IMS – Integrated Music Solution

Enjoying music with a minimal environmental impact

V.S.O. Verwer – TU Delft – Audiohuis Delft - August 2021

This page is intentionally left blank

Integrated Music Solution – Enjoying music with a minimal environmental impact

Master thesis by: Varik Steven Omar Verwer

Student number: 4159098

Graduation date: 31-08-2021

Master Integrated Product Design

Faculty of Industrial Design Engineering, Delft University of Technology

The Netherlands

Supervisory Team

Chair: Dr. Ir. Flipsen, S.F.J.

Mentor: Dr. Ir. Jansen, A.J.

Commissioned by:

Audiohuis Delft: Ing, Stoet, H.

This page is intentionally left blank

Preface

During this Design Research three mentors stood by my side to guide me along. Unfortunately the first two, Martien Bakker and Stefan van de Geer, could not support me until the end. Never the less, their input and valuable knowledge has guided me to where this report ends, thank you for that.

For as long as I can remember I have been intrigued by machines and electronic equipment. It used to be all about tractors, the bigger the better, not to mention the tools that could be attached to it. Making it a versatile piece of equipment without having to settle on functionality. This fascination for farming equipment is not as strange as it seems, knowing I had a strip of farmland right next to my house.

Touching and playing with little things has always been part of me, preferably things that make sound while doing so. Bringing me back to the first time I “played” with my dad’s, now vintage, Pioneer SA7500 Mk2 integrated amplifier. The feel of the different buttons was remarkable, until present day still the best “feel” of a volume knob. However I also was intrigued by the results of the loudness button, why didn’t it always sound like that? Big, warm and with such an impact!

It was a couple of years later, in a new home, listening to music with my sister, in my bedroom on the second floor of the house, that I found out. Using the same amplifier, but different speakers, I rediscovered the loudness button, quickly followed by a shouting mom at the bottom of the stairs. “Turn it down!”

Somewhere in those years my interest in music was born, and my journey began. I learned that different equipment changed the way you experienced music. As a result I did try a lot of equipment, speakers and setups, new and old mixed, in my own home and at friends or family.

Over the past ten years I have been working with PA and home audio systems, the last couple of years professionally focusing on the latter. Allowing others to discover the magic and beauty of music and letting them find their personal preference.

In the following project I want to achieve the same, guide people on their musical journey in a sustainable manner.

Enjoy!

This page is intentionally left blank

Executive Summary

In this design research the goal is to design a Sustainable HiFi Solution that the user can and are willing to use during their Audio Life.

Context

Listening to music in the domestic domain is something everyone does, but not all in the same way. In this research user of HiFi systems are the focus. HiFi Enthusiast listen to music to experience their Music. For decades HiFi systems were quite sustainable, put together out of separate components, if one failed only that one needs replacement. However things have changed, digital and analog systems are combined in one enclosure.

Problem

All-in-One HiFi solutions gain in popularity amongst Music Enthusiasts. All-in-One solutions are small, everything is contained in one enclosure. Easy to use, a mobile phone and application can be used to control the system. Analog and digital systems are put together to increase the use cases, however the technical lifetime of the different components is different. The digital parts can last for 5 to 10 years, the amplification part 10 to 20 years. A sustainable alternative needs to be designed, with the same benefits for the Music Enthusiast.

Approach

During this design research the double diamond approach is utilized. First to discover the current situation and fill in knowledge gaps using expert interviews and Hotspot Mapping. Thereafter online questionnaires and in-depth interviews provided the remaining data to start the design process. The design process is split in two, first the gathered data is used to design an overall ‘enclosure’, which is tested with the Music Enthusiast. Thereafter the technical implications of the design are researched, prototyped and implemented.

Findings

For the Sustainable HiFi solution to be saleable in traditional HiFi stores it has to be usable in a demo room. The HiFi solution should be adaptable to the changing needs and wishes of the Music Enthusiast during their Audio Life. By focusing on adaptability the sustainability aim can best be achieved via a new product design. For the Sustainable HiFi Solution to utilize its sustainable potential to the fullest different parts of the system should be designed using different circular design methods. In the new design unused functions should not be present in the system.

Results

The Critical Design Challenges for a Sustainable HiFi solution have been met. A modular design was made that can adapt to the Music Enthusiast wishes and needs with regards to Aesthetics, Functionality and Ease of Use. The different modules are easy to replace, without any tools, with the push of a button. The current status of the design is enough to clearly communicate the ideas and reasoning behind the concept. The next step would be to make a minimal viable product to demonstrate the potential of the IMS system to the Music Enthusiast.

List of Abbreviations

AHD	-	Audiohuis Delft
AV	-	Audio Video
AiOs	-	All-in-One solution
CRM	-	critical raw material
DAB	-	Digital Audio Broadcasting
DAC	-	Digital to Analog converter
EEE	-	Electrical and Electronic Equipment
Elco	-	electrolytic capacitor
EoL	-	end-of-life
ErP	-	energy-related products
HiFi	-	High Fidelity
MC	-	Moving Coil
MM	-	Moving Magnet
PCB	-	Printed Circuit Board
R&D	-	Research & Development
SMPS	-	A switched-mode power supply
WAF	-	Wife Acceptance Factor
WEEE	-	Waste Electrical and Electronic Equipment

Contents

1.0 Introduction

Music is an art form. Musicians compose a piece of music on paper or make it up on the spot, and portray it using instruments and their voice. Sound is a musicians equivalent to a painters paint. However, there is one major difference; a painting is made once, recorded sound can be reproduced indefinitely.

This report will look at sound systems, HiFi systems, for domestic use. HiFi equipment has been with us for decades, but the past decade something has changed. This chapter will start with a small crash course on HiFi, followed by the currently observed problems. The company and the design goal conclude this chapter.

1.1 Introduction to HiFi

Music has been part of humanity for millennia, the oldest notation of music dates back to around 2000 B.C. (Andrews, 2015). Before 1877 the only way to enjoy music was live, performed by musicians and artists. However, in 1877 “Thomas Edison amazed the world […] when he invented his “talking machine,” the first instrument ever to record and play back sound.”(Smithsonian, 2015). In figure 1 Edison is besides his “talking machine”, now known as the Phonograph. The Phonograph can be seen as the foundation on which modern HiFi is built. However, what does HiFi stand for, or mean?

Figure 1: The Phonograph was first marketed as a dictation device.

HiFi?

HiFi is an abbreviation for High Fidelity, a term which has been used since the 1930’s (Belk, 2007). The term was first introduced by manufactures in the 30’s, wanting to demonstrate the quality and capabilities of their products. HiFi was described as: “realistic and uncoloured reproduction of music”. (Morton, 2000) This description is still up to date, Google describes HiFi as: “relating to the reproduction of music or other sound with high fidelity” and “a set of equipment for playing recorded music in high-fidelity sound” (Google, 2021). The latter quote describes a HiFi system, a set of components, selected by the user, a Music Enthusiasts, to reproduce recorded music. In the next section a HiFi system will be closer examined.

A HiFi system

The sole purpose of a HiFi system is to reproduce music as the musician intended in a domestic setting, in a way that is appreciated by the Music Enthusiast. Owners and users of HiFi systems do not only want to hear music, playing in the background, they want to listen to the artists and their songs. Listening to music is an activity on its own. A decent HiFi system is capable of portraying the music in front of the listener, allowing them to “see” the individual musicians and connect to them.

A HiFi system is composed of four main product groups; Speakers, Sources, Amplification and Cables, see figure 2. In each product group there are multiple options for the Music Enthusiast to choose between, within his budget and contextual options. Most Music Enthusiast make changes to their system over time, upgrades, tuning the sound more to their liking.

Figure 2: Each product group is available at different price points, and some can be combined. Together they function as a HiFi system. (Own Image)

Another reason for change can be a partner of family member, who might be annoyed by the amount of HiFi equipment in the living room. In the past similar ‘complaints’ have resulted in a new product category, Integrated Amplifiers, marked by the light blue dot (Amplification) in figure 2. In the next section Integrated Amplifiers are briefly discussed.

INTEGRATED AMPLIFIER

Integrated Amplifiers have been around for approximately 60 years. The Luxman SQ-5A, Figure 3, was one of the first to be introduced in 1961 (Audiocircuit, 2010). Integrated amplifiers were introduced because they have multiple benefits for the user. The space required for a HiFi system is reduced, multiple devices could be replaced by one. This smaller footprint made a HiFi system to be accepted sooner by the spouses (Keightley, 1996). Furthermore, it eliminated the need for a start-up sequence, starting the equipment from source to power amplifiers, to prevent damage to the equipment.

Figure 3: Luxman SQ-5A Integrated Tube Amplifier.

An Integrated Amplifier is a combination of at least three functions; a preamplifier, power amplifier and power supply. Heretofore the Preamplifier and Power amplifier were separate devices. In figure 4 four different sections of a Marantz Model 30 Integrated amplifier can be seen. An Integrated Amplifiers allows a user to connect sources, E.g. a cd player, and speakers. Together functioning as a HiFi system. In appendix C – 'HiFi system components in detail', a more detailed overview of HiFi equipment can be seen, different architectures and functionalities that can be included in a system, or in an Integrated Amplifier.

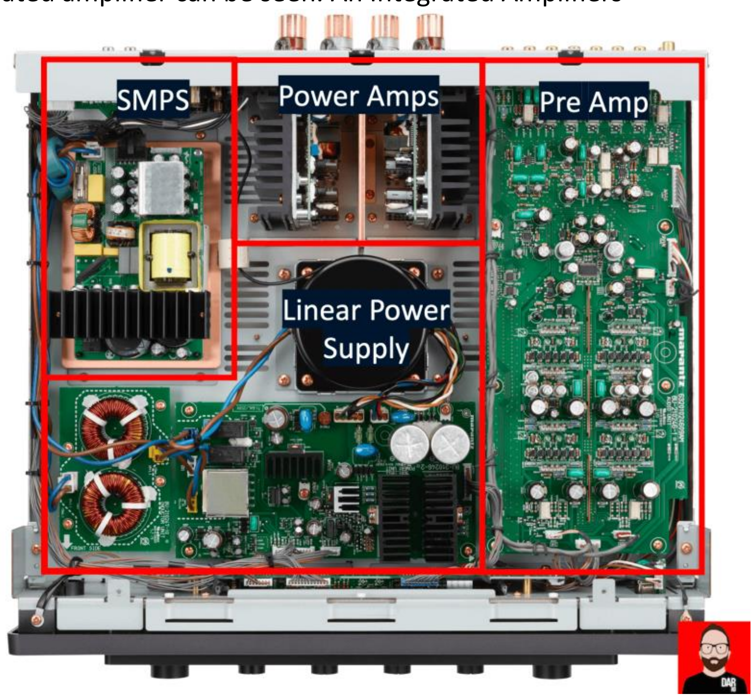


Figure 4: Two power supplies, the switching mode power supply (SMPS) is used by the Power Amps (Darko, 2020).

The Integrated evolved over the years, there are version with an radio build in, or a cassette deck. Over the past 10-12 years a new variant came to market, All-in-One solutions. All-in-One solutions are the primary focus during this design research, and are next to be introduced.

ALL-IN-ONE SOLUTIONS (AIOS)

All-in-One solutions (AiOs) surfaced somewhere around 2010 (Hifichoice, n.d.). AiOs combine the function of an Integrated Amplifier with one or more sources. The first All-in-One solutions housed the following functions in one enclosure; a pre- and power- amplifier, DAC, CD transport and FM/DAB tuner. Integrating the multiple sources in one piece of equipment reduced the footprint, increased its ease of use and eliminated the start-up sequence completely. The sequence is still there, but handled by a computer chip.

In 2008 a new method of accessing music was introduced to the market, Spotify (BBC, 2018). Spotify is the first, mainstream, streaming service. The NAD M33, visible in figure 5, is streaming music and portraying information to the user on the screen. Streaming either means that music can be downloaded from the internet and played, without storing it on a mass storage device, or via Bluetooth. This way of accessing and listening to music, streaming, has been embraced by the public for its ease of use.

Figure 5: NAD M33 – AiOs that is controlled using the Bluesound Application (NAD, 2020).

With the introduction of Spotify the need for a new HiFi apparatus appeared, a streamer. A streamer is able to play the music from Spotify and other streaming services, and is controlled via the users personal smartphone or equivalent. In current All-in-One solutions the CD players are often replaced by a Streamer and the FM/DAB tuner by DAB+ tuner. Please refer to the Glossary in appendix B for a brief description of these functions, and other HiFi related terms used throughout this report.

The inclusion of a streamer made that the whole All-in-One solution can be controlled via a software application. The latter has significant benefits for the users, it greatly increased the products ease of use. However, since day one there are issues associated with All-in-One solutions, mainly derived from the fact that analog and digital systems are used together. In the next section these risks are introduced and explained.

ANALOG VS DIGITAL

For decades HiFi systems have been purely analog. In analog systems all signals are "[…] time-varying and generally bound to a range (e.g. +12V to -12V), but there is an infinite number of values within that continuous range." (Monolithicpower, n.d). Analog systems are made of passive components, E.g. transistors, capacitors, etc., that result in equipment that has a technical lifetime of decades, if implemented correctly. (Bocock, n.d), (Audiokarma, 2010), (Guttenberg, 2010).

Since the introduction of CD players in All-in-One solutions, digital and analog systems were combined into one enclosure. "A digital signal is a signal that represents data as a sequence of discrete values. A digital signal can only take on one value from a finite set of possible values at a given time." (Monolithicpower, n.d.). In figure 6 the main differences between digital and analog systems can be seen. Digital systems are controlled by software, which runs on microprocessors and chips. With the combination of analog and digital systems the problems occurred, the technical lifetime of the different functions, within one enclosure begin to drift apart. A Cd player has a technical lifetime of 5 to 10 years, where amplifiers can last you 10 to 20 years. (Guttenberg, 2010).

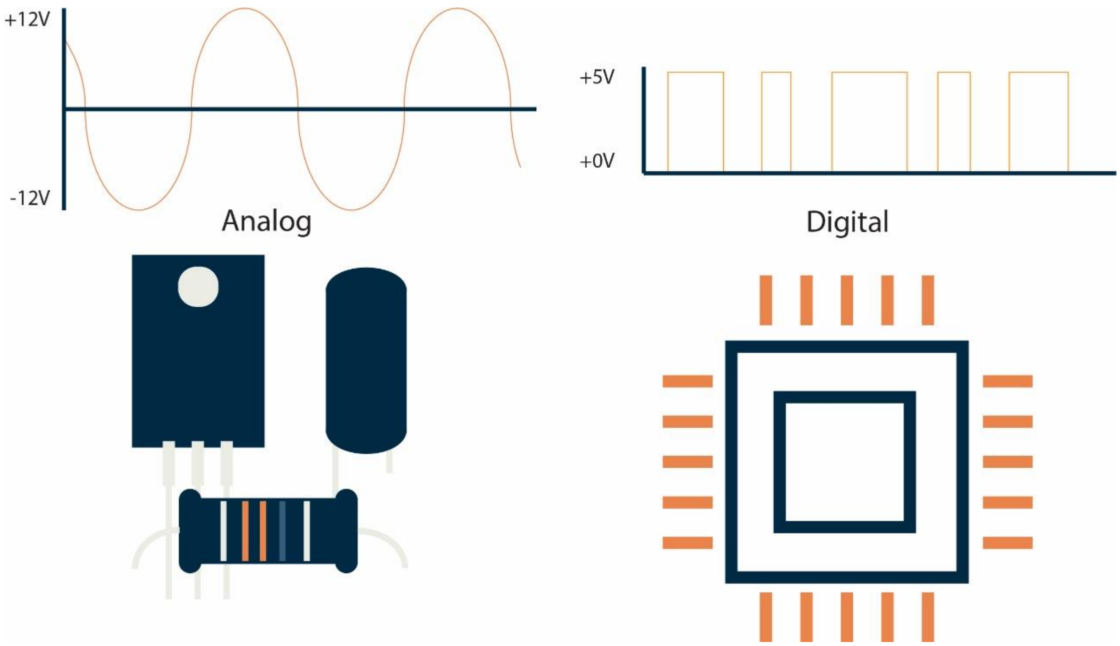


Figure 6: The mix of Analog and Digital systems causes sustainability problems.

CD players have been replaced by Streamers in current AiOs, and came with the addition of control via software. Both digital functions that have not reached maturity yet, new developments on a hardware level can make functions outdated before their technical End of Life (EoL). Bluetooth standards, invented in 1994 and implemented in consumer products since 2001, are a prime example. Since 2001 ten iterations are made, resulting in better performance and reduced energy consumption. Each new version renders the previous versions to be obsolete. Products using the older versions are prone to discarding before their technical and functional EoL. (Triggs, 2018).

The combination of analog and digital functionalities in one enclosure causes problems, which need to be solved. In the next paragraph the design challenge is introduced.

1.2 Preliminary Problem Definition / Preliminary Design problem

All-in-One solutions have a multitude of functions combined in one enclosure. These functions can be seen as ‘Building Blocs’, each Building Block fulfils its own task before handing it off to the next. The preamplifier controls the volume of the signal, before handing it off to the power amplifier. These Building Blocks can either be Digital or Analog, both with their own technical lifespan.

Over the past three years personal professional experience has shown me, and my colleagues, that All-in-One solutions are embraced by the customer. Its ease of use and small footprint are most often mentioned as a reason for their choice. The number of options available at Audiohuis Delft has almost quadrupled in three years, which shows that the HiFi market has also picked up on this trend.

However, from a technical perspective All-in-One solutions have a downside. Due to multiple factors they reach their End-of-Life (EoL) within years instead of decades. They are controlled by software which loses support after a certain number of years, everything is in one enclosure and often one printed circuit board, see figure 7.

Figure 7: AiOs with ‘everything’ on one, complex, PCB.

Currently there is no sustainable alternative that combines everything in one enclosure, with the same benefits for the users as current All-in-One solutions. The following problem statement summarizes the current problems, followed by the preliminary design problem.

PROBLEM STATEMENT

Putting ageing-sensitive Building Blocks, which have not reached technical maturity yet, and fully developed Building Blocks, of which no breakthroughs are expected, into one product, All-in-One solutions, increases the usability and functionality for the user. However, as soon as one of the Building Blocks is outdated, the risk rises of the whole being perceived as outdated by the user. Resulting in premature discarding of complete products, before the whole reaches its technical End-of-Life (EoL), and therefore being unsustainable.

Preliminary Assignment

I am going to design a sustainable HiFi Solution, that customers of Audiohuis Delft are willing to, and can use for the duration of their Audio Life, within the capabilities of the company. The HiFi Solution should be able to fulfil the same functionalities and benefits as currently available All-in-One solutions and utilize the maximum technical and functional lifetime of each Building Block, and therefore be more sustainable.

What is a HiFi solution

HiFi equipment comes in all shapes and sizes, levels of performance and price levels. In this research the majority of those functions are grouped by one Umbrella term: a HiFi solution. A HiFi Solution contains at least a preamplifier, power amplifier and power supply, see figure 8. Meaning a user can connect an analog source, control the volume and connect speakers. Besides those functionalities a variety of others can be included. What those functionalities are and more information can be found in the appendix C.

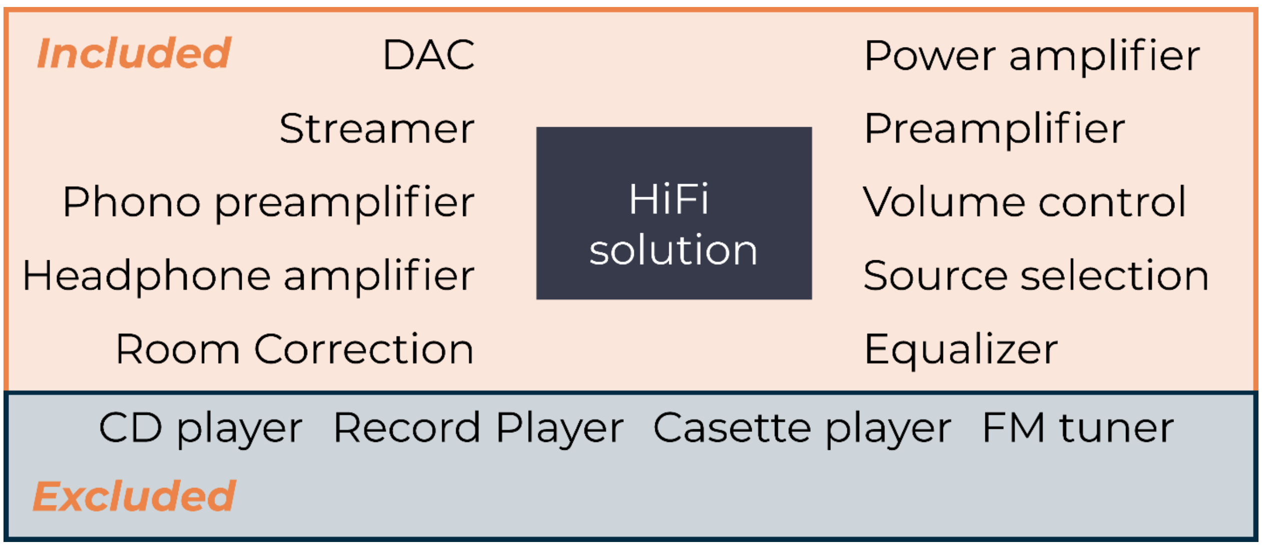


Figure 8:What falls under the umbrella term : ' HiFi solution'

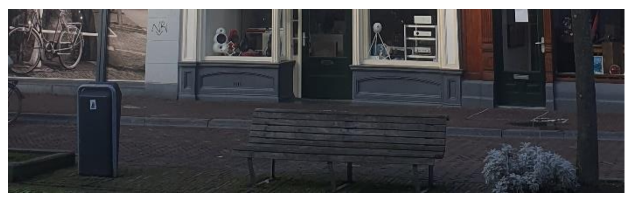
1.3 Company – Audiohuis Delft (AHD)

This assignment is commissioned by: Audiohuis Delft (AHD). Audiohuis Delft is a HiFi shop, located in the city centre of Delft, see figure 9. The store specializes in selling HiFi equipment and related products. AHDs goal is to let customers experience music, put together a HiFi system that suits their needs and wishes, within their given budget.

H. Stoet, the owner, does not only run three shops, but also has developed, and still does, multiple HiFi related products. From turntables, to amplifiers, to power management solutions. In appendix D background information regarding the store and previously developed products can be found.

AHDs goal is to let Music Enthusiast enjoy their music at home. The data gathered during this research will be used as input for a new product development project.

Figure 9: Audiohuis Delft, located on the ground floor in the white building.



1.4 Design Objectives

The goal of the design research to design a new product concept, a Sustainable HiFi solution, that Music Enthusiast can and will use for the duration of their Audio Life. To be able to design for Music Enthusiast their current and future needs and wishes are included in the design phase. To achieve this the current integration of analog and digital systems need to be redesigned, to counter the negative impact, while retaining the positive benefits of All-in-One solutions.

1.5 Reading Guide

This research report will continue with a description of the research design in Chapter 2, in which the research methodology will be explained. Subsequently, Chapter 3 will present the outcomes of the Analysis phase, in which the current context HiFi systems and related subjects are analysed. Chapter 3 concludes with a program of requirements, which will be used in Chapter 4. Chapter 4 focusses on the In Chapter 5 an evaluation of this research is given. To conclude, conclusions are drawn in Chapter 6, including recommendations for future research and a reflection. In chapter 7 the used references can be found, and in chapter 8 the list of appendices. The appendices themselves can be found in the separate appendices report.

2.0 Research Approach

The assignment was outlined in collaboration with the company. There was no predetermined direction or preferred path to be followed during this design research. Therefore, a classic design approach was used: the double diamond.

In the first part of the diamond, the 'discovery' phase, literature research was combined with expert interviews to experience what the different aspects of the current situation entail.

In the second part, ' explore and define', the gathered data was supplemented by customer input to fill he knowledge gaps. The input was gathered from the customers of the company via online questionnaires and in-depth interviews. Originally, guided interviews were intended to be used instead of online questionnaires, but Covid-19 made that impractical.

In the second diamond a classic design approach was followed of diverging and converging to iterate on the critical success factors. The first part was filled with brainstorming, drawing, prototyping and testing.

In the final part of the diamond, and this design research, the customers of Audiohuis Delft were asked for their input again, to select the most viable exterior appearance.

In the end a concept design of a sustainable HiFi solution was designed, according to the wishes and needs of the customers of the company.

This page is intentionally left blank

This page is intentionally left blank

3.0 Analysis Phase

This design research will start with an analysis phase. In the Introduction, chapter 1, HiFi systems have been introduced, and the problems associated to All-in-One solutions. The analysis phase will start with the HiFi purchase, how is HiFi equipment currently sold. In the following section the sustainability aspect of HiFi solutions will be investigated, followed by the way they are built and designed. Thereafter the Music Enthusiast and related stakeholders are researched, to conclude it all in a program of requirements.

3.1 HiFi purchase

In this section the process of buying HiFi equipment is investigated, how, why and where is it purchased. Thereafter the benefits of All-in-One solutions, their possible functionalities and additional drawbacks.

How is HiFi equipment sold, selected and traded in.

Music is an art form, as already mentioned in the introduction of chapter 1. But also, beauty is in the eye of the beholder, or in this case, the ear. Music is perceived differently, everyone has their own taste with regards to aesthetics, but also to the way the like their music to be played. The 'sound' they like can be direct, in the distance, 'analytical' or 'warm', etc..

For Music Enthusiasts, and 'new' customers to discover what their preferred sound is demo rooms are used. Demo rooms are acoustically treated rooms, made to listen and try out HiFi equipment. Guided by an employee customers are taken on a journey, within a certain budget combinations of equipment are made to get seek for their "preferred" sound. In figure 10 the demo room of Rik Stoet High End audio, The Hague, can be seen.

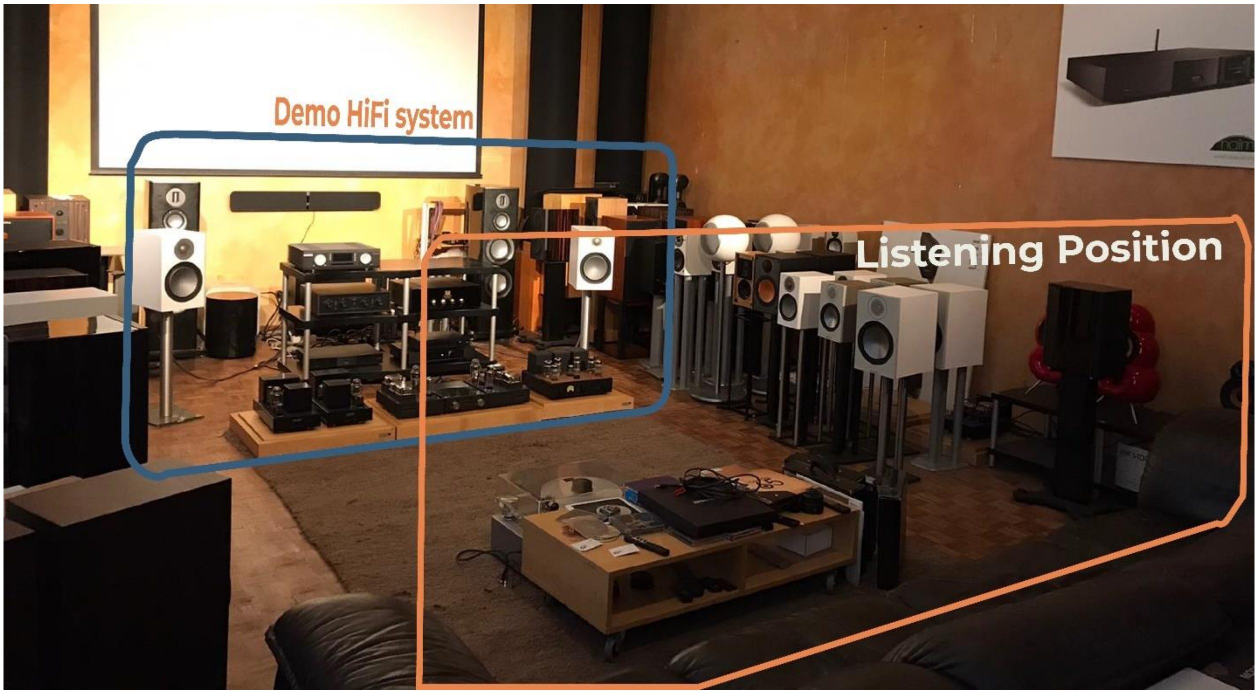


Figure 10: Demo Room in Rik Stoet High End Audio, The Hague.

After determining a Music Enthusiast preferred sound they might be looking for a higher level of performance. A higher level of performance is a broad term and can have multiple meanings. Soundstage and Imaging are often mentioned, amongst many others. Soundstage referring to the width of the music, how far left and right of the speaker does sound seem to come from. Imaging means how the musicians are positioned relative to each other; the lead singer in front, guitar player to the right, percussionist to the back, etc.

Soundstage and Imaging, see figure 11, can be improved in multiple ways, and it is up to the Music Enthusiast to describe what they are looking for. More control over the bass frequencies can be achieved via a more powerful power amplifier, improving imaging. A better DAC can improve soundstage and imaging. The knowledge and experience of the store employees is crucial in making the right decisions.

Figure 11: The tighter the circle, the more realistic the reproduction. More width gives the musicians room to 'breath'

Over the recent years demoing All-in-One solutions has come common practice, although a bit different. Since they contain, in most cases, all the functionalities desired by the Music Enthusiast, only the match between the speaker and the AiOs has to be made. And, don't forget, which AiOs has the sound the Music Enthusiast prefers, yet again, they all sound a bit different.

Changing equipment does not only happen to achieve a higher level of performance. Changes in an users contextual situation can result in the wish for change. This can be due to an aesthetic mismatch between the HiFi equipment and the home interior, or just the wish for something new.

If and after the desired upgrade is found, the currently owned equipment can be traded in, if it is of a certain quality. In the case of AHD the equipment is the sold via Studio 107 a second hand HiFi store, see appendix D.

What can an All-in-One do?

All-in-One Solutions are already briefly discussed in the introduction, what their problems are and what needs to be changed. In this section the benefits and functionalities of AiOs are analysed.

Benefits

User is in control via a smartphone application

An mobile application controls AiOs, on multiple devices at once. The software is not limited to one device, everyone can play at random. This freedom and ease of use has become normal nowadays in other domains, and is also expected from HiFi solutions.

The amount of equipment needs is reduced to a minimum

For a Music Enthusiast who only streams one 'box' and two speakers are all he needs. The one piece of equipment is easier to integrated into an interior.

The space required for a HiFi system is minimized

With the fact that music can be played using only one box the space required is minimized. All-in-One solutions come in all shapes and sizes, see figure 13 for another AiOs, but remain one box in most cases.

The start-up sequence is eliminated

Traditional HiFi systems have a certain start-up sequence, which can be seen in orange in figure 12. During start-up an delay of about 10 seconds is needed between the different pieces of equipment, to prevent damage by energy surges. Turing a HiFi system off is done in the exact opposite order, starting with the power amplifier. In AiOs this process is taken care off by a microcontroller.

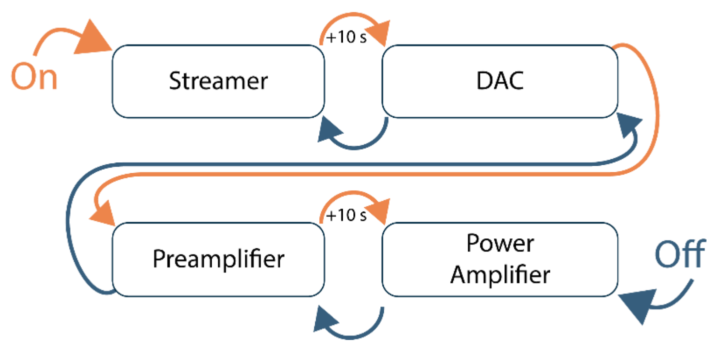


Figure 12: Turning on requires a 10s delay, turning off is in the opposite order.

Drawbacks

Besides the already mentioned problems of AiOs solutions from a HiFi perspective they have an additional drawback. AiOs don't offer their user the option of upgrading different functionalities. This not only takes away part of the fun, it can also be the cause of premature EoL. If something changes in the Music Enthusiasts context, new house, new speakers, etc. the AiOs might not be sufficiently powerful anymore.

Functionalities

AiOs can house a multitude of functionalities, the options of a HiFi solution are comparable to that of an All-in-One solution, see figure 8.

Figure 13: Moon Ace – All-in-One solution by Simaudio. (Wilbert, n.d.)

CONCLUSION

For the Sustainable HiFi solution to be saleable in the current HiFi setting it has to be usable in a Demo Room. The Music Enthusiast should be able to hear what the system can do, with different speakers. Furthermore it should be able to keep up with changes, with regards to aesthetics but also to performance. Different options should be available, to fulfil the functions of an All-in-One solution. If previously used equipment is discarded by the Music Enthusiast, HiFi stores are used to handling 2nd hand equipment.

In the next paragraph a range of sustainability aspects, concerning HiFi solutions, are researched and analysed.

3.2 HiFi's Sustainability

The assignment, as proposed in Chapter 1.2, is still broad and open to multiple design solutions. The goal is to design a Sustainable HiFi solution, therefore literature regarding circular design is analysed to determine viable directions. The literature research is complemented by a Means-End diagram. Thereafter the current situation regarding the environmental impact is analysed via literature and Hotspot Mapping.

CIRCULAR BUSINESS MODELS

The goal of reducing environmental impact can be achieved via multiple routes, however it is to be achieved using a new sustainable product design. In 'Products That Last' by Bakker et al. (2014) five circular business models are described. Products that Last helps designers to design for "[]much longer product life", therefore buying us time to switch from a linear economy to a circular [sustainable] economy. Each of the five circular business models is targeting a different primary revenue stream, in figure 14 the five business models can be seen.

- The classic long life model
- The hybrid model
- The gap exploiter model
- The access model
- The performance model

Figure 14: Primary revenue streams of the five circular business models (Bakker et al, 2014).

For the HiFi Solution to be sustainable the amount of E-waste generated should be minimized. The Classic Long Life Model, which generates revenue by sales of high quality equipment with a long lifespan at a high price point, is best suited. However, the HiFi business is a bit different than almost any other dealing with electric equipment, as described in chapter 3.1. The fact that the HiFi business are used to trading in 'old' equipment, on new sales, opens up opportunities. These opportunities can be exploited by utilizing the 'Gap Exploiter Model'. The Gap Exploiter Models generates revenue by repairing and selling refurbished products. Possibly the Gap exploiter Model could be combined with the Access model, to the parts that get upgraded.

E-waste are products discarded by the owner without the intention of reuse. However, in the HiFi market requirements differ between users. What does not meet one customers requirements, can be perfectly fine for the next. This can be exploited to reduce E-waste, by using products until its technical and functional lifetime has been reached. Passing it along to the next Music Enthusiast until repair and refurbishing is not economically viable anymore.

Circular design strategies

The sustainable HiFi solution could benefit from two circular business models; The Classic Long Life model, and the Gap Exploiter Model. But before sales can be made the product needs to be designed, 'Products that Last' also provide in this matter. Six circular design strategies are proposed, which all focus on different parts of a products design. The six design strategies are:

- Design for Attachment and Trust
- Design for Durability
- Design for Standardization and Compatibility
- Design for Ease of Maintenance and Repair
- Design for Upgradability and Adaptability
- Design for Dis- and Reassembly

Even though that all design strategies could be applied to a HiFi Solution, not all are deemed to be equally fruitful. To examine which strategies could be viable they are now briefly discussed.

Design for Attachment and Trust

The HiFi market is sceptic of new products until they are reviewed, tested and produced. Therefore designing for Attachment and Trust is not deemed viable at this point.

Design for Durability

As mentioned before there are parts of amplifiers that can last decades, however the new digital additions are not expected to have an equal life time. Therefore Design for Durability can be applicable to parts of the Sustainable HiFi Solution.

Design for Standardization and Compatibility

The standards that are already set for the HiFi market will be followed. Setting a new standard in this research is almost impossible, however at the end a starting point for a new standard might be set.

Design for Ease of Maintenance and Repair

HiFi Solutions have a limited amount, if any, of moving parts, and parts that wear out during use. However the parts that are prone to break or fail, as observed at Studio 107, see Chapter 3.3; Repairability, should be made easy. Therefore the enclosure(s) should be designed accordingly.

Design for Upgradability and Adaptability

Upgrading is a key component of the HiFi industry, as previously described in Chapter 3.1 higher levels of performance are sought throughout Music Enthusiast Audio Life. Designing for Adaptability can therefore increase the ease of upgrading.

Design for Dis- and Reassembly

Since amplifiers are mainly electronic products mechanical wear is not an issue. However there are parts that do need replacement or maintenance somewhere during their product life, as became clear in Chapter 3.3. The enclosures should be designed accordingly.

Ways to reduce impact of Music Enthusiast

In the previous section the Circular Business models to pursue and possible usages of the Circular Product Design Strategies are mapped and clear. In this section the theory will be combined with an 'Exploratory Systems Analysis'. The assignment is analysed further, to get to the core of the problem and the possible solution directions. The Means-End diagram is used for this exploration, as described in 'Policy analysis of multi-actor systems' (Enserink, 2010. P 57-69).

The means-end diagram is used to analyse the proposed problem. The problem is analysed at different levels, first by asking Why questions. The starting why question was; 'Why do HiFi users want to lower their environmental impact', which ended with; 'Because we have to save the planet'. With the why question answered the how questions followed. The starting question 'How question' of the Means-End diagram is; "How can a HiFi user reduce its environmental impact". In figure 15 till 18 the results of the Means-End diagram can be seen. The awnsers to the how questions are colour coded; Green being a direction to pursue, orange is intresting and might be integrated and red answers will not be included.

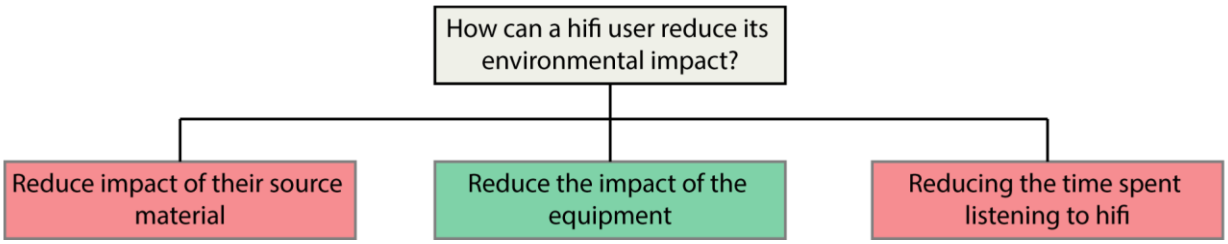


Figure 15: Reducing the impact of Music Enthusiasts equipment is the pursued branch, the others would force them to change their behaviour.

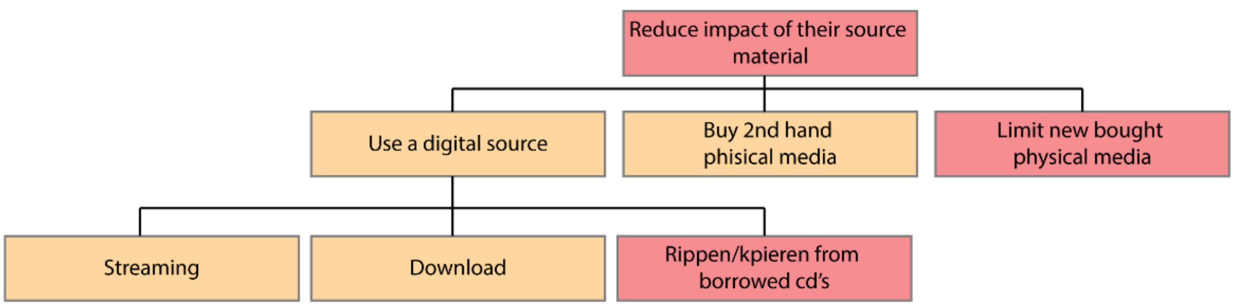


Figure 16: Streaming is to be incorporated in the assignment, since it has become a vital part of a HiFi solution, and a sustainable music source.

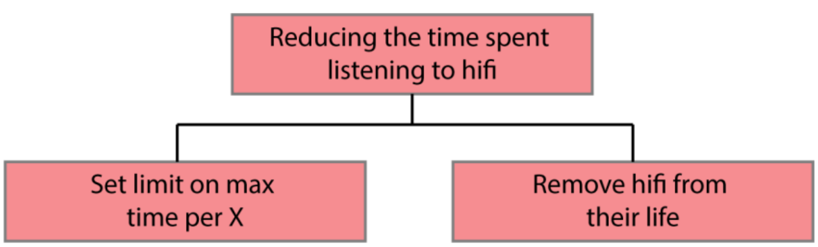


Figure 17: Forcing a Music Enthusiast to change its behaviour is not an option within this design research.

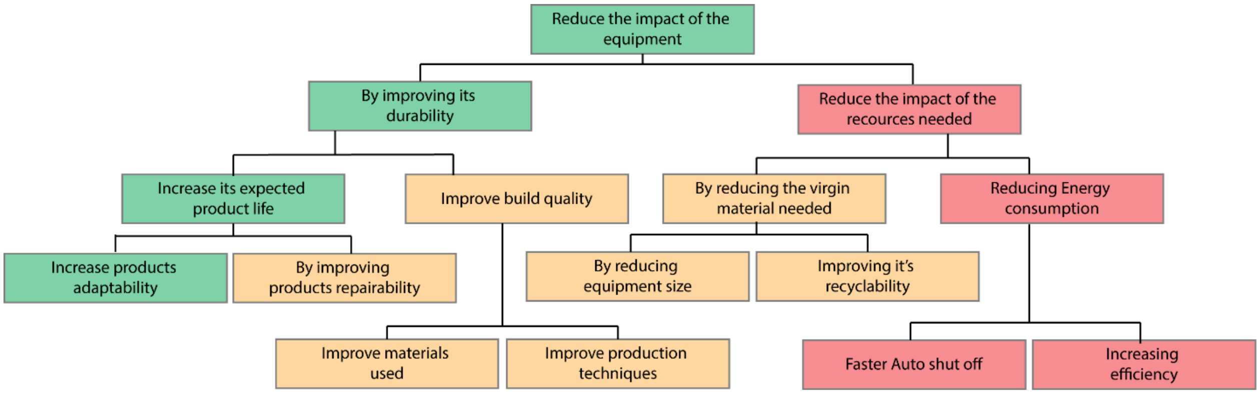


Figure 18: Increasing adaptability is most feasible, the other (orange) squares might be incorporated along the way. Increasing products adaptability matches the result from literature.

From literature and the Means-End diagram it is concluded that increasing the HiFi solutions adaptability, and therefore extending its technical product life, is a viable direction to pursue. However, for all parts EoL will come eventually, and the HiFi equipment will become E-waste. In the next section the current situation concerning E-waste are analysed.

How big is the current impact

"E-waste is a term used to cover items of all types of Electrical and Electronic Equipment (EEE) and its parts that have been discarded by the owner as waste without the intention of re-use." (Goodship, et al. 2019). In 2019 a worldwide total of 53.6 Mt (Metric tons) of E-waste was discarded, with an estimated value of at least 57 billion US Dollar.(Engels, 2020). Of those 53.6 Mt only 17.4% was recycled, see figure 19.

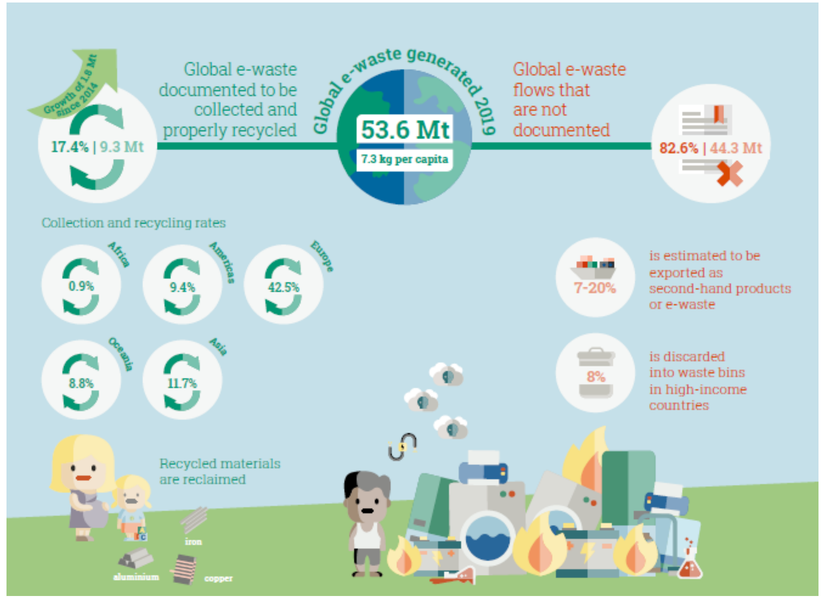


Figure 19: Estimations of uncertain E-waste (Forti et al,. 2020. P14).

Audio related E-waste

In 2018, in the Netherlands, 19kg of E-waste was generated per person. (Milieucentraal, 2018). To determine the percentage of HiFi related equipment, of those 19kg an estimation is made, based on a research trial conducted in Suffolk, England (Wrap, 2009).

Based on the aforementioned research it is estimated that 2% of the E-waste generated is discarded audio, HiFi, equipment for domestic use. A safe estimation, since the dataset dates back to 2008, and accounting for the following. Between 2010 and 2018 an increase of 33% of EEE (Electrical and Electronic Equipment) was put to market, and the amount of E-waste has grown by 13%, to 366kt. (Baldé et al,. 2020). For the full analysis please refer to appendix E– E-Waste in Detail.

Environmental Hotspots; which parts and procedure have the highest impact.

"[…] Hotspot Mapping helps designers in (re)designing their products for ease of disassembly, by assessing which parts in the product architecture are most critical for ease of disassembly. Critical parts are parts with a high failure rate or maintenance need and/or with a high economic and environmental value, that should be easily accessible with low effort to enable cost-effective recovery processes.". "The Hotspot Mapping method focuses […] on the product-related aspects. It assesses the product architecture […]." (Flipsen et al,. 2020).

In this research Hotspot Mapping (HSM) will not be used to redesign a product, its original use. In this research it will be used to learn from current Integrated Amplifiers and localize its hotspots. By HSM an Integrated Amplifier the crucial parts and assembly methods used within amplifiers are localized. For this research the Cambridge Audio – AM5 an entry level integrated amplifier, see figure 20, has been disassembled.

Figure 20: Opened up during disassembly, connectors at the back already removed.

In Appendix F an overview of the results from the HSM session can be found, and for a detailed description of the method please refer to "Hotspot Mapping for product disassembly' by Flipsen et al (2019). The most significant results are discussed next.

Results

In figure 21 the most critical parts can be seen, of which the printed circuit board (PCB) and transformer are the most crucial for the amplifier to work. Those two also have the highest environmental and economic impact, combined with the bottom plate.

Throughout the amplifier parts are held together using screws, bolts and nuts reusable fastening methods. However the number of screws, and therefore time needed to undo them resulted in a red flag in the left column.

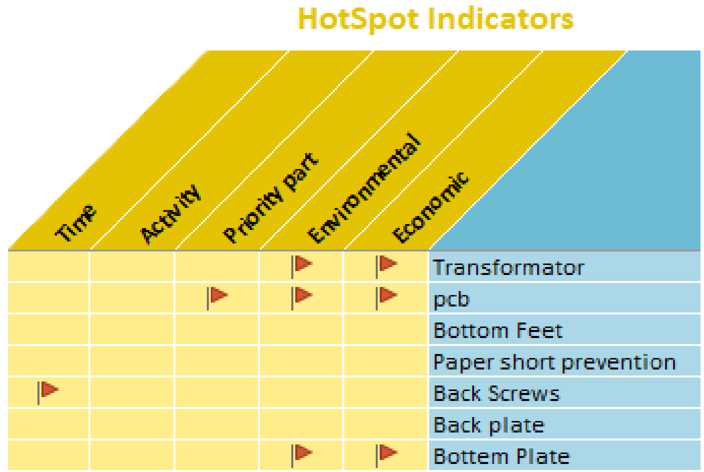


Figure 21: The bottom plate has a weight of 1.1kg and the back plate is secured using nine screws.

Materials

During the Hotspot Mapping process it became clear that the PCB's and power transformer have the highest environmental impact. However, where does this impact come from? Via literature research it became clear that Critical Raw Material's (CRM's) are used to produce the Printed Circuit Boards. Mainly in the different components used on the PCB's and of them at least 12 could be recovered. (Circular Industries, n.d.). Next to CRM's there are also precious metals used, gold on the contacts, and copper for the power transformers, wrapped in white in figure 7.

Continuation

After the first Hotspot Mapping Analysis it was decided not to disassembly additional, more expensive, Integrated Amplifiers or All-in-One solutions. First of all because no additional insights were expected to be made during disassembly, the electronic build up does not greatly change with more expensive models, see figure 31 (rega). The amount of electronics, and complexity of PCB's does increase but does not really affect the impact per kg. Secondly, further analysis could also be performed on online available images, which are also used in chapter 3.3 (Building Block Requirements). Finally, expert interviews, which will be described in the next chapter, will provide additional, similar data.

Overlapping Functions

In the previous section it became clear that the PCB's and transformers have the highest environmental impact in HiFi equipment. However, if they have the highest environmental impact, is their usage minimized by current manufacturers?

HiFi brands combine multiple functionalities into one enclosure to appeal to a broader customer base. By combining multiple functions the probability that customers select their product increases. However, customers might never use all functions because they do not need it. As a result materials and energy are used to produce parts that, at end of life, get discarded while being "brand new". Furthermore, the user pays for functions they do not need.

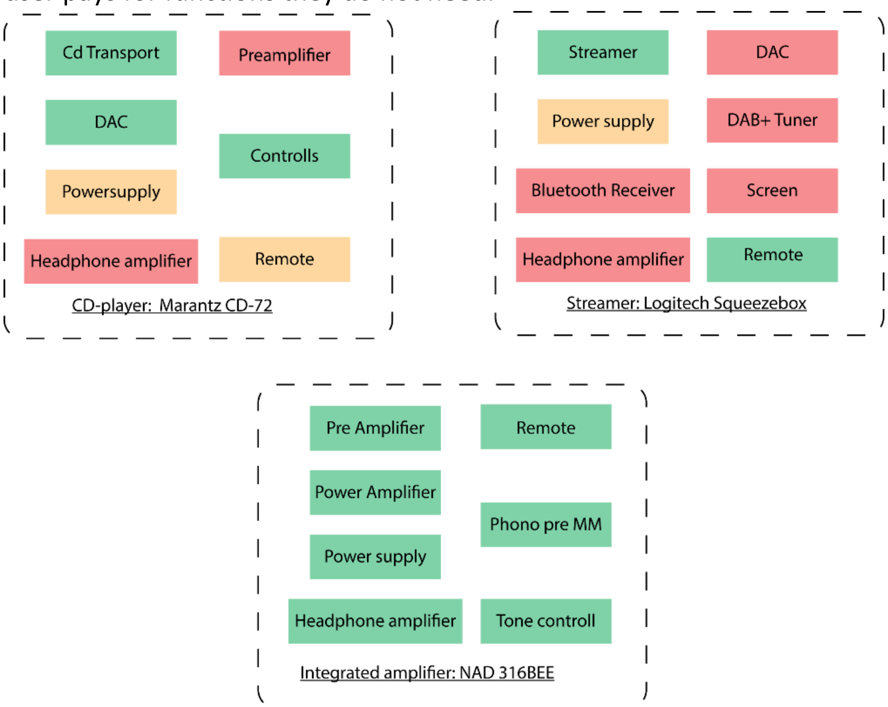


Figure 22: The dotted lines mark the different pieces of equipment, as a result the user has 3! headphone amplifiers.

In figure 22 an example is given, based on the setup of one of the research participants, more on them later. The three pieces of equipment together fulfil the function of a HiFi solution. The green boxes are all that is necessary for the HiFi solution to function as the user demands, the orange boxes are used but could be replaced by one, and the red are never used resulting in 'brand new' E-waste.

Conclusion

From the Means-End diagram and literature research it can be concluded that designing for adaptability is a viable direction to pursue. There are multiple circular business models that could be utilized for the sustainable HiFi solution. The Classic Long Life Model is the traditional business model of the HiFi market, and could remain in use. The Gap Exploiter Model is utilized via 2nd hand HiFi stores, which could also serve a purpose for the new concept design. With regards to the circular product design strategies multiple of them could be used during the design phase. However, if to design for adaptability not all parts of the HiFi solution will have to be designed equally. If the case is replaced every 5 years, it will be designed differently than the connectors on the back, which have to serve a life time.

Looking at current designs the environmental impact can be reduced in multiple ways. First of all should removing the PCB’s and power transformer, from their enclosures be possible. They have the highest environmental impact, they contain precious, critical and toxic materials. Besides their environmental impact they also have an economic value, in 2020 57 billion dollars of E-waste was discarded, not recycled, worldwide.

Finally, preventing the option of unused functions can reduce the environmental impact, and therefore increase sustainability. In current equipment functions are combined to appeal to a wider audience and be usable in more use cases. However, as a result consumers get functions they might never use, which results in ‘brand-new’ E-waste.

These factors, combined with products that did reach their technical EoL, result in, at least, 7.320.000 kg (2% of 366kt) of audio related E-waste in 2018.

3.3 HiFi Architecture

The literature research and Means-End diagram both showed increasing products adaptability, in this case the HiFi solutions adaptability, as a viable direction to design in. In this section current and previous HiFi solutions, with regards to product architecture, adaptability and repairability are researched.

MODULARITY IN HIFI SOLUTIONS

In 1967 a way of improving the functionalities of a piece of HiFi equipment was invented, modules. One of the first amplifiers to use modules was the Quad 33 Preamplifier (Quadrepair, n.d.). The Quad 33 preamplifier can be seen in figure 23, together with the two available modules. Since it started in 1967, what else is possible?

Figure 23: A Tape board to add a Tape deck (Left) and a Disc board to add a turntable(Right)

Internal & External modules

In the current product range of AHD there remain multiple HiFi solutions that make use of modules for different use cases. There are two ways modules usage is integrated in amplifier designs; internal and external modules.

External modules are placed from outside the enclosure, like the Quad in figure 23, and the modern NAD in figure 24. The benefit of external modules is that they can be placed by the user, or at purchase, without opening the enclosure. External modules often are (partly) enclosed to protect the PCB's from external influences.

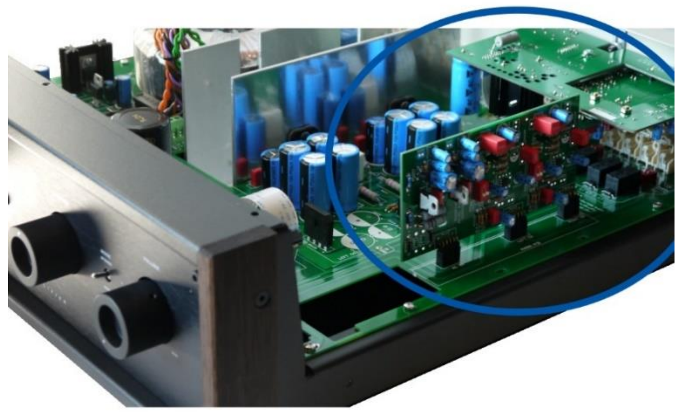


Figure 25: Phono Module (Vertical on the left) DAC (Horizontal on the right)

Internal modules do require the enclosure to be opened to install the modules. Internal modules are placed and connected internally either in the factory, or in a store by a professional, see figure 25. Thereafter the enclosure is closed again, and the new module tested. These modules often come without any enclosure, just a bare PCB. Simaudio has modules that are shared between different amplifiers, and modules specific to only one or two (Simaudio, n.d). Furthermore they have modules to add functionalities, or inputs to the amplifier.

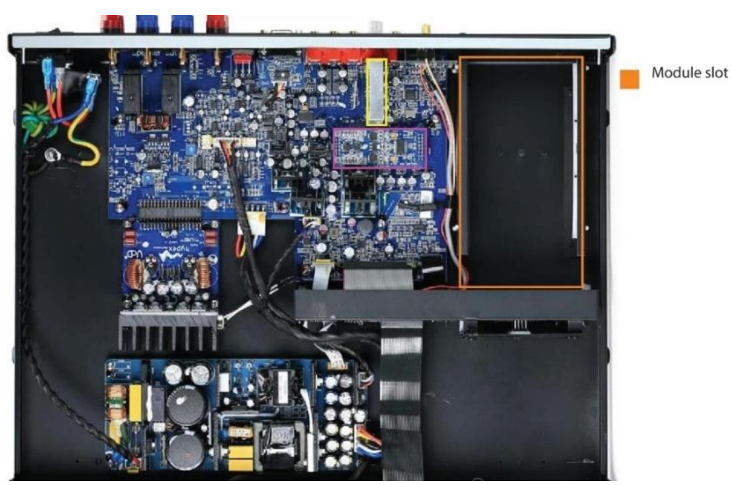


Figure 24: A double module slot, one above another, which can be installed from the back.

Viability of a Modular HiFi Solution

To increase the adaptability of a product a modular design approach can be adopted. By designing in modules, combined a modular product, multiple product characteristics can be influenced. A range of modular products has been analyzed, of which the results can be seen in appendix G. In the next section two examples of modular design in HiFi will be examined.

Modular Amplifier

Modules have not only been used to expand the functionality of amplifiers, it has also been used to create an entire amplifier. Cello was a High End HiFi manufacturer which introduced its first product in 1985, an equalizer; the Cello Audio Palette, figure 26. (Matthew-James, n.d.) The Audio Palette became a success and multiple products followed, amongst them the Audio Suite.

Figure 26: The Audio Palette together with its power supply, currently offered 2nd hand for around $21000,- (eBay: 07-2021)

The Audio Suite is a mainframe which accepts up to ten different modules. The modules were made at two price levels, which could somewhat be mixed. See figure 27 for the Cello Suite equipped with three modules.

Figure 27: Cello; Audio Suite setup as an Integrated Amplifier. 2nd hand worth around $25000,- (eBay: 07-2021)

Module manufacturer

In the early days of HiFi two groups of Music Enthusiasts could be identified; the Golden Ears, and the Do-It-Yourselves (Keightley, 1996). Those two groups still exists today, although the term Golder Ears is seldom heard anymore. Cello would appeal to the Golden Ears, well made and easy to work with.

For the DIY enthusiast there is a company, amongst others, in the Netherlands, Eltim (Eltim, n.d). Eltim offers a wide variety of DIY modules, designed to be combined to fully functioning products. The modules range from preamplifier modules, to HiFi power amplifiers, figure 28, to High-End Power amplifiers. Input modules, switching power supplies and Linear power supplies are also available.

Eltim does not only sell modules, customers can also contact them for to have an (Integrated) Amplifiers build to their specifications and wishes, within one of their suppliers enclosures. In figure 29 such an amplifier can be seen.

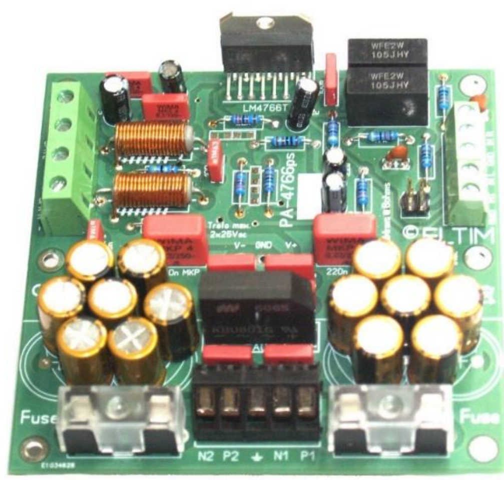


Figure 28: Class AB amplifier: PA-4766

Figure 29: Eltim: power amplifier built to order.

BUILDING BLOCK SPACE REQUIREMENTS

All-in-One solutions, can accommodate a multitude of functions and features within one enclosure. Every brand has their own approach for placement of parts and therefore internal layout. However, since the functionalities stays the same, how much space does every function and part require within the enclosure? To gain insights into the space requirements of the different functionalities, features and parts current amplifiers are analysed. This analysis is performed on online available images of Integrated Amplifiers and All-in-One's.

In figure 30 one of the analysed amplifiers can be seen, the Moon Ace All-in-One solution. The different functions are outlined using different colours. In this analysis 9 amplifiers were researched, of which the result can be found in appendix H – Function Dimension Analysis. The data is unused for now, but will be used later on, in chapter 4.4.

In table 1 the raw data of each function can be seen. Amplifiers capable of different levels of performance were used, the lower performing amplifiers used smaller sized PCB's.

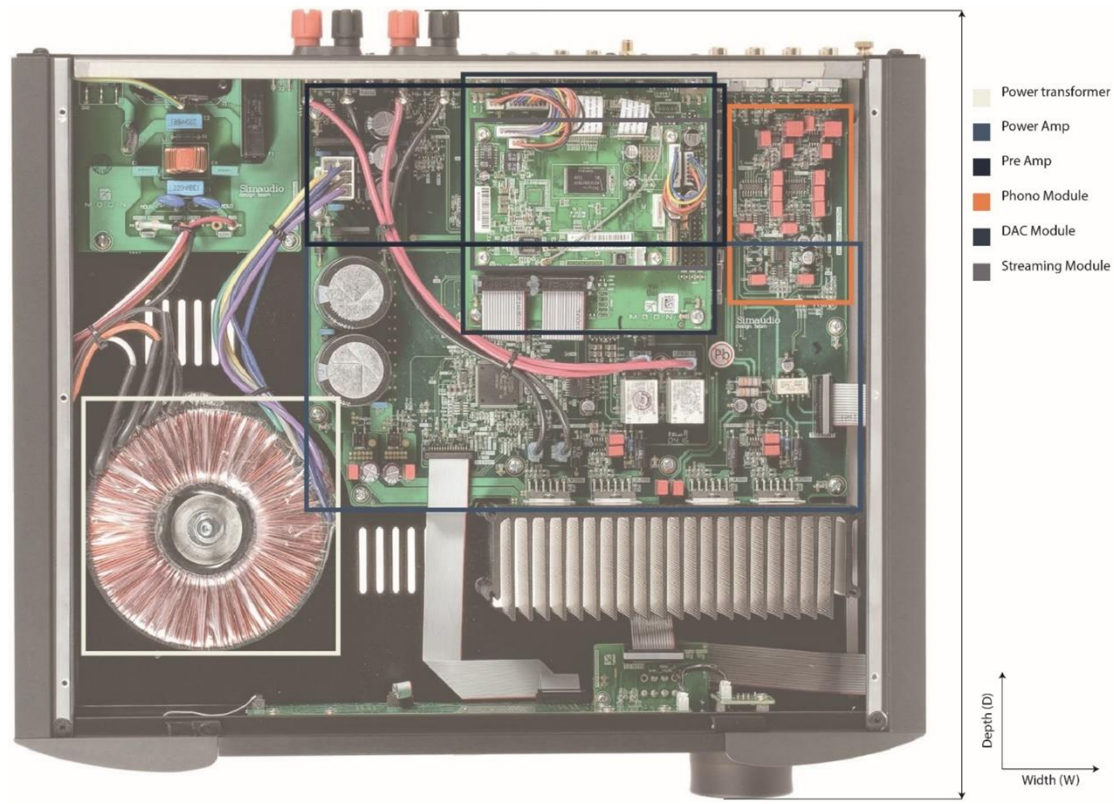


Figure 30: Moon Ace; Rough estimation of Function Dimensions in MM

Function	Smallest Cm^2	Biggest cm^2
Power transformer	90	255
Power Amplifier	94	250
Preamplifier	65	255
Phono Preamplifier	19	82
Streamer	20	80
DAC	18	138

Table 1: Used surface area per function

LEVELS OF PERFORMANCE INCREASE

In the previous section the overall dimensions of different functions has been analysed and grouped to functions. The Space Requirement analysis indicated that higher levels of performance require more space, but also that the implications depended on the manufacturer. However, during that analysis multiple brands were used, without an clear order or overview. To gain additional insights on the implications of higher levels of performance, with regards to the amplification circuitry, one brand from the UK is analysed; Rega.

In figure 31 the, open, top views of their amplifier models can be seen. All amplifier are purely analog and designed for musicality: “Every Rega product is designed to achieve the best musical performance and deliver a lifetime of enjoyment at an affordable price.” (Rega, n.d.). The main results of this image analysis are summarized below.

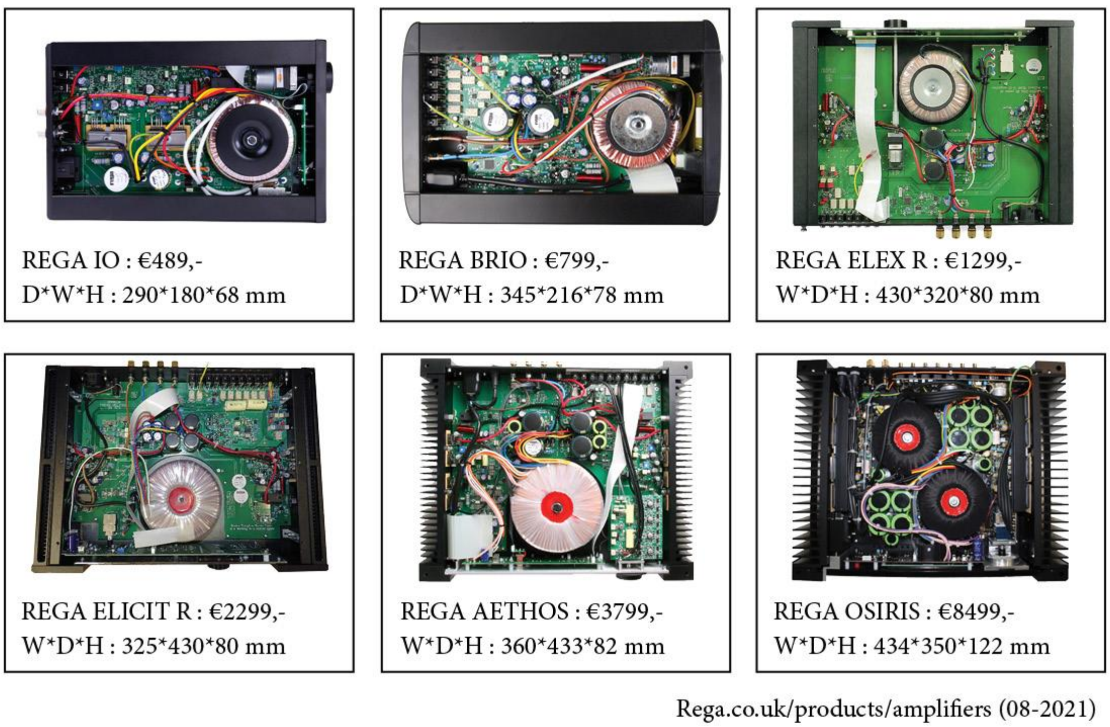


Figure 31: Analyse increasing levels of performance on an amplification level.

Results

- The power transformers increase in size to a certain point, thereafter two smaller transformers are used. They range between 90mm2 and 150mm2
- The higher the level of performance the more cooling is required.
- To distance between the Analog Inputs and the preamplifier is as short as possible.
- Internal cabling used remains more or less the same between the amplifiers.

Repairability: Expert interview at Studio 107

HiFi equipment has been around for decades in many shapes, forms and designs. And as all products, they do need maintenance or repair every once in a while. Studio 107 is a repair shop located in the Hague and also owned by Rik Stoet, see appendix D. At Studio 107 repairs are performed on modern and vintage HiFi equipment. During those repairs a wide range of defects is treated, resulting in a wide knowledge base by the repair technician. To learn from his experience and from direct observation, an expert interview is held. In the figure below, 32, the workspace of the technician at Studio 107 can be seen.

Figure 32: Workspace with rotating platforms and protective layers to protect equipment while handling

For the duration of a day the repair technicians normal working routine is observed. What are the problems he encounters during repairs and what can be learned from his experience. In appendix I a complete overview of photo documentation and lessons learned can be found. The most significant are mentioned below.

Results

- Assembly and disassembly takes more time than needed if both sides of the equipment needs to be visible, or if it is to be done based on touch.
- Crucial parts are sometimes hard to reach and require more disassembly steps than needed.
- Moving parts wear over time and need maintenance or replacement.
- Standby power supplies are a known weak point due to their small size, blown capacitors are often the cause.
- Different standards between countries make a relatively easy repair needlessly difficult.

CONCLUSION

Both literature and the Means-End diagram opted increasing a products adaptability as a viable direction to improve a products circularity, and therefore sustainability. Over 30 years ago Cello has already successfully made a Modular Amplifier, to expensive for most, which limited the commercial success, but still it was a working viable product. Modules themselves have been in use for decades to expand the functionalities of amplifiers, as proven by Quad amongst others.

For the HiFi solution to retain valuable, and usable, for the user in the long term future developments should be implementable. This can be achieved via the use of modules, since they are already accepted in the HiFi industry.

In current HiFi solution designs the space required, per function, differs between manufacturers. The available space is used differently, indicating that functions can be designed to the space available. However, it has to be noted that all functionalities require more space, as the level of performance increases. To be future proof this space should be available.

Assembly and disassembly of the Sustainable HiFi solution should be incorporated in the design phase. Since some parts are known to break, or wear down over time, these should be easily repairable. These known weak parts should be easily accessible, to reduce the time needed for such repairs. The use of standardized parts would further improve the HiFi solutions repairability.

3.4 Music Enthusiasts & Stakeholders

The current way of working, Sustainability and Technology aspects of HiFi solutions have been analysed over the past three paragraphs. In this paragraph the last unknown is investigated, the Music Enthusiast and related stakeholders. To map the preferences and needs of the customers two discovery methods are used: Online Questionnaires and In-Depth interviews. Stakeholder analysis defined the related stakeholders.

Stakeholder Analysis

The wishes and needs of the Music Enthusiast are priority number one while designing a sustainable HiFi solution. However, there might be more stakeholders involved who need to be included in the design phase increase the chances of success. (Mindtools, n.d.).

The stakeholder analysis is a combination of: literature research, brainstorming and professional experience, supplemented with knowledge of colleagues. The identified stakeholders are presented in a Influence/Interest grid (Medium, 2019) .

Results

Figure 33: To be included stakeholders, that come in contact with the product during its product life.

In figure 33 an overview of the defined stakeholders is presented, divided over the four quadrants of the Power/Influence grid. For now the stakeholders are clustered to groups with similar wishes and needs, an overview of the individual stakeholders can be found in appendix J – Stakeholders Wishes & Requirements.

Stakeholder groups

- *Users:* The users need to be willing to use, and keep using the concept. This concerns the technical functioning of the concept, but also the aesthetic part.
- *Retail:* Professionals need to be able to explain the benefits of the concept to potential users and retailers. They have to see the benefits of the system to be able to sell it.
- *Manufacturers:* Need to reach customers in an economical viable way. Might copy, be interested in the design results.
- *Government*: Rules need to be followed of the EU and local government.
- *Maintenance:* Technicians need to be able to work with the concept, in an economic viable way.
- *Competitors:* Competitors might copy parts. Competitors analyse developments in the market. If the concept becomes a success they might try to develop products that fit.

User Preferences

For the HiFi solution to be accepted by the prime user, the Music Enthusiast, it has to meet their wishes and needs, and those of their family members. During this design research the customers of Audiohuis Delft will be asked to partake in this research. The first round of user research should have been guided interviews, but were substituted by an Online Questionnaire to coop with the Covid-19 outbreak.

Research questions

- What are Music Enthusiasts wishes and requirements with regards to functionalities.
- What is Music Enthusiasts attitude towards modular products.
- What are the Aesthetic preferences of Music Enthusiasts.

Execution

The questionnaire is divided into five sections: Modular design, Wishes & Needs, Aesthetic preferences, General information and a Wrap up. Each section had their goal, which will be explained briefly.

Modular design

The aim of this section is to introduce participants to the research, and to modular products.

Wishes & Needs

In this section the participants are asked about; where and how they want to use the amplifier, which features they want, what kind of functions, and preferred way of purchasing.

Aesthetic preferences

The participants are asked to score nine current amplifiers, on a scale from 1 to 10, just like school grades. First based purely on aesthetics, second based on the perceived usability of the amplifier, ignoring other factors like functionality and costs.

General information

In this section general information was gathered, age, family composition and where and how they currently listen to music.

Wrap up

In the wrap up participants are thanked for their participation, and have the option for final remarks.

The online questionnaire was made and distributed via Google Forms. To invite customers to partake in the research small tickets were printed, with an QR code, that took them to the research, in Dutch or English. The questionnaire can be found in appendix K (English) and L (Dutch). The most influential results will be discussed next. In appendix J a more background information can be found, and an overview of the results.

Results

10 research participants partook in the research. The results are divided over two different sections; 'Context, Control, Functions & Modularity' and 'Aesthetical Preferences & Perceived Usability'

Context, Control & Modularity

All respondents indicated they would use the HiFi solution in the living room, see figure 34. In the living room 80% of the respondents would place the HiFi Solution in clear view, see figure 35, on top of a cabinet or in an audio rack. More than half of the respondents wants to be able to control the HiFi solution via an application, or via physical buttons. Finally, over 60% indicates that they would want to be able to swap modules themselves, if they were to buy a modular amplifier. Regarding the latter, 90%+ indicated to be interested in the concept of a modular amplifier.

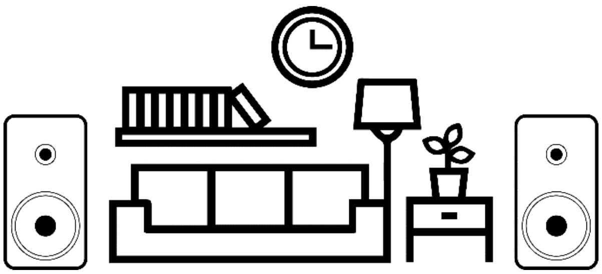


Figure 34: All respondents would use the HiFi solution in the living room.

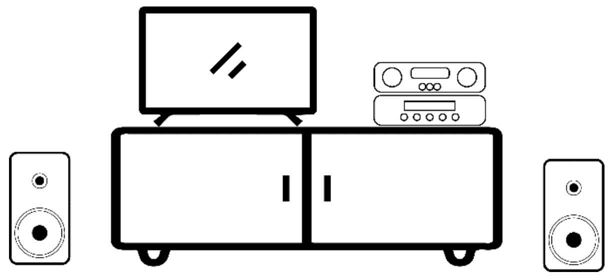


Figure 35: 80% of respondents would place the HiFI solution in plain sight.

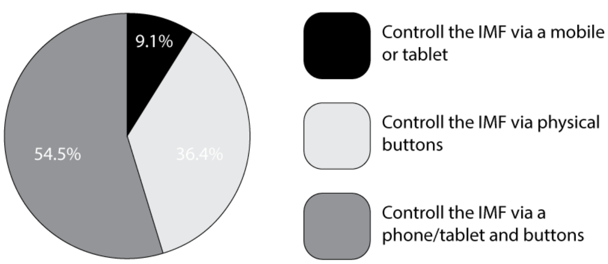


Figure 36: Only one respondent wants to control the amplifier using a software application. The majority would like to be able to control amplifier solution using a software application, or via physical buttons. Age does not make a difference in this regard.

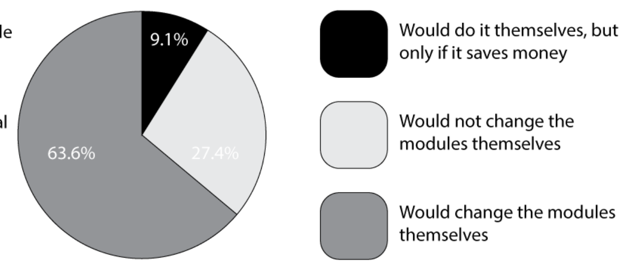


Figure 37: The majority of the respondents indicates to be willing to swap the modules themselves, even if this does not have a financial benefit. Age seems to be a factor in this case, the older respondents seem to choose the easier route and let it being taken care of.

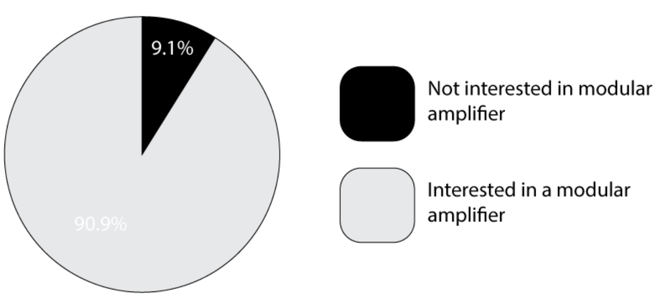


Figure 38: 90%+ would be interested in a modular amplifier.

Aesthetical Preferences & Perceived usability

The aesthetic preferences and perceived usability was researched using the nine different amplifiers that can be seen in figure 39. These amplifiers were, at time of the research, all part of the product range of AHD. Number 4, the NAD M10 All-in-One solution has been replaced after 2 years.

The low number of respondents, ten respondents, made it impossible to get to statistically significant conclusions. However, there are some observations to be made.

Darker colours seem to have a strong preference amongst the respondents, in both sets of questions, regarding aesthetical preferences and perceived usability, the darker colours are marked highest, as can be seen in figure 40 & 41.

Figure 39: 9 amplifiers, available at AHD.

The amplifier with only a screen, no buttons, is market the lowest, number 4 in figure 40, even though it is black. The reason for this might be the fact that no buttons are present in this design, it might be to far apart from traditional HiFi.

Figure 41: To many buttons does not seem to be preferred.

Figure 40: The NAD M10, scoring a 4.8, is darked but is least aesthetically pleasing.

In-Depth interviews

To allow the sustainable HiFi solution to be used throughout a Music Enthusiasts Audio Life it has to be able to keep up with their changing demands. Every Music Enthusiast has their own story, and more often than not, they are more than happy to talk about it.

During the in-depth interviews the goals was to gather data of real Music Enthusiast. Information regarding their previously, currently and want to be owned equipment was the central topic, together with their reasons for change.

Unfortunately only two In-Depth interviews were held, of which the results can be seen in figure 42and 43. Both images represent one of the interviewee's 'Audio Life's'; the equipment they have had, currently have and would like to have. The vertical line marks present day.

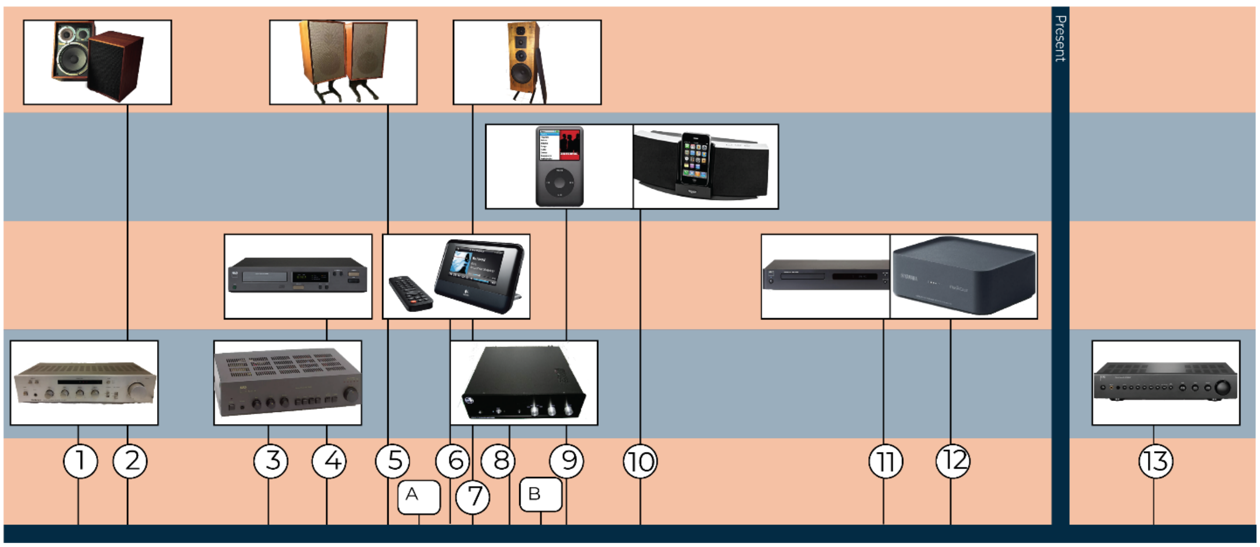


Figure 42: Interviewee #1 was almost satisfied with his system, the only thing he would like to 'add' is the option of a remote. Currently he would need a whole new preamplifier (number 13).

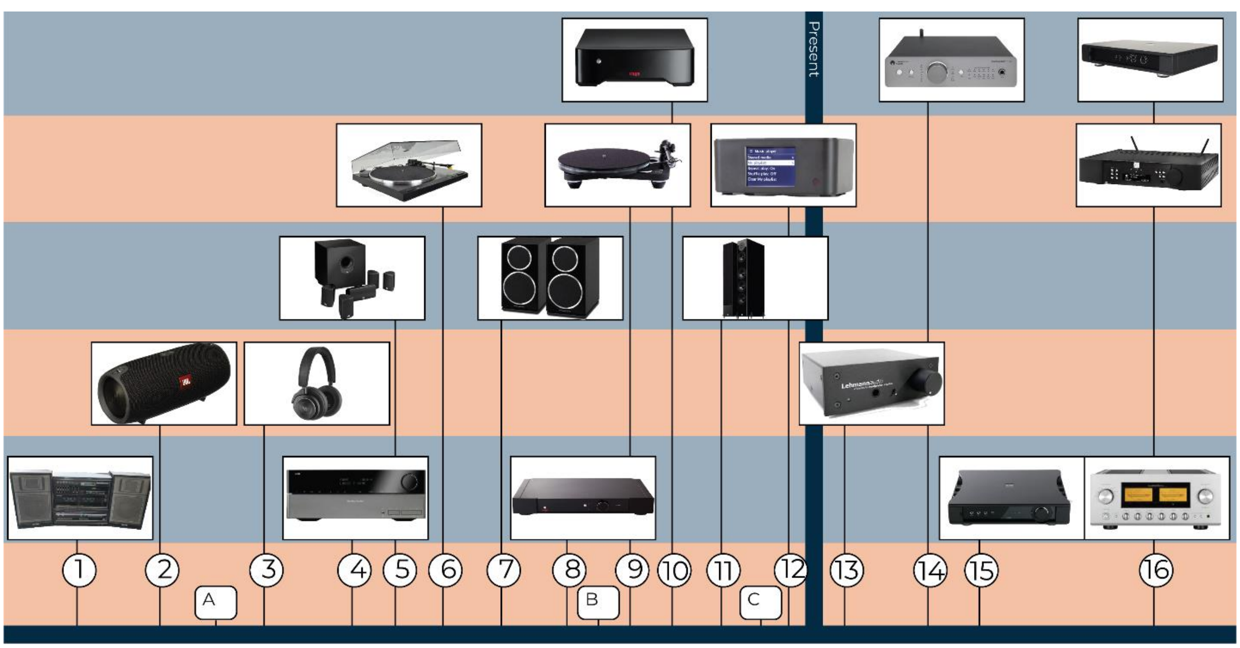


Figure 43: Interviewee #2 was half the age of #1, however he has a clear vision of where he wants his HiFi system to go.

Observations

Based on the two In-Depth interviews alone no significant conclusions can made. However, combined with professional knowledge of my colleagues and myself, and online sources (Qwerty, 2018), some observations can be derived.

- Music Enthusiast upgrade the amplification section of their HiFi system at least twice during their Audio Life
- Speakers get upgraded at least once, but more often twice.
- New functions are tried out at an affordable level, before any 'real' investments are made.
- Upgrades are made to; increase functionality, usability, or reach a higher level of performance. 3.5

CONCLUSION

The HiFi solution will be used in the living room, a room shared with other family members. In most cases it will be placed in plain sight, in or on top of cabinet or HiFi rack. Because everyone has their own preferences, with regards to aesthetics and usability there is no one solution or design for everyone. However, a dark base colour seems to be a safe choice, and deciding on one colour is environmentally friendly, only one colour needs to be kept on stock. To counter the other factor, that everyone is different, the visible aspects of the amplifier should also be adaptable. This way Music Enthusiast and their family members can make the HiFi Solution fit their wishes of that time.

The wishes and needs of Music Enthusiast with regards to performance also change over time. During their Audio Life they upgrade their amplification section at least twice, and other functions once if they meet their expectations. Upgrades are not only made to increase performance or add a function, but also to increase ease of use. Adding a remote control to a system can make a great difference in usability. The Music Enthusiast would like to be able to make changes to the HiFi solution themselves.

The factors stated above only strengthen the previous conclusion that an adaptable HiFi solution should be designed. The Sustainable HiFi Solution should be usable by a Music Enthusiast during their Audio Life. In the next paragraph the requirements, that the HiFi solution will have to meet, are set out.

3.5 Design Goal of a Sustainable HiFi solution

For over 2500 years a thought experiment has kept philosophers thinking, Heraclitus and Plato amongst them; The Ship of Theseus. Picture a wooden ship; over the years all the planks and parts get replaced with an exact copy, is it still the same ship? (Levin, 2019)

The answer is still open for debate, however the concept can be applied to a wide variety of products, the Modular HiFi solution is one of them. If designed correctly the HiFi solution can be used 'indefinitely', replacing only the parts that need replacement to meet the requirements of the user.

During the design research a multiple aspects were analysed. The analysis were conducted in multiple directions, concerning the User, Technology and Sustainability. Insights gathered, with regards to requirements and wishes are all gathered in a Program of Requirements, which can be found in appendix R. However, the program was and will never be complete and does not direct selection in this design phase yet. Therefore the following design goals will be the basis further choices are made upon.

Ease of Use.

Music Enthusiasts indicated they want to work with the system themselves. Therefore all further decisions should aim at enabling them to. This means that no specialised tools or knowledge should be required to putting the Building Blocks of the IMS system together or make altercations.

Sustainability

All design choices should be made with the environment in mind. If there is no functional benefit the more sustainable option will always be preferred.

Durability

The goal of the IMS system is to be used for the duration of a Music Enthusiast Audio Life. The duration is not defined in years, since it changes from person to person, however the non-electric parts should selected on durability.

Repairability

Repairability is tied together with Durability. The IMS system should not only be easy to use, but also easy to repair in case of a defect. Complex design can obstruct the ease of repair.

Adaptability

In the first and final place, Adaptability is key. For the IMS system to be used during a Music Enthusiast Audio Life it has to be flexible to their changing wishes and needs. The IMS system should be adaptable to its limit, without crossing the design goals.

DESIGN VISION

The Design Vision that accompanies the design goal is; "Nothing More, Nothing less". This means that the Sustainable HiFi Solution should give the Music Enthusiast the functions he needs at that time, there is no room for unused functions, which could result in "brand new E-waste".

4.0 Concept Design

The results and findings of the Analysis phase will be used during this Concept Design phase. During the concept design phase a solution to the proposed assignment, see chapter 1.2, will be designed. First a schematical representation of the concept is introduced, followed by a design problem refinement. The refinement concludes in four critical design challenges, regarding adaptability through time and its technical implications. To finalize will these four critical design challenges be integrated in a final concept design.

4.1 IMS – Integrated Music Solution concept

Concluding the Program of Requirements a quick and dirty brainstorm followed. How to be able to implement all the different requirements, targeting different aspects of the Sustainable HiFi solution, into one product design. The answer was; 'impossible' unless? The answer to the unless will be explained in the next section.

Concept

The Integrated Music Solution (IMS) concept is a modular HiFi solution, designed to fulfil the wishes and demands of Music Enthusiasts over time. The IMS concept is divided into five different layers to utilize its sustainability potential to the fullest. In figure 44 a schematic representation of the concept can be seen. The IMS has to evolve and adapt to be able to keep up with its user, but not all layers with an equal interval. Each layer is therefore designed using the most suitable circular product design strategy, see chapter 3.2. The function of each layer will briefly be introduced, before exploring them in detail.

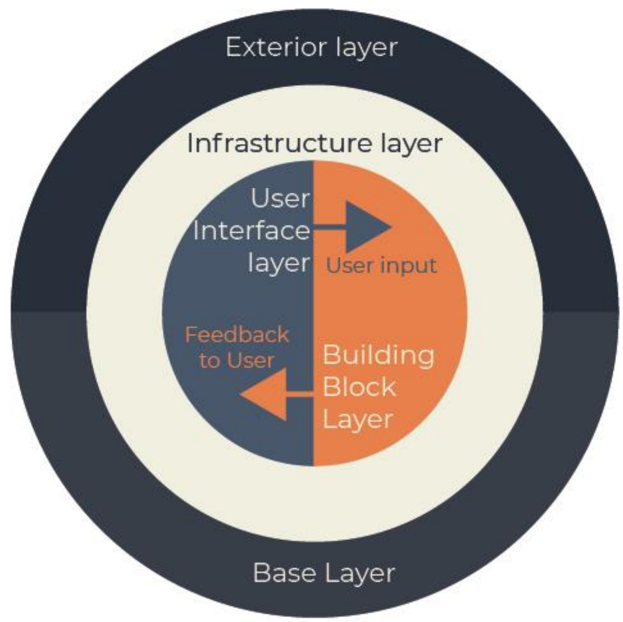


Figure 44: Schematic representation of the IMS concept, the five layers together fulfil the function of a sustainable HiFi Solution.

The Building Block Layer and User Interface layer together form the core of the system, they contain the actual electronics and accept user input and give feedback to the user.

The Infrastructure layer interconnects the core.

The Exterior layer protects the underlying layers.

The Base layer supports all the layers above, it can be seen as the foundation on which the other layers are built.

IMS - Layers

Base Layer (BL) – Designed for Durability

The Base layer is the one layer that is not primarily designed to be changed, upgraded or altered during use. It is designed to survive a Music Enthusiast Audio Life, or longer. It allows all the other layers to change, evolve and adapt. Because it needs to survive the test of time and accommodate change, it might end up 'over engineered' at the beginning, but be most sustainable in the long run.

Building Block Layer (BBL) – Designed for Upgradability and Adaptability

The Building Block layer is made up of a number of individual modules. Each module, Building Block, fulfils one function of a HiFi solution. The number of modules depends on the wishes of the user. It depends on which functionalities he wishes to have, at what level of performance, at a certain point in time, in his Audio Life.

User Interface Layer (UIL) – Design for Upgradability and Adaptability

The User Interface Layer is, just as the BBL, composed of separate modules. The modules depend on the users wishes, and the installed Building Blocks. Because both the Building Block Layer and User Interface Layer change over time, they are designed for Upgradability and Adaptability.

Infrastructure layer (IL)– Standardization and Compatibility

The Infrastructure Layer is het interconnecting layer between the Building Block Layer and the User Interface layer. Because the two aforementioned layers change over time, are removed and replaced, the Infrastructure Layer is designed for Standardization and Compatibility. This way a defect to one of the connections can be repaired 'relatively' easy.

Exterior layer (EL) – Design for Attachment and Trust

The Exterior Layer is what is visible to the user, it does not have to be a separate part, it can also be part of the modules or the Base. Because it is what the user primarily sees, it is designed for Attachment and Trust.

CONTINUATION

By dividing the Sustainable HiFi solution in five different layers each can be designed using the most suitable circular product design method. However, designing all layers would take years and inefficient for a one man team. Therefore the knowledge gaps have to be defined, the design problem needs refinement. In the next paragraph that refinement will take place, to result in Critical Success Factors.

4.2 Design Problem refinement; Critical Success Factors

The aforementioned four Critical Success factors are derived from a brainstorm session on each of the five layers of the IMS concept. Each layer was explored to look for knowledge gaps, for which problems were there no direct solutions available. Or what is needed for the concept to be viable. The main questions asked are How, What and Which; an overview of these can be seen in appendix M.

Critical Success Factors: Design Challenges

In this section the Critical success factors are grouped in two clusters: 'Adaptability and Aesthetics' and 'Technical implications of Adaptability'. The first focusses on the implications of being adaptable on a Building Block level. How do the functions, each placed in a Building Block, change over time and what are the Aesthetic implications of those changes. The 'Technical implications of Adaptability' focusses on the how of connecting the different layers together.

Adaptability and Aesthetics

The goal of the IMS concept is to be used by Music Enthusiast throughout their Audio Life. During this timeframe changes are inevitable and need to be accounted for. The following two design challenges aim to account for those changes.

Configuration Stages

Keeping up with the Music Enthusiast wishes and demands is crucial for the IMS system to achieve its sustainability goal, reducing E-waste. Based on the data gathered, see Chapter 3.4 and appendix N, different stages are configured, that keep up with their requirements.

Configuration Lay-out

The different configurations stages will have implications of the number of modules installed, and the size of these modules. To be aesthetically pleasing throughout these stages different lay-out models will be designed and tested with the customer panel using an online questionnaire.

Technical implications of adaptability

The user experience of adapting the IMS system should be easy and safe. This should be able via a durable connection between the Building Blocks and the Base. Furthermore the Infrastructure layer should be implemented in the Base, in way that is flexible, in means of layout and connectivity.

Building Block – Base Connection

The customer panel wishes to make adaptations to the IMS concept themselves, a suitable connection that is safe to work with, between the Building Blocks and Base need to be designed. This is done by first mapping the possible connection methods, followed by a design, prototype and test phase.

Building Block – Infrastructure Layer connection

Changing the Building Blocks has implications for the Infrastructure layer. How can the Infrastructure layer be designed that is safe and understandable. The infrastructure layer should adapt to the different configuration stages, in the aesthetical lay-out that is preferred by the respondents panel.

CONTINUATION

The following paragraphs will cover the different Critical Susses Factors, clustered in the two groups. The following paragraph: '4.3 Keeping up with the users demands' will focus on the Configuration Stages, how to remain in use during a Music Enthusiast Audio Life. Thereafter the Aesthetic implications of the defined stages will be designed.

4.3 Keeping up with the users demands

[a HiFi system] ‘‘continues to evolve in order to keep up with changing consumer preferences and add the latest performance-enhancing technologies’’ (Consumer Electronics Association, 2003a).

During the Analysis phase, see chapter 3.4, it was concluded that Music Enthusiast upgrade their amplification equipment at least twice during their Audio Life. New functions, for individual Music Enthusiasts, are tried out at an affordable level and upgrade at least once. The latter is if the new functionality meets their expectations or if.

To keep up with the changing demands of the Music Enthusiast, and possibly those of whom they are living with, different stages will be designed. These stages succeed one another, they are adaptations of the previous stage. These adaptations can be the addition or replacements of Building Blocks, either on the Base or in the User Interface.

CONFIGURATION STAGES

Four stages are proposed in this section, they depicture a possible configuration used by a Music Enthusiast during their Audio Life. Each succeeding stage achieves a Higher level of performance or adds functionalities. The stages are a guideline based on the available information, but are flexible and can be combined freely.

The four stages represent different moment throughout a Music Enthusiast Audio Life. The time each stage is used depends on the Music Enthusiast. Even the duration of a Music Enthusiasts Audio Life is hard to define, for some it equals a life time, others ‘move on’ after a couple of years or decades. The stages are also not set in stone, but more on that later.

The configurations of each stage will be put together based on the results from the In-Depth interviews, see chapter 3.4, combined with professional knowledge. This is my personal professional knowledge, supplemented by that of my colleagues and company mentor.

Each stage is made up of two sections, the Building Block Layer and the User Interface Layer, both using Building Blocks. The Building Blocks that make up the Building Block Layer are connected to the Base Layer and contain the primary functions; power supply, pre-, power- amplifier, Phono, DAC and Streamer. The BB’s installed in the User Interface contain supporting and secondary functions; Volume control, Control Centre, Standby Power supply, etc. In figure 45 the different sections and their Building Blocks can be seen.

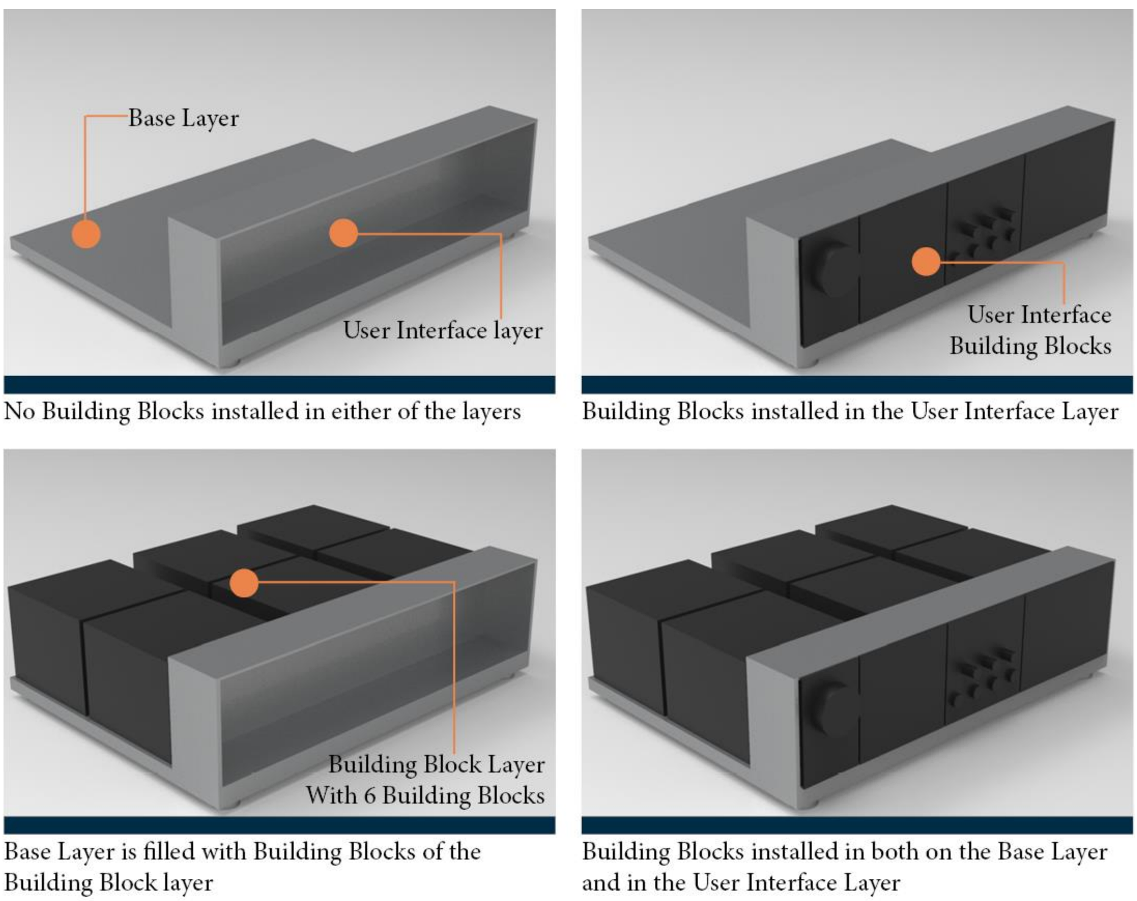


Figure 45: The Building Blocks in each layer are interdependent on each other, together they are a HiFi solution.

Stage Description

In this section the configurations of the different stages are defined. The functionalities of the stages are described and the differences between the stages. Each stage is accompanied by a figure representing the stage by currently available equivalents. This representative image helps to create an image of the Level of Performance that is to be achieved and the associated costs.

In all the comparison stages a Rega amplifier, previously used during the analysis in chapter 3.3, will be used to represent the amplification circuitry. For the same reasons as before, the increase in performance as the rest of the equipment stays the same. Accomplished by the matter that the price between each level is comparable.

- *Stage 1*

  Stage 1.1 is put together to be affordable and offer the basic functionalities to a starting Music Enthusiast, or as a secondary system. The main functionality offered is a Streamer and DAC combined. This is supported by a preamplifier and Class AB power amplifier. The package is concluded by a linear power transformer.

Figure 46: Musicality is most important, levels of performance not so much yet.

Stage 1.2 can be seen as copy of 1.1. The main difference is the replacement of the Streaming-DAC Building Block by a Phono Pre Amplifier BB, offering the option to connect a turntable to the HiFi solution.

- *Stage 2*
  Stage 2 improves on multiple facets compared to stage 1. The major changes are the level of performance and its ease of use. Stage 2 is equipped with a digital control centre, allowing the system to be controlled using a software application and a remote control.

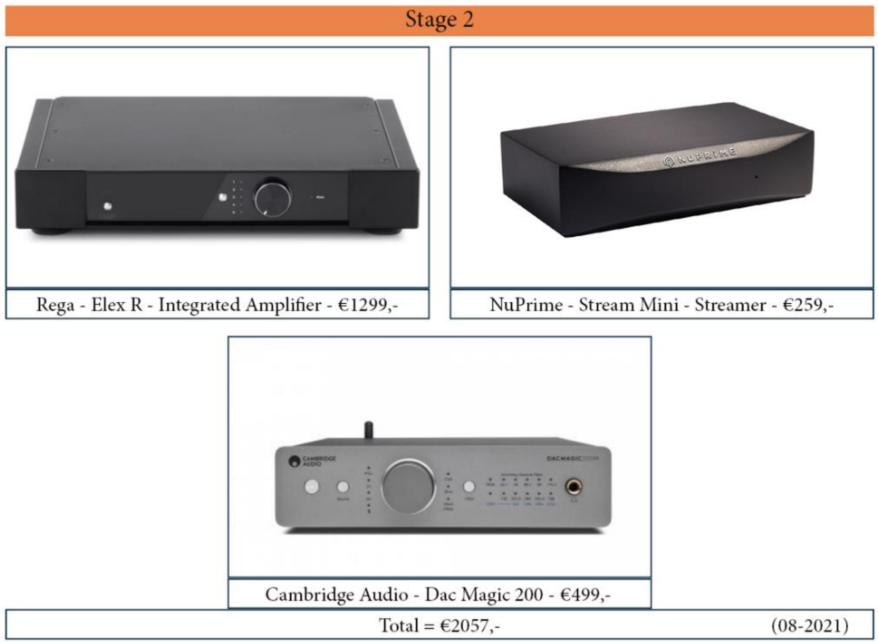


Figure 47: Capable of driving speakers in a way that makes you see the musicians.

- *Stage 3.*
  Stage 3 is the highest performing configuration that still fits on one Base layer. The performance of each Building Block is the best, as one can expect to achieve in this form factor.

Figure 48: Soundstage and Imaging are on spot, detail and clarity could be improved, but wow.

- *Stage 4.*
  Stage 4 is for those who seek the highest level of performance, just before entering the stage of a true Audiophile (Who would want to have nothing to do with the IMS system). In Stage 4 the Primary Building Blocks are divided over 2 bases, one for the low and medium voltage functionalities (pre amplifier, DAC, Streamer, etc.) one for the High voltage functionalities (Power amplifier and its accompanying Power Supplies). More information on the different voltages will follow.

Figure 49: Live like performance in your living room, bass is controlled and well positioned. Reliving all your music.

Base Layer: Primary Building Blocks

Each stage is made up of a combination of Building Blocks. However, the internals of the BB's differs. The internals can contain PCB's, power transformers or related electronic components. The level of performance, achieved by each Building Block increases between the stages. However, as can be seen in figure 50, the dimensions of the Building Blocks do not increase between the stages, besides the power transformers.

Generally, reaching higher levels of performance increases the size of the electronics needed. What these dimensions are was determined in the space requirements analysis, see chapter 3.3. However it is decided to dimension the Building Blocks according to the highest level of performance. This way the number of Building Block enclosures can be kept to a minimum, which is positive for the environment and the manufacturers. By limiting the number of Building Block enclosures the risk of not having the right size in stock reduces. Over dimensioning the BB enclosures is also in compliance with literature; "[…] leaving sufficient room for later adaptation and additions in a subsequent round that are not necessarily included in the present stage provides much more balance in the efforts to achieve the desired progress in a feasible manner […]" (Goodship et al, 2019).

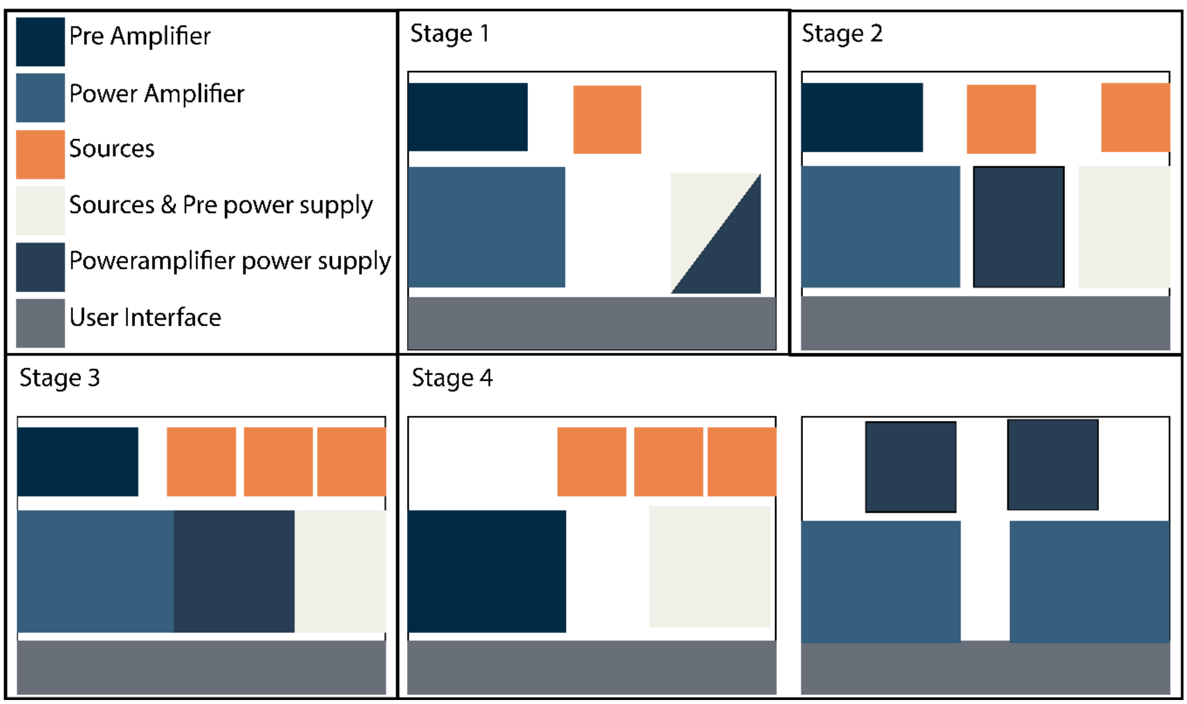


Figure 50: Top view: Stage development, number of Building Blocks on The Base Layer & Number of Base Layers

Primary Building Block Specifications

In the previous sections the different configurations stages are presented, with currently available comparison products. Previously it was mentioned that the Stages were not set in stone, meaning they are just meant as a guideline. In Table 2 the specifications of the different parts of the stages can be seen. But, for example, the power amplifier from stage 2 (Class AB, 80W) might end up having an equivalent of 50 watts, that sounds just different, but costs roughly the same.

	1.1	**1.2**	**2**	**3**	**4**
Pre amplifier	Basic	Basic	Medium	High	High
Power Amplifier	Stereo; Class Ab (30-40W)	Stereo; Class AB (30-40W)	Stereo; Class AB (70-80W)	Stereo; Class A (30W)	Dual Mono; Class A (40w)
Streamer (Source)	Basic	X	Medium	Medium	High
DAC (Source)	Basic	X	Medium	Medium	High
Phono amplifier (Source)	X	MM	X	MC	MM / MC High
User interface	Volume control Source selection	Volume control Source Selection	Volume Control Source selection Tone control Digital Headphone amplifier Control centre	Volume Control Source selection Tone control analog Control Centre	Volume Control Source selection Control Centre
Power supply	Toroidal transformer	Toroidal transformer	2x Toroidal Transformer	2x Toroidal Transformer	3x Toroidal Transformer

Table 2: Primary Building Blocks

User Interface Layer: Secondary Building Blocks

The User Interface Layer is located on the front of the IMS concept, pictured in grey in the layouts, see figure 50. In the User Interface Building Blocks are placed that allow the user to control the system, see figure 51. Volume control and source selection will be the minimum needed, but this can be expanded with a range of functionalities. The Control Centre and Standby Power supply are a bit special amongst them, and will be discussed more in detail.

Controls can be analog or digital and possibly require power. Besides control modules there are also smaller functions integrated in the UIL, a possible headphone amplifier, tone control, etc. These modules are free for the Music Enthusiast to select to their needs.

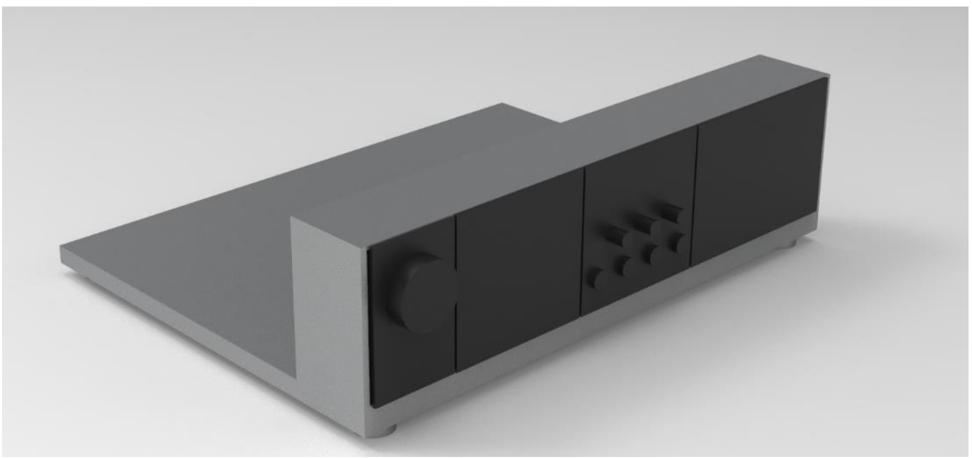


Figure 51: Building Blocks for stage 1, placed in the User Interface.

Control Centre

Software and computing hardware are part of almost any electric product nowadays, and a problem in AiOs, as described in chapter 1.2. Preventing loss of software support is impossible, but designing for it isn't. Therefore the Control Centre, which runs the software of the IMS system, is placed in the User Interface.

The Control Centre will be a Asus Tinker board, Raspberry Pi, see figure 52, or something equal. A microcomputer with in- and outputs, allowing custom integration in the systems. In figure 53 a Streamer can be seen, with an Asus Tinker Board at its core.

Figure 52: Asus Tinker Board: A microcomputer designed for integration and custom builds.

The functions the Control Centre will fulfil can be seen in figure 54. It will control the start-up sequence, and translate the user input into action. It runs the software that communicates with the application installed on a mobile device, and passes the commands along to the designated modules. User input can come from another Building Block in the User Interface, or via the internet through the application. The Control Centre could also power a display if desired by the Music Enthusiast.

Figure 53: Volumio Primo: A HiFi Streaming DAC

In the User Interface the Control Centre is easy accessible. As time goes by, and the systems changes it can be replaced if needed. Because software is one of the issues with current AiOs, support often stops before end of life of the product, it needs to be easily replaceable. Furthermore, it is close to its power supply, the standby power supply, and there was unused space.

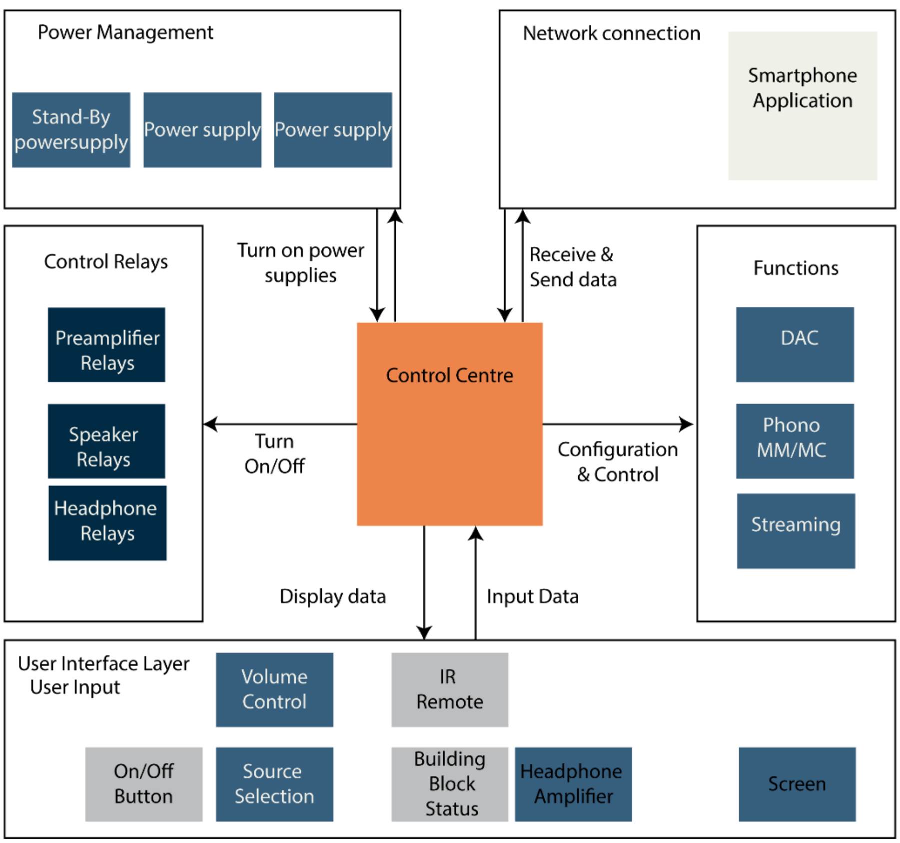


Figure 54: Control Centre functions and connections

Standby Power Supply

The Standby Power Supply is needed for the IMS concept to respond to input from a remote, and from the previously mentioned software. The Standby power supply powers the Control Centre. Standby power supplies are efficient, see figure 55, using as low as 0.5W, but susceptible to failure as learned during the field research, see chapter 3.3 . Since they are essential for IMS System to function they need to be replaced easily. Finally the requirements of the government, concerning standby power usage, change over time, rumours of a maximum power usage of 0.3W have already been heard. Therefore the power supply needs to be replaceable for even more efficient models and in case of a defect.

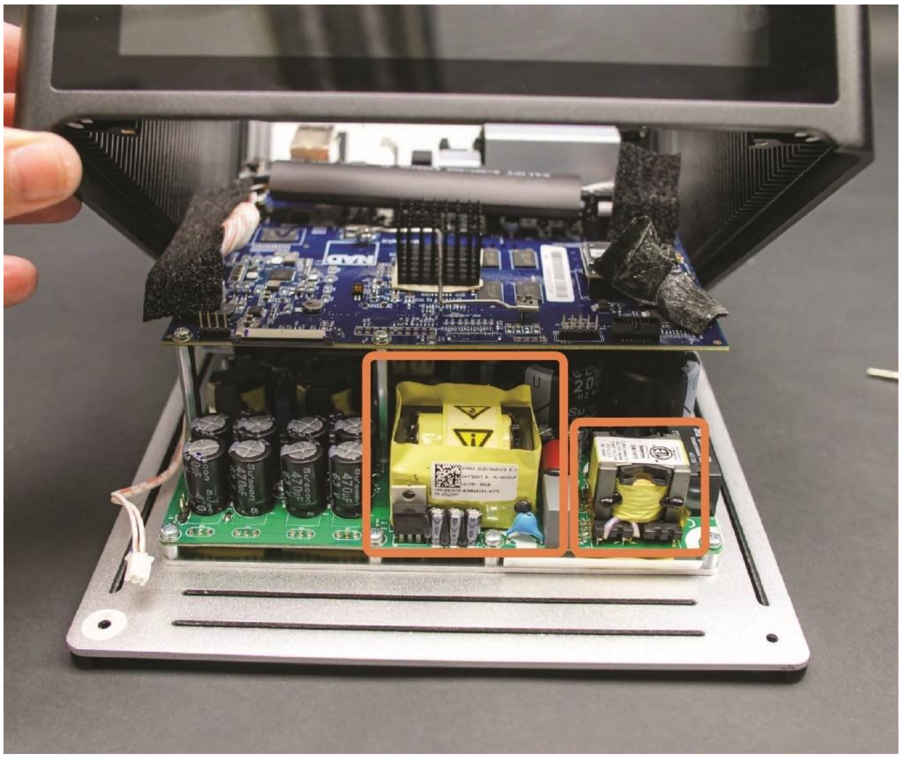


Figure 55: NAD M10 – AiOs – Standby power supply (Right) and the main power supply (Left).

Secondary Building Block Specifications

Function	Stage 1	Stage 2	Stage 3	Stage 4
Volume Control	Blue Alps Non-motorized	Blue Alps Motorized	Blue Alps Motorized	Blue Alps Motorized
Input Selection	Analog switch	Digital + Relays	Digital + Relays	Digital + Relays
Control Centre	X	Microcomputer	Microcomputer	Microcomputer
Strand-By power supply	X	Yes	Yes	Yes
Headphone Amplifier	X	Yes	X	X
Tone Control (Analog / Digital)	X	X	Yes	Yes

Table 3: Secondary Building Blocks

Infrastructure layer (IL)

The Infrastructure layer "surrounds" the core of the IMS system, the Building Block layer and the Interface layer, as could be seen in figure 44. The Infrastructure layer is a connecting layer, it makes the connections between the different Building Blocks installed in each layer.

The Building Blocks installed will change over time, which will have an impact on the Infrastructure Layer. The research described in chapter 3.4 indicated that 80% of the respondents, would like to be able to change the Building Blocks themselves. Therefore they will also have to make changes to the infrastructure layer. The Infrastructure Layer needs to be understandable for the Music Enthusiast, and safe to work with.

For the IL to be flexible and support al those changes an overview of the connections in each stage is made. This overview indicates from where to ware signals flow and the changes between the stages. Later on this overview will be used to implement the Infrastructure Layer in the Base Layer.

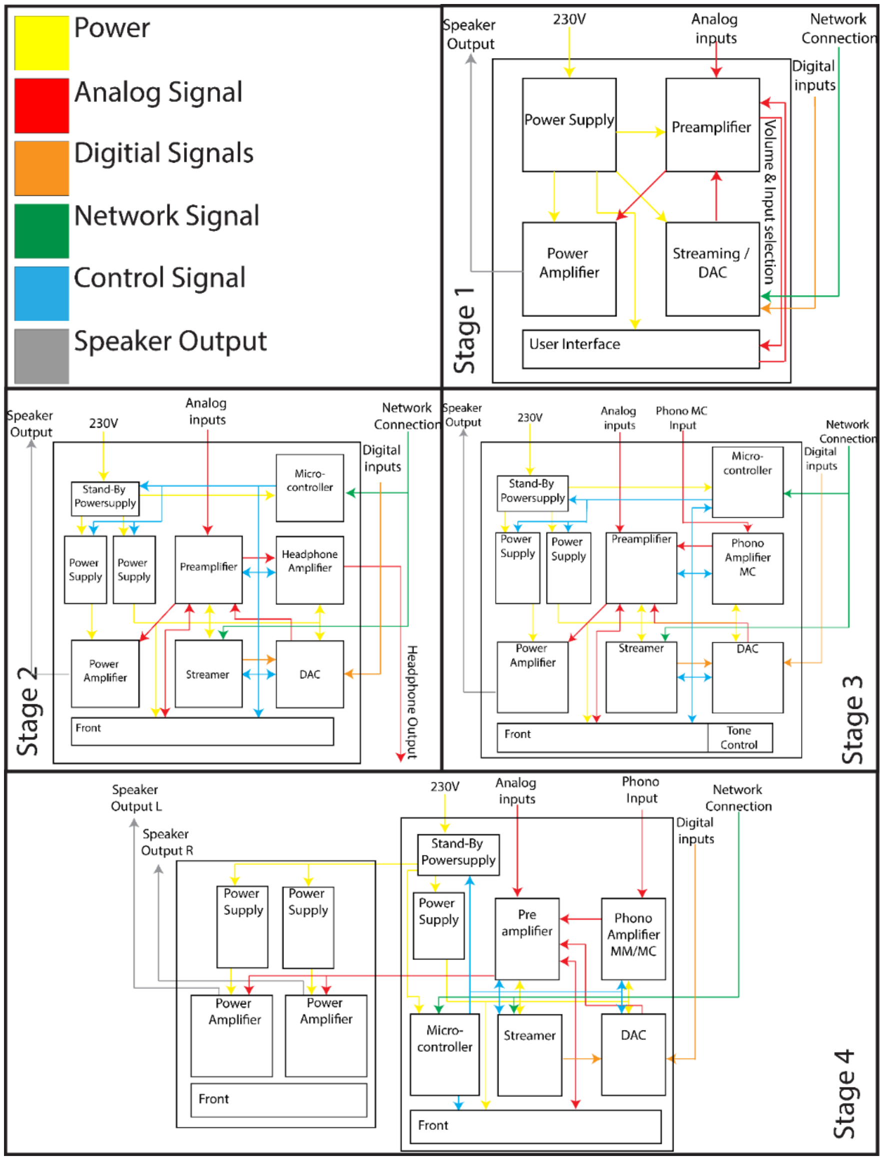


Figure 56: Infrastructure Layer development in each stage

Continuation

In previous paragraph multiple facets concerning the configuration stages are covered. First of all the stages are defined and their functions explained. Thereafter the Infrastructure layer is mapped, from where to where do the connections go. In the next paragraph the Exterior layer, and with it the configuration layouts are designed.

4.4 Modular HiFi Solution: Exterior layer exploration

The configuration layouts will be based on the configuration stages proposed in the previous paragraph. For the configurations layouts to be designed an overall appearance, the Exterior Layer, needs to be designed first. Thereafter different layouts within the Exterior Layer are designed. This paragraph concludes with the starting point of the next paragraph, User Evaluation.

IMS Concept – Overall exterior layer designs

Traditional HiFi Solutions are all designed more or less the same, buttons on the front, connectors on the back and a "box" filled with electronics in between, see figure 57. It is made to be put together once, used and at EoL discarded.

The IMS Concept however will need to be able to undergo changes throughout its usage. During the analysis phase (please refer to chapter 3.4) it was noted that 80% of the respondents would like to be able to make changes themselves. To accommodate changes by the users the overall Exterior Layer is explored, see appendix M for more information, with regards to usability, sustainability and (mechanical) complexity.

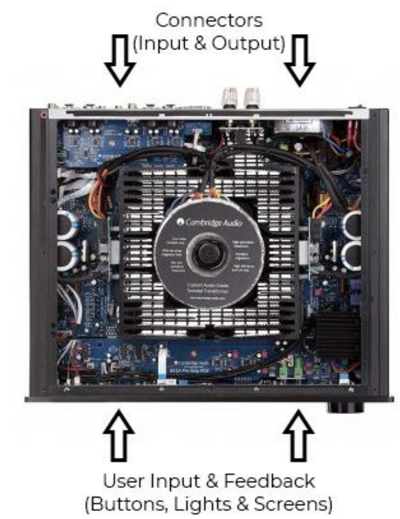


Figure 57: Traditional HiFi solution built up, in the past alternative designs have been tried out.

Exterior Layer Design

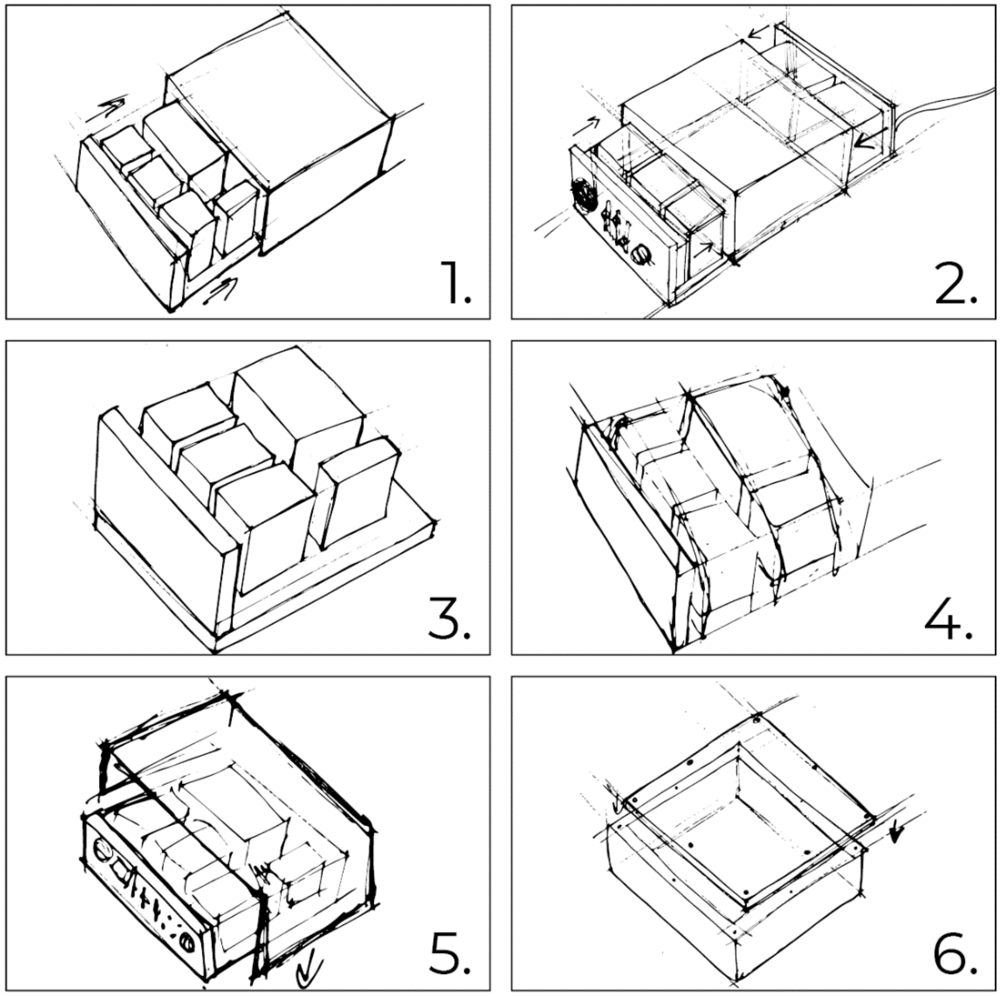


Figure 58: 6 Exterior layer designs

1. The **Drawer** archetype protects the Building Blocks (BB's) by placing them inside a solid enclosure. The BB's can be reached by pulling the amplifier open, like a drawer. The BB's are mounted to the bottom of the drawer. The connectors, User Input and Feedback are located at the traditional locations.
2. The **Double Drawer** reduces the risk of tipping over while replacing or altering the layout of the IMS Concept. Cable management can also be improved, by arranging the modules according to their input and output connectors. An additional benefit is the space between the two drawers, this space can be used for thermal and/or magnetic barriers.
3. **Bare** shows its guts, the BB's are not covered by an external enclosure. Primarily the Building Blocks themselves are the enclosures, mounted to a common base. The User Input and Feedback are in the traditional location, the front. However, the connectors can be incorporated in the BB's or (partly) clustered at the back.
4. **Fabric Flex** is an alternative way to enclose the modules, resulting in a more traditional look of the IMS Concept. For the Fabric an environmentally friendly material can be selected, in different colours to match the users preferences.
5. **Traditional solid** is, as the name suggest, not much different from current amplifier designs. The enclosure consists of two main parts, U shaped, fitting together to form a 'box'. The Connectors, User Input and Feedback are located at the traditional locations.
6. The **SolidCover** design consists of a solid base bucket and a solid cover. In the basket the different buildings blocks are placed, which are thereafter enclosed by the cover. The Connectors, User Input and Feedback are located at the traditional locations.

EXTERIOR LAYER SELECTION

The Exterior layer is not a focus point during this research design, but did became part of it. During the analysis phase it became clear the wishes and needs of Music Enthusiast differ and the same applies to their aesthetical preferences. The design vision “Nothing More, Nothing Less” is a clear indication of it, the exterior layer should be as little as possible. This is strengthened by the third design goal: Durability; no moving parts are preferred. Combined with the Sustainability design goal, always have the environment in mind, the concept ‘Bare’ (3) is selected to further build upon.

Overall Exterior Layer: ***Bare***

‘Bare’ shows its guts, the BB’s are not covered by an external enclosure, see figure 59. Primarily the Building Blocks themselves are the enclosures, mounted to a common base. The User Input and Feedback are in the traditional location, the front. However, the connectors can be incorporated in the BB’s or (partly) clustered at the back.

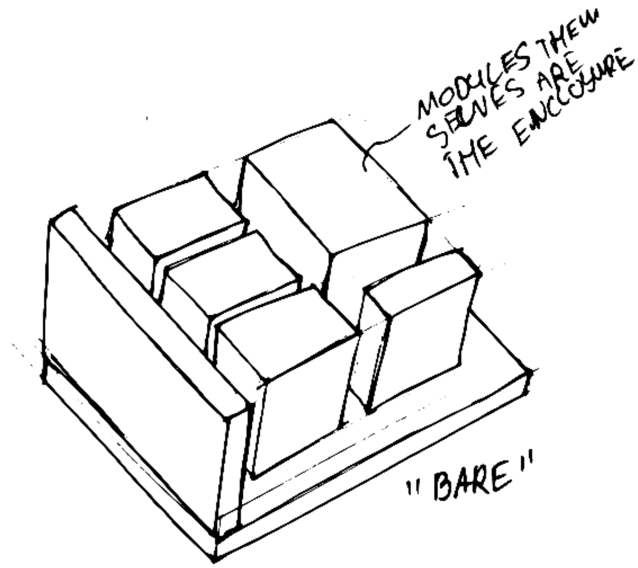


Figure 59: Bare Exterior Layer, Building Blocks Visible

Drawbacks: The open structure, showing the individual BB’s, might not be aesthetically pleasing to everyone. Therefore there should be attachment points to add an additional exterior layer, allowing the Music Enthusiasts and their family members to match the IMS to their aesthetical preferences and interior.

Building Block Layout

In the previous sections the different stages and Exterior Layer are defined and designed. “Bare” is the starting point for the further concept design. In Bare the individual Building Block’s remain visible during a Music Enthusiast Audio Life. During this time the number of Building Blocks and dimensions will change, which will have an influence on the perceived aesthetics of the IMS system. In this section different lay-out designs, models, will be made of each stage. The goal is to fit all the needed Building Blocks, of both the Interface Layer and the Building Block Layer, on the Base Layer.

Design process

In chapter 3.3, HiFi Architecture, it became clear that the different functionalities, within a HiFi solution greatly differ in size. The size differs between manufacturers, but also between the different levels of performance. The different shapes and sizes would probably result in chaos if no order was introduce, which could be achieved using different principles. “One of these principles, ‘unity-in-variety’, states that product designs combining a maximum of unity or order with as much variety as possible are the most aesthetically pleasing.” (Post et al, 2013). The theory of ‘unity-in-variety’ is combined with another field of science, that of mathematics. “It’s a matter of common observation that patterns can be a source of aesthetic pleasure, whether they are found in nature or in the creative output of mathematical imagination” (Huntley, 1970).

The starting point of the layout design are mathematical series; Fibonacci, Tetranacci, Lucas and Padovan. The different Building Blocks are grouped to be roughly the same size, and the dimensions of the Base Layer were still flexible. These parameters were the input for a quick, iterative, computer aided design process, where multiple options were put together, based on Tetranacci. One of the result of this session can be seen in figure 60.

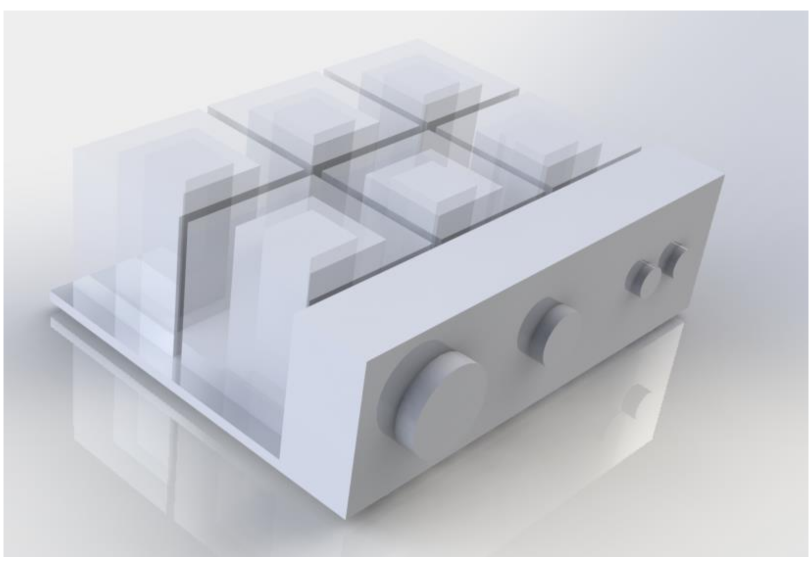


Figure 60: Layout Model based on Tetranacci.

The model of figure 60, amongst others, was to be used for the User research, which will follow in chapter 4.5. However, during the final check a mistake was found, the Base Layer needed to contain 7 Building Blocks in stage 3, instead of the 6 that would now fit. The whole process was repeated, but in this time the raw data, gathered in chapter 3.3 was used, after which the mathematical series of Padovan matched the data best. (geeksforgeeks, 2021) . The results from the second layout design session can be seen in figure 61.

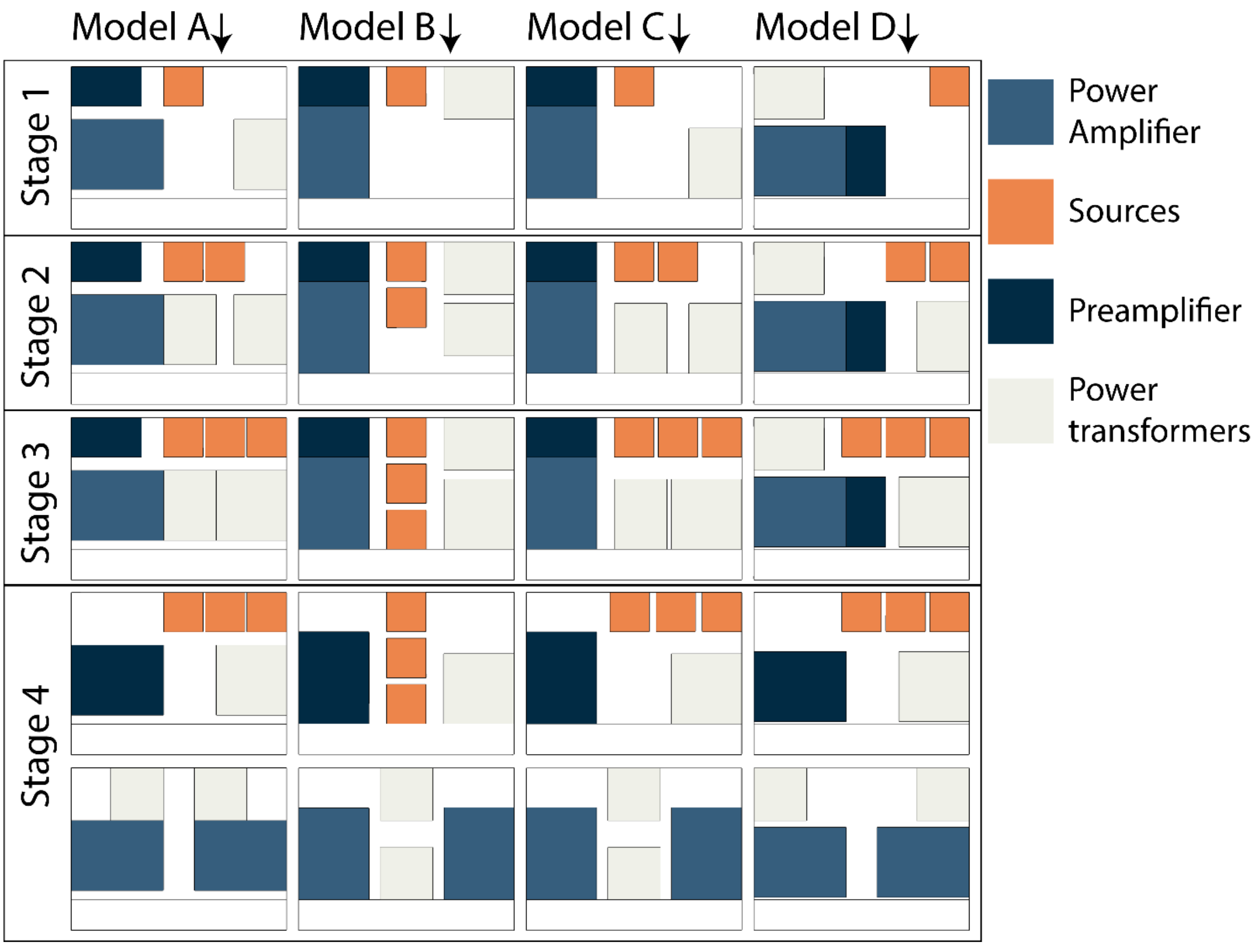


Figure 61: Top views of the four different models, at the four different stages

The images in figure 61 only give an indication of the layout in 2D, from a top view. However, the IMS concept is to be used for the duration of a Music Enthusiast Audio Life, and should therefore be rated by the Music Enthusiast. The rating, or User research is part of the next section. In figure 62 the 3D, renders, of the model layouts can be seen that are used during the User Research.

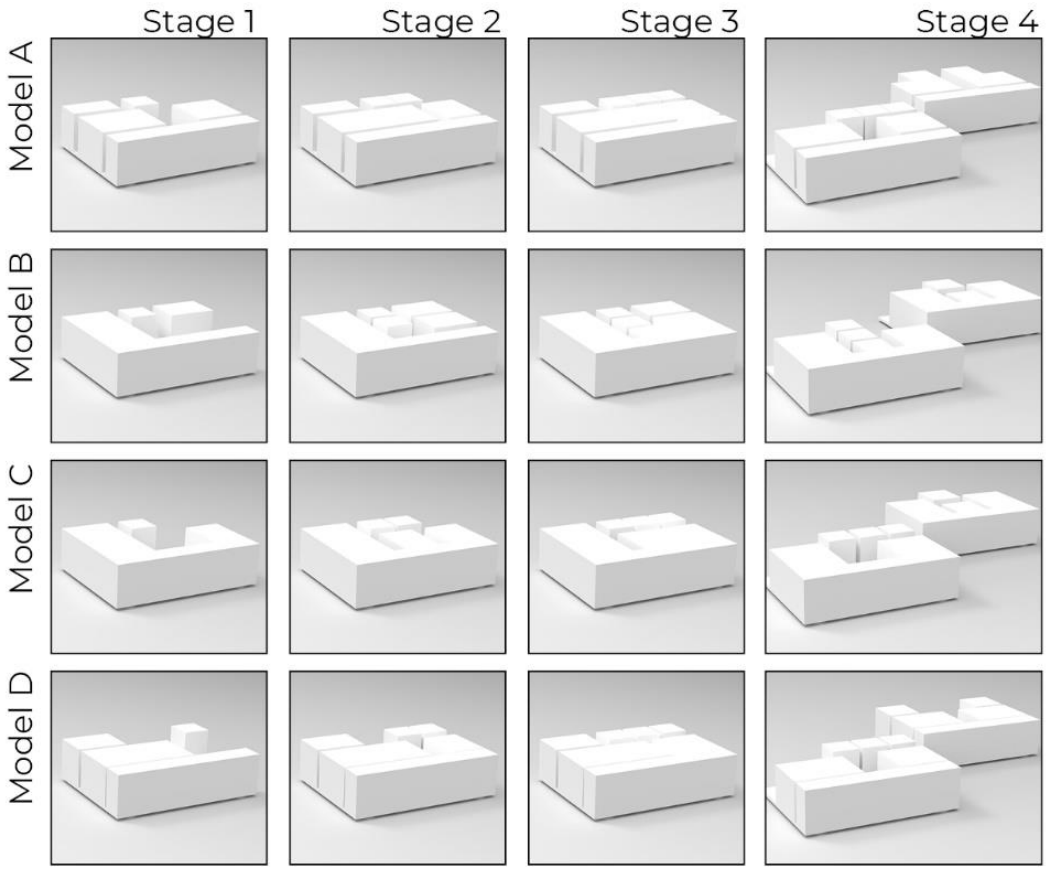


Figure 62: Models and Stages in Isometric View, as presented in the Aesthetic User Research

4.5 User E(valuation)

The goal of the IMS system is to be used by Music Enthusiast during their Audio Life. During that, unquantified, time period different stages of the system will pass by, and with it its appearance will change. The customer panel, that partook in the previous user research, are asked to partake in a new online questionnaire. The focus will be on the four models, see figure 62, in different colour combinations, see figure 63. The aim is to determine which model and which colour(combination) is preferred by the Music Enthusiasts during the different stages.

For this questionnaire the ranking method is the main question type used. "If you're asking your respondents about things that they find desirable, or if you want to see what is important to them, a ranking question will help" (Qualtrics, 2021).

In this new research the previous observation will be tested, are darker colours preferred. Furthermore, multiple possible lay-outs of the IMS concept are presented to the Music Enthusiasts to determine their preference. The designs are tested using the ranking method. For an complete overview of the research please refer to appendix O.

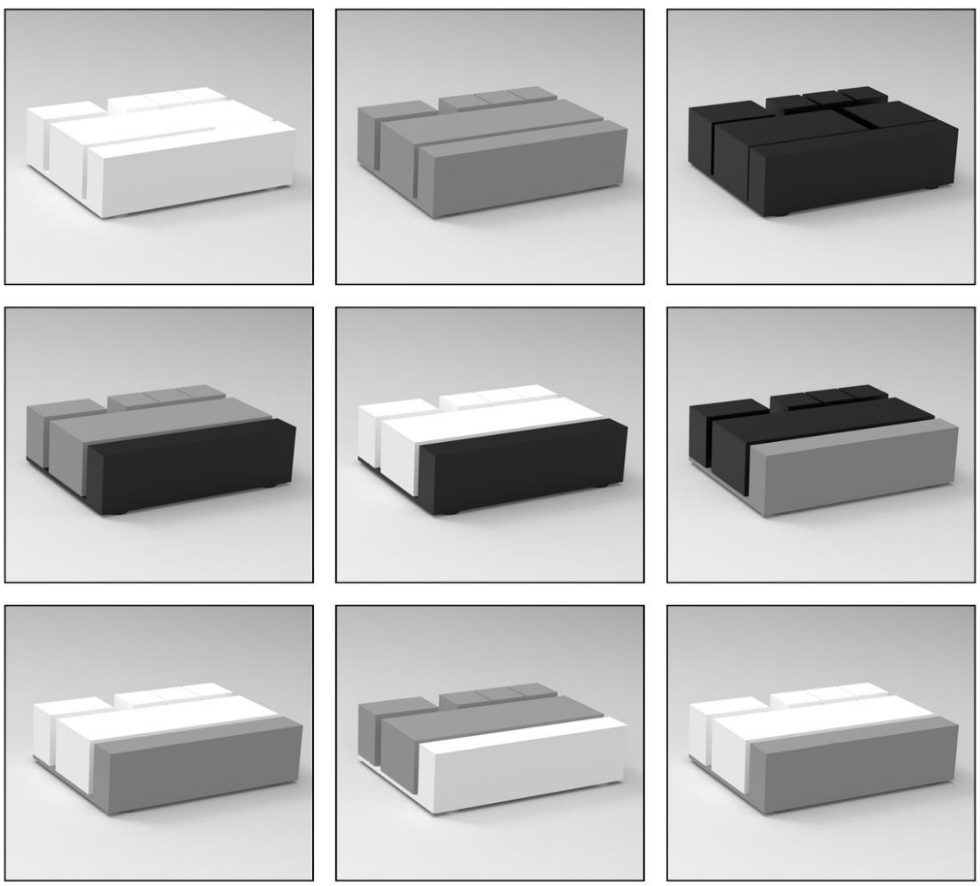


Figure 63: Nine colour variants and combinations

Results

The results are analysed using SPSS, using the Friedman Test. In table 4 it can be seen that Model B is preferred in 3 of the 4 stages. In the other stage, 3, it came second. Stage 2 and 3 three are the preferred stages, followed by 1 and 4, which can be seen in table 5. In table 6 it becomes clear that the black & white colour combinations are least preferred.

	Stage 1	rank	Stage 2	rank	Stage 3*	rank	Stage 4	rank
Most preferred	Model B	1,56	Model B	1,78	Model A	1,67	Model B	2,22
	Model A	2,67	Model A	2,33	Model B	1,89	Model A	2,33
	Model D	2,83	Model D	2,78	Model D	3,00	Model C	2,67
Least preferred	Model C	2,94	Model C	3,11	Model C	3,44	Model D	2,78

*Table 4: Model b is in 3 of the 4 stages preferred. * results appear to be statistically significant at p=0.05 level.*

	Model A*	rank	Model B	rank	Model C*	rank	Model D*	rank
Most preferred	Stage 2	1,78	Stage 2	1,78	Stage 2	1,56	Stage 2	1,78
	Stage 3	2,22	Stage 3	2,22	Stage 3	2,11	Stage 3	1,78
	Stage 1	2,44	Stage 1	2,67	Stage 1	2,44	Stage 1	2,89
Least preferred	Stage 4	3,56	Stage 4	3,33	Stage 4	3,89	Stage 4	3,56

*Table 5: Stage 2 and 3 are preferred, in all Models. * results appear to be statistically significant at p=0.05 level*

Black and White colour combinations are always ranked the lowest.

	Ranking 4	rank	Ranking 5	rank	Ranking 6	rank
Most preferred	B3, Black	2,44	D3, Black & Grey	2,22	B2, Grey & Black	2,11
	C2, Grey & Black	2,67	C3, Grey & White	3,00	A3, White & Grey	2,56
	C3, Grey	3,33	D2, Grey & Black	3,22	A3, White & Black	3,89
	A4, White & Grey	3,78	B4, White & Grey	3,78	B1, Grey & White	4,11
	C2, White	4,33	A2, Black & White	4,22	C4, Black & Grey	4,11
Least preferred	D4, Black & White	4,44	B1, White & Black	4,44	D3, Black & White	4,22

*Table 6: The Black & White combinations score the lowest. * No results appear to be statistically significant at p=0.05 level*

Conclusion

Based on this user research further developments will be made based on Model B. Regarding the stages it can be concluded that the systems should not be to empty, that it should be kept to one Base Layer. Those who seek an All-in-One solution really want an all in one. Therefore stage D will not be further developed.

4.6 Critical Layer Connections

IN THE PREVIOUS SECTION MUSIC ENTHUSIASTS CUSTOMER PANEL WAS ABLE TO PROVIDE ITS INPUT. MODEL B CAME OUT AS THE PREFERRED MODEL IN MOST OF THE STAGES. THEREFORE IT WAS DECIDED TO CONTINUE WORKING IN THAT MODELS LAYOUT CONFIGURATION.

Now it is time for the Technical implications of adaptability; The Building Block – Base connection needs to be designed. During the Music Enthusiast Audio Life the Building Blocks will have to be replaced. Even if it just for maintenance, or to remove dust and clean the system. The Music Enthusiasts indicated they wanted to be able to do so themselves, therefore the connection has to be safe to work with. Furthermore, the Base layer will be designed for a lifetime requiring a durable, reliable system. To achieve this first the different connection methods are analysed, eight concepts are designed, of which two are further developed. To finally integrate the most feasible and viable option in Model B.

BUILDING BLOCK – BASE CONNECTION METHODS

To start off the design phase of the Building Block Layer (BBL) – Base Layer (BL) connection first the possible connection methods are mapped out. The four identified methods are portrayed below, with working principle, benefits and drawbacks.

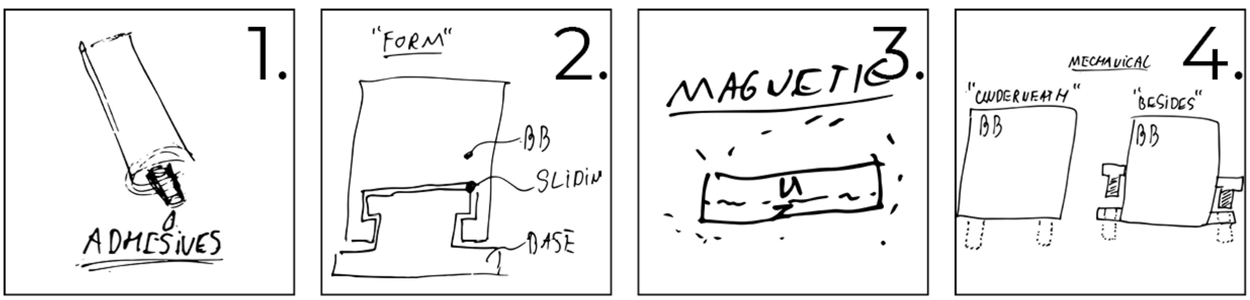


Figure 64: Connection methods

1. Adhesives rely on material specific properties, glue and resins are two familiar types of adhesives. It is easy to apply and use, but can't be reused and hampers recycling.
2. Form connections rely on physical properties of materials to keep them in place. Form connections are easy to be made, but require room to move the object around.
3. Magnetic connections rely on the magnetic properties of magnets and steel materials. The steel is held in place by the magnetic field exerted by the magnet. Magnets are ideal for flush, seamless integration, but can have a negative impact on sound and need to be big to hold a significant force.
4. Mechanical connections rely on mechanical principles to hold the building blocks in place. These fastening methods can be reused, but do take time to put together.

CONNECTION CONCEPTS

In this section an overview of eight different BBL-BL connections is presented. The eight concepts are based on one of the connection methods. Adhesives are not used in any of the concepts, because of its significant drawbacks. From the eight concepts two are selected for further development. In appendix O the connection concepts are portrayed in more detail, with working prototypes.

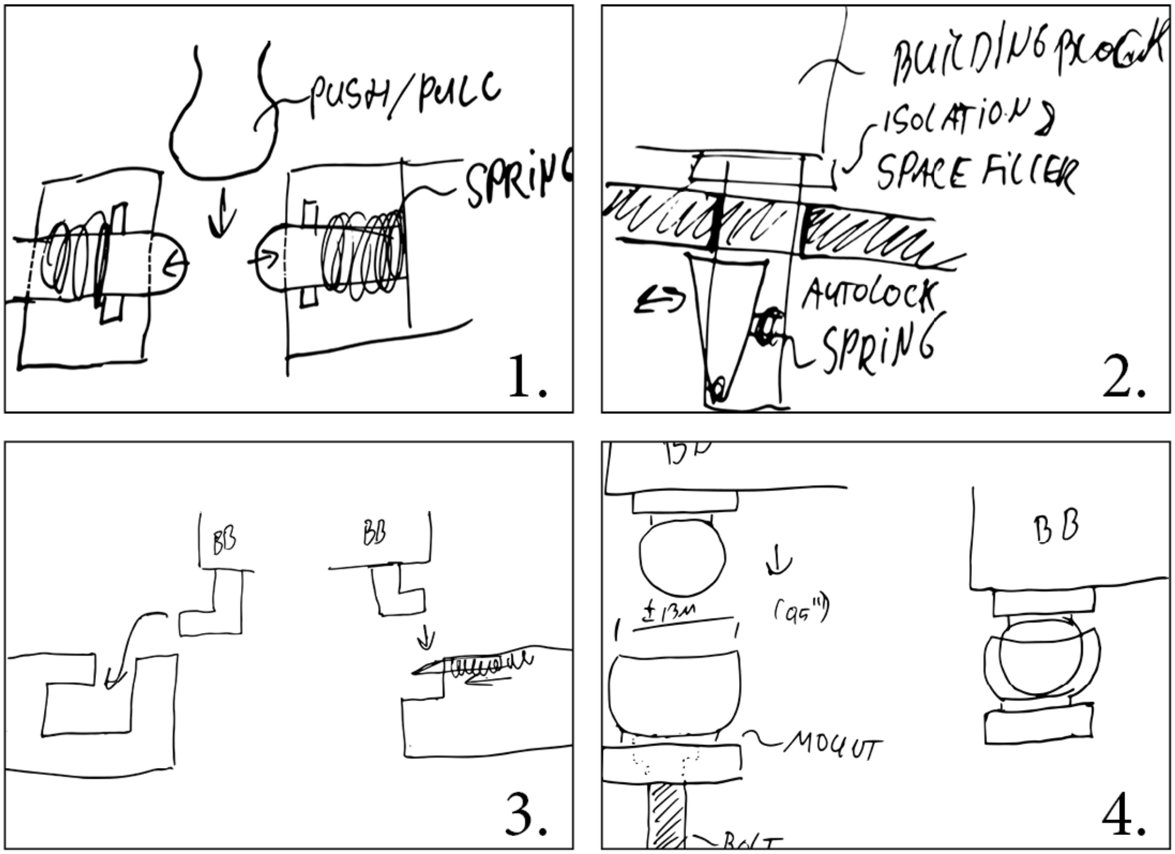


Figure 65: Variants of the same principle can be found in appendix O

1. The Ball Spring connection concept locks the building blocks in place using a mechanical connection. To the bottom of the BB four pins are connected. The pins fall into holes in the Base, under which the locking mechanism is placed. The locking mechanism is made up of two balls, which are pushed inwards by springs. The Pin, attached to the Building Block, pushes the balls sideways, after which they lock the pin in place by the force exerted by the springs.
2. Attached to the bottom of the Building Blocks are Click Fingers, variants of snap fittings. The Click Fingers slide through holes in the Base, where the Base compresses the Click Fingers. If they are pushed all the way through, the Click Fingers expand again and lock the Building Block in place. To remove the BB (Building Block) a tool needs to fitted around the Click Fingers, compressing them, after which the BB can be pulled out.
3. This concept uses a combination of a form connection and a mechanical connection. First the form connection is made, followed by the mechanical connection. Combining the two methods reduces the number of moving parts and improves its durability.
4. The Lock-Line concept is based on the product developed by Lok-Line USA. A ball is pushed into a negative cavity, after which a form connection holds it in place.

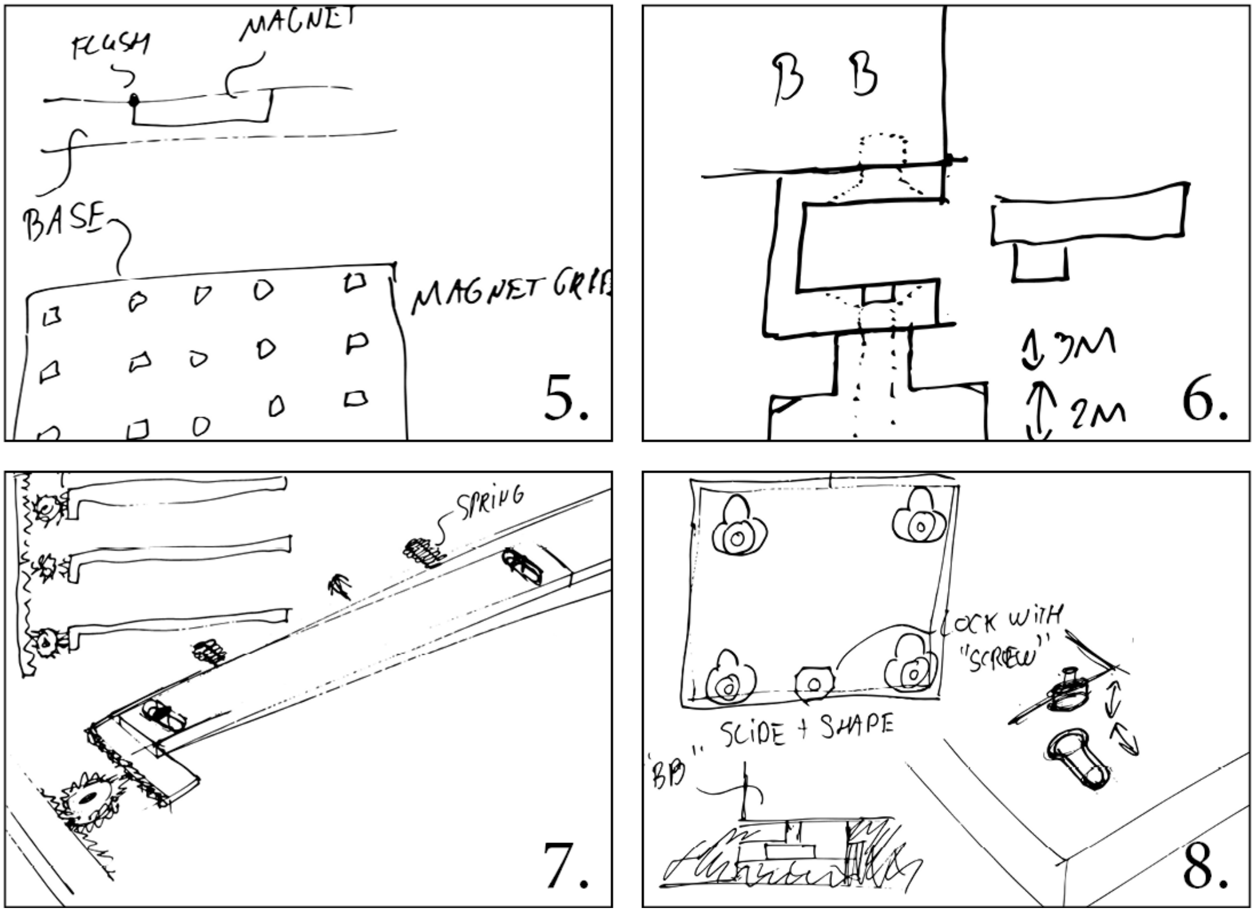


Figure 66: Variants of the same principle can be found in appendix O

5. Magnets are used for multiple applications in the HiFi market, first of all in speaker drivers and to hold speaker grills in place. To hold the BBs in place they would be sufficiently strong, and would require a secondary locking mechanism for safety.
6. The Rotating – Standoff concept is also derived from the arms industry. This is the mechanism used to attach the mounting plates. A quarter turn locks the feet in place. Drawback is the room needed underneath the Building Block.
7. Row Lock is based on a mechanisms found in optician stores, the display stands for (sun) glasses. These stands are equipped with a system that can lock and unlock all sunglasses at once. By integrating a similar mechanism in the Base, all Building Blocks could be unlocked at once.
8. Two variants of a 'slider' connection are tested. The First is based on blind hanging mechanism, often used for picture frames. The second on a modular shelving system. This concept has the drawback of movement room and exact positioning.

Building Block Base Connection Selection

The 8 proposed connection methods is reduced to two for further development. Looking back at the Design Goals, chapter 3.5, the possible viable options can be greatly reduced. Option 2 a 8 are not viable because of their ease of use, and durability. By using number 2 the whole system would have to be flipped to take out one module. Option 8 needs exact positioning. Number 5 would need serious magnets, which are not very sustainable. Number 6 and 4 would create an open space below the Building Blocks, which poses risk to the internals of the IMS system. Number 3 has potential, however number 1 and 7 are deemed most viable at this point, both because of their ease of use.

CONCEPT REFINEMENT

In the next sections the two selected concept are further developed and tested using CAD software, and verified by the use of 3D printed prototypes. In the first section the Row Lock concept is portrayed, followed by the Spring Lock concept.

Row Lock

In this section the Row Lock concept is further developed using CAD software and testing by the use of 3D printed prototypes. The aim of further development is reduction of moving parts and integration in the Base Layer, to gain insights in the room available and needed. In figure 67 the development process can be seen in six images.

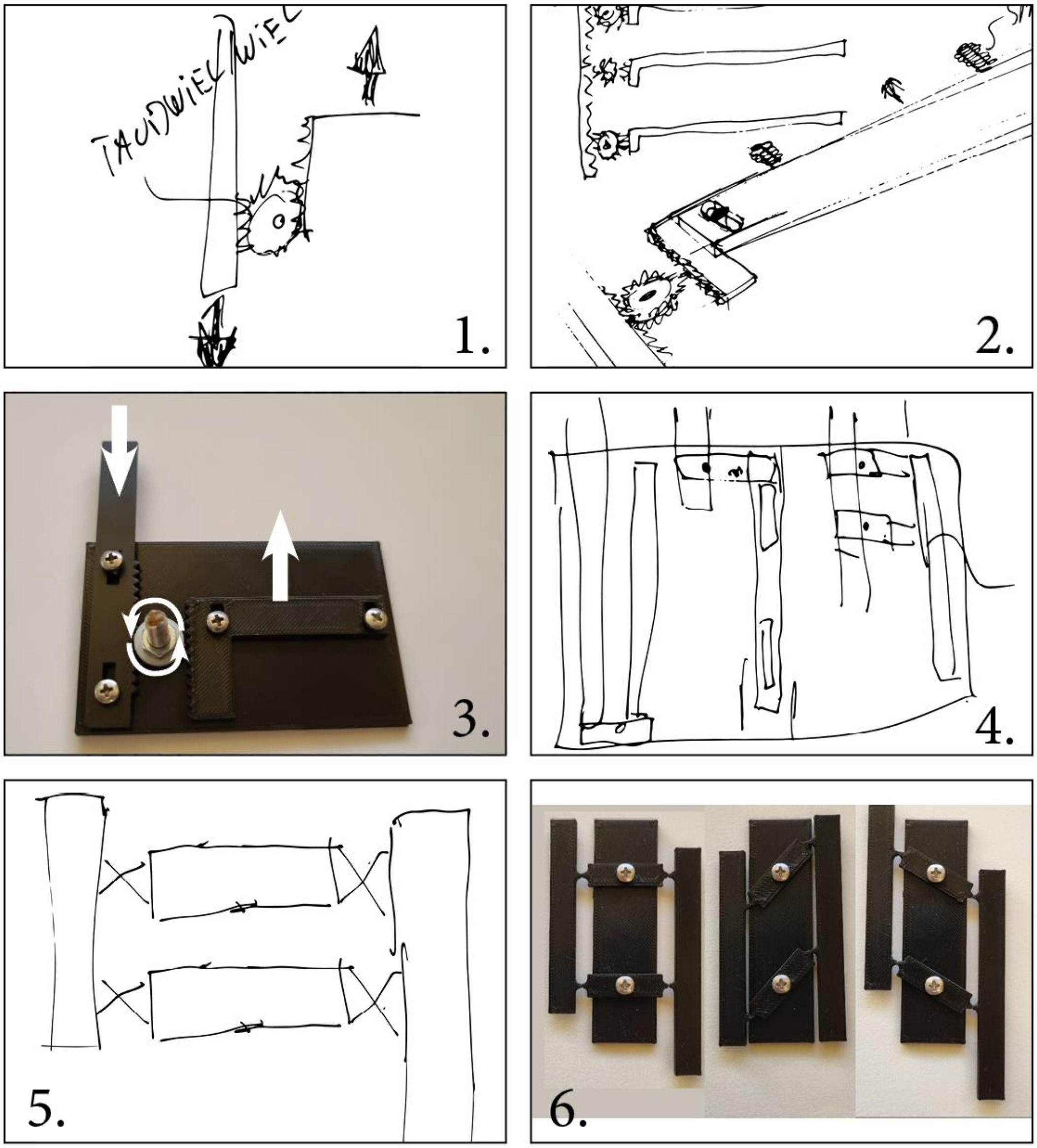


Figure 67: Development stages of the Row Lock mechanism, resulting in a compliant mechanism.

Image descriptions

1. The initial concept relies on a gear to transform the linear motion, which makes uses of moving parts.
2. By the use of guidance slots and springs the motion is restricted, and the building blocks secured in place.
3. The mechanism works, but can't move freely due to friction. A design session followed to remove or reduce the moving parts, and increase durability.
4. First the gear is replaced by a seesaw mechanism at the bottom. Secondly it is placed in top to shorten the beams used. Finally the whole is replaced by a 'Four-bar Linkage mechanism'
5. The Four-Bar linkage mechanism is redesigned to a compliant mechanism, one part that can deform without moving parts.
6. 3D printed prototype to verify its functioning

INTEGRATION IN BASE

The Base layer is previously described as the foundation on which the rest is build. The Building Blocks rest on top of the Base, but the locking mechanism is integrated. In this section the way of integration is presented.

In figure 68 a top view of the base layer can be seen, with a see through top layer. The grid of holes in the top layer is for the feet of the Building Blocks to slide through. The compliant mechanism, visible in light grey, holds the building blocks in place.

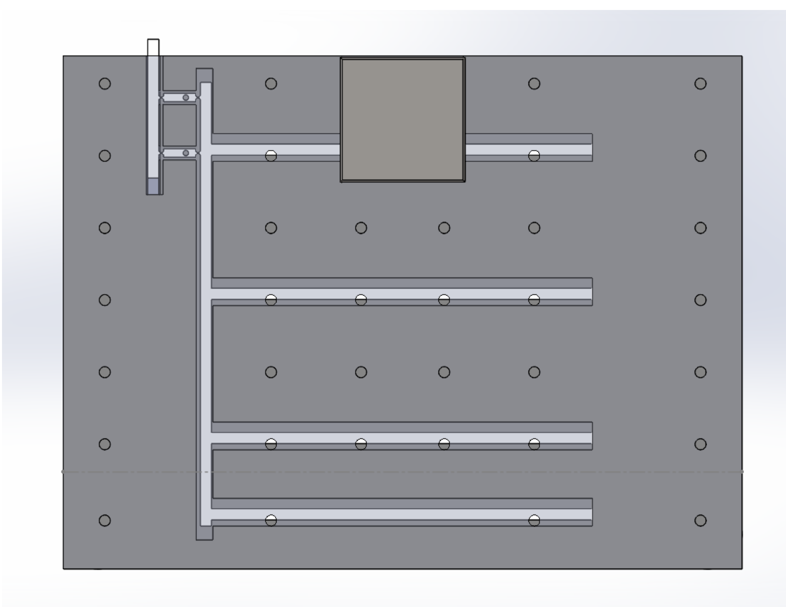


Figure 68: Row Lock Mechanism integrated in the Base Layer

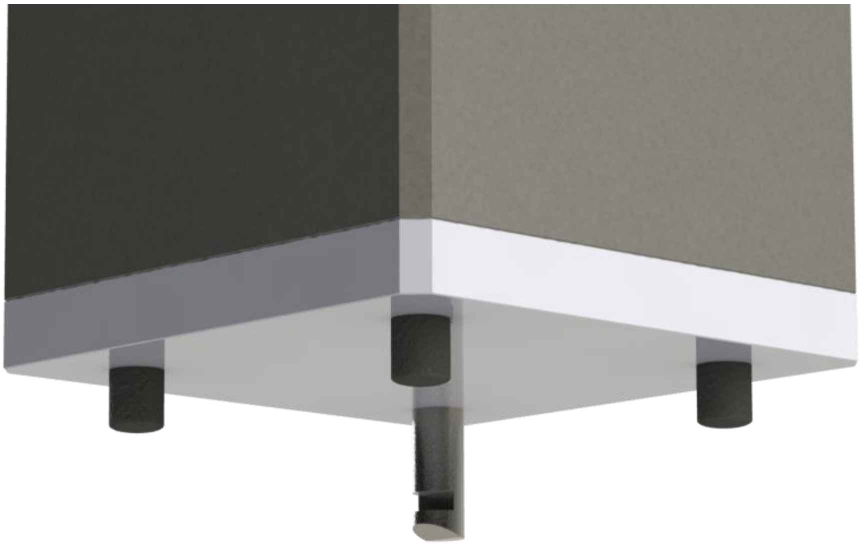


Figure 69: Four attachment points, three made of rubber, one to fixate the Building Block

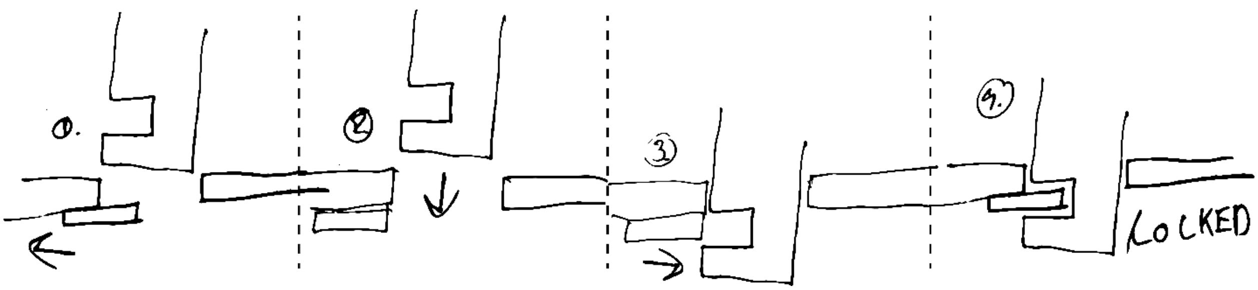


Figure 70: The hypotenuse is used to push the compliant mechanism aside.

The locking feet, that attach to the compliant mechanism, can be seen in figure 69. The slit in the feet in the back right hooks around the compliant mechanism, as can be seen in figure 70. The three other feet are made of rubber, just a bit bigger than the holes. The friction created reduces the possibility of unwanted vibrations. In figure 71 the Building Block is locked in place by the compliant mechanism.

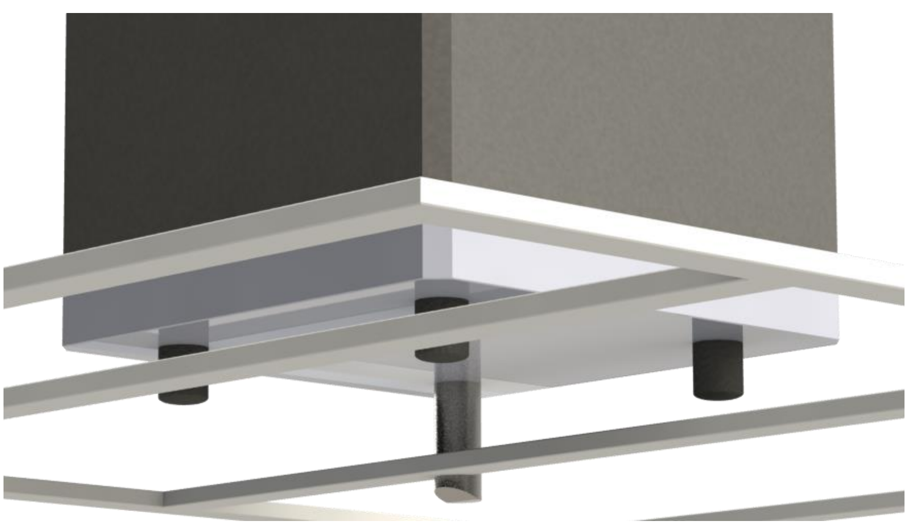


Figure 71: The Building Block is locked in place.

Unlocking the Building Blocks is done with the push of a button. In figure 72 the locking and release mechanism can be seen. Pushing on the top left, moves the whole right side up, pivoting around the two points. The spring in the bottom left pushes the compliant mechanism back in place.

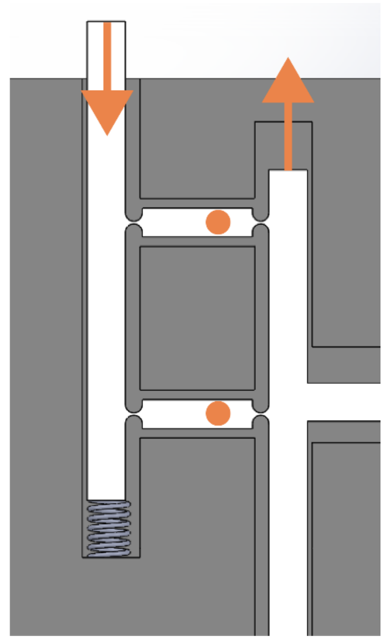


Figure 72: The mechanism is locked using a spring, and safety pin (not visible in the figure)

When the Building Blocks is pushed into the Base it rests flush on the surface, with minimal room for dust and other debris to get in the system, see figure 73.

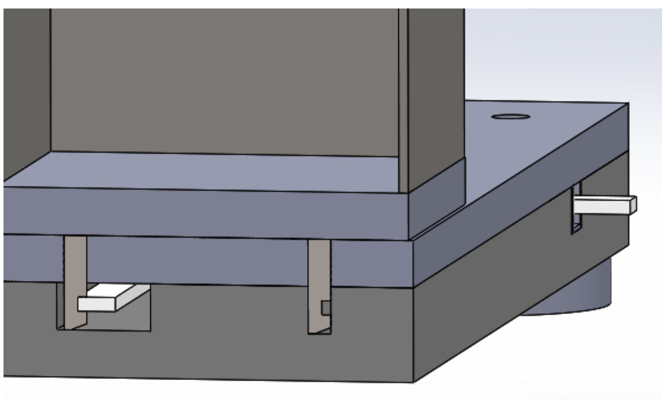


Figure 73: The feet, attached to the Building Blocks, are locked in place by the locking mechanism.

Benefits

- Requires only view on one side
- No tool need to remove the Building Blocks
- No moving parts and therefore minimal wear
- Can be produced using readily available production techniques, and requires only one specialized injection moulded, or 3D printed part.

Drawbacks

- The orientation of the Building Blocks is not yet guided
- Unclear whether there is enough room to also integrate the Infrastructure Layer.

Continuation

The Row Lock concept has been developed to a level where its functioning is clear and can be communicated. In the next section the other concept, Spring Lock, is developed to a similar level.

Spring Lock

The Spring Lock concept is inspired by the attachment of a windsurf mast to the board. A pin is pushed through two spring loaded locking pins. In figure 74 the further development steps of the concept can be seen.

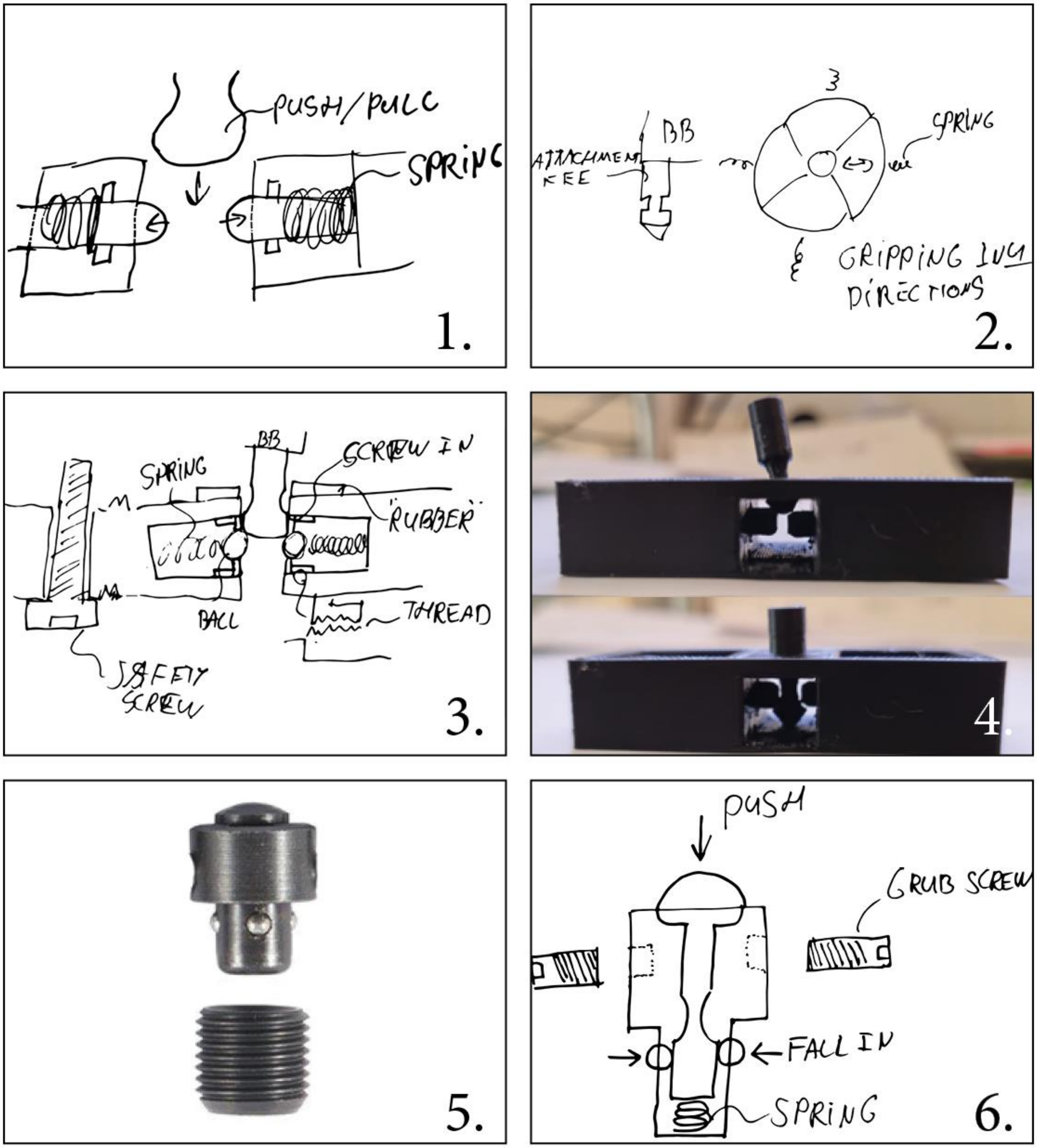


Figure 74: Evolution of the Spring Lock concept

Image description

1. The locking pins are pushed aside as the feet is pushed in between them.
2. Gripping from four sides, with flat disks increases the gripping strength, and reduces the space used.
3. The mechanism would be integrated in the base, making it invisible, but complex to made due to the overhang.
4. 3d printed prototype to test the working principle, a success but relatively complex to make.
5. A substitution mechanism is found, a 'Quick Detach' (QD) mechanism used by the military. The top part would be integrated in the Building Block, the bottom part screwed in the Base Layer.
6. The mechanism inside the top part also relies on a spring, and four balls. It can be held in place, in the bottom of the BB by the use of grub screws.

INTEGRATION IN BASE LAYER

In this concept the Base Layer is also covered in a Grid of holes, clustered per four. The biggest of the holes accepts the Quick Detach (QD) mechanism. In the middle there are three Building Blocks visible.

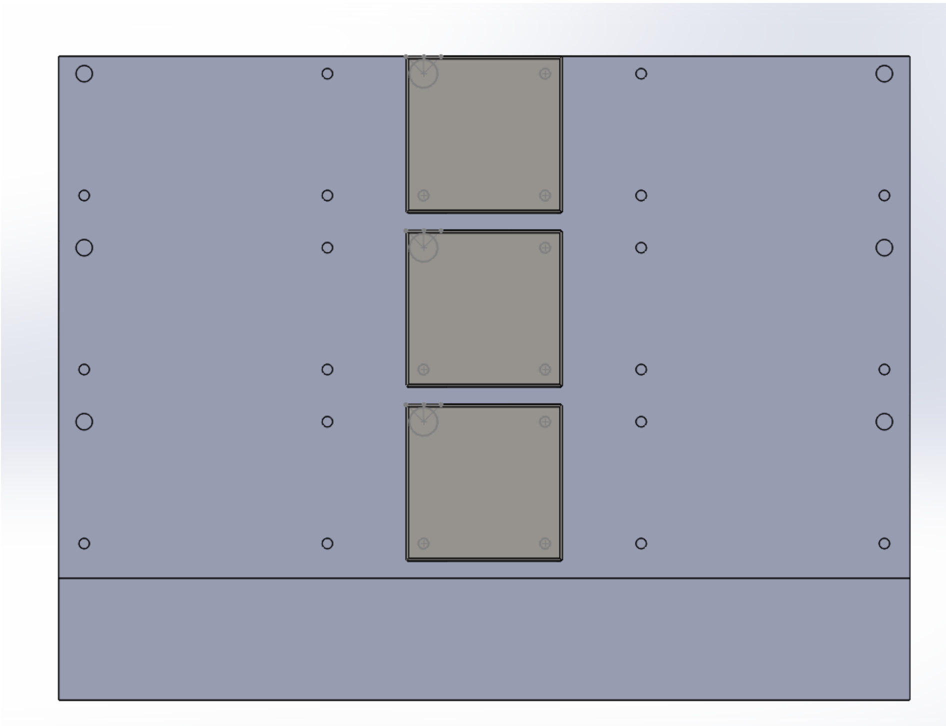


Figure 75: Grid of holes in the Base Layer

In figure 76 the QD mechanism is integrated in the base of the Building Block. Only one QD mechanism is needed to safely hold the BB in place, since it is tested with 300 pounds. (Luth-ar, n.d.)

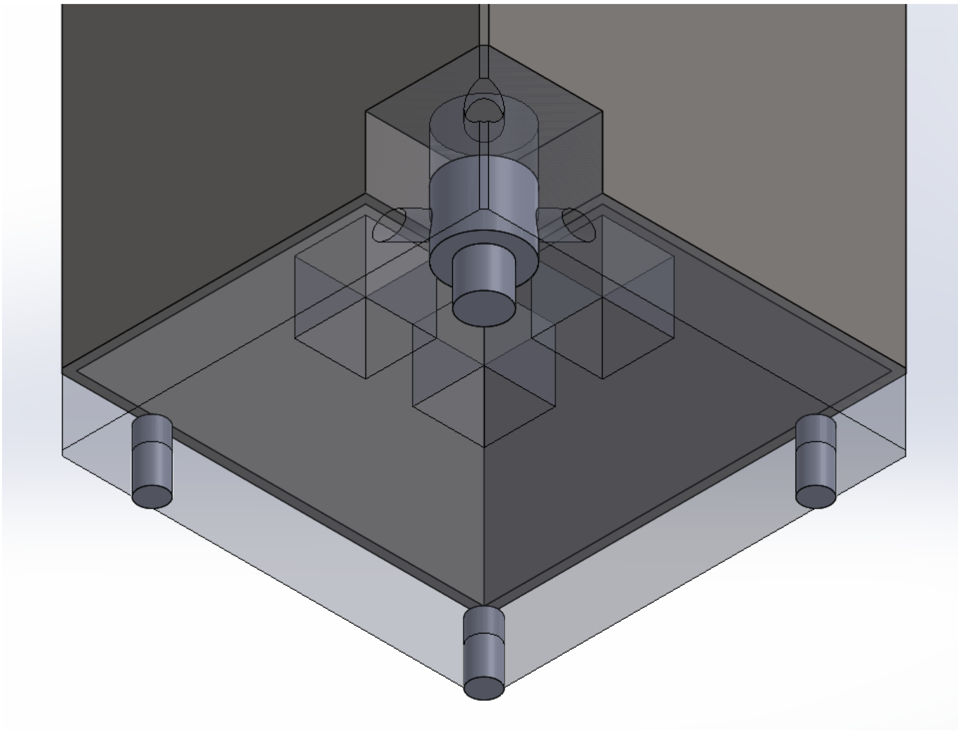


Figure 76: Locking Mechanism Integrated in the Base of the Building Block, tested at 300 pounds (pulling)

The Quick Detach mechanism is released by pushing the button on top. A tool is supplied, see figure 77, that can be slit into a small cavity, to be able to push in the button, while it is inside the Building Block base.

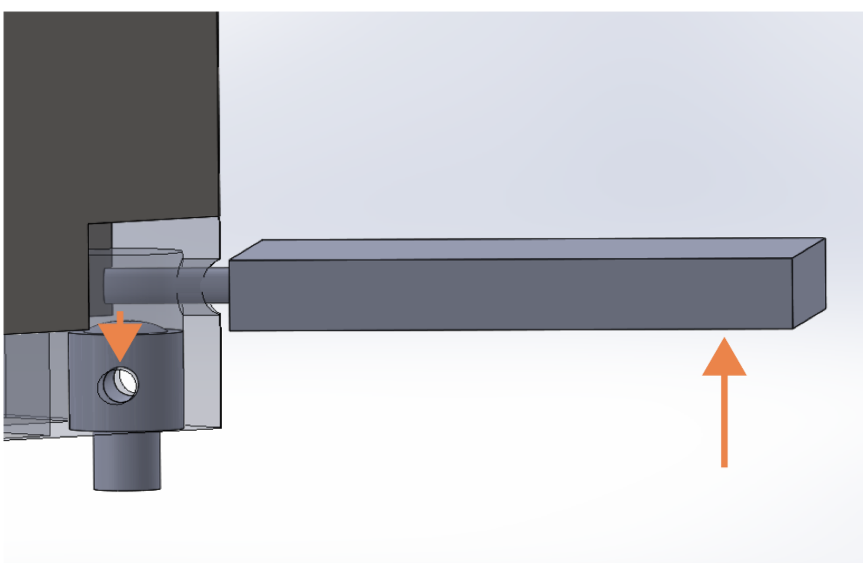


Figure 77: Grub screws in the bottom holes keep the QD mechanism in place.

In figure 78 three Building Blocks can be seen, attached to the Base Layer. The Building Blocks are flush with the Base Layer.

Figure 78: 3 Building Blocks, showing the quick detach mechanism. On the right the holes for the Tool and grub screws are visible.

Benefits

- Easy fabrication of base layer
- Based on an existing mechanism

Drawbacks

- Tool needed to release the Building Blocks
- Complex machining needed for the bases of the Building Blocks

Continuation

In the next section the most viable and feasible Building Block – Base connection is selected, based on the requirements.

Final concept selection

Both the Row Lock and Spring Lock concept have potential and their functionality is proven to a certain extend. The Spring Lock concept makes use of an existing fastening technique, however it is used in a different domain. In the latter regard is not yet tested. The Row Lock concept has been tested, via 3D printed prototypes. Based on the 5 design goals the most feasible and viable concept is selected.

Ease of use

The Spring Lock concept requires a tool for the removal of Building Blocks, Row Lock only the push of a button.

Sustainability

The Row Lock concept requires the base to be heavily machined, probably most efficiently on a 5 axis CNC machine. The same applies to the base layers of the Building Blocks in the Spring Lock concept. However, the base of the building blocks will of smaller dimensions, making them harder to position correctly in the machine and there are more different dimensions needed.

Durability

Both concept score almost equal in this regard, however the compliant mechanism technically does not move but deform. Resulting in zero moving parts. In balls of the Spring Lock mechanism do move and could get jammed by debris.

Repairability

The deforming part is placed inside the Base layer when using the Row Lock concept. Spring Lock has their moving parts integrated in the Building Blocks. The Building Blocks are easier to disassemble than the Base Layer.

Adaptability

Both concept score equal in this regard, even though that the Spring Lock concept requires a tool to remove the building blocks, this is already covered by ease of use.

Conclusion

Based on the statements above it is decided to further develop the Row Lock concept, into the final concept design.

Final iterations: Row Lock

During the final selection the Row Lock Concept is the most viable and feasible locking mechanism to use in the IMS System. In this section final iterations and improvements are designed and presented. First the locking mechanism is prototyped in more detail to ensure its functioning. There the conclusions are integrated in the final concept design.

Working prototype

The locking mechanisms is a compliant mechanism. “Compliant mechanisms perform their function through the elastic deflection of their members. The advantages of compliant mechanisms include increased performance, reduced or eliminated assembly, no friction or wear, fewer parts, lower cost, and lower weight.” (Zirbel, n.d). Because the whole peace is made out of one material, which deforms within its elastic region, no wear is to be expected resulting in a long, indefinite, lifetime of the part.

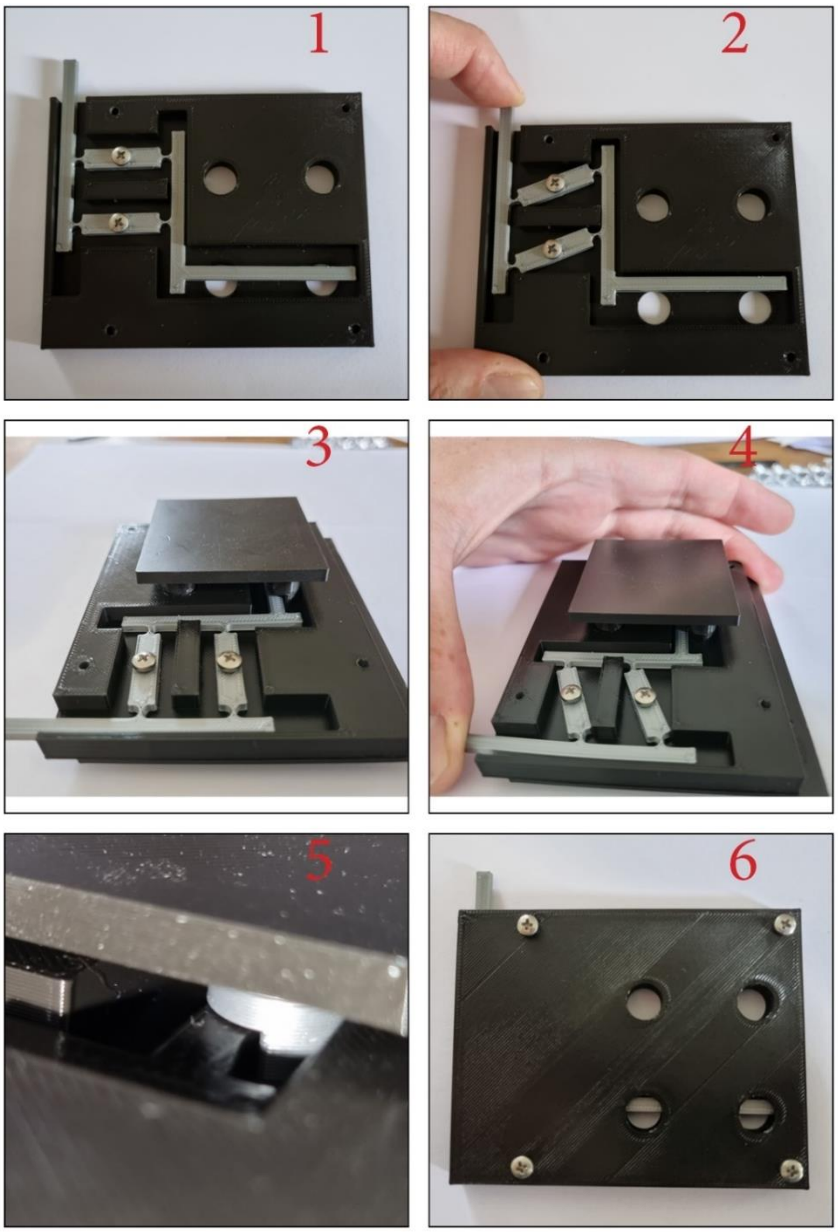


Figure 79: Working prototype in detail.

1. Locking mechanism in rest: Building Blocks Locked
2. Locking mechanism Compressed: Building Blocks Unlocked
3. Locking mechanism in rest: Building Blocks Locked
4. Locking mechanism Compressed: Building Blocks Unlocked
5. Building Block Feet locked by the Row Locking Mechanism in the Base
6. Row Lock mechanism integrated in the Base Layer.

Areas of Work

After making the final prototype a few discoveries were made, and other areas to improve are defined.

Improvement

1. With the final prototype it became clear that the Building Blocks could be placed in all directions. They would only lock in one direction, but the Music Enthusiast would not have to notice.
2. The stiffness and shape of the compliant mechanism needs to be increased.

To do

1. The grid of holes needs to be optimized to make room for the Infrastructure Layer.
2. Implementation of the Infrastructure Layer.

In the next two sections the final implementations and iterations are visualized. Thereafter, in paragraph 4.7, the infrastructure layer is integrated in the Base Layer.

Building Block alignment.

To ensure correct positioning of the Building Block the shape of one of the 4 connections holes is changed. As can be seen in figure 80, the square holes accept the locking feet in only one direction. By making the locking feet square they are also easier to manufacture.

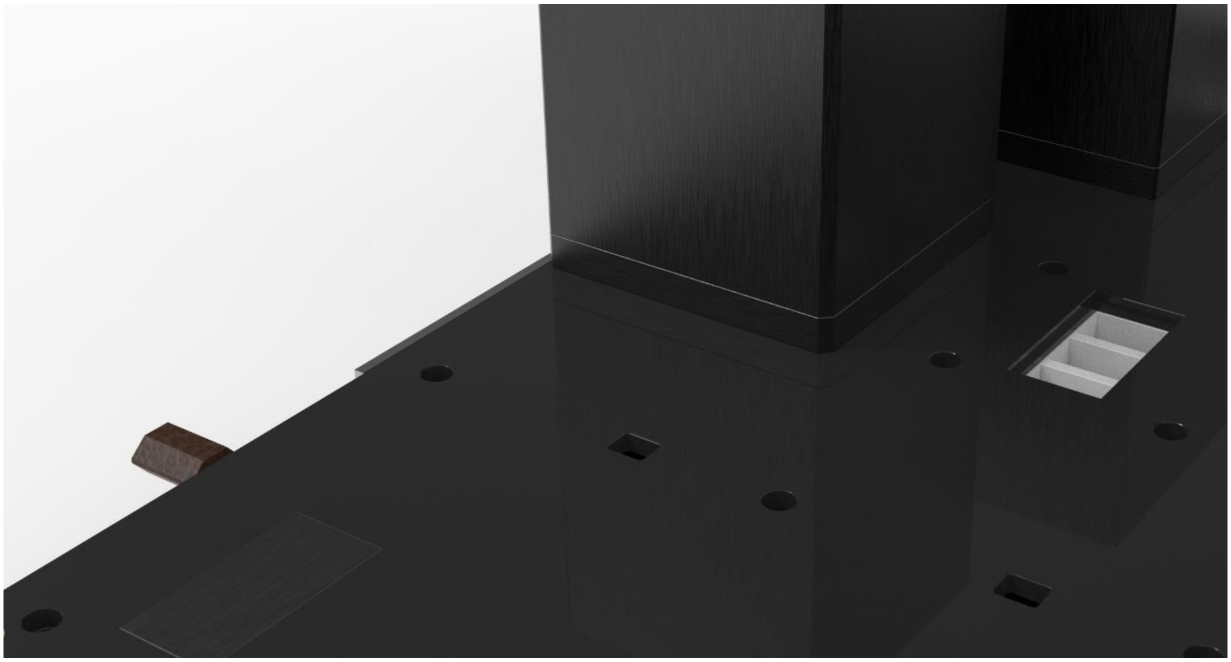


Figure 80: The locking feet is made square, with a square hole in the Base Layer. Allowing the Building Block to be placed in 1 direction only.

The compliant mechanism rests upon Nylon inserts, visible as the white rectangles in figure 81. These nylon inserts should provide near frictionless movement, minimizing wear of the mechanism. The user will feel resistance, due to the spring that pushes the mechanism back.

Figure 81:The compliant mechanism rest on nylon pads, to move freely with minimal friction.

The Locking feet are tightly secured in place, with a minimal clearance to prevent tolerance issues.

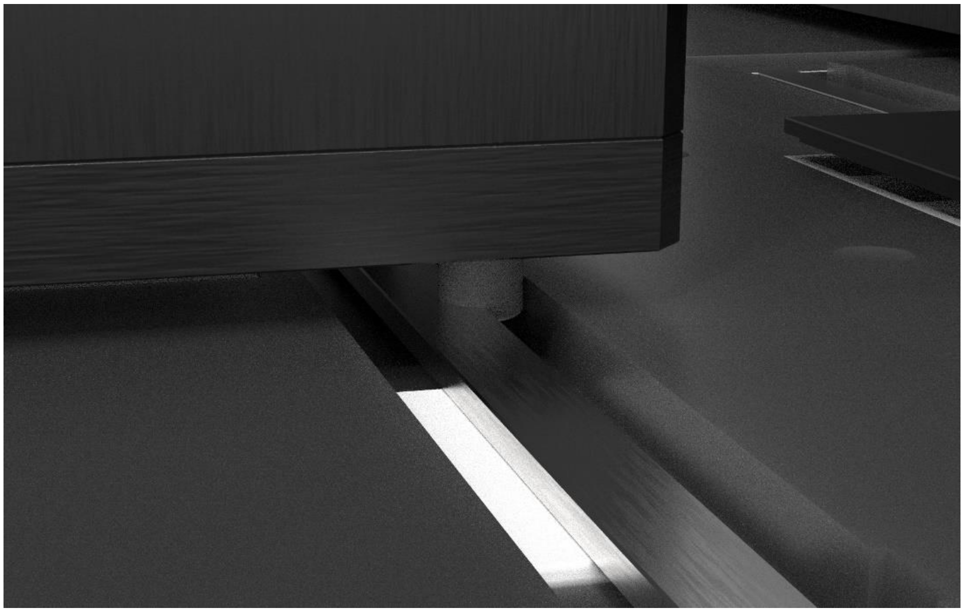


Figure 82: The square locking feet wrapped around the compliant mechanism.

Compliant mechanism

The shape of the compliant mechanism is reduced in width, to increase the stiffness of the part. It is also closed off, connected, on the right side to further improve stiffness, and ensure that all horizontal beams move linear.

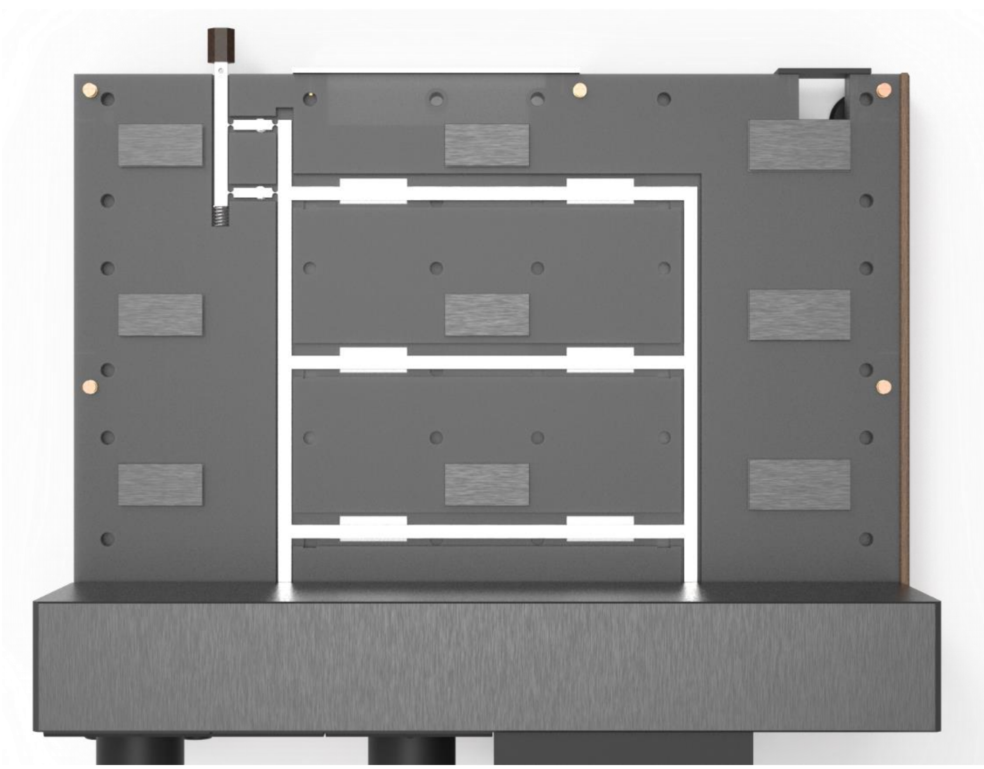


Figure 83: The compliant mechanism is reduced in width, and closed at the right to increase stiffness.

Base Layer

On front, left, and right side of the base layer M6 inserts are integrated in the Base layer, see figure 84. These inserts can be used for magnets to attach to, the wooden front strip is magnetically connected to the Base. Removing the screws opens up the M6 insert, after which an additional external enclosure can be placed.

Figure 84: M6 inserts, for magnets to attach to, or an additional cover/exterior layer.

In figure 84 three horizontal layers can be seen in the Base Layer (Black, Grey, Black). The middle, grey, layer is the machined layer, in which the cavities and slots for the compliant mechanism, inserts and Infrastructure layer are made. The two black layers, top and bottom, are the Aesthetical layers and seal the mechanism inside.

Technical drawings

To give an impression of the overall dimensions, see figure 85, more technical drawings can be found in appendix S.

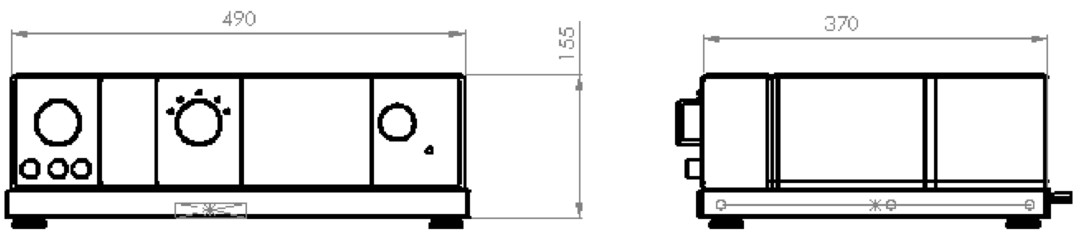


Figure 85: Outer dimensions of the IMS System

Continuation

The Building Blocks Layers is now attached to the Base Layer. The only remaining challenge is to integrate the Infrastructure Layer into the Base Layer. The goal of the Infrastructure Layer was to interconnect the User Interface Layer with the Building Block layer.

4.7 Building Block - Infrastructure layer

In paragraph 4.3 a start was already made with the infrastructure layer. In figure 56 the directions and number of connections between the Building Block Layer and the Infrastructure Layer can be seen. In figure 86 these same connections are integrated in the Base Layer of Model B. The main difference is that in this figure routing is also included. The routing is important to retain the signal, a power cable can have a negative influence on a analog cable. During the layout design of the Building Blocks this was also kept in mind, however there was no optimal situation. Therefore the power is routed via the front of the system, surrounding almost all other Building Blocks.

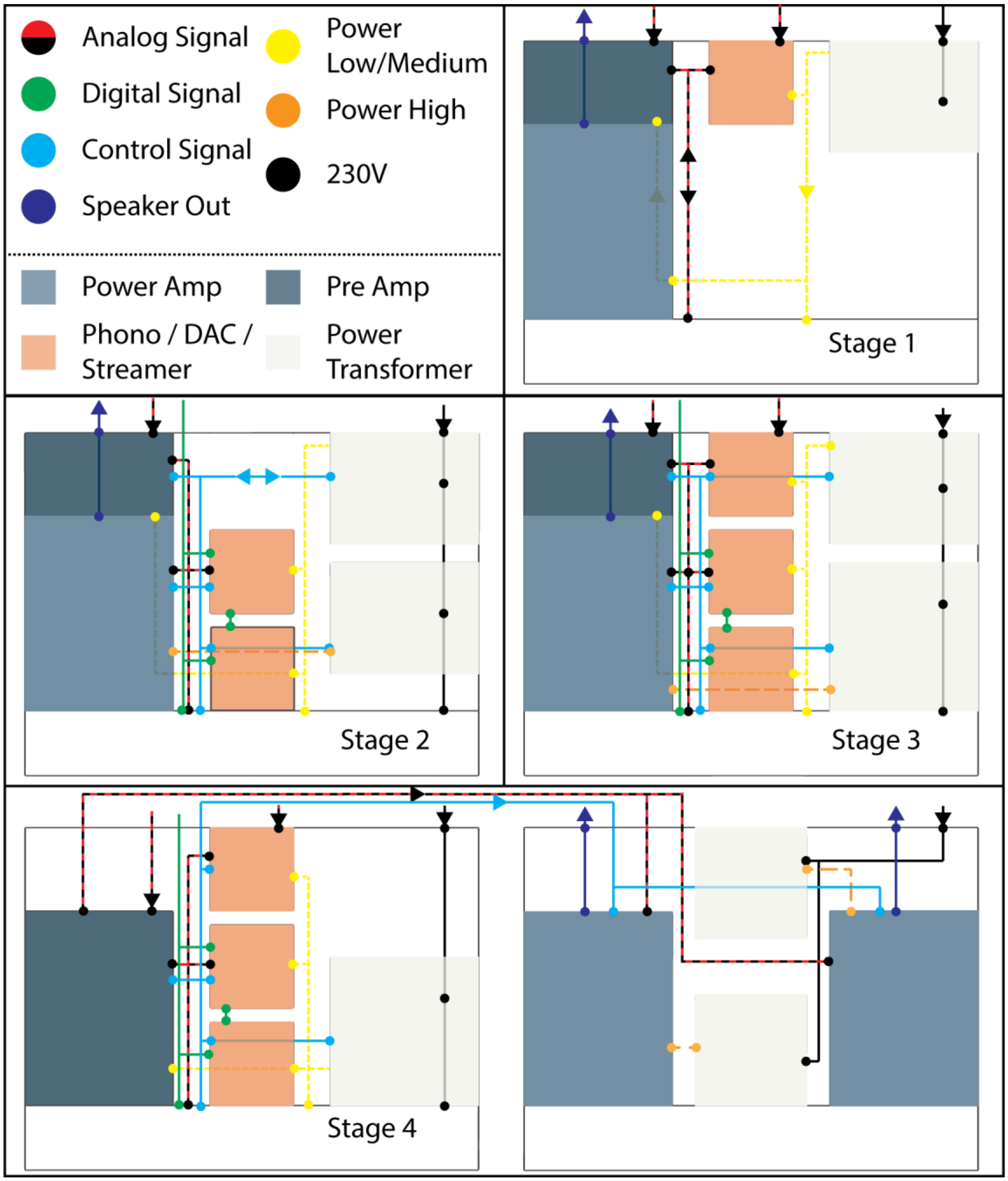


Figure 86: Routing of the different signal types, Integrated in the Base layer of Model B.

Voltages

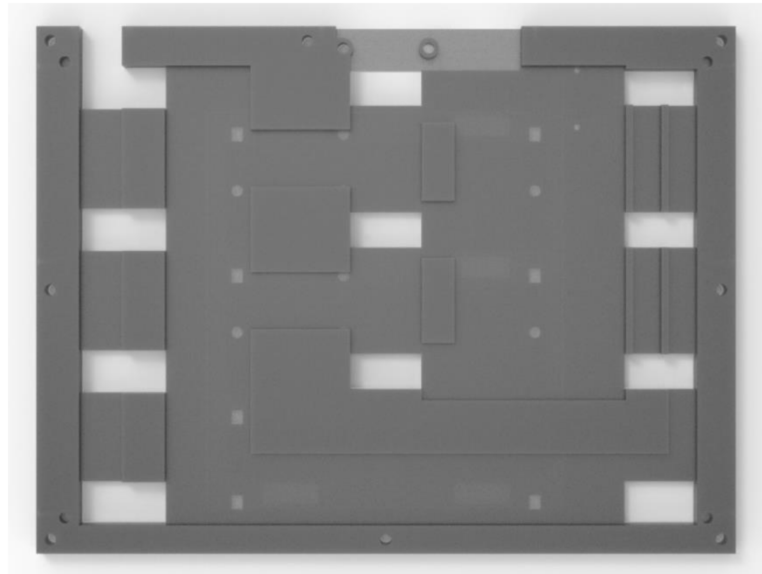
In the stage description different voltages were mentioned. HiFi equipment can be designed to run on AC and DC power, at different voltages. For this research the available voltages are divided in 3 categories; low (0-6V), medium(6-25V) and high(25V +). Low voltages are used by control logic, in the IMS concept the Control Centre. Medium voltages can power secondary building blocks, and everything but the power amplifier. The high voltage categories is used by the power amplifier.

From Stage 2 onwards the configurations all have two power transformers or more, of which one is for the preamplifier and functions, the other for the power amplifier. The Control Centre is powered by standby power supply, because it always has to be on, an needs a dedicated power supply for reliability (Field research at Studio 107).

Routing

The infrastructure layer is integrated in the Base Layer from the bottom (the row locking mechanism is integrated from the top). The different signal types are separated from each other to prevent degradation of the signal. In figure 87 the results of implementing the Infrastructure layer can be seen. With the power connector on the left, and the connector in/output on the right. In figure 87 the base can be seen, without the covering Aesthetical layers.

Figure 87: Infrastructure layer integrated in the Base Layer. On the left the power connector can be seen, on the right the input output panel.



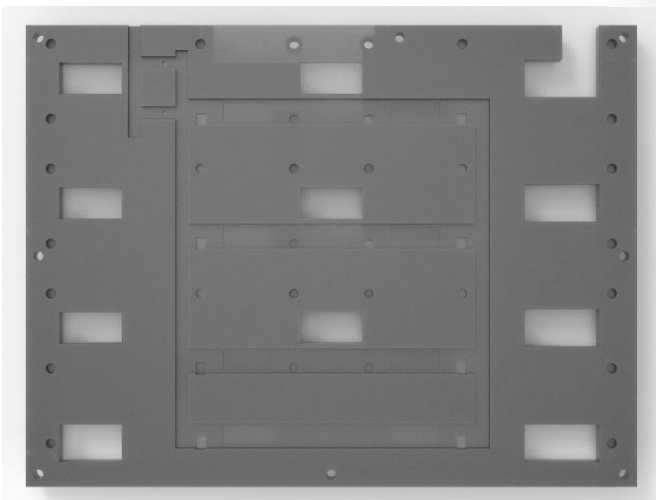


Figure 88: Top view (Left) Bottom View (Right) of the Base, with all slots and holes machined in.

Connections

Designed for standardization, the connectors that are used are widely and readily available. The cables used are specifically designed, mainly the cables that carry the Audio signal. Degradation of the Audio signal will result in lower levels of performance which is not acceptable.

The connectors and cables to be used are not yet defined, however the room in the Base Layer is allocated for the connectors. In figure 89, nine squares can be seen, covered, with the connector bracket or empty. The squares are located underneath the position of the Building Blocks, and can be adapted to the installed Building Block. In figure 90 the connector can be seen in white, on the left of the locking mechanism.

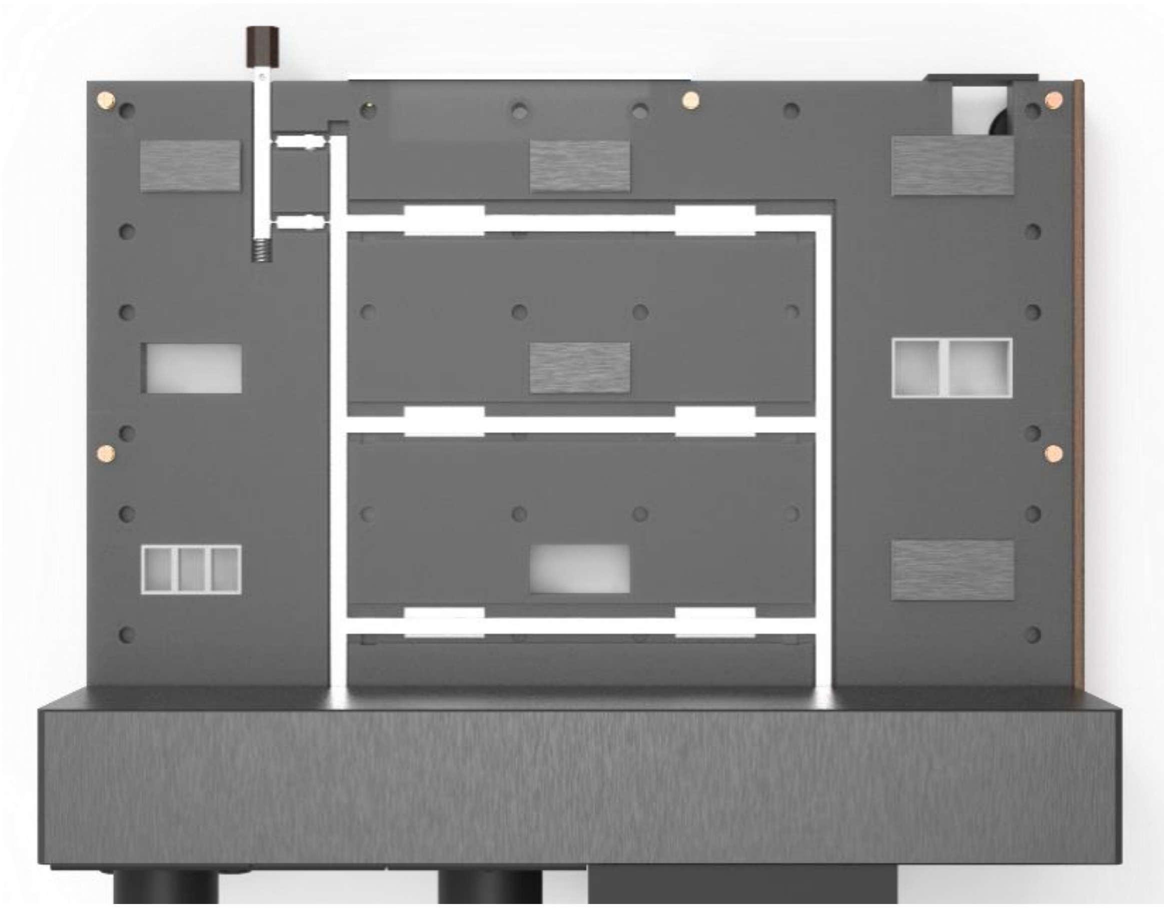


Figure 89: 9 squares for the connectors to fit in, 5 covered, 2 open, 2 empty.

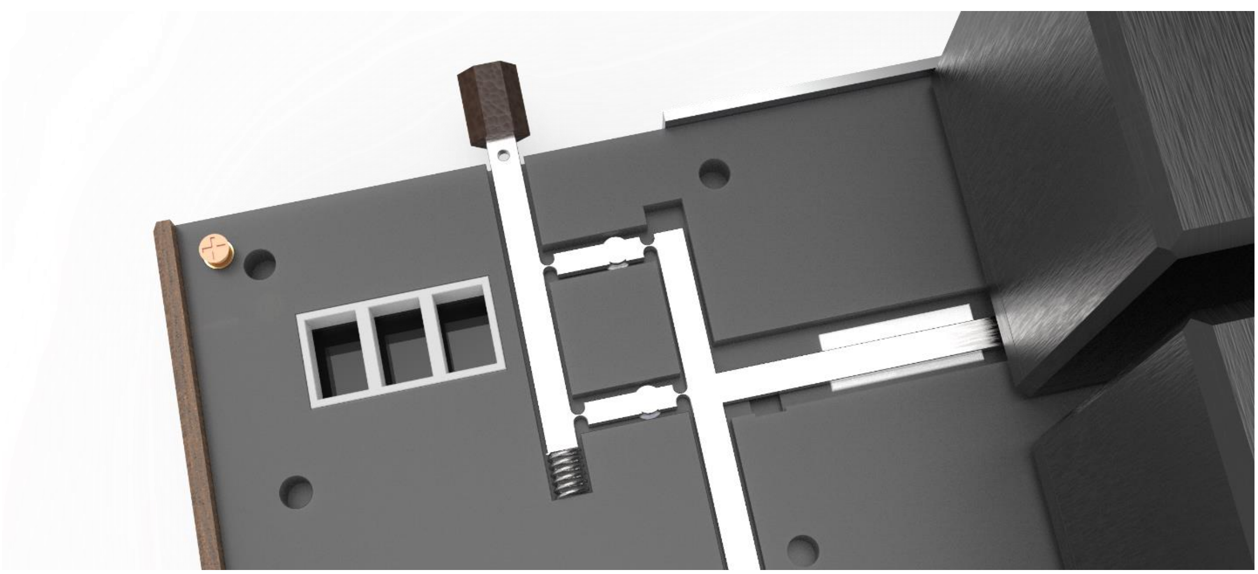
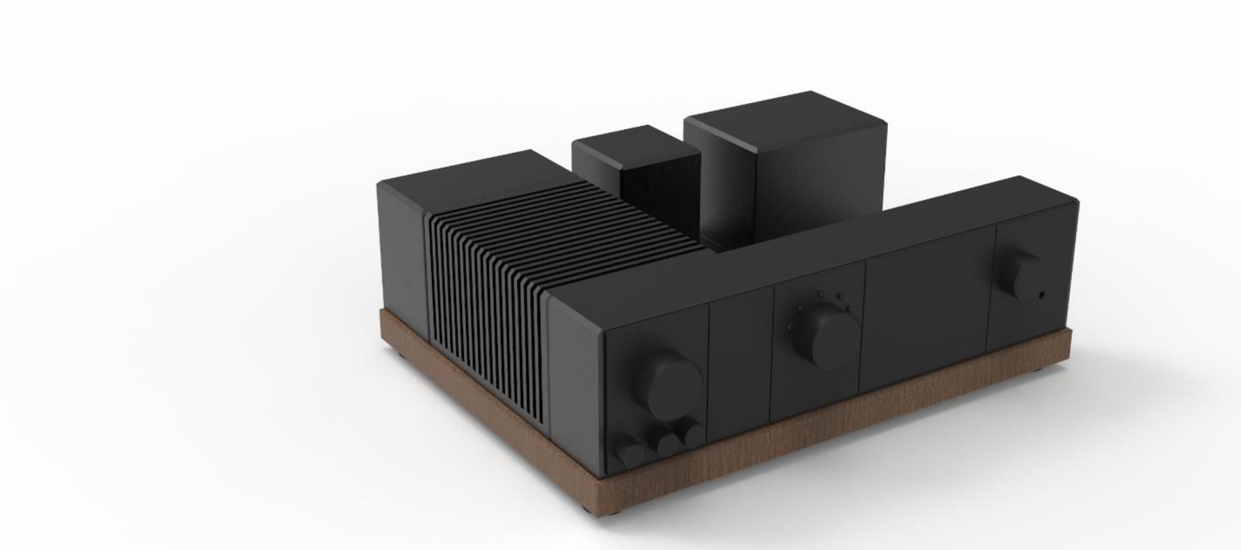
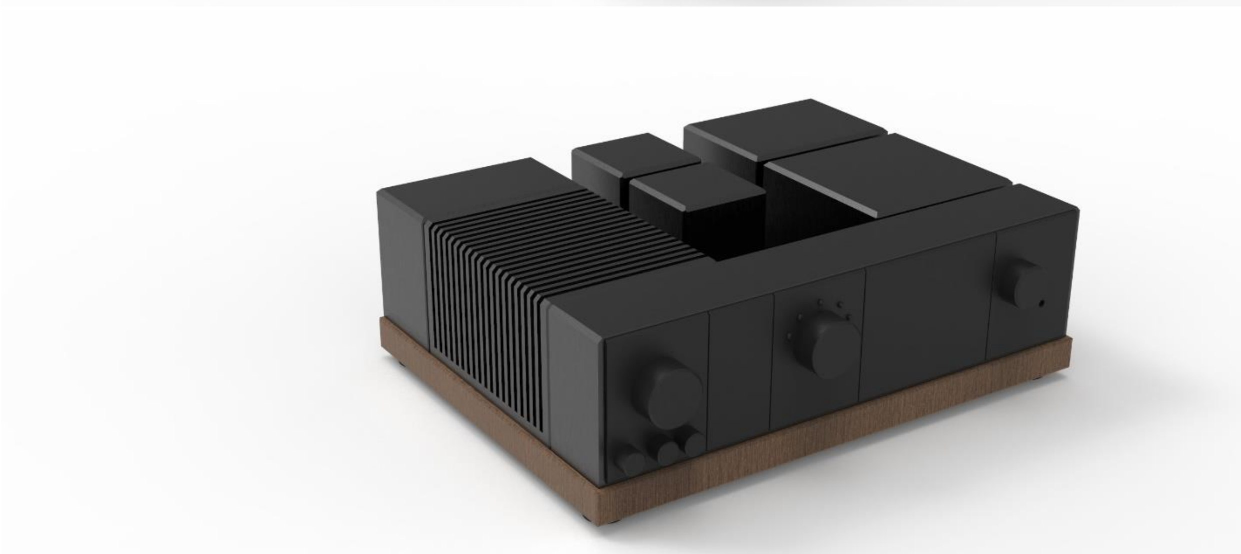


Figure 90: Connector housing, located next to the Compliant Mechanism unlocking Mechanism.

Renders





5.Evaluation

5.1 Discussion

During this research the line between research, ‘knowing’ and thinking were sometimes vague and unclear. The topic of this research, HiFi audio, is quite abstract and personal to begin with. What can be fact for one Music Enthusiast, can be nonsense to the next.

The idea behind this research was that the Music Enthusiast would be central, taking them along every step to ensure the results would be to their liking. Unfortunately the Covid-19 pandemic greatly reduced the number of people coming to Audiohuis Delft, and with those who came by the contact options were limited. As a result the Music Enthusiast has not been as engaged in the research as been planned in advanced.

The planned guided interviews were replaced by online questionnaires, suitable for most user research. However, in this case the information derived from the questionnaires is only a fraction of what it could have been, looking at the results of the In-Depth interviews. This is also due to inexperience in making questionnaires.

During the validation phase key input moments, with the Music Enthusiast are left unused. In chapter 4.4 the Exterior layer is selected based on the design goals, not on input from the Music Enthusiast, which would have been more valuable. And make the final design more viable.

In the next section the results of the design research are discussed, has the concept become feasible?

5.2 Conclusion

To be able to draw an overall conclusion on the design, first the preliminary assignment :

I am going to design a sustainable HiFi Solution, that customers of Audiohuis Delft are willing to, and can use for the duration of their Audio Life, within the capabilities of the company. The HiFi Solution should be able to fulfil the same functionalities and benefits as currently available All-in-One solutions and utilize the maximum technical and functional lifetime of each Building Block, and therefore be more sustainable.

The IMS system is a modular HiFi solution that has was designed to be more sustainable than the currently available All-in-One solutions. By designing a system that can adapt to the user, and only in that region that the Music Enthusiast wants changed, the sustainability potential is there. But it has not been tested yet, with the Music Enthusiast, and therefore no hard conclusions can be drawn.

After the analysis phase the preliminary assignment was refined, focusing on four different aspects of the Sustainable HiFi Solution. Different Stages during a Music Enthusiast Audio life, the aesthetical implications of those stages, followed by the connection between the Building Block and the Base Layer, to finalize with the connection between the Building Blocks and the Infrastructure layer.

Of those four aspects two have been tested and validated, the others remain. The aesthetical implications of the stages have been presented to the Music Enthusiast, which resulted in a preferred model. However, it was not verified whether the stages would fulfil all their needs, even though they are based on the first user research.

The connection between the Building Block Layer and the Base layer has been designed and made. This connection is tested and validated using prototypes and they worked better than expected. There are no problems expected in this regard.

The final critical aspect, the infrastructure layer – building block connection, has been partly designed. The groundwork has been done, there is room for the Infrastructure layer and the connectors. But the connectors themselves and their requirements have not yet been specified.

Overall the preliminary assignment has partly been designed, and partly tested, but further validation of the concept is required.

5.3 Recommendations

The end result of this design research is the concept design of the IMS system. Parts of the concept are further developed than others, the Building Blocks themselves are mere dummies for now. However, Music Enthusiast like to hear, read and see before they buy. With this report reading and seeing is partly possible, therefore the next step to continue this research is to develop a minimal viable product.

Minimal Viable Product

A minimal viable product should be made that captures the ease of use of the concept. Easy replacement of Building Blocks to create the preferred system. This MVP can be made with the in-house knowledge of the company, and related companies. The electronics used should not be specifically designed, but borrowed from other products.

Product development

The company has indicated they became enthusiastic about the modular HiFi solution. However, the way it is currently designed is too expensive to develop for such a small player. Therefore the company should revise and discuss internally which direction they want to pursue and use this research as guidance.

Modular Product Design

In chapter 3.3 appendix G is briefly mentioned, in which the start of an analysis on modular products can be found. The analysis is not done and should be revised, but more research on the goal of modular design could be beneficial for science.

7. References

- Alvarado, S., Maldonado, P., & Jaques, I. (1999). Energy and environmental implications of copper production. Energy, 24(4), 307–316. https://doi.org/10.1016/s0360-5442(98)00093-0
- Andrews, E. (15-12-2015). *What is the oldest known piece of music?*. Retrieved on: 12-12-2020. Retrieved from: https://www.history.com/news/what-is-the-oldest-known-piece-of-music#:~:text=nine%2Dstringed%20lyre.-,%E2%80%9CHurrian%20Hymn%20No.,a%20woman's%20gravesite%20in%20Turkey
- Ankosko, B., (10-09-2020). The Model Eighteen: The First Marantz Receiver , Retrieved on: 27-07-2021). Retrieved from: https://www.soundandvision.com/content/model-eighteen-first-marantz-receiver
- Audiokarma. (Jan, 14, 2010). Should I replace transistors and diodes in a working 36 year old amplifier. Retrieved on: 14-08-2021. Retrieved from: https://audiokarma.org/forums/index.php?threads/should-i-replace-transistors-and-diodes-in-a-working-36-year-old-amplifier.274845/
- Bakker, C., Hollander, M., Hinte. & Zijlstra, Y. (2014). *Products that last : product design for circular business models*. Delft: TU Delft Library.
- BBC. (01-03-2018). How Spotify came to be worth billions. Retrieve on: 02-03-2021. Retrieved from: https://www.bbc.com/news/newsbeat-43240886#:~:text=Founded%20by%20Daniel%20Ek%20and,the%20music%20industry%20was%20facing.
- Belk, R. and Sperry, J., 2007. *Consumer Culture Theory*. Bingley, U.K.: Emerald, pp.94-114.
- Bobba, S., Carrara, S., Huisman, J., Mathieux, F. & Pavel, C. (2020). *Critical raw materials for strategic technologies and sectors in the EU : a foresight study*. Luxembourg: Publications Office of the European Union.
- Bocock, G., (n.d.). Electrolytic Capacitors Determine The Lifetime Of A Power Supply. Retrieved on: 16-08-2021. Retrieved from: https://www.xppower.com/resources/blog/electrolytic-capacitor-lifetime-in-power-supplies
- Broekhoff, M. (2007). *Starten met marktonderzoek : snel en praktisch aan het werk*. Groningen etc: Wolters-Noordhoff.
- Celloseattle. (n.d.) Products&Services. Retrieved on: 08-03-2021. Retrieved from: http://www.celloseattle.com/ctdocs/prodserve.html
- Circular Industries. (n.d.) Critical Raw Materials. Retrieved on: 08-03-2012. Retrieved from: http://www.circular.industries/critical_raw_materials.html
- Consumer Electronics Association. (2003a). Overview. Retrieved from http://www.ce.org/publications/books_references/digital_america/audio/default.asp
- CRMAlliance. (n.d.). What are Critical Raw Materials? Retrieved oN: 08-03-2021. Retrieved from: https://www.crmalliance.eu/critical-raw-materials#:~:text=Critical%20Raw%20Materials%20(CRMs)%20are,risk%20associated%20with%20their%20supply.
- Eltim. (n.d.) ELTIM AUDIO modules. Retrieved on: 29-03-2021. Retrieved from: https://www.eltim.eu/nl/
- Engels, J. (03-07-2020). De wereldwijde berg aan elektronisch afval groeit zorgwekkend hard. Trouw. Retrieved on: 18-01-2020. Retrieved from: trouw.nl/wetenschap/de-wereldwijde-berg-

aan-elektronisch-afval-groeit-zorgwekkend-hard~b41d41b9/?referrer=https%3A%2F%2Fwww.google.com%2F

- Enserink, B. (2010). *Policy analysis of multi-actor systems*. Hague Netherlands: Uitgeverij LEMMA.
- Flipsen, B., Bakker, C. A., & de Pauw, I. C. (2020). Hotspot Mapping for product disassembly: A circular product assessment method. In M. Schneider-Ramelow (Ed.), *Electronics Goes Green 2020+ (EGG): The Story of Daisy, Alexa and Greta*
- Geeksforgeeks. (April 16, 2021). Padovan Sequence. Retrieved on: 12-08-2021. Retrieved from: https://www.geeksforgeeks.org/padovan-sequence/
- Goodship, V., Stevels, A., & Huisman, J. (2019). Waste Electrical and Electronic Equipment (WEEE) Handbook (Woodhead Publishing Series in Electronic and Optical Materials) (2nd ed.). Woodhead Publishing.
- Guttenberg, S. (July, 7, 2010). How long should your hi-fi last?. Retrieved on: 11-08-2021. Retrieved from: https://www.cnet.com/tech/home-entertainment/how-long-should-your-hi-fi-last-poll/
- Hifichoice. (n.d.). All-in-one systems. Retrieved on: 28-02-2021. Retrieved from: https://www.hifichoice.com/taxonomy/term-p/800?page=2
- Huntley, H. E. (1970). The divine proportion: A study in mathematical beauty. Dover Publications.
- Keightley, K. (1996). 'Turn it down!' she shrieked: gender, domestic space, and high fidelity, 1948–59. Popular Music, 15(2), 149–177. https://doi.org/10.1017/s0261143000008096
- Luth-ar. (n.d). Grovtec QD Push Button Side Sling Swivel and Cup. Retrieved on: 21-07-2021. Retrieved from: https://www.luth-ar.com/product/grovtec-push-button-side-sling-swivels/
- Matthew-James. (n.d.) History. Retrieved on: 08-03-2021. Retrieved from: https://www.matthew-james.net/History/
- Medium. (07-11-2019). Creating a Stakeholder Analysis; How do you do that? Retrieved on: 19-02-2021. Retrieved from: https://medium.com/the-value-maximizers/creating-a-stakeholder-analysis-how-do-you-do-that-b2b8198ca6c
- Milieucentraal. (2018). Afval scheiden: cijfers en kilo's. Retrieved on: 14-01-2021. Retrieved from: https://www.milieucentraal.nl/minder-afval/afval-scheiden/afval-scheiden-cijfers-en-kilo-s/#:~:text=In%20Nederland%20gooien%20we%20per,in%20Europa%20beter%20dan%20gemiddeld
- Mindtools. (n.d.) Stakeholder Analysis, Winning support for your Projects. Retrieved on: 22-02-2021. Retrieved from: https://www.mindtools.com/pages/article/newPPM_07.htm
- Monolithicpower. (n.d.). Analog Signals vs. Digital Signals. Retrieved on: 12-08-2021. Retrieved from: https://www.monolithicpower.com/en/analog-vs-digital-signal
- Morton, D. (2000). *Off the Record: The Technology and Culture of Sound Recording in America.* New Brunswick: Rutgers University Press.
- NAD. (n.d.). C316BEE Stereo Integrated Amplifier. Retrieved on: 23-01-2021. Retrieved from: https://nadelectronics.com/product/c-316bee-stereo-integrated-amplifier/
- NAD. (n.d.). C368 Hybrid Digital DAC Amplifier. Retrieved on: 24-01-2021. Retrieved from: https://nadelectronics.com/product/c-368-hybrid-digital-dac-amplifier/
- Post, RAG., Blijlevens, J., & Hekkert, PPM. (2013). The influence of unity-in-variety on aesthetic appreciation of car interiors. In s.n. (Ed.), Proceedings of IASDR 2013:International association of societies of design research (pp. 1-6). s.n..

- Quadrepair. (n.d.). Quad 33. Retrieved on: 1-03-2021. Retrieved from: https://www.quadrepair.nl/modellen/quad-33
- Qualtrics. (January 21, 2021). Survey ranking questions: Definition, examples and dos and don'ts. Retrieved on: 11-07-2021. Retrieved from:https://www.qualtrics.com/blog/the-dos-and-donts-of-ranking-questions/
- Qwerty. (Februari 12, 2018). Poll: How often do you change your stereo system's components?. Retrieved on: 15-08-2021. Retrieved from: https://forums.stevehoffman.tv/threads/poll-how-often-do-you-change-your-stereo-systems-components.732497/
- Rega. (n.d.). Amplifiers. Retrieved on: 28-02-2021. Retrieved from: https://www.rega.co.uk/products/amplifiers
- Rega. (n.d.). io. Retrieved on: 23-01-2021. Retrieved from: https://www.rega.co.uk/products/io.
- Rega. (n.d.). ELEX-R. Retrieved on: 23-01-2021. Retrieved from: https://www.rega.co.uk/products/elex-r.
- Simaudio. (n.d.). 340i X Integrated Amplifier. Retrieved on: 23-01-2021- Retrieved from: https://simaudio.com/en/product/340i-x-integrated-amplifier/
- Simaudio. (n.d.) ACE All-in-One Music player. Retrieved on: 23-01-2021. Retrieved from: https://simaudio.com/en/product/ace-all-in-one-music-player/#
- Smithsonian. (26-01-2015). *"Hear My Voice" Alexander Graham Bell and the Origins of Recorded Sounds. Retrieved on: 12-12-2020.* Retrieved from: https://americanhistory.si.edu/documentsgallery/exhibitions/hear-my-voice/2.html
- Triggs, R. (March 23, 2018). A Quick History of Bluetooth. Retrieved on: 22-07-2021. Retrieved from: https://www.androidauthority.com/history-bluetooth-explained-846345/
- Wrap. (02-2019). Compositional Analysis of Kerbside Collected Small WEEE. Retrieved on: 14-01-2020. Retrieved from: https://www.resource-recovery.net/sites/default/files/axion_weee_composition_report_-_final_260209.3ff6dd40.6642.pdf
- Zirbel, S. (n.d.) Compliant Space Mechanisms.. Retrieved on:12-08-2021. Retrieved from: https://www.nasa.gov/directorates/spacetech/strg/2012_nstrf_zirbel.html

Images

https://www.hobo.nl/media/catalog/product/cache/1/image/26d6d6170cc9616a9c43276880bb9be2/n/a/nad-m33-masters-bluos-streaming-dac-versterker.jpg

https://nadelectronics.com/nad-masters-m33-bluos-streaming-dac-amplifier-becomes-first-integrated-component-to-feature-purifis-ultra-quiet-amplification-technology/

https://volumio.org/product/volumio-primo/

https://tinker-board.asus.com/product/tinker-board.html

https://i2.wp.com/darko.audio/wp-content/uploads/2020/08/marantz-model30-1.png?ssl=1

https://wilbert.nl/images/stories/virtuemart/product/moon/moonneoace2tone.jpg

https://argonaudio.com/products/stream-2m

https://argonaudio.com/products/phono1-riaa-pre-amp https://nuprimeaudio.com/product/stream-mini/?v=796834e7a283

https://www.cambridgeaudio.com/row/en/products/hi-fi/dacmagic/dacmagic-200m

https://www.vinylvinyl.nl/graham-slee-gram-amp-2-se.html

https://www.hobo.nl/moon-110lp.html?sqr=110lp&

https://www.hobo.nl/moon-neo-mind-2-streamer.html

https://media.s-bol.com/qw2N06lgE0p/1200x585.jpg

https://simaudio.com/en/product/760a-power-amplifier/

https://www.hobo.nl/moon-neo-mind-2-streamer.html

https://www.hobo.nl/moon-390-netwerkspeler-voorversterker-zwart.html?sqr=390%20moon&

8. Appendices

Appendix A – Project Brief

Appendix B – Glossary

Appendix C – HiFi system components in detail.

Appendix D – Audiohuis Delft

Appendix E – E-waste in Detail

Appendix F – Hotspot Mapping, Design & Materials

Appendix G – Modular product analysis

Appendix H – Function Dimension Analysis.

Appendix I – Field research at Studio 107

Appendix J - Stakeholder Wishes & Requirements

Appendix K & L – User Questionnaire Usage, Requirements and Aesthetical preferences (Dutch & English)

Appendix M – Design Challenge Exploration

Appendix N – Stage compositions, infrastructure layer & model layout

Appendix O – Aesthetic research Results

Appendix P - Aesthetics User Test - Google Forms

Appendix Q – Attachment Options & Concepts

Appendix R – Program of Requirements.

Appendix S – Technical Drawings – Overall Dimensions