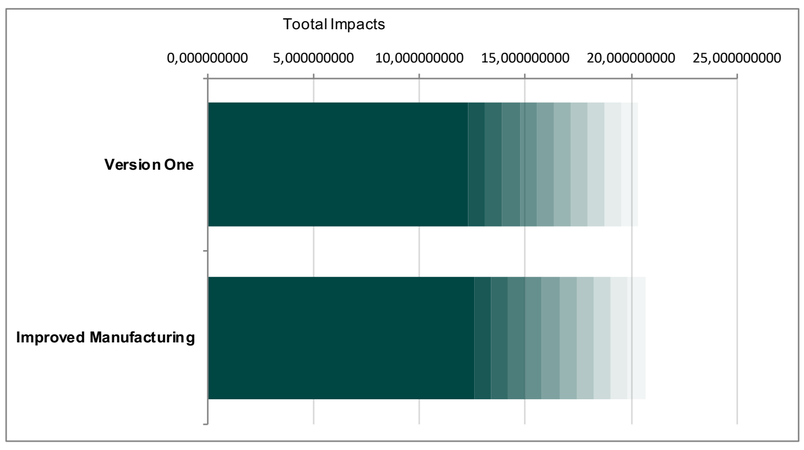
End of Life	Eco-Intensity (impacts/g)	Mass per item (g)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Landfill Motorised Pot	0,0001	124,370	3,00	100%		0,043277775
Landfill H-Bridge	0,0001	0,960	1,00	100%		0,000111352
Recycling Aluminium	-0,0017	357,631	3,00	30%		-1,773324076
Recycling PMMA	-0,0010	0,659	3,00	30%		-0,002049604
Recycling Steel	-0,0002	2,512	3,00	50%		-0,001863487
Landfill Electronics	0,0000	140,930	1,00	100%		0,006594447





Comparison

Version One
Improved Manufacturing



Graphing - itemized

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Aluminium	0,071890748	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Brass	0,014750159	0	0	0	0	0	0	0	0	0	0
PE	0,029003580	0	0	0	0	0	0	0	0	0	0
Steel	0,004847680	0	0	0	0	0	0	0	0	0	0
Galvanized Steel	0,006346867	0	0	0	0	0	0	0	0	0	0
PCB	0,072541146	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
POM	0,004453620	0	0	0	0	0	0	0	0	0	0
Motor	0,131955460	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
H-Bridge Chip Manuf	0,000000000	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19
Aluminium	0,635786757	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Steel	0,002711678	0	0	0	0	0	0	0	0	0	0
Aluminium Extrusion	0,131871008	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Aluminium CNC	0,004208060	0	0	0	0	0	0	0	0	0	0
Aluminium Anodising	0,042029340	0	0	0	0	0	0	0	0	0	0
Aluminium Sheet Las	0,000716259	0	0	0	0	0	0	0	0	0	0
Aluminium Sheets Be	0,000000000	0	0	0	0	0	0	0	0	0	0
Aluminium Welding	0,000000000	0,13	0,13	0,13	0,13	0,13	0,13	0,13	0,13	0,13	0,13
Aluminium Sheet Rol	0,000000000	0	0	0	0	0	0	0	0	0	0
Steel Cold Rolling Fo	0,000000000	0	0	0	0	0	0	0	0	0	0
Plexiglass (PMMA)	0,002061964	0	0	0	0	0	0	0	0	0	0
Power Supply	0,136870961	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Processor	0,175100790	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14
Cabling	0,000000000	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04
Motorised Pot AirMail	0,733090886	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
H-Bridge AirMail (AM	0,007962519	0	0	0	0	0	0	0	0	0	0
Housing AirMail (AMS	2,725798788	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
Main Electronics AirM	0,109484638	0	0	0	0	0	0	0	0	0	0
Motor Active Energy	0,024727949	0	0	0	0	0	0	0	0	0	0
H-Bridge Idle Energy	7,596426047	0,17	0,17	0,17	0,17	0,17	0,17	0,17	0,17	0,17	0,17
H-Bridge Active Ener	0,01758432	0	0	0	0	0	0	0	0	0	0
Processor	0,769138137	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
Landfill Motorised Po	0	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Landfill H-Bridge	0	0	0	0	0	0	0	0	0	0	0
Recycling Aluminium	-1,137305676	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1
Recycling PMMA	-0,001434723	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
Recycling Steel	-0,000931744	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
Landfill Electronics	0	0	0	0	0	0	0	0	0	0	0

Graphing - by life cycle stage

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Materials & M	1,46714608	0,62	0,62	0,62	0,62	0,62	0,62	0,62	0,62	0,62	0,62
Transport	2,83528343	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
Use	8,40787645	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19
End of Life	-1,13967214	-0,09	-0,09	-0,09	-0,09	-0,09	-0,09	-0,09	-0,09	-0,09	-0,09

Graphing - itemized

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Aluminium	0,071890748	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Brass	0,014750159	0	0	0	0	0	0	0	0	0	0
PE	0,029003580	0	0	0	0	0	0	0	0	0	0
Steel	0,004847680	0	0	0	0	0	0	0	0	0	0
Galvanized Steel	0,006346867	0	0	0	0	0	0	0	0	0	0
PCB	0,072541146	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
POM	0,004453620	0	0	0	0	0	0	0	0	0	0
Motor	0,131955460	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
H-Bridge Chip Manuf	0,000000000	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19
Aluminium	0,693937603	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
Steel	0,002711678	0	0	0	0	0	0	0	0	0	0
Aluminium Extrusion	0,170938081	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Aluminium CNC	0,004208060	0	0	0	0	0	0	0	0	0	0
Aluminium Anodising	0,042729302	0	0	0	0	0	0	0	0	0	0
Aluminium Sheet Las	0,000691494	0	0	0	0	0	0	0	0	0	0
Aluminium Sheets Be	0,000000000	0	0	0	0	0	0	0	0	0	0
Aluminium Welding	0,000000000	0,13	0,13	0,13	0,13	0,13	0,13	0,13	0,13	0,13	0,13
Aluminium Sheet Rol	0,000000000	0	0	0	0	0	0	0	0	0	0
Knob Milling	0,001927146	0	0	0	0	0	0	0	0	0	0
Steel Cold Rolling Fo	0,000000000	0	0	0	0	0	0	0	0	0	0
Plexiglass (PMMA)	0,002061964	0	0	0	0	0	0	0	0	0	0
Power Supply	0,136870961	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Processor	0,175100790	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14
Cabling	0,000000000	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04
Motorised Pot AirMail	0,733090886	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
H-Bridge AirMail (AM	0,007962519	0	0	0	0	0	0	0	0	0	0
Housing AirMail (AMS	2,980775968	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,07
Processor AirMail (AM	0,109484638	0	0	0	0	0	0	0	0	0	0
Motor Active Energy	0,024727949	0	0	0	0	0	0	0	0	0	0
H-Bridge Idle Energy	7,596426047	0,17	0,17	0,17	0,17	0,17	0,17	0,17	0,17	0,17	0,17
H-Bridge Active Ener	0,017584320	0	0	0	0	0	0	0	0	0	0
Processor	0,769138137	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
Landfill Motorised Po	0,000000000	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Landfill H-Bridge	0,000000000	0	0	0	0	0	0	0	0	0	0
Recycling Aluminium	-1,241326853	-0,11	-0,11	-0,11	-0,11	-0,11	-0,11	-0,11	-0,11	-0,11	-0,11
Recycling PMMA	-0,001434723	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
Recycling Steel	-0,000931744	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
Landfill Electronics	0,000000000	0	0	0	0	0	0	0	0	0	0

Graphing - by life cycle stage

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Aluminium M	1,56696634	0,63	0,63	0,63	0,63	0,63	0,63	0,63	0,63	0,63	0,63
Aluminium Tr	3,83131401	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09
Aluminium Us	8,40787645	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19
Aluminium Er	-1,24369332	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1

Graphing - itemized

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Version One	12,311687219	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Improved Manufactu	12,562463483	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81

Purpose: Concept Development Impact comparison
Boundaries:
Functional unit: g
Impact unit: Eco-cost

Use Scenario	Idle	Active
Years	20	20
Days per Year	200	200
Hours Per Day	8	0,1
Total Use (sec)	115200000,00	1440000

Alu CNC Ecoinvent	Alu CNC	ALU Bending	SS CNC EcoInvent	SS CNC	SS Bending
0,012	868	0,8	3,4392822	708	2
1E-05			0,0097155		

Uncertainty rubric: 10% for database perfect match, 30% for plausible substitution, 100% for wild guess

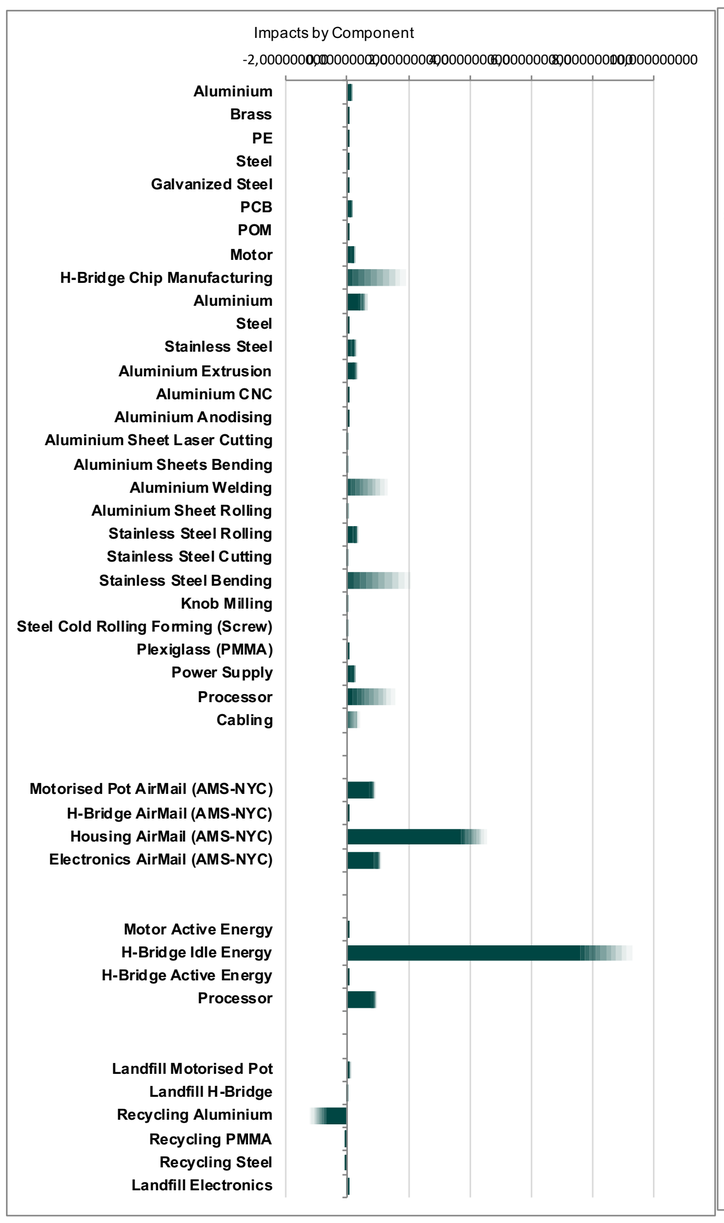
Design option:
Stainless Steel Sheet Body

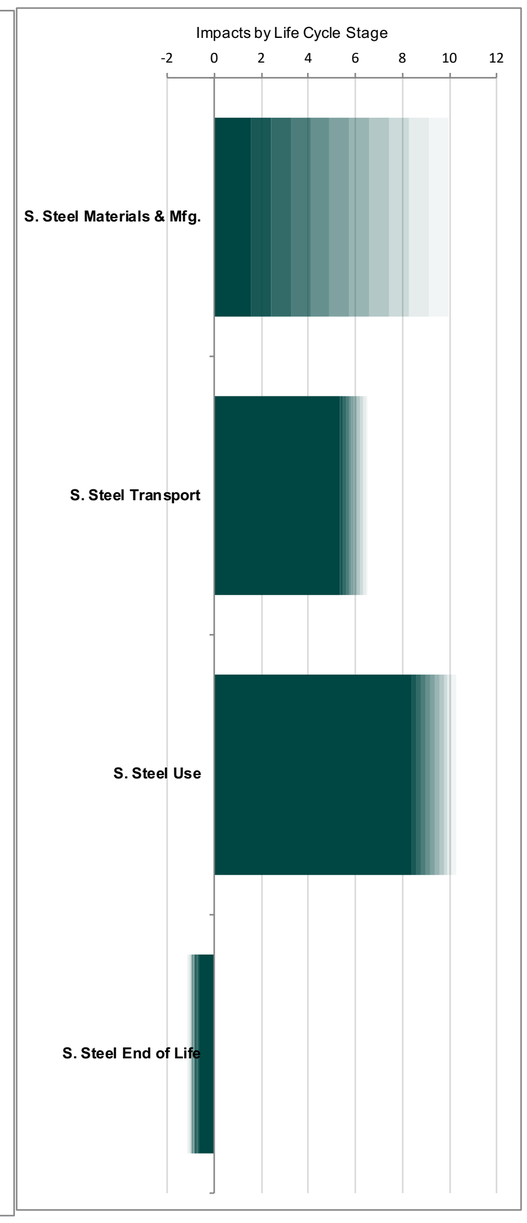
Manufacturing	Eco-intensity (impacts/g)	Mass per item (g)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Aluminium	0,000924	37,050	3,00	30%		0,10270107
Brass	0,005321	1,320	3,00	30%		0,02107166
PE	0,001178	11,720	3,00	30%		0,04143369
Steel	0,000514	4,490	3,00	30%		0,00692526
Galvanized Steel	0,000514	8,230	3,00	50%		0,01269373
PCB	0,007851	4,400	3,00	30%		0,10363021
POM	0,000411	5,160	3,00	30%		0,00636231
Motor	0,002244	28,000	3,00	30%		0,18850780
H-Bridge Chip Manufacturing	0,337045	0,960	3,00	100%		0,97069007
Aluminium	0,000924	186,621	3,00	30%	Housing	0,51730653
Steel	0,000514	2,512	3,00	30%	Housing	0,00387383
Stainless Steel	0,000275	260,276	3,00	30%		0,21434660
Aluminium Extrusion	0,000137	595,398	3,00	30%	Housing	0,24419726
Aluminium CNC	0,000012	135,193	3,00	10%	Housing	0,00467562
Aluminium Anodising	0,000014	1117,427	3,00	10%	Housing	0,04747700
Aluminium Sheet Laser Cutting	0,028664	0,009	3,00	10%	Housing	0,00076833
Aluminium Sheets Bending	0,000011	23,400	3,00	100%	Housing	0,00074588
Aluminium Welding	0,044905	5,000	3,00	100%	Housing	0,67356950
Aluminium Sheet Rolling	0,000012	53,978	3,00	100%	Housing	0,00186680
Stainless Steel Rolling	0,000287	312,548	3,00	30%		0,26893258
Stainless Steel Cutting	0,000002	6,909	3,00	100%		0,00003705
Stainless Steel Bending	0,009715	35,600	3,00	100%		1,03761395
Knob Milling	0,000012	61,914	3,00	10%	%	0,00214127
Steel Cold Rolling Forming (Screw	0,000075	0,314	3,00	100%	Housing	0,00007103
Plexiglass (PMMA)	0,002086	0,659	3,00	50%	Housing	0,00412393
Power Supply	0,006583	29,7	1	30%	Electronics	0,19552994
Processor	0,088435	9,90000	1,00	80%	Electronics	0,87550395
Cabling	0,005364	20,000	2,00	100%	Electronics	0,21455286

Transport	Eco-Intensity (impacts/ ton-km)	Distance per item (km)	Total Weight (g)	Uncertainty %	Items	Calculated Impact
Motorised Pot AirMail (AMS-NYC)	0,52	5862,2	88,39	10%	3,00	0,814545428
H-Bridge AirMail (AMS-NYC)	0,52	5862,2	0,96	10%	3,00	0,008847243
Housing AirMail (AMS-NYC)	0,52	5862,2	448,64	10%	3,00	4,13463707
Electronics AirMail (AMS-NYC)	0,52	5862,2	322,45	10%	1,00	0,990547206

Use	Eco-Intensity (impacts/MJ or other)	Amount per item (MJ or other)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Motor Active Energy	0,02544	1,08	1	10%		0,027475499
H-Bridge Idle Energy	0,02544	110,592	3	10%		8,440473386
H-Bridge Active Energy	0,02544	1,3824	1	50%		0,035168639
Processor	0,025440277	33,59232	1	10%		0,85459793

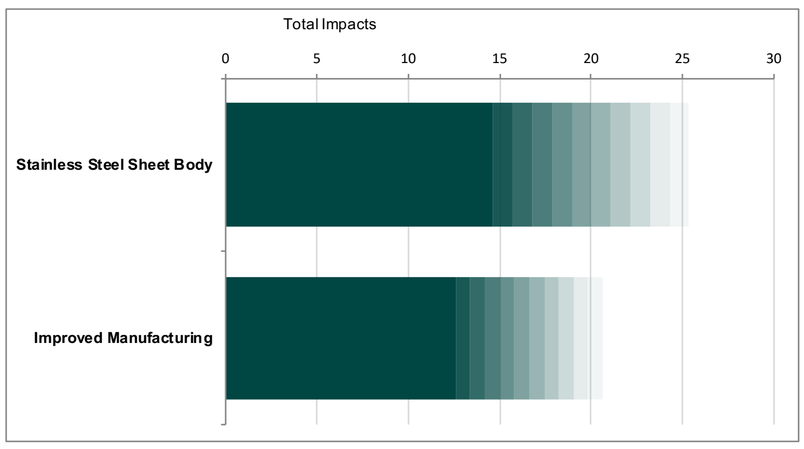
End of Life	Eco-Intensity (impacts/g)	Mass per item (g)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Landfill Motorised Pot	0,0001	124,370	3,00	100%		0,043277775
Landfill H-Bridge	0,0001	0,960	1,00	100%		0,000111352
Recycling Aluminium	-0,0017	186,621	3,00	30%		-0,925366319
Recycling PMMA	-0,0010	0,659	3,00	30%		-0,002049604
Recycling Steel	-0,0002	2,512	3,00	50%		-0,001863487
Landfill Electronics	0,0000	140,930	1,00	100%		0,006594447
Stainless Steel	-0,0002	260,276	3,00	80%		-0,193112354

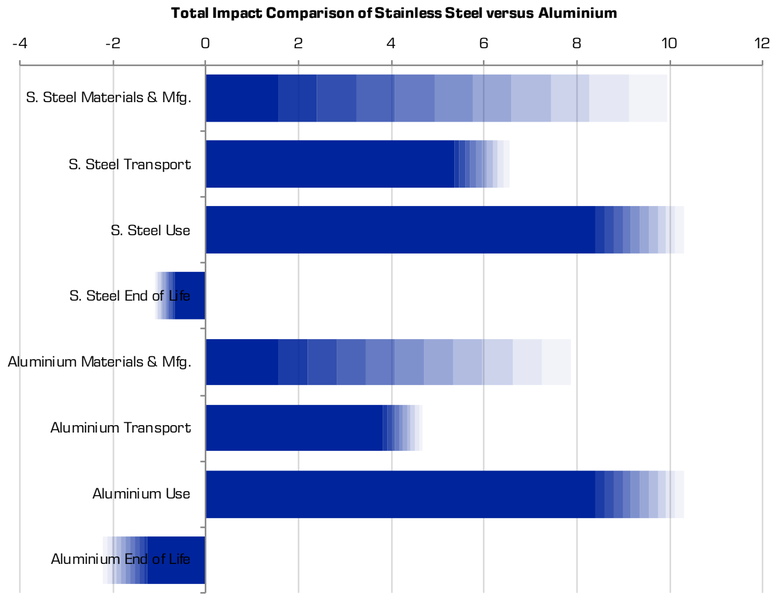




Comparison

#REF!
Stainless Steel Sheet Body





Graphing - itemized

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Aluminium	0,071890748	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Brass	0,014750159	0	0	0	0	0	0	0	0	0	0
PE	0,029003580	0	0	0	0	0	0	0	0	0	0
Steel	0,004847680	0	0	0	0	0	0	0	0	0	0
Galvanized Steel	0,006346867	0	0	0	0	0	0	0	0	0	0
PCB	0,072541146	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
POM	0,004453620	0	0	0	0	0	0	0	0	0	0
Motor	0,131955460	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
H-Bridge Chip Manuf	0,000000000	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19
Aluminium	0,362114570	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
Steel	0,002711678	0	0	0	0	0	0	0	0	0	0
Stainless Steel	0,150042623	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Aluminium Extrusion	0,170938081	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Aluminium CNC	0,004208060	0	0	0	0	0	0	0	0	0	0
Aluminium Anodising	0,042729302	0	0	0	0	0	0	0	0	0	0
Aluminium Sheet Las	0,000691494	0	0	0	0	0	0	0	0	0	0
Aluminium Sheets Be	0,000000000	0	0	0	0	0	0	0	0	0	0
Aluminium Welding	0,000000000	0,13	0,13	0,13	0,13	0,13	0,13	0,13	0,13	0,13	0,13
Aluminium Sheet Rol	0,000000000	0	0	0	0	0	0	0	0	0	0
Stainless Steel Rollir	0,188252804	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
Stainless Steel Cuttir	0,000000000	0	0	0	0	0	0	0	0	0	0
Stainless Steel Bend	0,000000000	0,21	0,21	0,21	0,21	0,21	0,21	0,21	0,21	0,21	0,21
Knob Milling	0,001927146	0	0	0	0	0	0	0	0	0	0
Steel Cold Rolling Fo	0,000000000	0	0	0	0	0	0	0	0	0	0
Plexiglass (PMMA)	0,002061964	0	0	0	0	0	0	0	0	0	0
Power Supply	0,136870961	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Processor	0,175100790	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14
Cabling	0,000000000	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04
Motorised Pot AirMail	0,733090886	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
H-Bridge AirMail (AM	0,007962519	0	0	0	0	0	0	0	0	0	0
Housing AirMail (AMS	3,721173363	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08
Electronics AirMail (A	0,891492485	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
Motor Active Energy	0,024727949	0	0	0	0	0	0	0	0	0	0
H-Bridge Idle Energy	7,596426047	0,17	0,17	0,17	0,17	0,17	0,17	0,17	0,17	0,17	0,17
H-Bridge Active Ener	0,017584320	0	0	0	0	0	0	0	0	0	0
Processor	0,769138137	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
Landfill Motorised Po	0,000000000	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Landfill H-Bridge	0,000000000	0	0	0	0	0	0	0	0	0	0
Recycling Aluminium	-0,647756423	-0,06	-0,06	-0,06	-0,06	-0,06	-0,06	-0,06	-0,06	-0,06	-0,06
Recycling PMMA	-0,001434723	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
Recycling Steel	-0,000931744	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
Landfill Electronics	0,000000000	0	0	0	0	0	0	0	0	0	0
Stainless Steel	-0,038622471	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03

Graphing - by life cycle stage

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
S. Steel Mate	1,57343873	0,84	0,84	0,84	0,84	0,84	0,84	0,84	0,84	0,84	0,84
S. Steel Tran	5,35371925	0,12	0,12	0,12	0,12	0,12	0,12	0,12	0,12	0,12	0,12
S. Steel Use	8,40787645	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19
S. Steel End	-0,65012289	-0,05	-0,05	-0,05	-0,05	-0,05	-0,05	-0,05	-0,05	-0,05	-0,05
Aluminium M	1,56696634	0,63	0,63	0,63	0,63	0,63	0,63	0,63	0,63	0,63	0,63
Aluminium Tr	3,83131401	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09
Aluminium Us	8,40787645	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19	0,19
Aluminium En	-1,24369332	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1

Graphing - itemized

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Improved Manufactu	12,56246348	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81
Stainless Steel Shee	14,646289079	1,07	1,07	1,07	1,07	1,07	1,07	1,07	1,07	1,07	1,07
Improved Manufactu	12,56246348	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81

Purpose: Concept Development Impact comparison
Boundaries:
Functional unit: g
Impact unit: Eco-cost

Use Scenario	Idle	Active
Years	20	20
Days per Year	200	200
Hours Per Day	8	0,1
Total Use (sec)	115200000,00	1440000

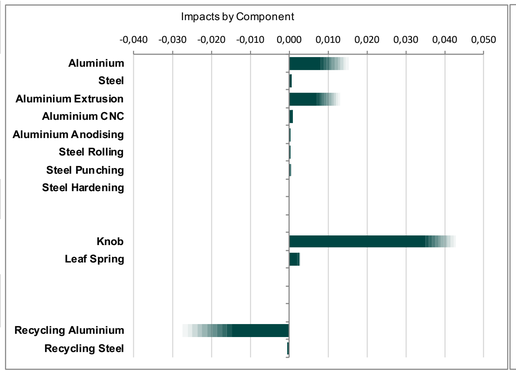
Uncertainty rubric: 10% for database perfect match, 30% for plausible substitution, 100% for wild guess

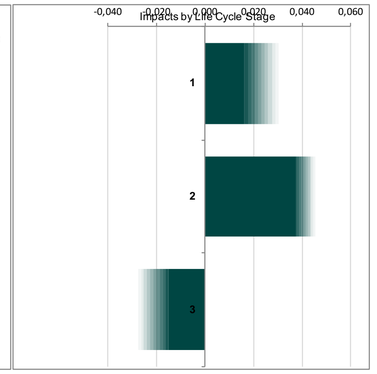
Design option:
Aluminium Machined Knob

Manufacturing	Eco-intensity (impacts/g)	Mass per item (g)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Aluminium	0,00092	12,73050	1,00	30%	Knob	0,011762807
Steel	0,00051	0,77236	1,00	30%	Leaf Spring	0,000397088
Aluminium Extrusion	0,00014	74,64424	1,00	30%	Knob	0,010204901
Aluminium CNC	0,00001	61,91374	1,00	10%	Knob	0,000713758
Aluminium Anodising	0,00001	2,31876	1,00	10%	Knob	0,000032840
Steel Rolling	0,00015	0,31395	1,00	100%	11,00	0,000045672
Steel Punching	0,00053	0,31395	1,00	100%	40,00	0,000166082
Steel Hardening	0,00012	0,31395	1,00	100%	9,00	0,000037368

Transport	Eco-Intensity (impacts/ ton-km)	Distance per item (km)	Total Weight (g)	Uncertainty %	Items	Calculated Impact
Knob	0,52	5862,2	12,73	10%	1,00	0,03911
Leaf Spring	0,52	5862,2	0,77	10%	1,00	0,00237
						0
						0

End of Life	Eco-Intensity (impacts/g)	Mass per item (g)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Recycling Aluminium	-0,00165	12,731	1,00	30%		-0,021041499
Recycling Steel	-0,00025	0,772	1,00	30%		-0,000191017





Graphing - itemized

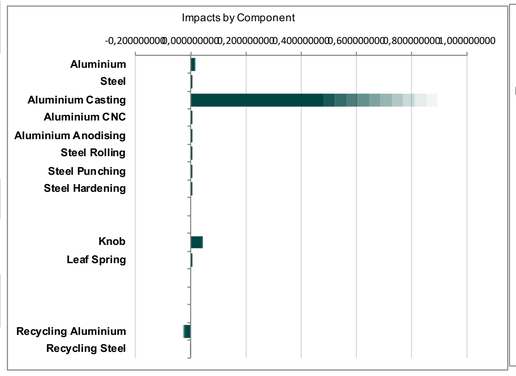
Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Aluminium	0,008	0	0	0	0	0	0	0	0	0	0
Steel	0,000	0	0	0	0	0	0	0	0	0	0
Aluminium Extrusion	0,007	0	0	0	0	0	0	0	0	0	0
Aluminium CNC	0,001	0	0	0	0	0	0	0	0	0	0
Aluminium Anodising	0,000	0	0	0	0	0	0	0	0	0	0
Steel Rolling	0,000	0	0	0	0	0	0	0	0	0	0
Steel Punching	0,000	0	0	0	0	0	0	0	0	0	0
Steel Hardening											
Knob	0,035196823	0	0	0	0	0	0	0	0	0	0
Leaf Spring	0,002135385	0	0	0	0	0	0	0	0	0	0
Recycling Aluminium	-0,01472905	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
Recycling Steel	-0,000133712	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0

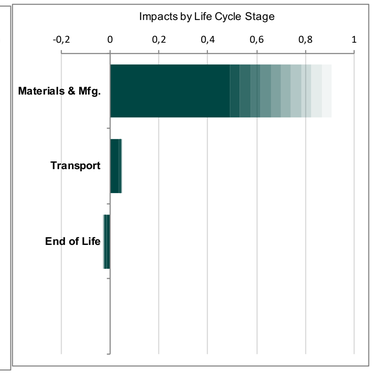
Design option:
Aluminium Cast Knob

Manufacturing	Eco-intensity (impacts/g)	Mass per item (g)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Aluminium	0,000924	12,731	1,00	30%	Knob	0,011762807
Steel	0,000514	0,772	1,00	30%	Leaf Spring	0,000397088
Aluminium Casting	0,037559	18,292	1,00	30%	Knob	0,687033535
Aluminium CNC	0,000012	5,562	1,00	10%	Knob	0,000064116
Aluminium Anodising	0,000014	2,319	1,00	10%	Knob	0,000032840
Steel Rolling	0,000145	0,314	1,00	100%	11	0,000045672
Steel Punching	0,000529	0,314	1,00	100%	40	0,000166082
Steel Hardening	0,000119	0,314	1,00	100%	9	0,000037368

Transport	Eco-Intensity (impacts/ ton-km)	Distance per item (km)	Total Weight (g)	Uncertainty %	Items	Calculated Impact
Knob	0,52	5862,2	12,73	10%	1,00	0,039107581
Leaf Spring	0,52	5862,2	0,77	10%	1,00	0,00237265

End of Life	Eco-Intensity (impacts/g)	Mass per item (g)	Items per func.unit (#)	Uncertainty %	Notes	Calculated Impact
Recycling Aluminium	-0,0017	12,731	1,00	30%		-0,021041499
Recycling Steel	-0,0002	0,772	1,00	30%		-0,000191017

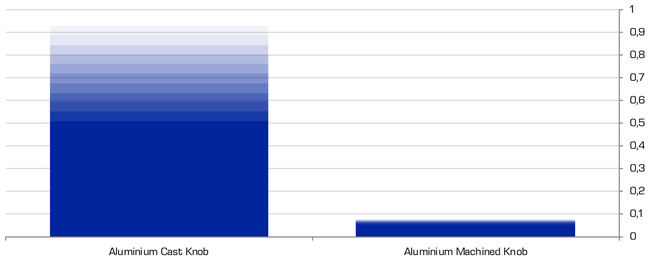




Graphing - itemized

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Aluminium	0,008233965	0	0	0	0	0	0	0	0	0	0
Steel	0,000277961	0	0	0	0	0	0	0	0	0	0
Aluminium Casting	0,480923475	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04
Aluminium CNC	0,000057705	0	0	0	0	0	0	0	0	0	0
Aluminium Anodising	0,000029556	0	0	0	0	0	0	0	0	0	0
Steel Rolling	0,000000000	0	0	0	0	0	0	0	0	0	0
Steel Punching	0,000000000	0	0	0	0	0	0	0	0	0	0
Steel Hardening	0,000000000	0	0	0	0	0	0	0	0	0	0
Knob	0,035196823	0	0	0	0	0	0	0	0	0	0
Leaf Spring	0,002135385	0	0	0	0	0	0	0	0	0	0
Recycling Aluminium	-0,014729050	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0
Recycling Steel	-0,000133712	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0

Comparison
Aluminium Machined Knob
Aluminium Cast Knob



Graphing - itemized

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Aluminium Machined	0,053659502	0	0	0	0	0	0	0	0	0	0
Aluminium Cast Knol	0,511992107	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04

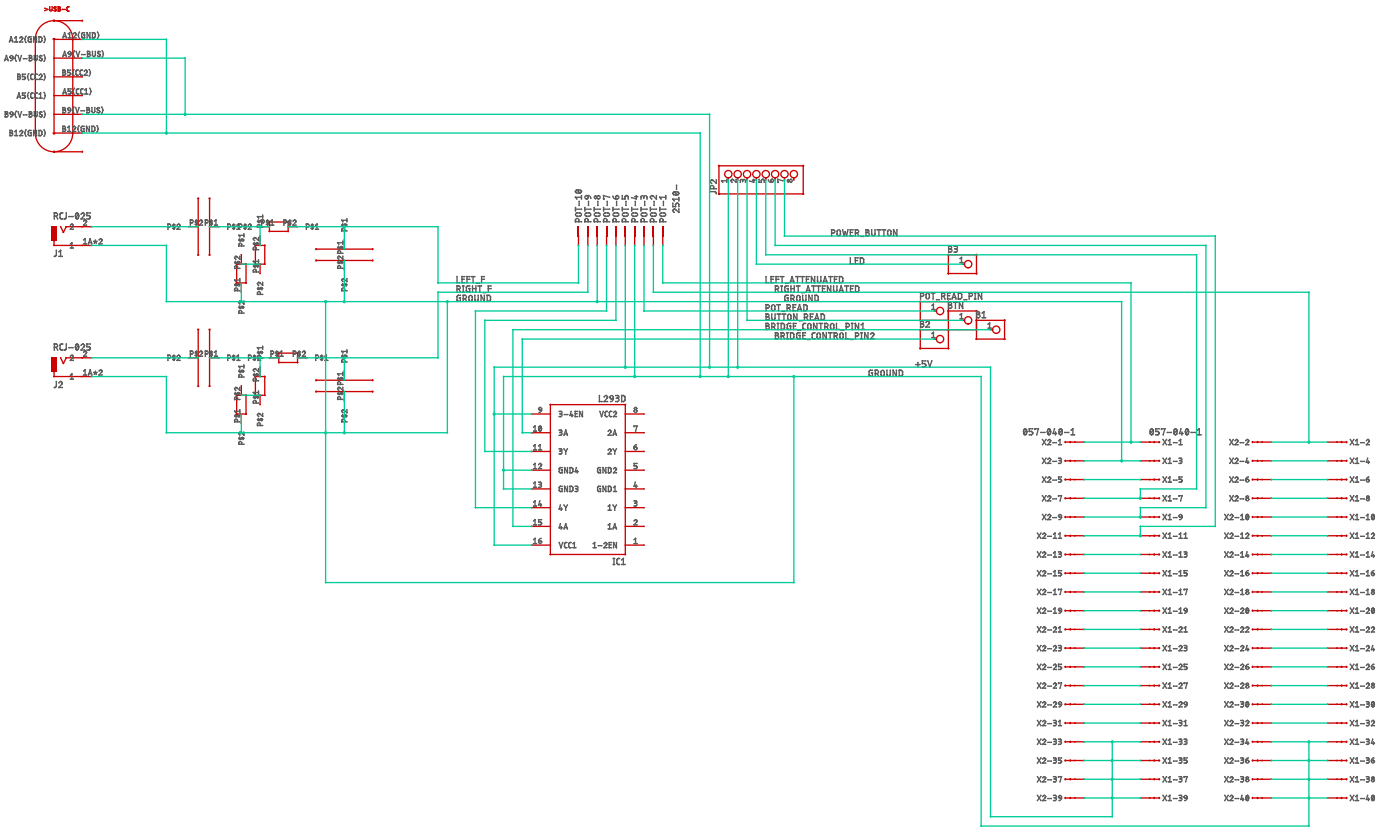
Graphing - by life cycle stage

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Materials & M	0,016	0	0	0	0	0	0	0	0	0	0
Transport	0,037332208	0	0	0	0	0	0	0	0	0	0
End of Life	-0,014862762	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0

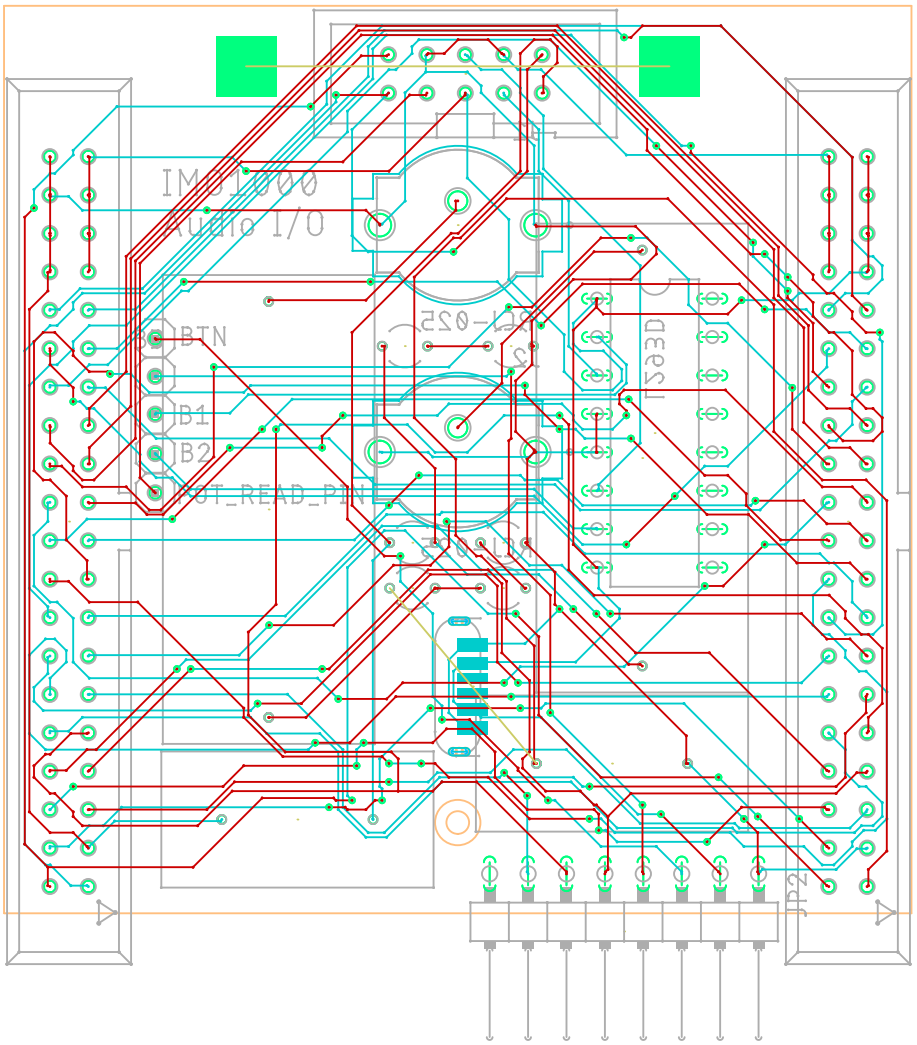
Graphing - by life cycle stage

Item	Impact - uncertainty	Impact + uncertainty gradient ---------->									
Materials & M	0,489522661	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04
Transport	0,037332208	0	0	0	0	0	0	0	0	0	0
End of Life	-0,014862762	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0

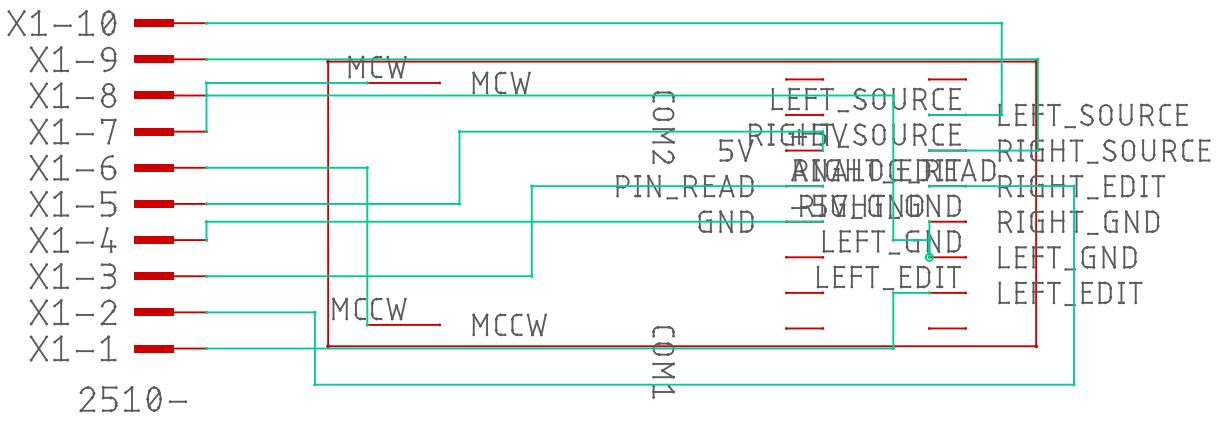
Audio I/O Schematic



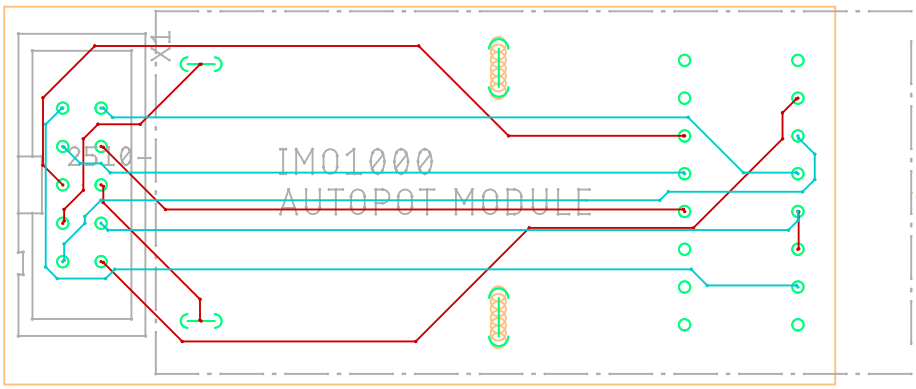
Audio I/O PCB Layout



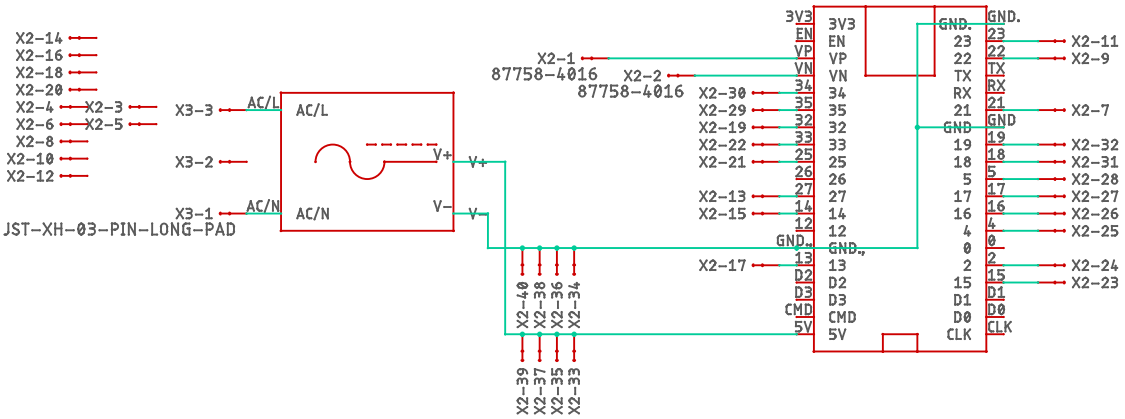
Autopot Modul Schematic



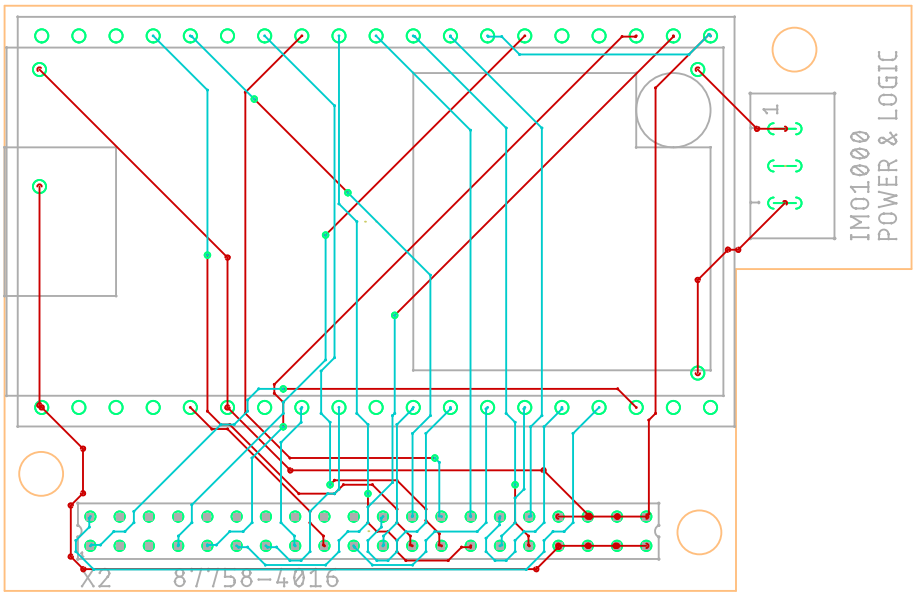
Autopot Module PCB Layout



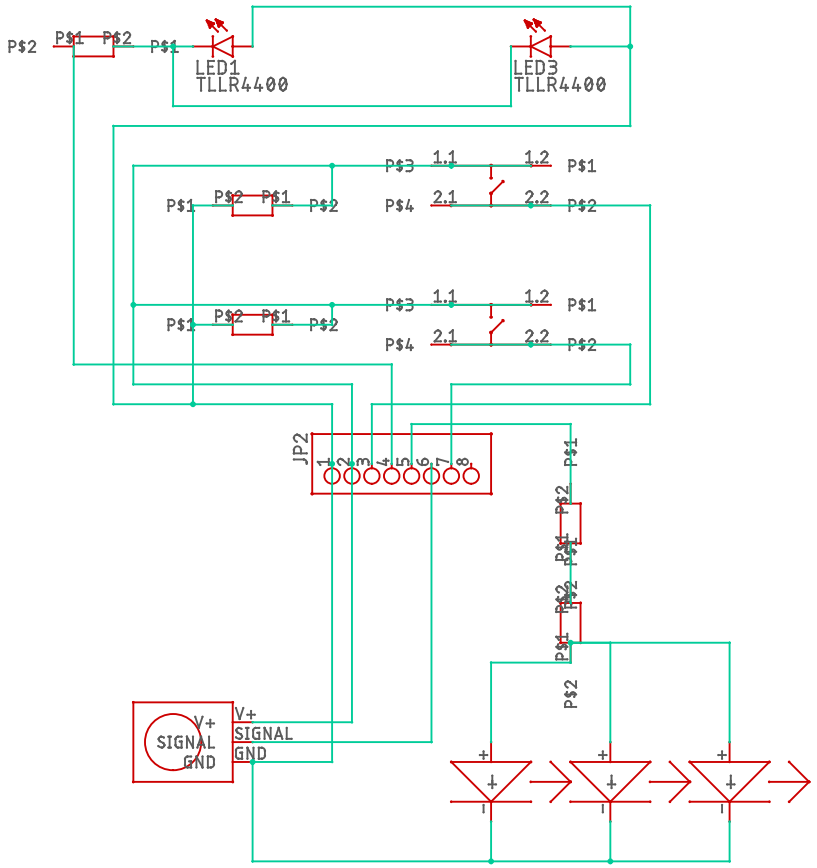
Power & Logic Schematic



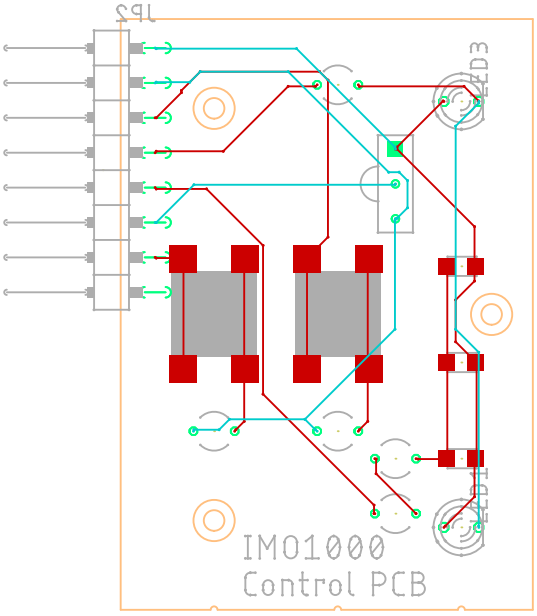
Power & Logic PCB Layout



Control Schematic



Control PCB Layout



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 _____
initials _____ given name _____
student number _____
street & no. _____
zipcode & city _____
country _____
phone _____
email _____

Your master programme (only select the options that apply to you):

IDE master(s): ( ) IPD ( ) DfI ( ) SPD
2nd non-IDE master: _____
individual programme: __-__-____ (give date of approval)
honours programme: ( )
specialisation / annotation: ( )
( )
( )

SUPERVISORY TEAM **

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

** chair _____ dept. / section: _____
** mentor _____ dept. / section: _____
2nd mentor _____
organisation: _____
city: _____ country: _____

comments (optional)

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 ____-____-____ 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: _____ EC

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

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

YES all 1st year master courses passed

NO missing 1st year master courses are:

name _____ date ____-____-____ 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: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name _____ date ____-____-____ signature _____

Initials & Name _____ Student number _____

Title of Project _____

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 - - 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, ...).

space available for images / figures on next page

Initials & Name Student number

Title of Project

introduction (continued): space for images

image / figure 1:

image / figure 2:

Initials & Name _____ Student number _____

Title of Project _____

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.

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.

Initials & Name _____ Student number _____

Title of Project _____

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 ____-____-____ ____-____-____ end date

Initials & Name _____ Student number _____

Title of Project _____

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.

FINAL COMMENTS

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

Initials & Name _____ Student number _____

Title of Project _____