MASTER THESIS | Integrated Product Design

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Embodiment design of a hi-fi speaker with a full range cardioid radiation pattern

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ABSTRACT

This master thesis describes the embodiment design process of a new full-range directional hi-fi loudspeaker using a cardioid radiation pattern for Dutch & Dutch. Directional speakers minimize room boundary reflections to ensure the listener listens only to the direct sound waves coming from the speaker instead of also listening to the non-direct sound waves that come from reflections against the wall, floor, and ceiling. Dutch & Dutch current 8C-speaker implement a directional cardioid radiation pattern for frequencies above 100Hz. However, as the human hearing goes to as low as 20Hz, a new concept was developed to accommodate a full-range cardioid radiation pattern.

An analysis of the company and its portfolio, sound acoustics, the target group, and design language is presented. The analysis provided guidelines to start the embodiment design, which focuses on aesthetics, materialization, production, and assembly. Experts on these different topics were consulted to provide expertise-feedback and evaluation of the designed solutions. Multiple prototypes were made for evaluation and communication purposes. The final design proposition beholds an embodied concept, including acoustical concept, aesthetical design, and materialization of a full-range directional high-end hi-fi loudspeaker reflecting the values of Dutch & Dutch.

ACKNOWLEDGMENT

I wish to thank my supervisors from the faculty of Industrial Design Engineering, René van Egmond and Stefan Persaud, for providing feedback and creative inspiration during the project. The sessions always led to new insights that were helpful for the design process and boosted the final results' quality.

My thanks also go to Eric van Duin, the supervisor from Dutch & Dutch. I am thankful to have gotten the opportunity to take on this design project and for all the resources that were available to me. Eric's pragmatic view helped identify challenges ahead and sparked creativity for coming up with concrete solutions.

I would also like to thank Howan Lau from Hamwells and Martijn Mensink and Sergio van Vliet from Dutch & Dutch for enlightening my project by looking at it from their expertise.

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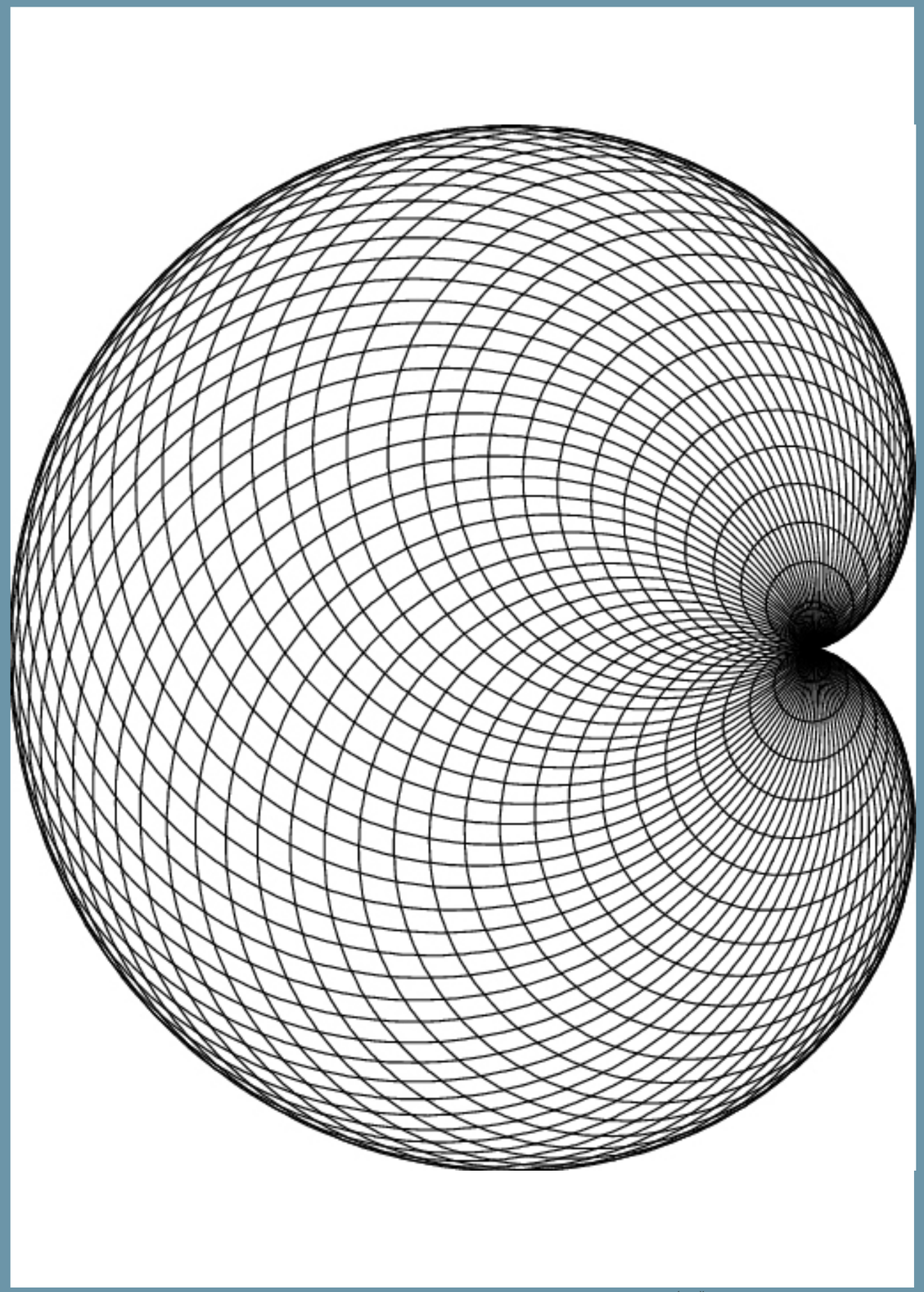


FIGURE 1. TOP VIEW OF CARDIOID RADIATION PATTERN (BIZZARRI & LÁVIČKA, 2009)

1
INTRODUCTION

The quality of a Hi-fi audio setup depends not only on the amplifier and speakers used but also on the acoustic properties of the listening room. Sound waves spread all around a listening room, and via reflections against room boundaries, this indirect sound reaches the listener's ears moments later than the direct sound. Not only are the timing of these reflections off, but different boundaries also reflect different frequencies more efficiently. The result is an unnatural emphasis on some frequencies, a 'coloration' of the sound. Moreover, indirect sound waves are often already colored before hitting walls, floors, and ceilings, as most speakers' off-axis response is not flat.

Dutch & Dutch's mission is to overcome these problems by building a directional speaker. By canceling out the non-directional sound waves, a cardioid-shaped radiation pattern, as seen in Figure 1, is achieved. Sounds are canceled out at the speaker's rear side. So as the listener walks from front to back around the speaker, a decreasing sound amplitude is perceived. Less non-directional sound waves lead to fewer room-boundary reflections and a far better music listening experience independent of the listening room. However, the 8C-speaker cardioid radiation pattern stops below the frequencies played below 100Hz. So a new speaker with full-range cardioid radiation is the next step.

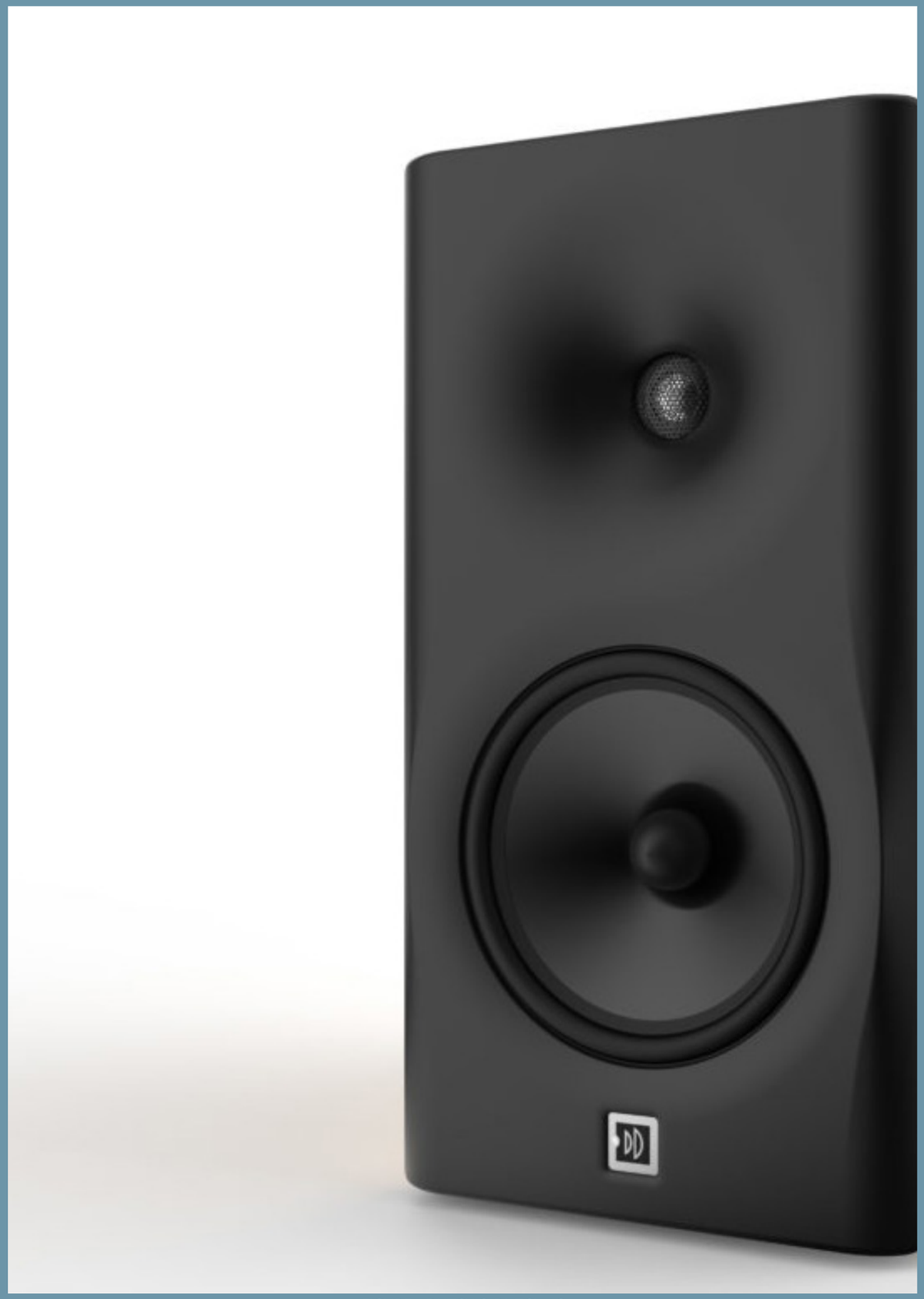


FIGURE 2.DUTCH & DUTCH 8C

2
COMPANY BACKGROUND

2.1 MISSION & VISION

Dutch & Dutch was founded in 2014 and started as a spin-off from the engineering agency Rinnic/Vaude. Currently, Dutch & Dutch has designed three different sound systems:
- A system for professional use only
- A more simplified two-way system for domestic use called the 8M
- A three-way called the 8C-speaker

The 8C is the only loudspeaker Dutch & Dutch is still selling today. The company's office has just moved from Rotterdam to Capelle aan den IJssel, and this is also where the company assembles its loudspeakers (Dutch & Dutch.com, 2022).

Dutch & Dutch sells high-end equipment to professional sound engineers and music enthusiasts. Although the company started as a professional-audio brand, Dutch & Dutch now also sells a large percentage of its speakers on the domestic audio market. The team consists of around 15 people with different expertise like Acoustical experts, sound engineers, and software developers.

Dutch & Dutch strives to adapt the speaker to the listening room instead of adapting the room to a speaker. Dutch & Dutch claims to make the room disappear, and they do this by minimizing the speaker's interaction with the room. How this is achieved will be explained in the next Paragraph. Dutch & Dutch has tried to make their speakers sound the same regardless of the room's dimensions and acoustical properties. The vision of Dutch & Dutch is to have a linear frequency response over the entire audible frequency band, which is from 20Hz upwards to 20kHz. It means the speaker is not 'colored,' meaning the speaker reproduces every frequency equally loud. It sounds like an apparent mission, but many speakers are 'colored,' meaning they have a distinctive sound character. Having a flat frequency response over the entire audio band is hard to accomplish due to the many limitations involved in producing sound waves. Dutch & Dutch goes far beyond wanting speakers just to sound good; the company wants speakers to measure perfectly linear.

FIGURE 3.TEAM OF DUTCH & DUTCH

2.2 PRODUCT PORTFOLIO

Currently, Dutch & Dutch only sells the 8C-speaker, see Figure 4. The 8C is designed for use in engineering studios (pro audio applications) and domestic environments. The 8C does not need a separate amplifier to work, making it an active speaker. Instead, the 8C is a streamer, an amplifier, an equalizer, and a loudspeaker in one package. Therefore, the 8C can more accurately be called an 'integrated sound system' rather than a speaker. Active speakers are already popular in less high-end consumer audio applications. Examples are the JBL charge Bluetooth speakers or the Sonos speaker systems. What makes Dutch & Dutch unique is that the company targets the high-end hi-fi community with its active speakers. This target group of high-end hi-fi enthusiasts -often referred to as audiophiles-passive systems- has favored passive systems for years. A passive system consists of separate components rather than an all-in-one solution, like active speakers. The option to upgrade every part of a sound system individually according to personal preferences. Fanatic audiophiles will go as far as comparing if one audio or power cable sounds better than another. See Figure 5 for an example of a passive audiophile setup.

See confidential appendix x1.a

FIGURE 4. THE 8C FROM FRONT SIDE AND REAR

FIGURE 5.TRADITIONAL AUDIOPHILE SETUP

FIGURE 6. SEE FIGURE IN CONFIDENTIAL APPENDIX X1.B

2.3 KEY FINDINGS

- Dutch & Dutch focus on both the domestic and the professional market.

- Dutch&Dutchmakesactivespeakers:anamplifier,astreamer, and a loudspeaker in one package; The user only has to plug in the power cable before listening to their favorite music.

- The company aims at 'uncolored' sound reproduction. The linear frequency response should be as flat as possible between 20Hz and 20kHz. They describe this as reproducing sound signals as accurately as possible.

- See confidential appendix x1.c

FIGURE 7. BOTTOM VIEW OF THE 8C

3
D&D 8C SPEAKER ANALYSIS

3.1 COMPONENTS & MATERIALS

This chapter will provide an analysis and description of the materials and working principles of the Dutch & Dutch 8C loudspeaker that is currently the only product the company sells.

Speaker drivers

The 8C-speaker houses four speaker drivers:
- One 1" tweeter handling the high-range frequencies from 1,250 up to 20,000Hz,
- One 8" midrange driver produces the low-mid and mid frequency range between 100 and 1,250Hz ,
- Two 8" subwoofers are located at the back of the speaker's cabinet, working together to reproduce the lowest frequencies from 15 to 100 Hz.

The 8C has three integrated sound systems, each responsible for a specific part of the frequency band. Each of the three frequency channels is handled by a separate amplifier.

Structural cabinet body

The structural cabinet is made of solid oak with internal structures made of Birch Multiplex. Dutch & Dutch also sells a specific studio version of the 8C-speaker entirely made out of Multiplex and only available with a black satin gloss cabinet. The 'standard' solid oak version is available with a bleached, darkened, or natural satin finish on the oak. Internally the 8C is divided into three separate compartments. This internal separation is necessary as the closed-box design requires each speaker driver to be in a separate air-tight enclosing. One compartment at the bottom of the cabinet holds a casing with all electronics and connection terminals. A second compartment holds the midrange driver, and the third and largest compartment holds the two subwoofers. The two subwoofers produce the same frequency band and should therefore be in the same enclosure. The tweeter only needs a small volume compartment, and this compartment is integrated into the speaker driver itself. The separation of each volume is necessary as each speaker driver can be seen as a separate system responsible for a different part of the frequency spectrum. Interference between the different speaker drivers leads to unwanted interference effects that will be further discussed in Chapter 3. The two subwoofers are responsible for the same part of the frequency spectrum and are working together; therefore, they can be seen as one system. The main body is stuffed with dampening material to make it 'acoustically dead' from the inside.

Electronics

Inside the 8C, three class-d amplifiers from the manufacturer Pascal can be found. Next to a BeagleBone ARM processor. As explained, each of the three speaker systems has a separate amplifier. A 500-watt amplifier powers the subwoofer system. The midrange and tweeter each have a separate 250-watt amplifier. The Beaglebone holds all custom-designed Dutch & Dutch software, including

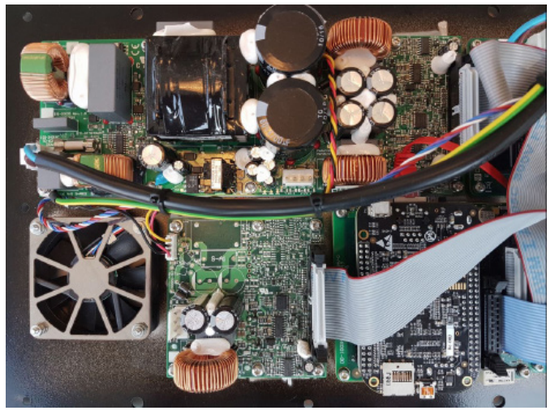


FIGURE 8. ELECTRONICS OF THE 8C

FIGURE 9. MAIN BODIES OF THE 8CTHE 8C

everything needed for DSP: Digital Signal Processing. Dutch & Dutch uses DSP to create equalization filters to make the speaker behave 'uncolored,' with a perfectly linear frequency response.

Side vents

The side vents are perforated metal roasters with cloth attached to the back. The roasters cover up the large holes necessary for a cardioid radiation pattern. The roasters with cloth are acoustically transparent and are placed as a visual closing of the side openings. Removing the roaster would not affect the sound quality, but besides improved aesthetics, they prevent dust or curious hands from getting stuck and potentially harming the speaker driver.

Front baffle

The front baffle is an injection molded part made out of ABS. The baffle is available in white and black colors. There are six threaded inserts on the back of the baffle, making it possible to attach the baffle to the cabinet with bolts that are screwed in from within the cabinet. An essential function of the front baffle is to improve the linearity of the off-axis response. This is because sound frequencies radiate differently depending on their wavelength. Lower frequencies have longer wavelengths that radiate in a spherical pattern, and higher frequencies have shorter wavelengths and radiate in more narrow beams. This change in radiation characteristics is a smooth transition, and each frequency has its unique radiation behavior. The sides of a speaker cabinet can break up sound waves that are radiated off-axis, and the smooth curve on the side of the speakers prevents this. In fact, the front baffle is entirely smooth, with no mounting screws visible from the front. Measurements showed that even the roughness of small screw heads on the front baffle led to sound waves breaking up. Sound break-up introduces distortion, and this 'colors' the sound. Around the tweeter, there is a custom-designed waveguide to decrease off-axis distortion. This waveguide also guides the soundwaves to make the tweeter's radiation pattern match the rest of the speaker drivers.

3.2 ASSEMBLY

The final assembly of the different parts and subassemblies takes place in Capelle aan den Ijssel; this is the last step before the 8C-speakers are sent out to customers.

Sergio van Vliet is the production manager at Dutch & Dutch and is responsible for all incoming orders. It all starts with the pre-assembled housing of the 8C. When the solid oak (or MDF for the studio version) body arrives at Dutch & Dutch, it already holds the openings for the side vents and speaker drivers. The internal compartments described in the previous Paragraph are also already in place. At the assembly line of Dutch& Dutch, the electronics boards are all mounted in place into a metal casing and then connected to the wires that carry the amplifier signal towards the speaker drivers. Next, the stuffing is inserted, and the midrange speaker driver is connected to the wires coming from the amplifiers and mounted. Next, the tweeter is screwed onto the front baffle. The front baffle with tweeter is then mounted onto the front of the cabinet with long screws. Lastly, the two subwoofers are installed and then covered with a plate to cover up the woofer's mounting screws. Now, the 8C-speakers are ready for performance tests.

In performance tests, each assembled speaker will first be tested on air leakage. A 15Hz test tone is reproduced at high sound pressure levels. The test personnel listens if they hear a 'whistling' noise from the speaker, which indicates that the cabinet is not air-tight. Possible leaks are repaired when they are small, but sometimes the solid oak cabinet cannot be made air-right and is rejected. The components will have to be placed in another cabinet.

For the second test, a Frequency Response Diagram is made, showing the linearity of the speaker over its full frequency response. The FRD shows how a sweep from the lowest audible frequencies (15Hz) up to the highest audible tones (20kHz) is reproduced at an output level of exactly 1 Watt and measured at 1-meter distance from the speaker. The 8C's FRD can be seen in Figure 10. After assembly, each 8C-speaker is compared to a Dutch & Dutch reference response diagram. The DSP applies a small filter to compensate for deviations from this reference diagram to ensure that each speaker measures the same. If the measurements are too far off, this indicates manufacturing imperfections of the speaker drivers. Too large errors cannot be solved by applying filters with DSP. Furthermore, production errors can also cause problems later on in the lifetime of the speaker. In this case, the faulty speaker driver is replaced, and the tests are performed again.

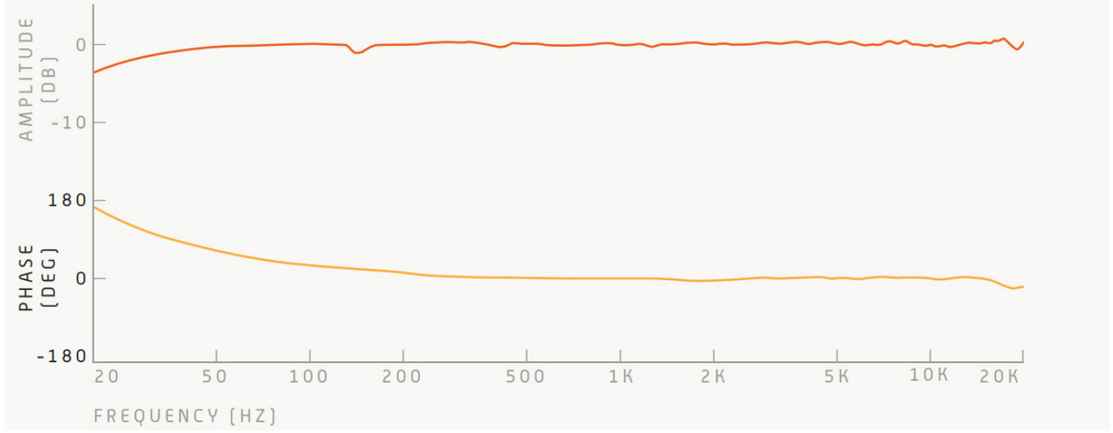


FIGURE 10. FRC OF THE 8C AND ITS PHASE BEHAVIOR

3.3 TECHNICAL ANALYSIS

Dutch 8C has a total of four speaker drivers. One 1" tweeter for the highest frequencies, one 8" midrange speaker, and at the back of the 8C, two 8" aluminum subwoofers can be found that produce the lowest frequencies.

Within the body of the 8C, there are three separate enclosures, as can be seen in Figure 14. The compartment where both woofers are situated occupies the most significant part of the 8C's volume. Producing low frequencies is more efficient with bigger enclosures. The resonant frequency (Fs) of a system increases if the volume of a speaker enclosure becomes smaller. Below the Fs, a speaker starts rolling 12dB/octave, meaning that these low frequencies are produced less loud than those above the Fs. When the Resonant Frequency of a system gets higher because of a smaller enclosure, more low-end notes become unhearable. The second enclosure within the 8C holds the midrange driver, and the third enclosure is at the bottom of the 8C containing all electronics. The tweeter is off-the-shelf mounted within its own enclosure.

Room reflections

The 8C claims to 'make the room disappear' (Dutchdutch.com, 2022) and does this by minimizing unwanted reflections against surfaces like walls and objects. When listening to a recording, people not only hear the sound coming directly from the speakers but are unavoidably also listening to the sound reflections in a room. Sound moves through a room and is reflected from the floor, the ceiling, and the side walls before reaching the listener's ears slightly later than the direct sound. It means that people are not just listening to the reverb of a studio or concert hall embedded in the recording; a listener is also listening to in-room reflections that were not accounted for by the music producers. Reflection surfaces are made of different materials, and different materials reflect different frequencies better than others. Thus when these reflections reach the listener's ear, they are 'colored' and not accurate sound signals anymore. By making the 8C directional, plus engineering the speakers so that the off-axis frequency response is as linear as possible, Dutch & Dutch has minimized the adverse effects caused by reflections in the listening room, making sure the user listens to the recording as it was intended.

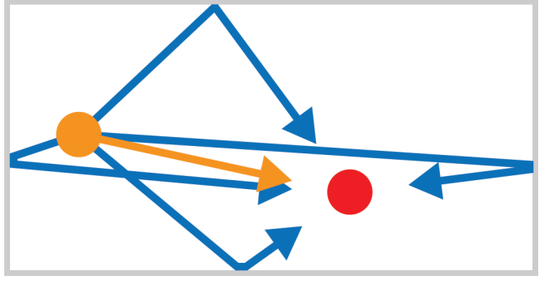


FIGURE 11. A SOURCE (ORANGE), LISTENER (RED), DIRECT (ORANGE) AND INDIRECT SOUND (BLUE) (K.AJ. KNAAPEN, 2014)

Sound physics

It is important to mention that the directivity It is essential to mention that the directivity of the sound from speakers is dependent on the frequency of the sound and the size of the speaker's front baffle. Wavelengths (λ) are dependent on the velocity of sound (v) in a given medium and frequency (f). The formula to calculate wavelength is:

$$\lambda = \frac{v}{f}$$

Thus, low frequencies have longer wavelengths than high frequencies, and these low-frequency wavelengths are long relative to most speakers' front baffles. The result of wavelengths far longer than the width of the front baffle is that low-frequency waves bend around a speaker's cabinet. It results in an omnidirectional or spherical radiation pattern.

Noise canceling is a popular technology in modern consumer audio and is often used in modern headphones. It is essential to mention and explain this technology as its principles are critical for understanding how the 8C-speakers cardioid sound radiation works. In consumer audio, this technology is often used to suppress background noises and enables the listener only to hear the music playing through their device.

The principle of noise cancellation works with so-called anti-noise. Anti-noise is a sound 180° out of phase with its reference sound; in the case of the noise-canceling headphone, this reference sound is the background noise. Theoretically, if a reference sound and anti-noise meet, they completely cancel each other out. Resulting in complete silence. See Figure 13.

Noise-canceling headphones use a microphone to record the background noise in their environment. This recording is then 180° degrees phase-shifted and combined with the music played through the headphones speaker driver. Now, the user is listening to the music + the surrounding noise + the anti-sound of the surrounding noise. These last two cancel each other out; the user only hears the music. The microphone quality, the headphone speaker driver, the software algorithm, and the processing speed determine how well the noise-canceling works in practice. For example, if a processor is slow, this will cause the anti-noise to arrive milliseconds later than its reference sound. This will result in non-optimal noise-canceling as the background noise's frequency, amplitude, and phase will have changed slightly. For example, only monotone low-frequency sounds will be canceled out effectively with a slow processor. People's voices will, in this case, not be canceled out effectively.

Active speakers

Active speakers are not new, but the technology has been waiting for broader acceptance within the (conservative) hi-fi community. Today, an increasing number of high-end audio companies are becoming involved with making active speakers, which has much to do with the increasing quality of class-d amplifiers and Digital Signal Processors.

Many technologies used in modern speakers were invented long ago. For instance, the moving coil dynamic speaker driver was first built by Peter L. Jensen in 1915 (Jensen, 1927). This technology has been optimized but has not radically changed since. Another exciting development was the solid state amplifier in the 60s. This amplifier took over from fragile, inefficient, and expensive vacuum tube amplifiers, paving the way for smaller and more powerful amplification and even all-in-one 'active' speakers with integrated amplifiers. Although solid state amplification has many benefits over vacuum tubes, some audiophile equipment still uses these vacuum tube amplifiers as they find the sound is better to their taste than Solid state amplifiers. It is an example of how conservative the high-end hi-fi market can be, and it can be difficult for new technologies to take over and become accepted by the hi-fi audio public. A more modern innovation with impact is the successor to solid state amplifiers: class-d amplifiers. Currently, these amplifiers have gained popularity and dominate the consumer audio market. Their market share within the high-end hi-fi market is still limited. The digital amplifier is even more compact and efficient than their solid state ancestors, and class-d

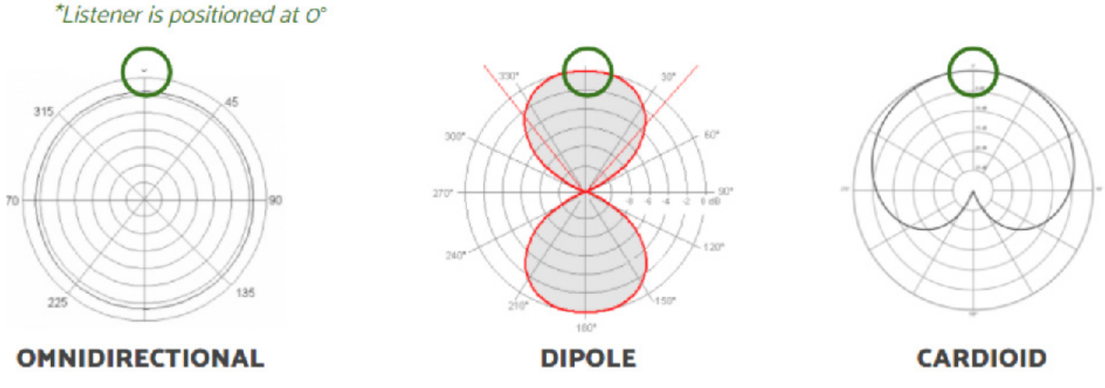


FIGURE 12. HORIZONTAL RADIATON

is ideal for small active speakers, especially portable ones. Examples are the Sonos systems and the Bluetooth speakers from JBL. Class-d amplifiers have long been of lesser quality than solid state ones, and although the quality of class-d has improved, not every high-end hi-fi company is convinced yet. Still, many companies are attracted by the promise of a smaller form factor, higher efficiency, and more power and are willing to invest in this relatively new technology.

Dutch & Dutch can be called an early adopter of implementing class-d in high-end audio and have fully embraced the technology. The class D technology made it possible to make the 8C as powerful and compact as it is. With a solid state technology, this would never have been possible.

Cardioid midrange

A speaker driver can be imagined as a piston moving air back and forth. At the backside of the piston, the air is also moved but in the opposite direction. It means that the sound at the back of the speaker driver has a 180° phase difference from the sound at the speaker driver's front. Sounds are often a combination of multiple sinus waves; one full sinus is 360 degrees, a full wavelength. So 180° phase difference equals half a wavelength. Most common speakers are closed box designs, which absorb the back wave of a speaker driver using dampening materials. In this case, the back wave is absorbed and transformed into cabinet vibrations and heat.

The compartment in which the mid-range speaker driver of the 8C is situated is a semi-open enclosure, meaning that the sound waves produced at the speaker driver's rear side can escape and are not absorbed. The side vents on each side of the 8C-speaker allow the backward energy to escape from the mid-range driver compartment. When considering how noise-canceling works, it becomes clear that these sound waves will eventually meet the waves coming from the front of the driver and cancel them out. This noise-canceling results in a dipole radiation pattern where a speaker produces an equal amount of sound towards the rear- and front sides. At the sides of a dipole speaker, the sound is canceled out. See Figures 12 and 15 for a top view of a dipole radiation pattern. This results in fewer side wall reflections in a listening room, but the reflections at the front wall -the wall that is in front of the listener- will be more than in a speaker having a sealed enclosure.

The 8C uses something slightly different; the radiation of the 8C's mid-frequency speaker driver is cardioid shaped; this results in almost no sound radiation towards the side and the backside of the speaker. The next Paragraph dives into this cardioid radiation pattern.

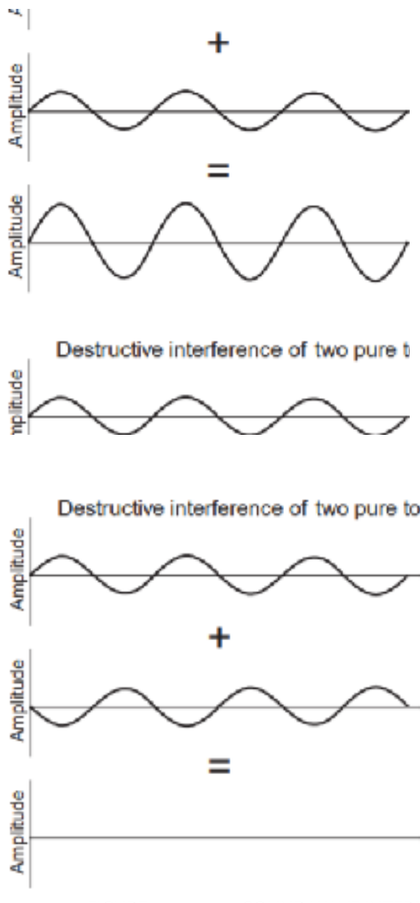


FIGURE 13. SOUND WAVE INTERFERENCE

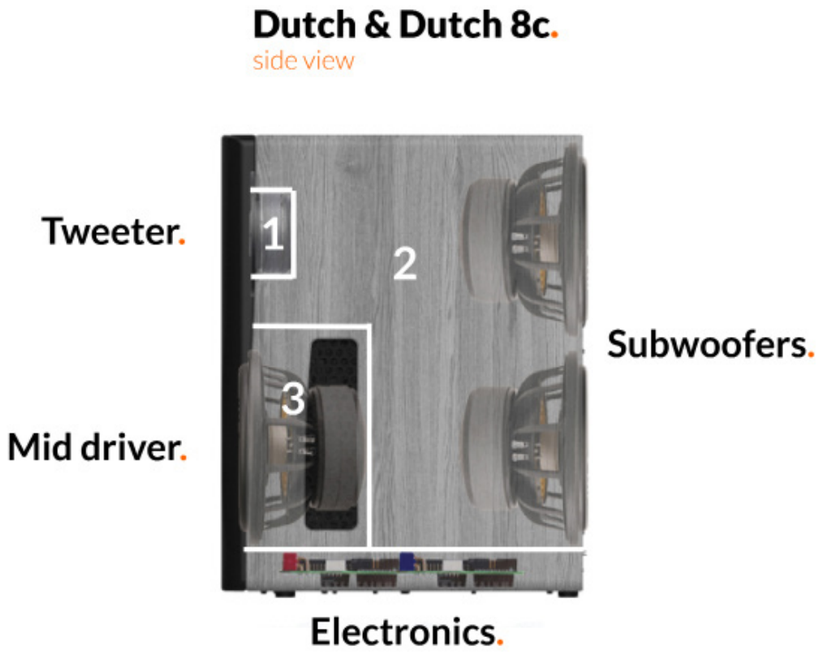


FIGURE 14. THE INTERNAL ENCLOSURES WITHIN THE 8C

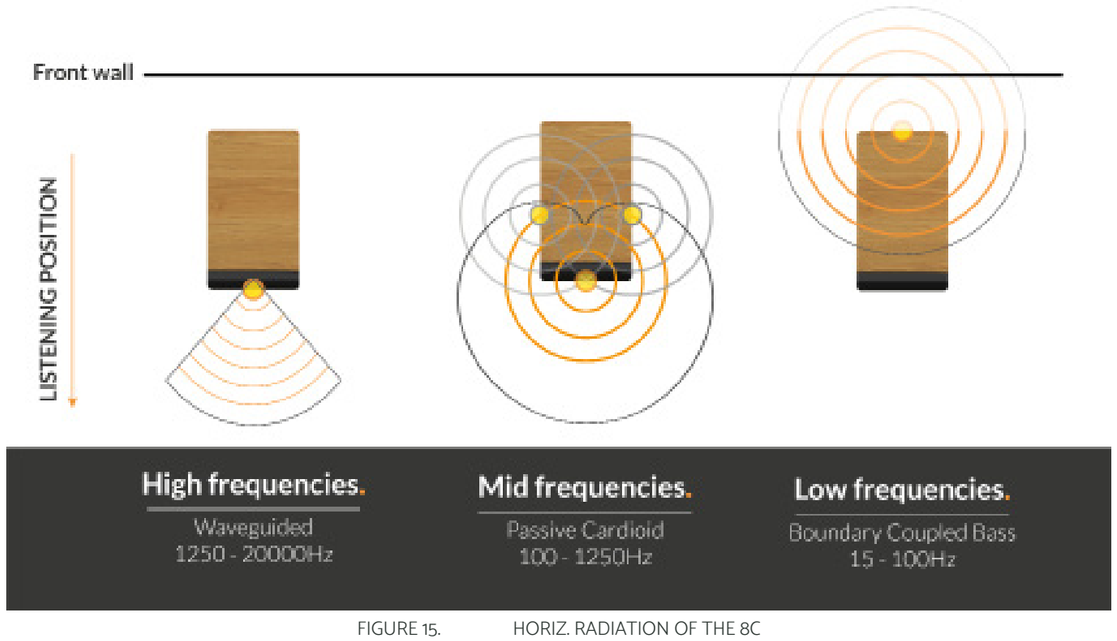


FIGURE 15. HORIZ. RADIATION OF THE 8C

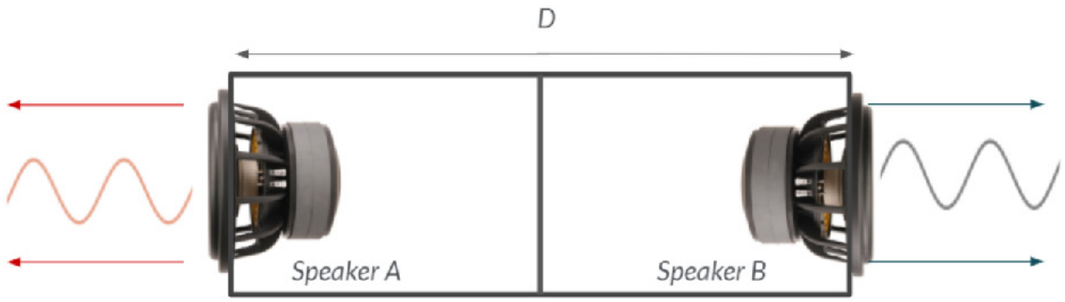


FIGURE 16. ACTIVE CARDIOID SPEAKER

Active Cardioid

The creation of a cardioid radiation pattern is explained using the example shown in Figure 16. Speaker A and B are two similar speakers, each placed in a separate enclosure and positioned back-to-back. For simplifications, it is assumed that all backward energy of both speaker drivers is dampened and absorbed by internal damping material. If speaker A produces a constant tone of 80Hz, this low-frequency tone has a wavelength of 4.2875m and will behave omnidirectional in the room. This means that the tone will also bend around the corners of the cabinet and reach speaker B. The distance D between speaker A and B is 0.5m. In this case, it will take the 80Hz tone T(80Hz)= D/v, where v is the velocity of sound, which is 343m/s in a room at 20 degrees Celcius. T(80Hz)~0.0015s.

To create the cardioid radiation pattern, speaker B also reproduces the same 80Hz tone. However, it is phase inverted relative to speaker A, meaning the signal is 180° shifted in phase compared to speaker A's signal. The signal of speaker B is then delayed by the exact amount of time it takes the signal from speaker A to reach speaker B. As mentioned before, this is 0.0015s. After applying this delay which is done digitally with an all-pass filter in a DSP, a cardioid radiation pattern is achieved for the reproduction of an 80Hz tone as the tone is canceled out at the back of the speaker.

Passive cardioid

In the 8C-speaker, these same principles are applied, but it is not done by using two separate speakers. Instead, the backward energy coming through the side vents has the same function as speaker B in the active setup. This sound coming through the side vents is already a natural phase inverted signal and must only be delayed to create the cardioid radiation pattern. The delay time is, again, precisely the time it takes the signal from signal a to reach signal B, which is, in this case, the time it takes the soundwaves to travel from the front baffle towards the side vents. The delay is then applied by adding acoustic resistance inside the cabinet. The acoustic resistance acts as a replacement for the medium through which the soundwave travels; by adding a dense material, the velocity of sound decreases. As the velocity of sound moving through the inside of the cabinet decreases, it causes the sound coming out of the side vents to be delayed. By engineering the acoustic resistance material, a specific delay can be achieved.

Boundary coupled bass

The bass drivers of the 8C are positioned at the back of the cabinet, and it is recommended to place the 8C-speakers close to the front wall. A distance between 0.2 and 0.5 meters is advised. This way, the distance between the front wall and the speaker's driver is relatively small compared to the wavelength at the reproduced frequencies, causing it to work as one system acoustically. This way, the radiation of low frequencies is half-hemispherical. The 8C is designed to be positioned close to the front wall. This is in contrast with most high end-speakers, as they are often recommended to be placed at least 0.5 meters away from the front wall to minimize the effects of room boundaries on the sound. This is often inconvenient within a domestic living room as these traditional speakers have to stand far into the room, taking up much space.

Waveguided tweeter

The tweeter of the 8C is attached to its custom-designed waveguide, which is a reversed funnel that guides the sound waves coming out of the tweeter. This is done to control the sound's directivity and increase the tweeter's efficiency. The efficiency of loudspeakers is expressed in dB per watts (dB/W). A more efficient loudspeaker needs less amplifier power to reach a certain sound pressure level and thus is more energy efficient.

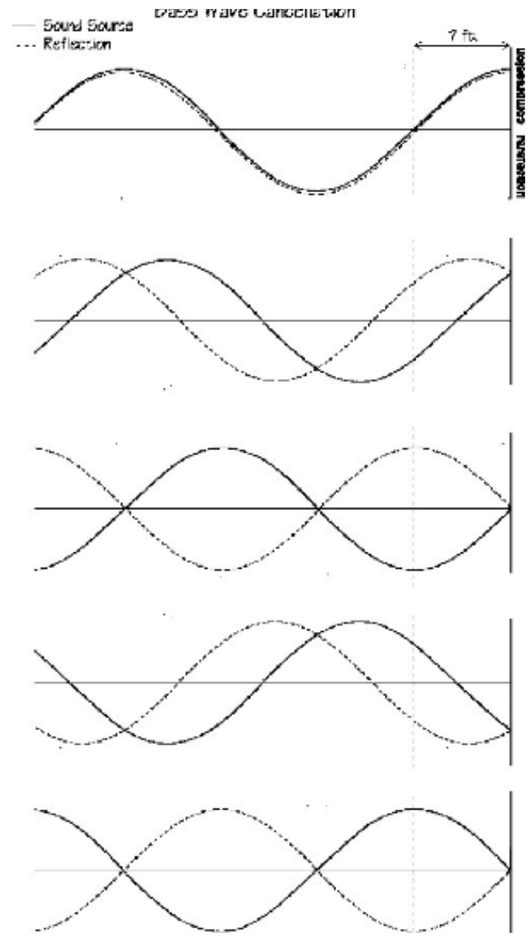


FIGURE 17. BASS WAVE CANCELATION

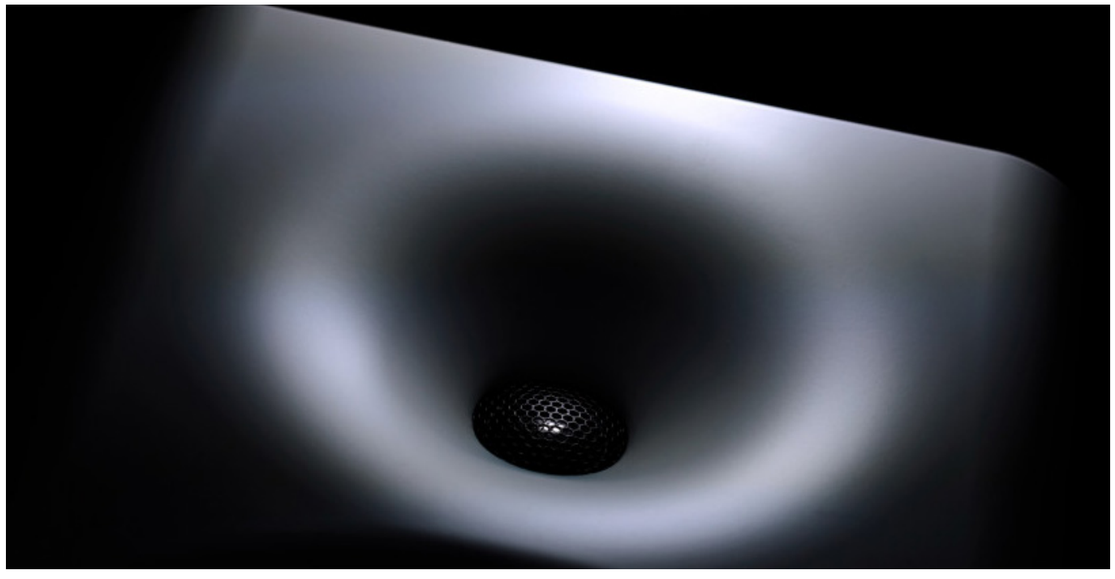


FIGURE 18. TWEETER WAVEGUIDE TWEETER

3.4 KEY FINDINGS

- Dutch & Dutch has experience in producing and assembling small to medium batch of speakers.

- The company has a network for sourcing materials and subassemblies and have partners to cooperate with for producing custom parts.

- Lower frequencis are more omdirectional than higher frequencies as low frequencies have large wavelgnths than bend around a speaker's cabinet more easily.

- Dutch & Dutch uses cardioid technoogy, a waveguided tweeter and boundary coupled bass to create a speaker that is as directional as possible -resulting in the least possible room reflections- within the limitations of size and cost price.

FIGURE 19. EXPLORATIVE PROTOTYPE BUILD BY DUTCH & DUTCH

4
ASSIGNMENT

4.1 COMPANY'S VISION

This paragraph explains Dutch & Dutch's initial ideas on the graduation project, including the work they have already accomplished on the new speaker and their vision of what should be done to make it a commercial success.

See confidential appendix x1.d

Some current users who use their 8C in a domestic environment have come to Dutch & Dutch and said they think the 8C is 'too small' for them. They would love to see a larger speaker capable of delivering a higher sound pressure level, especially in the bass regions. In addition, some studio professionals said they see it as a center monitor rather than the main left and right speaker.

Ideas are worked out in a technical explorative prototype, aiming at an increase of around +12dB for all frequencies below 100Hz. The cardioid radiation pattern should also be accomplished for frequencies below 100Hz. The prototype consists of multiple MDF boxes and uses active cardioid technology -as explained in Chapter 3 to provide the cardioid radiation pattern at frequencies below 200Hz. The prototype has a total of ten speaker drivers. Two electronic boards from the 8C, both including three amplifiers, are used to drive them all.

Material selection, drawings of the aesthetical design, and electronics integration should be completed to create a product that can be manufactured in a small batch.

4.2 TECHNICAL EXPLORATIVE PROTOTYPE

Dutch & Dutch did a technical exploration of possible solutions to the problems discussed in the previous Paragraph. Based on the 8C, they developed a rapid prototype but implemented extra speaker drivers, a new crossover behavior, and new working principles, as shown in Figure 21. The speaker holds a total of six amplifiers. Each is responsible for a different sound signal. Currently, the identical amplifiers in the 8C, manufactured by Pascal, are used for the explorative prototype. However, they are not powerful enough to drive the system to the desired maximum SPL. Therefore, evaluation of the desired power needed from the amplifiers is still needed.

For mid-frequencies, the cardioid implementation is similar to that of the 8C, being a passive solution. However, the mid-frequency crossover point is higher than in the 8C, at 200Hz instead of 100Hz. This way, the mid-range speaker driver has to produce fewer frequencies on its own, making it capable of reaching higher SPL with less distortion.

Frequencies between 100 and 200Hz -the low mids- are reproduced by a separate driver unit. The cardioid radiation of these low-mid frequencies is controlled by an active cardioid system, as explained in Chapter 3. In addition, it uses an extra woofer at the rear side of the speaker enclosure, which is positioned at a distance of 0.4m behind the front woofer.

The lowest frequencies -below 100Hz- are produced by no less than three drivers. As the cardioid of these lowest frequencies is also actively facilitated, another three driver units are mounted at the backside of the prototype at a 0.5m distance from the front three woofers. Accumulating this leads to a total of ten drivers which handle six different sound signals (low, low-mid, mid, high, delayed phase shifted low, delayed phase shifted low-mid). The rapid prototype enclosure is internally (currently also externally) divided into separate spaces for each sound signal; the prototype consists of six different speakers stacked on top of and next to each other.

At the bottom, the three subwoofer drivers at the front are positioned 0.5m apart from the subwoofers

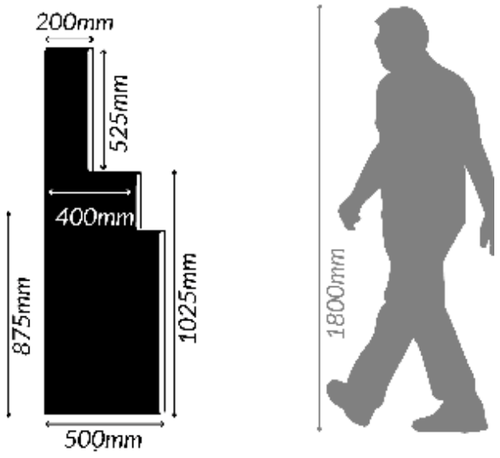


FIGURE 20. DIMENSIONS OF PROTOTYPE

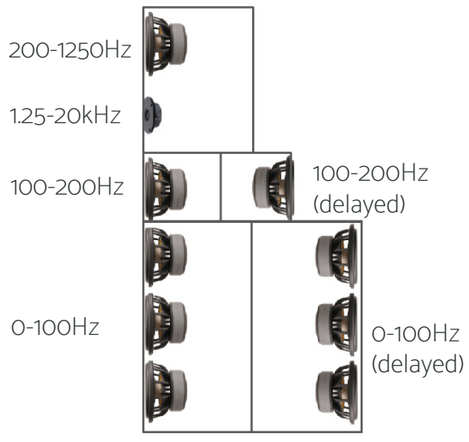


FIGURE 21. PROTOTYPE SPEAKER DRIVERS

at the speaker's backside. This distance greatly influences the interference of sound waves at the speaker's front side, where the listener is positioned. The interference causes specific frequencies to be boosted and others to be canceled out depending on this distance. The most boosted frequency is the one that equals:

$f_{boost} = \frac{1}{4} * \lambda$

Thus for a 0.5m distance, the frequency with a total wavelength of 2.0m is boosted the most, being 171.5Hz. This frequency is boosted with 6dB relative to the SPL of only the front woofer. Below this frequency, the intensity of the interference decreases with a gentle slope of -6dB/octave. Above the maximum boosted frequency, the slope is much steeper, as shown in Figure 22. The dip occurs at the frequency which has half the wavelength of the distance between the front and sound sources:

$f_{minimum} = 1/2 * \lambda$

Figure 23 shows a simplified version of the one shown in Figure 22. Again the interference between the front and rear speaker is shown from the perspective of the listening position. When the distance between the front and rear sound source increases, the curve shifts towards the left, thus towards lower frequencies. A simple calculation will make this clear.

If no filtering is applied and the distance between the front and delayed rear sound source is 400mm, the canceled-out frequency at the listening position is 430Hz. The frequency that is boosted most -with 6dB- is 215Hz.

Changing the distance towards 500mm, as done with the technical prototype's subwoofers, results in a boost happening at 172Hz and a cancellation at 344Hz. Making the distance even larger results in a lower frequency being boosted at the front side.

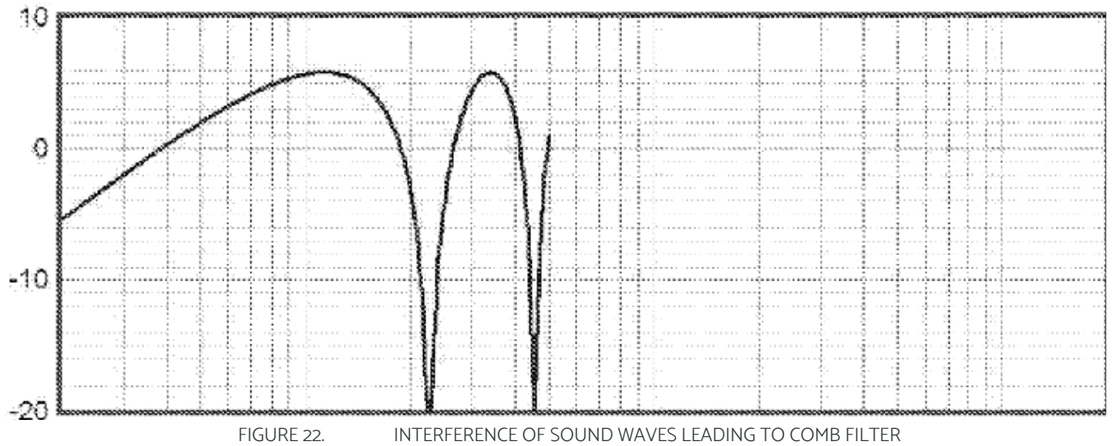


FIGURE 22. INTERFERENCE OF SOUND WAVES LEADING TO COMB FILTER

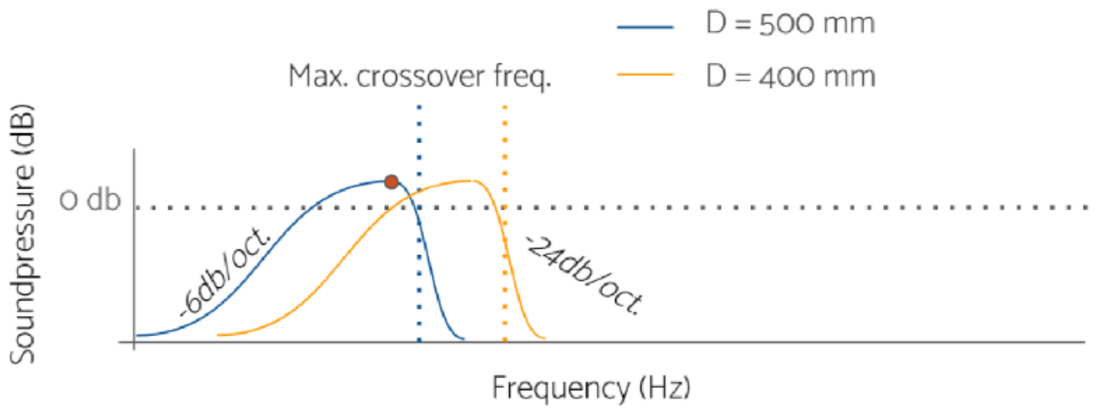


FIGURE 24. RESULT OF DISTANCE ON INTERFERENCE AT LISTENING POSITION TWEETER

4.3 PERSONAL VISION

The explorative prototype, as described in the previous Paragraph, offers a solution to the acoustic requirements Dutch & Dutch set at the start of the development of this concept. They wanted to solve the main acoustical challenge of making a speaker with a cardioid radiation pattern up to the lowest frequencies. Furthermore, the speaker must be a floor-standing speaker, larger and capable of reaching higher SPL than the 8C. However, the provided solution offered by the explorative prototype is not set in stone for the final design, and changes can be made if there is a good reason to do so.

The prototype is large, with a height of over 1.8m, a depth of 0.5m, and a width of 0.3m. Making the speaker look slimmer is necessary to improve overall aesthetics and fit better in living room environments where space is not unlimited. Furthermore, the speaker is currently a combination of multiple cabinets, and it looks like stacked boxes instead of a single product. However, the separate cabinets bring some benefits to the product regarding assembly and transportation. The explorative prototype is large and heavy, making it challenging to handle. The total weight of the prototype with all electronics is estimated to be over 75kg. It is recommended not to lift more than 23kg during work daily (fnv.nl, 2022) to avoid injuries. For example, being able to separate the different bodies of the speaker makes it possible for one person to handle the speaker better and more safely. This makes the design of the assembly of great importance.

All driver units -except the tweeter- are 8-inch in diameter, which is a relatively small size for woofers producing the lowest frequencies. In domestic speakers, 10-inch or even 12-inch speaker drivers are commonly used for subwoofers. In addition, many speakers have differently sized units for the different frequency bands. However, Dutch & Dutch aim to have a uniform size of all woofers to ensure each speaker driver has a matching vertical radiation pattern which is essential for creating the optimal cardioid radiation pattern.

4.4 KEY FINDINGS

- Dutch & Dutch succesfully built an prototype to create a speaker with full-range cardioid pattern. A significantly higher maximum SPL is not yet accommodated because of limited amplifier power.

- The technical prototype is a full-range cardioid six-way design making use of both passive (>200Hz) and active cardioid (<200Hz) technology.

- The distance (D) between the front and delayed rear sound source is carefully chosen, as interference of the two drivers at the listening location causes amplitude boost with D=1/4 λ, and frequency cancellation happens when D=1/2 λ.

FIGURE 25. AUDIOBOOKS TWEETER WAVEGUIDE

5
RESEARCH

5.1 MARKET POSITION

Speakers with a cardioid radiation pattern are not uncommon in the professional audio scene, especially in subwoofers of large PA systems the technology is implemented often. However, in the hi-fi market, it is a relatively new technology, not often seen in speakers. The main benefit of implementing this feature is extensively discussed in Chapter 2.

Dutch & Dutch is operating in an extremely small niche market, if you look at the few hi-fi companies involved in cardioid technology. However it is likely that a small number of customers look at it this way, as their main goal is not to buy a speaker with cardioid technology, but a speaker that sounds best within their budget. Therefore, the actual competitors will all be companies that sell speakers to the same target group within the same price range.

Still, there is another part of the 8C's design that makes its market position more distinctive: it is an active speaker. Active speakers are not a new phenomena, but the technology has been waiting for a wider acceptance within the (conservative) hifi-community. Today, the majority of high-end audio equipment is aimed at a passive setup, thus with all components separated, this became increasingly visible at a visit to the Dutch Audio Event. Not everyone within the audiophile community is 'ready' for modern active speakers and customers of Dutch & Dutch and competitors can be called early adopters of active speaker systems within hi-fi.

Therefore, the target group of Dutch & Dutch has to be open for buying an active speaker setup. This narrows down the competitors to take into account, as only active speaker companies will be included.

5.2 COMPETITOR ANALYSIS

The Dutch & Dutch 8C's are one-of-a-kind speakers, and, because of their acoustical design and price, it has quite a clear market position with some apparent competitors. There are not that many full-range active speakers with a price of around 10,000 euros that use cardioid technology. Cardioid technology is more often used in subwoofers designed for the professional market, targeted at recording studios or concert venues. With the 8C, private customers are also targeted, making the speaker different from most. Multiple reviews of the 8C can be found online, and one competitor that is always mentioned in these reviews is Kii Audio with the Kii Three speaker, as seen in Figure 28. The Kii Three is a different-looking speaker than the 8C, but technically it has similarities. The Kii Three is also an active speaker system using cardioid technology. Its price is slightly higher but comparable to the 8C. The big difference between the two are looks and the fact that Kii Audio uses an active cardioid setup instead of a passive cardioid.

Kii Audio, Musikelectronic Geithan, and Fulcrum acoustics are other speaker brands that use cardioid technology. Fulcrum is wholly focused on the professional audio market, and its speakers are not designed for use in domestic environments. All of their speakers are entirely black and made to be transported and moved all the time. See Figure 26 for the Fulcrum Acoustics CCX12 – 12" Coaxial Cardioid Loudspeaker.

Geithan is also involved in the professional audio market, although they also have some speakers designed for home use. These speakers can be personalized with different wood veneers. Figure 27 shows the ME180, which is one of those domestic speakers. Geithan only has dealers in Germany, which means they reach far fewer customers than Dutch & Dutch.

Kii Audio has the Kii Three speaker, also sold with an optional Bass eXTension module. This BXT module adds three subwoofers to Kii Three and changes its internal DSP settings to optimize this configuration change. The standard Kii Three - see Figure 28- is a cardioid stand mount speaker designed for both professional and domestic environments, just like the Dutch & Dutch 8C. The Kii Three has a more futuristic -less traditional- look than the 8C. Bright colors, contrasted with matte black details, a high gloss finish, and large rounded edges contribute to a completely different design language than the 8C's. The price of the Kii Three is around 16 thousand dollars a pair, which is more costly than the 11 thousand dollars needed to acquire a pair of 8C speakers (Ohm Audio bv - The AUDIOSHOP, 2022).

FIGURE 26. FULCRUM ACOUSTICS CX12 (CX12 – COMPACT 12" COAXIAL LOUDSPEAKER, 2021)

FIGURE 27. GEITHAN ME180 (KEIM, 2021)

FIGURE 28. KII THREE (PURA AUDIO, 2022)

5.3 TARGET GROUP ANALYSIS

To get a better understanding of the audiophile target group of Dutch & Dutch and the context of the high end audio community, two deakers of Dutch & Dutch were interviewed. Han van Slingerland from Multifoon in Rotterdam and Roel Derckx from Pura audio in Vaals. To come closer to the esthetical preferences of audiophiles interested in Dutch & Dutch speakers, a online questionaire was set out on online audio fora, leading to insights regarding esthetical values of different speakers.

Multifoon visit

Multifoon is one of the three official dealers of the Dutch & Dutch 8C. It is located on the same street as Dutch & Dutch's office. When visiting Multifoon it becomes immediately clear that this dealer is all about service and quality. The store is decorated as if you are visiting someone's luxurious and tidy house, they aim to make customers feel at home and to give listening experiences that come close to listening to music at home. Han van Slingerland is an employee at Multifoon and immediately explains that he experiences his job more as if he is a consultant rather than a seller of audio products. At Multifoon, customers are advised on which component to try and listen to in order to fulfil the need they have. The component itself has to do the selling in a listening test. Somedays, multiple components and entire systems are sold and some days, not a single customer comes by. It is a niche-market and prices of hi end audio gear are high, meaning quantity is of little importance for Mutifoon, customer loyalty and high quality customer service are.When people tell Han about their setup and state that they find their setup sounding too warm or their bass too 'boomy', Hand will try to find out which part of an audio system or its listening room could be altered to fulfil the customers wishes.

Among audiophiles, Multifoon is widely known and its customers come from all over the Netherlands. Many customers of the audiostore are traditional audiophiles and have a passive system, consisting of separate dedicated equipment for each function within an audio system. Multifoon has only a very small number of active speakers as they are mainly focused on passive components. The Dutch & Dutch 8C can be called a unique product within the store's catalogue. Han explains that meeting the guys from Dutch & Dutch made Multifoon enthusiastic about supporting them. It is also a nice and interesting story to tell customers that the speakers are built by hand just around the corner.

Han explained that his customers are almost exclusively men and most of them are older than 50. However, the revival of vinyl some years ago also brought some new and younger customers to the store. Men between the age of 30 and 40 are especially interested in turntables and everything else needed to play vinyl. These people are also more often starting from scratch and are coming to Multifoon to buy an entire system instead of a single component.

Active systems are seldomly sold at Multifoon, even the younger customers coming to the store are more inclined to buy passive systems. Above all, the 8C is not cheap and is a large sum of money to spend at once. Many audiophiles upgrade their system over the years resulting in a maybe even more expensive system in total, but having to spend over then thousand euros at once is sometimes a deal breaker for them.

The people who have come to Multifoon and bought an 8C, were often familiar with the speaker beforehand and were visiting Multifoon for the first time. They especially made an appointment at Multifoon so they could listen to the Rotterdam-built speaker before buying. These customers already knew a lot about the 8C and had seen online reviews, specifications of the speaker and sometimes also forum discussions about it, Han told.

FIGURE 29. HAN VAN SLINGEREN IN FRONT OF MULTIFOON WITH A KEF SPEAKER

FIGURE 30. DEMO ROOM AT PURA AUDIODESIGN

Pura Audio

Roel Derckx is the man behind Pura Audio, official dealer of Dutch & Dutch. Pura Audio is not a standard dealer as Roel only sells two different speakers: The Dutch & Dutch 8C and Kii Three. Pura Audio has a beautiful looking demo room near Vijlen in the far south of the Netherlands, see Figure 30. Roel has been selling the 8C's since 2018 and later on added the Kii Three to his catalogue. The customers who come to Roel are mostly familiar with both Dutch & Dutch and Kii Audio and are mainly interested in a good listening test before buying one of the speakers.

According to Roel, the difference between the Kii Three and Dutch & Dutch 8C is difficult to pinpoint. The Kii Three is slightly more compact and there is a little bit less bass present. However, the size of the 8C is never mentioned as a downside, most customers are used to bigger speakers, most having owned large floorstanding-types. Looks are not often mentioned as a fator why customers choose one of the speakers over the other. The sound test between the two is how people make their decisions. Customers describe the looks of the 8C as a nice combination between a traditional wooden enclosure with the matte front baffle as a nice modern touch. The looks of the Kii are described as a bit more modern or even futuristic compared to the 8C. Pura audio sells almost exclusively to people who are going to use the speakers in their living room, seldomly (around 10% of total sales) the speakers are sold to professional sound studios.

A benefit of the Kii Three -most often mentioned by customers above the age of about 60- is that the Kii Three comes with a remote controller: the Kii control. Dutch & Dutch can only be controlled via a mobile phone or pc and some customers prefer the idea of a physical remote to change volume or playback source. Still, more customers buy the 8C than a Kii Three. Roel thinks this is because of two reasons. First of all, the 8C is newer on the market and Pura Audio was one of the first dealers in the Netherlands. At that time, nobody in the Netherlands had an 8C speaker. The Kii three was already on the market for longer when Roel started selling them, Pura Audio was one of the latest Kii dealers in the Netherlands. Therefore, Roel thinks most people who wanted a Kii, already had one by the time Roel started selling them. Furthermore, as Pura Audio sells Dutch & dutch speakers already for a longer period of time and the fact that Roel knows Martijn personally, he thinks that the blogs on his side are maybe slightly biassed in favour of Dutch & Dutch and this could influence his customers.

The 8C is sold in different colour options. The three most popular colour options are the natural wood version with white or black front baffle or the complete black version. The bleached one and black cabinets with white front are seldomly sold. The studio version is sold without a streamer and only available in polished black mdf, it is less expensive and it is sometimes sold to non-studio users who already have their own streamer.

Conclusion of questionaire

In order to get insights into preferences regarding looks of audiophiles and their perception towards Duch & Dutch in relation to competitors, a questionnaire was made and distributed via hi-fi fora audiosciencereview.com (international audio forum) and hififorum.nl (Dutch audio forum). The questionnaire started with questions regarding the background of the respondents and their speaker setup(s) at home. An overview is given, full results can be foud in Appendix 1.

General looks :	5.1 (highest)
Quality:	5.6 (highest)
Traditional:	4.4 (second most traditional)
Cold clinical:	4.7 (warmest of all)
Ordinary:	4.5 (most ordinary of all)
Studio environment:	4.8 (close to average)

The looks of the Dutch & Dutch 8C are perceived well by the respondents as it is regarded as the most beautiful speakers of the selection.This is interesting as it differs from what I am used when talking with fellow-students friends and relatives who are not audiophile When I ask them about the looks and design of the speaker, they respond that they think the speaker is ugly and looks like a studio speaker: functional and a bit boring. These results indicate what was already clear from looking at forum discussions about the 8C: There is a specific group of people who are really into the 8C and are also keen on how it looks. I think this shows there is a very specific target group and it is important that their preferences are met when making a design.

The speaker's design is considered as relatively traditional and warm looking and therefore it also sounds logical that people rate it as quite an ordinary looking design. The Wilson is also regarded as a traditional and ordinary looking speaker. However, instead of warm and embracing, the Wilson Sascha DAW is regarded as the most clinical and cold looking one of all. Comparing the aesthetic properties of the two speakers, it can be seen that the WIlson has a satin blue finish on its main body side with a matte black front. The shape is very geometric with sharp looking edges.The surfaces of the Sasha DAW are large and uncomplex. The 8C has a matte white front which has less sharp edges, more smooth transitions and looks more complex than the Wilson. It is a kind of mask on the speaker where the front of the Wilson is part of the main body. The main body of the 8C is made out of oak with a natural matte finish and has a metal side vent that also draws the attention when looking at its side.

Whether it was better suited for use at home or in a professional studio gave mixed results, this is completely within line of Dutch & Dutch marketing approach. On the website, the 8C is advertised and visualised in both environments. Dutch & Dutch's extreme goal of having a perfect linear speaker is interesting for studio environments as it is necessary for making a 'neutral' sounding audio mix.

Aesthetic goals for the new to-be-designed speaker is to make it more modern looking, this will be verified by putting out a second questionnaire after the aesthetical design is finished. In this second questionaire, people rate the new speaker on the same aspects as was the case in the first Google forms, results wll be compared to see if the intended outcomes are reached. Furthermore, it is desirable to make the speaker a bit more unique and distinctive as it will be an expensive product that will also act as marketing tool for the company. The price and working principle of the speaker result in the fact that this is not a speaker for everyone. The looks can also be more distinctive as the target group of this speaker must be wanting something special that communicates the same class and style as its performance. This goal will also be verified by the second questionnaire that will be sent out after aesthetical design is finished.

To get more insights into modern looking products, a study was done on how other products have been redesigned to stay up to date. Goal of this study was to see how small changes can make a product more modern looking while still keeping the original look and feel of a product alive.

5.4 NEW GENERATION PRUDUCT DESIGN

To create a better understanding of desired looks of the new speaker, products that recently had an update are analyzed to see what esthtic elements are changed in order to update a design to make it more modern without losing the initial design language. The 6C is taken as first study. Furhtermore, the JBL charge, B&W PX7 headphones and the Logitech Master computer mouse are analyzed.

Conclusion on how to design for next gen

When looking at the studied products, there are some overlapping themes dictating the looks of new generation products. A trend seen in all examples is that shapes are simplified. Meaning, that the focus lays more on the coherent whole than on the individual parts. Transitions between different materials and parts are becoming more smooth and details are kept simple, the B&W headphones are a great example of these properties. Shapes used are mainly symmetrical and formed out of basic shapes like circles and squares. The transition of the front baffle of the Dutch & dutch 8C speakers compared to the 6C is a good example of this simplification of shapes and parts just like the overall form of the new Logitech pc mouse. Lines are kept straight and more '2d'. Overall, details are kept thin and contribute to giving the new generation designs a slim look. Examples are the sides of the JBL speakers and the baffle and space holders in the Dutch & dutch speakers. Lines are looking to become a bit softer in the product designs of the examples. For the form study of the new Dutch & Dutch speakers, these findings are kept in mind and will be translated to new form concepts.

It is important to keep in mind that these trends are specific for this product category of consumer electronics. When looking at cars, the opposite is true regarding the smoother/softer lines. In the automotive design industry, new generation cars are mostly having sharper lines, especially seen in the transition of head- and rear lights that have become straight lines of LED lights in modern car designs.

FIGURE 31. TWO GENERATIONS OF THE JBL CHARGE

FIGURE 32. DUTCH & DUTCH 8C AND 6C

FIGURE 33. TWO GENERATIONS OF B&W HEADPHONES

5.5 KEY FINDINGS

- Dutch & Dutch customers are modern audiophiles, they value ease of use and are attracted by the all-in-one solutionoffered by the 8C-speaker. They do not however accept compromises on sound quality.

- The target group values measurements and technical aspects of loudspeakers highly.

- The 8C is an all-in-one active speaker that seems expensive for many buyers as they compare it to passive speakers. Spending the same amount of money on an entire system consisting of separate components is done more often as the money spend can be spread out over a period of time.

- The looks of the 8C-speaker are appreciated by many serious audio listeners The speakers design language is a balance between modern and traditioal, it is regarded as warm and embracing sproduct and the overall quality is perceived as high.

- Adding simplicity in shapes together with smoother lines and surface transitions, are seen when it comes to redesigning a product to createits succesor. Details become more small and subtle.

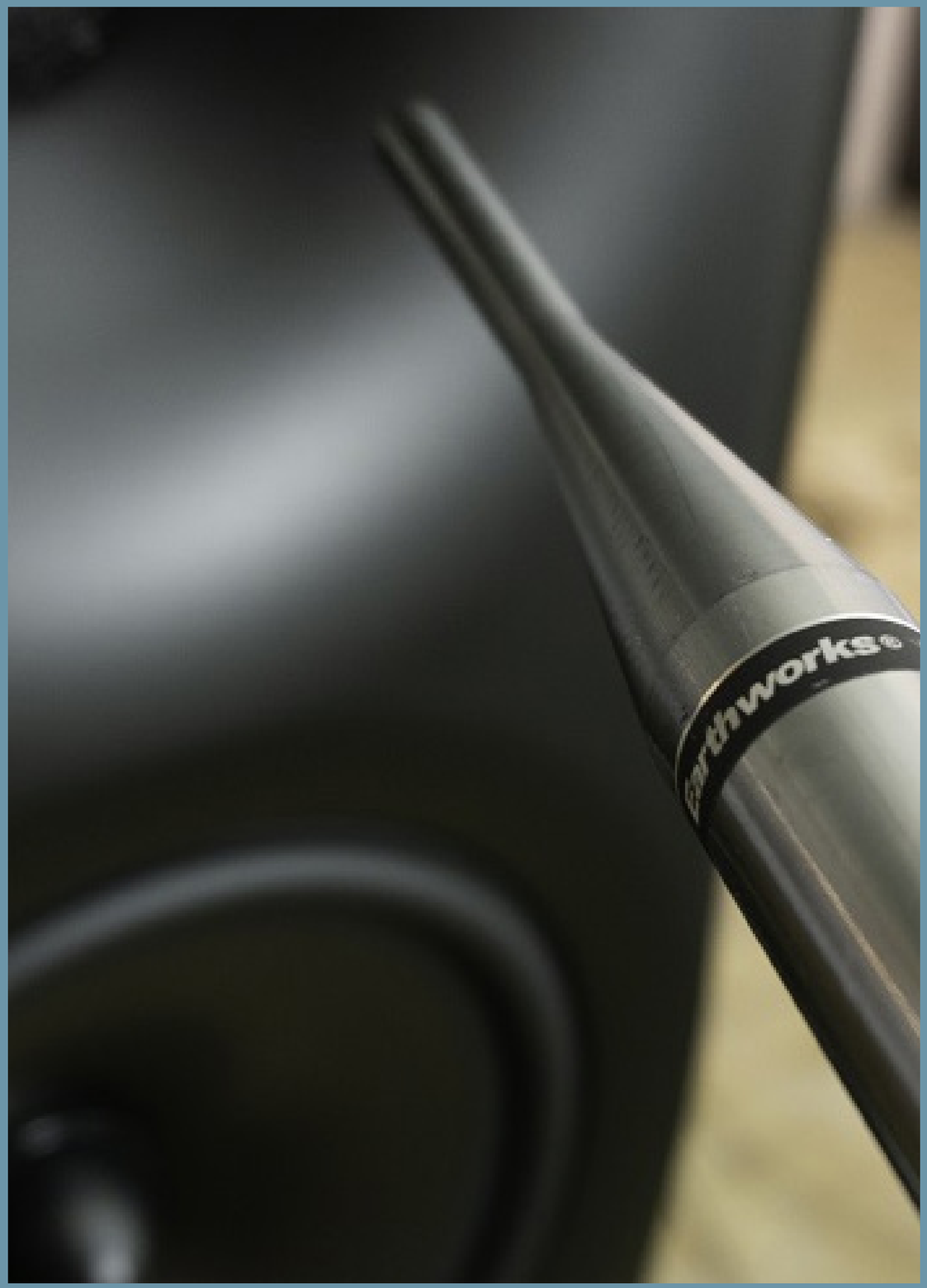


FIGURE 34. ACOUSTIC PERFORMANCE TEST OF THE 8C SPEAKER

6
PROBLEM DEFINITION

6.1 PROGRAM OF REQUIREMENTS

The full program of requirements can be found in Appendix F and is defined by looking at the entire lifecycle of the speaker. Each phase of the product's life is accessed:

- Material sourcing
- Manufacturing
- Assembly
- Distribution &transportation
- Maintenance
- Use
- Reuse
- Disposal

Looking at the requirements per phase of the product's life provides a structured way to make the Program of Requirements more complete and specific. However, making the program of requirements as complete as possible is not the end goal; more importantly, it must provide the proper framework for the design to be evaluated to ensure the right product for the right target group is designed. The final design will be reviewed in Chapter 8 to see if all the design goals are reached.

6.2 DESIGN LANGUAGE

The design language is where all previous research about the company, the users, and technology comes together. It provides the direction for the form study and acts as the guideline for the final design looks.

The impact of a new product on the overall perception of a brand's design language can be significant in the case of Dutch & Dutch. With currently only one product on the market, the new product will automatically contribute to 50% of the design language. The goal is not to make a radical change in design language but to stay close to the current looks that represent Duch & Dutch but make it more modern and give it a slightly more distinctive touch to match the new and more expensive market position.

The mood board on the next page gives inspiration for the form study and communicates shapes, materials, and finishes that fit the desired outcome of the form study and the speaker's looks. The mood board represents a balance between a 'trustworthy familiar' and a modern innovative look. In the concept creation phase, these esthetical values need to be considered.

Materials used in the 8C-speaker form a starting point to stay within the design language of Dutch & Dutch. The matt black and white finish of the front baffle and the classical wooden body form a recognizable Dutch & Dutch style; therefore, the new design should also have a combination of these material looks.

FIGURE 35. DESIGN LANGUAGE COLLAGE

6.3 KEY FINDINGS

- To keep the looks recognizable it the material combinaton of oak wood with matte black and white baffle must be respected.

- Overall shape of the design must give the large body of the new product a coherent look, smooth surface transition, thin details and subtle roundings can accommodate this.

- A right balance between satisfying the currently well-regarded looks of Dutch & Dutch and adding extra character/distinctiveness must be found to position the new product perfectly in the higher quality market segment compared to the 8C.

FIGURE 36. ABSTRACT CONCEPT SHAPES

7
CONCEPT CREATION

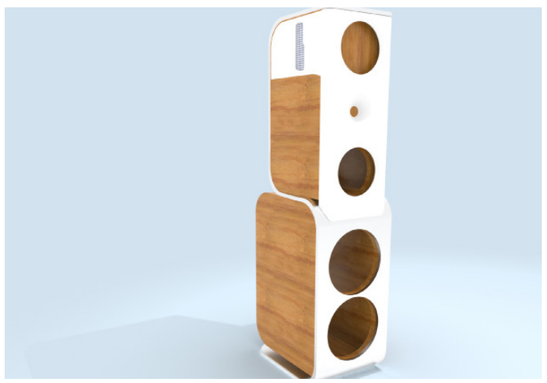
7.1 SHAPE ANALYSIS

A shape analysis was done to create a form design in line with the design language described in Chapter 5. Then, drawings were made, developed into SolidWorks shape models, and rendered using KeyShot. The drawings were all explorative and were only used to get the creativity going.

The shape heavily depends on the dimensions and dimension-relations of each speaker driver compartment and dimensions, as elaborately described in Chapter 2. As shown in Figure 20, the shape is the starting point for this form study as it includes all functional necessities for the speaker to fulfill its full-range cardioid radiation pattern. Volumes can only be added to the basic shape, and this is done to create a fitting design that is in line with the design language. During the process, the progressions were discussed with Howan Lau, designer and CEO of Hamwells b.v, and Eric van Duin, director of Dutch & Dutch and also a designer.

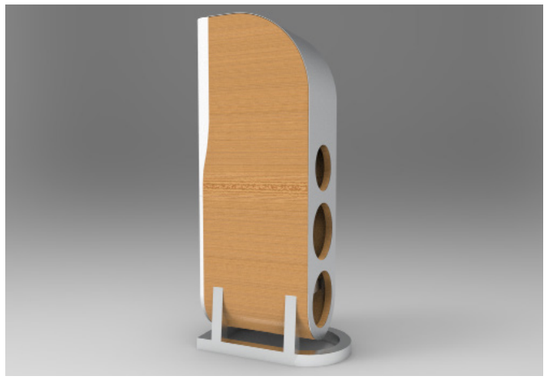
Form idea I
This form idea the basic rectangular shape where the speaker's character has to come from detailing; this time, the side vents are detailed to accommodate both the midrange and the low-midrange cardioid sounds to escape the body. The speaker is also placed on a platform stand which slightly elevates the whole body from the ground.

Form idea II
This shape is also rectangular but has some details of the design of the 6C speaker. The top and bottom are visually separated, which is interesting but makes it look like two separate speakers instead of one.



Form idea III
A separate top and bottom enclosure like idea II but connected via a curved 'skeleton 'that bends around the two bodies. The baffle only covers the design's top part and bends toward the speaker's side. It is very different from the current forms of Dutch & Dutch designs. Detail: the bottom section explroes the option of two woofers of 10" diameter instead of three 8" woofers. However, this option was reconsidered as oly three 8" were considered feasible.

Form idea IV
This idea follows the shape of the speaker enclosures more precisely. The top and bottom enclosures are again separated. The materials are also different. It looks more coherent than form idea II because of its shape, but it is still two enclosures put together instead of one uniform speaker. The side vents are enlarged as a visual detail. In this form idea, a stand is also added. It is not perse that other designs will not have one, but here it is an integrated part of the form design.



Form idea V
This form is more distinct than the previous ones and has a vast curve at its backside. The detailing of the mid-woofer compartment is incorrect as there is no vent shown at the speaker's side. The stand is also a statement making it rise from the ground. The looks are unique and high-end but are maybe a bit over the top for the Dutch & Dutch target group.

Detail of form idea V
Here a detailing of form idea V with dust cover can be seen. It was a tryout and gave the speaker a different look. It can be seen as an option, but it will make the speaker very different from the current design language of Dutch & Dutch. However, because of its oversized appearance, implementing a dust cover can be a way to integrate the speaker better into people their homes.

Form idea VI
This form idea has an enormous front baffle and a rough shape at its rear side. The harshness of the rear does not perfectly integrate with the smoother looks of the bottom curve and the front baffle. It is also placed on feet to give it a specific character. Like form idea III, it has the two 10" woofers instead of the three 8" ones.

Form idea VII
This idea is an iteration of the previous form. The back is shaped more smoothly, and a vent is added for the sound from the rear-mounted low-mid driver to escape. It is again placed on a stand.

FIGURE 37. OVERVIEW OF CONCEPT 1

7.2 FIRST CONCEPTS

CONCEPT 1
This concept is a combination of multiple form ideas. The idea of the large wooden side panels that curve over the rear and front of the body is inspired by form idea IV. However, this feature has been exaggerated by almost removing the front baffle. The front and rear look very alike, and the detailing of the side vents is minimal. The shape is rectangular with a small step at the rear side to accommodate the low-mid at the back to freely radiate the sound. Spacers separate the wooden side panels from the rest of the body. These spacers form a contrast, as is seen in the design of the 6C speaker. The wooden panel is curved so that it is slimmer at the speaker's rear side, and large roundings are applied at the top of the panels.

FIGURE 38. OVERVIEW OF CONCEPT 2

CONCEPT 2
This shape is more rectangular and accommodates an extra large air vent at the rear side that also bends around the backside of the speaker. The design does not only have a front baffle, but it also has a relatively large rear one. The detailing of the rear side vent is very distinctive and catches the attention. The top of the cabinet is curved, making the back slightly lower than the front side. The front baffle has a minimum of details and is rendered in a white and black matte finish. The shape is a simplified version of form idea V combined with the body of form idea I.

FIGURE 39. OVERVIEW OF CONCEPT 3

CONCEPT 3

The concept is inspired by form ideas VI and VII but is more simplified. As the large curve is removed, the looks are closer to the current Dutch & Dutch designs. The front baffle is very large and bends around the speaker's side. The back has minimal details, with the rear vent accentuating the smooth shape at the back. The speaker's top is curved at the backside, making the top and rear surface one. In practice, it would stand flat on the ground, but like the other concepts, it could be elevated slightly with a platform stand. The front baffle is of large dimensions and must be cast in composite or milled.

7.3 DECIDING FINAL DIRECTION

Each concept was assessed in three ways to come to the final decision. First, the concepts were shown to Martijn Mensink, founder of Dutch & Dutch, and Howan Lau, CEO of Hamwells, who has also worked with Dutch & Dutch. A Harris profile was made in the second stage to access each concept on different requirements. Lastly, a personal assessment of the two previous stages was made to draw a conclusion and make the final decision.

Talking with Howan and Martijn revealed that concept 1 was not what they would have in mind for a Dutch & Dutch product. It does not look typical Dutch & Dutch, and they were also convinced that this concept would be the most difficult to add to the company's portfolio as it is too different from the 8C and the new 6C design. Especially, the front baffle is not in line with the desired looks. The second concept was to the liking of Martijn; the curved top and the unique rear roaster did spark his interest. Howan also liked this concept better than the first one but thought the rear roaster was too dominant in the overall aesthetics. He preferred concept 3, a speaker he could imagine owning. Martijn also liked concept 3 but said he liked concept 2 or 3 equally.

Next, a Harris profile was made to access the concepts on different requirements; elaboration on the ratings can be found in Appendix C; the Harris profile is seen in Figure 40. This method provides a comparison, and the concept that looks like it is tilted to the right the most is scoring best. Concepts 2 and 3 scored almost similar, with concept 3 having a slight advantage on the high-end looks and a small disadvantage for its assembly score.

To finally choose a concept, personal preference also plays a role. Concept 1 is less in line with what Dutch & Dutch is currently doing and, therefore, not the best concept of the three. Concepts 2 and 3 scored similarly but communicated different design directions for the company. Concept 3 is more unique when compared to concept 2 and slightly different from what Dutch & Dutch is currently doing than concept 2. Whereas concept 2 is a safer choice, closer to what Dutch & Dutch is now doing. Details could make concept 2 a luxurious new Dutch & Dutch product that is very much in line with the 8C and 6C. However, the intended design direction was to make something more unique than the 8C and the 6C; concept 3 looks like the most logical choice. It is the best balance between typical Dutch & Dutch while enriching the design portfolio with new influences, forms, and shapes. Therefore, concept 3 was chosen to continue with.

FIGURE 40. HARRIS PROFIL

7.4 KEY FINDINGS

- Multiple aesthetic concepts were created, and further detailing led to three definitive aesthetical concept directions. Eventually, concept 3 was chosen to continue with for the embodiment design.

- Emphasizing the separate enclosures creates a pro audio look and is not suited for the design of the new product.

- A Harris profile, an evaluation with Dutch & Dutch employees, and personal evaluation led to a final concept direction.

- Concept 3 is chosen to continue with, as it offers the best balance between being typical Dutch & Dutch loudspeaker while also enriching the design portfolio with new influences, forms, and shapes.

FIGURE 41. EMBODIMENT PROTOTYPE WITH THREADED INSERT FOR BOLT CONNECTION OF DRIVER

8
EMBODIMENT

8.1 ITERATION ON AESTHETICS

The aesthetics of a design is more than renders and SolidWorks drawings. It is also essential to have physical models, mockups, and prototypes to see how details work out in reality and to better understand the actual scale of details. First, a carton mockup was built that represented the latest version of the design. This mockup was reviewed, and iterations were proposed, leading to a new design version. After several iterations, a prototype was built, resembling the design materialization more closely. The carton mockup was only made to iterate on esthetical details quickly, and the actual prototype was made with materials as close to the end product as was possible within time and budget.

Carton prototype

The first carton mockup -shown in Figure 42, gave a better understanding of all design dimensions. Up to this point, these dimensions were only explored in the digital CAD programs and renders. Seeing the shape in full scale also revealed aesthetical aspects that were not in line with the design language and were boring-looking. For instance, the side panels of the front baffle are too bulky. They look undefined, and the side vent is too small and subtle compared to the bulkiness of the front baffle surface that bends over to the speaker's side. The white sides form a large surface that contrasts with the more subtle and elegant-looking curved rear of the speaker. Furthermore, the vents at the side are large and stretch up to where it meets the front baffle. It may be more interesting to make the vents shorter and match their shape better to the top vent located behind the mid-driver.

The front baffle was also prototyped in more detail by FDM 3d printing it. First, the digital model of the front baffle was sliced into nine parts that were each printed. Next, the separate parts were glued together, and putty was used to smoothen the parting lines. The result was a detailed front baffle that could be evaluated on aesthetics elaborately. The first 3d printed version of the front baffle is shown in Figure 43.

The element of thickness that was not present in the thin carton prototype enhanced the bulkiness of the front panel. Also, the rear side was very pointy, which made it look unfinished and cheap. The 3d printed

FIGURE 42. FIRST CARTON MOCKUP

prototype also showed that the fillets around the speaker driver were too round, making it look toy-like and not in line with the desired design language. Therefore these fillets were adjusted to chamfers with minimal roundings, making the front baffle look more modern and in line with the product examples shown in Chapter 6.

Expert discussion

Mark Sypesteyn was contacted to make the final aesthetical iteration before building the embodiment prototype. Mark is a design drawing teacher at the IDE faculty, and his knowledge and view on aesthetics of design were used to bring the design to the next level. During the discussion, Mark gave guidelines on what aspects to focus on for making an aesthetical iteration.

Renders and carton prototypes were shown to Mark, and the first guideline was to look into different design principles to iterate in a more structured way. The nine design principles are:

- Balance
- Movement
- Repetition and Rhythm
- Emphasis
- Simplicity
- Contrast
- Proportion
- Space
- Unity

During the discussion, some principles were discussed more elaborately. First, Mark talked about the proportion of the design. The two roasters were spaced the same distance from the separation line formed by the surface transition of the wooden panel and the front baffle, see Figure 46. However, the rear roaster is much more slim-looking and smaller than the top. Therefore, they have different proportions and are visually not equally dominant; Right proportion does not mean that everything must be the same. An excellent example of how different proportions can still be in balance is the artwork of Piet Mondriaan, as shown in Figure 47. Implementing this means it makes no sense to make this distance equal as the top roaster is way more visually present than the rear roaster behind the low-mid driver. The large roaster with a small distance to surface transition and small roaster with a longer distance to the transition results in better relationships between the different proportions.

FIGURE 43. FIRST VERION OF 3D PRINTED FRONT BAFFLE

FIGURE 44. SECOND CARTON MOCKUP

FIGURE 45. ITERATION ON LINING OF SIDE PANEL

According to Mark, the oak side panels were a bit too large and dominant and not in visual balance with the rest of the design. Breaking up the large surface area with the speaker stand could be a solution to enclose the oak wood in the white of the cultured marble material and create a more exciting and interesting side view of the design.

The third principle discussed was movement, which is more important for some products than others, but when movement is strongly present in a product that does not intend to communicate it, it looks off. Mark said that the top line of the speaker communicates much movement and reminds him of an automotive hood design. Therefore, he recommends adding a rounded edge at the rear of the top line. This slightly curved rear top line makes the speaker look more consumer product-like and communicates less fast movement in the design.

The speaker consists of multiple sub-assemblies, which are part of the integrated product. In the next section, each sub-assembly is discussed individually. The structural wooden body, the front & rear baffle, the electronics, speaker drivers, and stand mount are further discussed and worked out in more detail in the next paragraph.

Findings:
- Iterations are necessary to make the top part/sides of the front baffle more elegant and less bulky.

- Make the front baffle more modern and elegant, looking more like a modern car, less like a toy.

- Side vents in the front baffle are too small and do not communicate similarly to the larger rear/side vent in the oak wood.

- Make the front baffle smaller at the sides. Add rounding at the rear top side of the baffle.

A second carton mockup was made to verify iterations once more before the final prototype was built. As seen in Figure 44 this carton prototype included the iterations stated previously and was also used to try different shapes for the side vents located at the oak side panels and on the side of the front baffle. The main conclusion was to enlarge the vent behind the mid-driver and make the vent of the read low-mid woofer slightly smaller. Furthermore, the radius of the curve at the speaker's side was enlarged, resulting in a larger oak panel and a smaller front baffle. The top of the design was also changed, adding a subtle bend intended to make the entire shape of the speaker's aesthetics more interesting. See Figure 45 for the difference in the aesthetical lines seen from the speaker's side. The top curve is similar to the top of the second concept described in Chapter 7. This prototype was more in line with the intended design language, and a design freeze of the overall aesthetics was done at this point. The current shape will be used for the final design, and an embodiment prototype would provide evaluation and iteration of the design's details.

FIGURE 46. PROPORTION OF SIDE VENTS

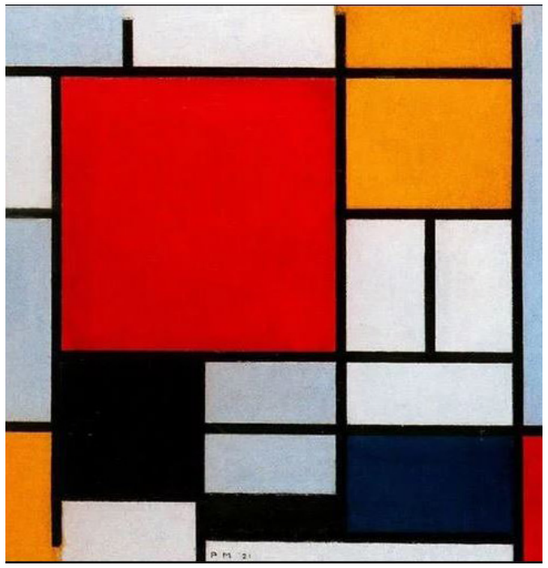


FIGURE 47. COMPOSITION WITH LARGE RED PLANE, YELLOW, BLACK, GRAY AND BLUE (1921), PIET MONDRIAAN

8.2 EMBODIMENT PROTOTYPE







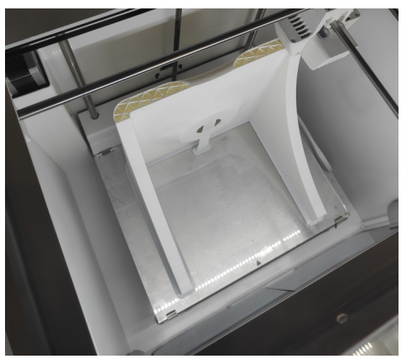


FIGURE 48. OVERVIEW OF MAKING THE EMBODIMENT PROTOTYPE 1/2





FIGURE 49. OVERVIEW OF MAKING THE EMBODIMENT PROTOTYPE 2/2

As mentioned, a final embodiment prototype was made to evaluate aesthetics and the assembly method. The making of this prototype can be seen on the previous page. Details that were changed during prototyping are described per sub-assembly.

Structural cabinet

The body was made of solid oak wood panels; the other parts were a mix of MDF and multiplex. MDF was chosen as the primary material, but later on, some scrap multiplex panels that were found in the PMB workshop of the IDE faculty were used. The panels were glued with PVC wood glue, and for the oak side panels, construction glue was used that expands as it dries. This was done in an attempt to get a better airtight seal. The construction of the body can be seen in Figure 52. The concept for the structural body was shown to Dutch & Dutch cabinet manufacturing partner Multidesk and optimized for manufacturing with their expertise.

Oak panels used by Multidesk have a standard height of 1.2 meters and are more than one meter wide. Unfortunately, longer oak panels are more challenging to obtain, making them significantly more expensive. The oak panel used in the design is 1,1m high and 0.5 meter wide, which means it is possible to cut it out of a standard oak panel used by Multidesk. Milling the oak is no problem; this can be done up to a minimum thickness of about 2 to 3 mm (thus removing up to 17mm thickness of the 20mm oak panel). Milling specifications are interesting as the side vents behind the rear low-mid speaker driver are positioned inside a cavity that needs to be milled out of the oak; see Figure 50.

Treating the oak to ensure its humidity level stays constant is essential as oak wood is a very open type of wood that quickly absorbs water in a humid environment and dries out quickly in dry environments. Therefore, applying stain to the inside and outside of the oak side panel is crucial. Otherwise, the material can deform or, in the worst case, even crack. According to Multidesk, the oak panels ideally have a humidity level of just below 10%.

Many oak panels are sourced in Ukraine and Russia. Because of the current conflict that is going on in Ukraine, these panels have become very difficult and expensive to obtain for Multidesk, as production has stalled and alternative sources can not cope with the demand. It also affects all other wood types, as companies look for alternative wood types to keep costs down. It is uncertain how this will develop in the upcoming months.

Multidesk uses dowels for larger furniture and cabinets. The 8C-speaker is not constructed using dowels, but adding them to this new speaker design is recommended. Where possible, miter saws are used to create large gluing surfaces in the corners of the cabinet. Using miter saws is also recommended to add to this design.

Expanding construction glue is used to get the speakers airtight. However, getting the cabinets airtight is still tricky, and about 20% of the cabinets delivered to Dutch & Dutch need extra 'repair' to make them airtight. Oak is only available in 20mm; 18 mm not standard. Multiplex has more tolerance problems than MDF, making manufacturing slightly more complicated. However, Multidesk is highly experienced in working with multiplex and does not see any problems with this cabinet design. Screwing directly into the multiplex or MDF is undesirable; repeated removal of the screwed part results in a loose fit. Panels are mounted perfectly perpendicular using a small 5mm cavity. This results in more surface area to fit the glue, better air tightness results, and accurate positioning of the parts. See Figure 51..

All points mentioned by Multidesk were considered for the final design proposition, but as building the embodiment prototype had already started, not all recommendations were added to this prototype. The cavities of 5mm for perpendicular fits were not included, just like no miter saw was used to cut corner connections. MDF and multiplex were used, and the final design only consisted of multiplexes.

Front baffle

The front baffle was not made using cultured marble as there was no possibility to prototype using this technique within the given budget. Instead, two options were considered. The first option was to make the front baffle out of different smaller 3d prints glued together. This method would result in a high level of detail but a lightweight and vulnerable part. The second option was to make the front baffle out of wood and finish it using putty. This method would result in a less detailed result but would be more studied and less prone to failure. Furthermore, it would also be faster to prototype. Eventually, the 3d-print method was chosen as a high level of detail was desired for optimal evaluation of the aesthetics of the design. Magnet inserts were used to position the front baffle onto the wooden cabinet, then secured with bolts from inside the cabinet. Threaded inserts in the front baffle provided the thread for the bolts. This way, the installation of

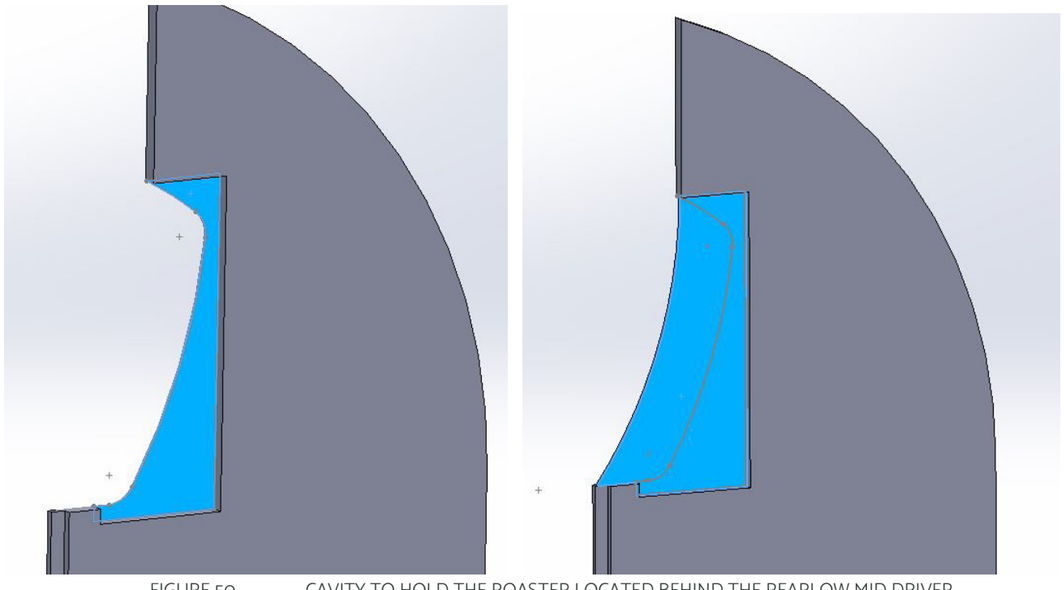


FIGURE 50. CAVITY TO HOLD THE ROASTER LOCATED BEHIND THE REARLOW MID DRIVER

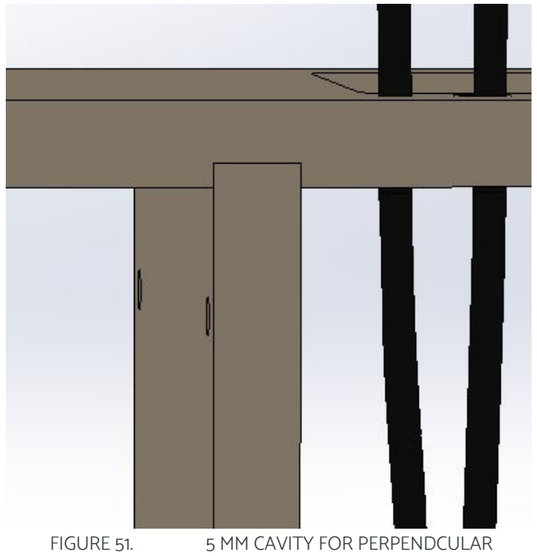


FIGURE 51. 5 MM CAVITY FOR PERPENDCULAR CONNECTION OF MULTIPLEX

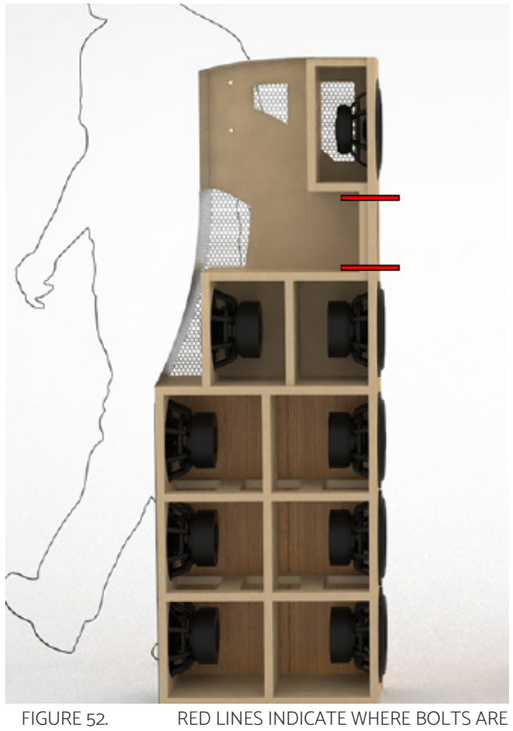


FIGURE 52. RED LINES INDICATE WHERE BOLTS ARE LOCATED TO ATTACH FRONT BAFFLE TO CABINET

the front baffle would be blind, not visible from the outside, while it is still possible to remove the front baffle for servicing the speaker.

The roaster covering the vents needed for the passive cardioid of the mid-driver was made out of perforated aluminum. The roasters were cut to size. Prototyping and assembling the front baffle resulted in the following insights:

- Using putty to cover glue lines works nicely.

- White is a difficult color; a darker color would hide imperfections better. Furthermore, the white color got people thinking the baffle is unfinished and will be painted

- Gluing the parts results in a strong bonding, sufficient for this application.

- It is challenging to install the bottom bolts as they are only accessible when the speaker is lying on its front or sides.

- Adding the magnets is a complicated solution as powerful magnets are needed to lift the weight of the more than 15kg heavy front baffle. A more straightforward solution like guiding pins can provide sufficient form locking before bolting the front baffle to the structural wooden body.

- The acoustical vent on the side of the front panel must be deep-drawn to make them more flush with the side surface of the speaker. Now, a cavity is printed for the roaster to be installed in, but this would result in too thin part thickness of the cultured marble in the actual product. If it is attached to the inside of the front baffle, there will be a 20mm deep cavity wherein the vent is positioned. This is not desirable from an aesthetical point of view, which is why this roaster must be deep drawn in the shape of the vent to make the cavity smaller. See Figure 53 for a detailed overview of the problem.

Rear panels

Three aluminum panels were cut to size to provide the panels closing off the rear of the design. The aluminum rear panels are the last part added to the speaker when assembling. In the prototype, they are screwed into the wood using wood screws onto 'spacers' that provide an offset from the wooden rear panel of the cabinet to fit the thickness of the rear low bass speaker drivers. The top two panels were bent using a rolling mill.

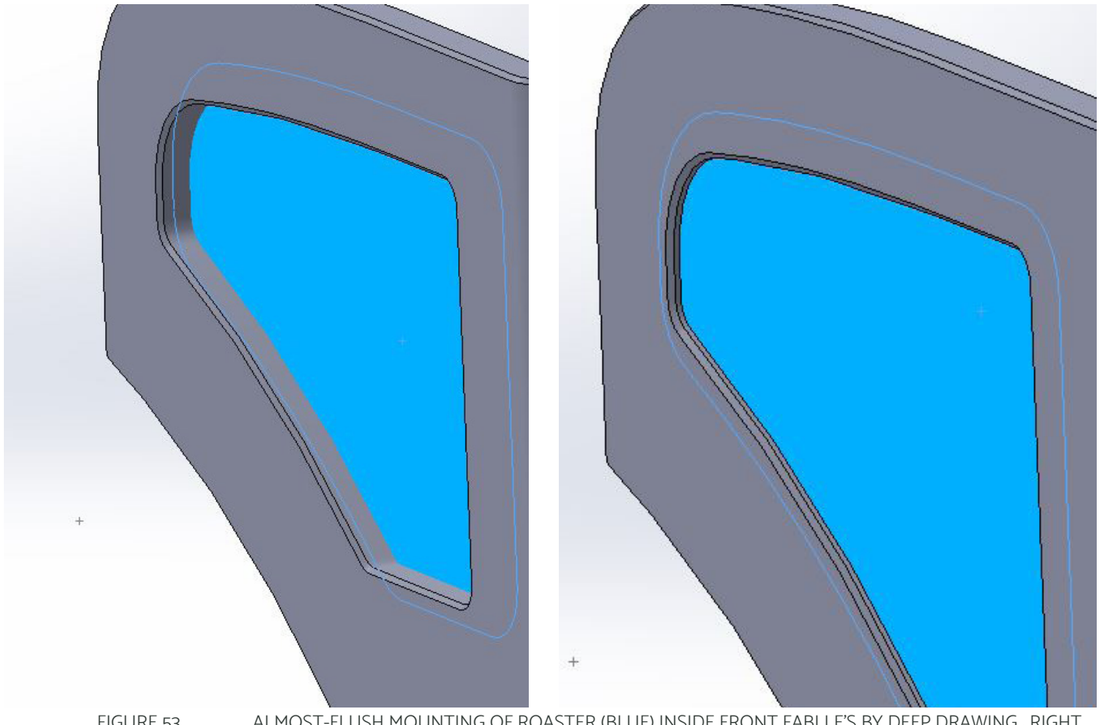


FIGURE 53. ALMOST-FLUSH MOUNTING OF ROASTER (BLUE) INSIDE FRONT FABLLE'S BY DEEP DRAWING . RIGHT IS DESIRABLE

Finally, the panels were installed into the wooden cabinet using wood screws. The panels are shown on Figure 49. The prototyping of the rear panels provided the following insights:

- The rear vent provides only a tiny space between the back panel and woofer; it will probably vibrate too much in the current design. It will have to be secured more tightly, and the possibility of enlarging this vent should be explored.

- Accurate metal bending was difficult by hand as rolling mills can only be adjusted by eye and trial-and-error. Resulting in inaccurate bends.

- A gasket needed between MDF and aluminum is needed to prevent vibrations.

- Aluminum vulnerable to scratches.

- The curved panel behind the rear low mid speaker driver is sticking out 5mm, this is dangerous for hurting the user and assemblers, and this should be taken care of, see Figure 54.

- Screws at the backside look fine, but the top screws are distracting, and further connection possibilities should be explored.

- Aluminum with the oak wood is a nice-looking combination that aligns with the desired design language.

- Some form locking between the vent behind the rear low mid driver and the curved aluminum back panel is desired to create a more stiff solution that will not vibrate against each other and remove visual gab caused by tolerance issues.

- 5.5mm thick spacers were too short. Distance must be 7.5mm thick to provide enough space to fit the speaker drivers.

Speaker drivers

The prototype was built at the PMB workshop of the IDE faculty and then transported to Dutch & Dutch to install the speaker drivers. Faulty rejected components were used. Installation was pretty straightforward, but the problem was that the thickness of the mounting ring of the drivers was 7.5mm instead of the digitally measured 5.5mm, which resulted in less than perfect fitting of the front baffle and rear panels. This needed to be adjusted for a better visual fitting. Furthermore, wooden thread inserts should be used instead of wood screws to increase the durability of the speaker cabinet.

Speaker stands

The speaker stands in the design will be of the same material as the front baffle. Therefore, it was also prototyped using the FDM 3d printer. The four printed parts were glued, and putty was used to smoothen them, just like the front baffle.

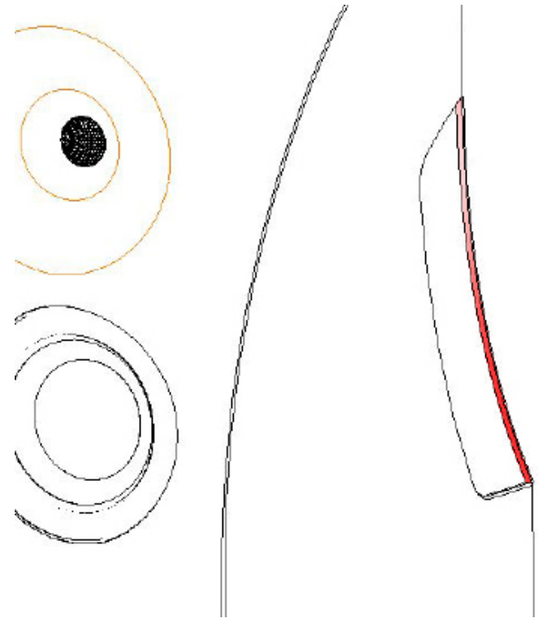


FIGURE 54. ALUMINUM EDGE STICKING OUT

8.3 PARTS AND ASSEMBLY

A prototype is not a final design proposition, and this Paragraph describes the dimensions and recommendations for the final design. In addition, optimizations are described, and more manufacturing and assembly considerations are elaborated upon.

Structural cabinet

Most modern speaker cabinets are made out of different types of wood. However, it is not the only material used. Aluminum -see Figure 55- and plastics -see Figure 56- are also widely used. More recently, concrete -see Figure 57- and glass have been experimented with. However, the low cost, excellent stiffness properties, and vast processing possibilities of MDF and plywood make it a popular choice for speaker cabinet building. Dutch & Dutch has a good partnership with Multdesk, a company specializing in woodworking and making furniture and speaker cabinets. Changing the cabinet material was not explored elaborately for this product as the desired look, as defined in the Design Language, includes the side panels made of oak wood, making it convenient to make the cabinet's interior out of wood. However, applying veneer to the outside was briefly considered, as a cheaper wood type could be used while still having the visual appeal of oak. Furthermore, it would make assembly easier as the tolerances on oak wood make part dimensions less accurate. Still, solid oak wood was chosen as it has a more premium feel, and the material used should not be inferior to the 8C's

The product is large, and stiffness is essential. Therefore, plywood was chosen over MDF for the inner structure of the cabinet. Perpendicular to the board, plywood has a higher young's modulus than MDF, ranging from 5.02 - 7.97GPa, compared to 2.8 - 5.0 for MDF (CES EduPack, 2019). The solid oak side panels have a comparable modulus ranging between 4.98 - 5.6. The panels are thus not only part of the aesthetical outer design but are also

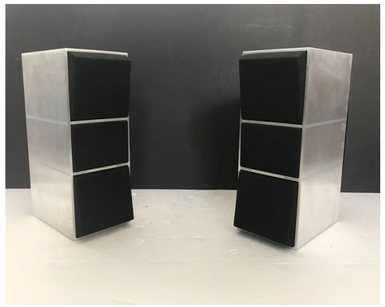


FIGURE 55. ALUMINUM BEOVOX CX100

FIGURE 56. PLASTIC CABINETS ON THE KEF LS50 SPEAKERS

FIGURE 57. THE YKMA OC.1 AR E MADE OUT OF CONCRETE

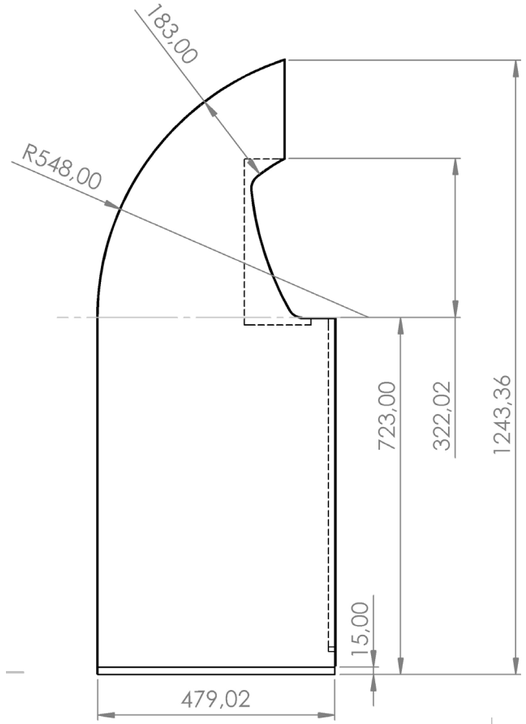


FIGURE 58. DIMENSIONS OF THE SOLID OAK LEFT SIDE PANEL

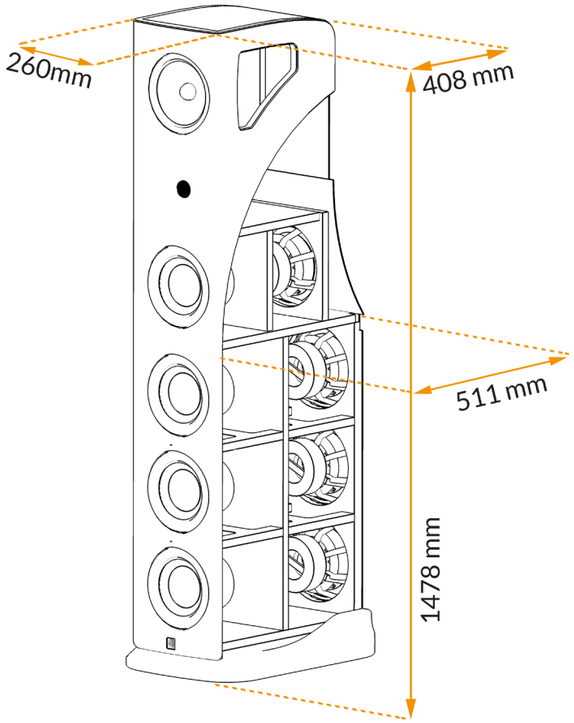


FIGURE 59. DIMENSIONS OF THE LOUDSPEAKER

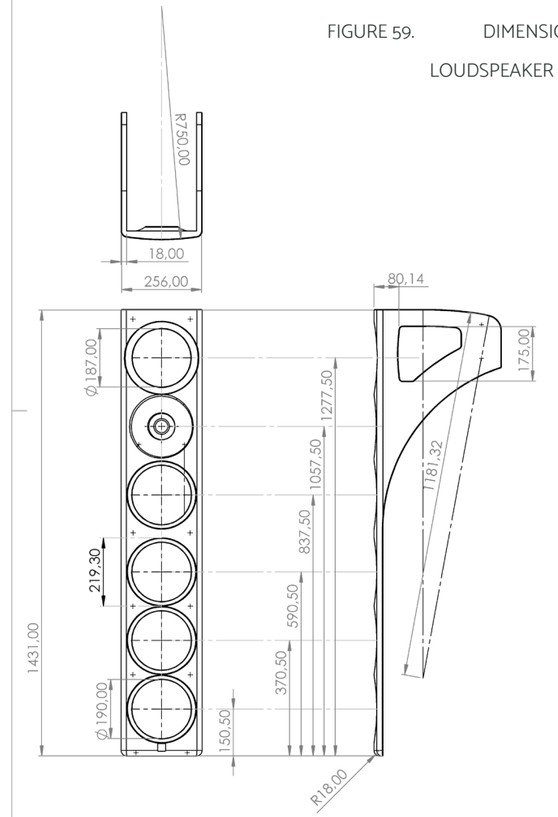


FIGURE 60. DIMENSIONS OF THE COMPOSITE MARBLE FRONT BAFFLE

an integrated part of the structural body providing stiffness for the whole speaker. A standard thickness solid oak panel of 20mm is used. For the internal plywood structure, 18mm is used, just like in the 8C; this is also a standardized thickness that is widely available.

The volumes of the different bodies are:

Teeter housing (1x)	0L
Mid driver (1x)	3.9L
Low midd driver (2x)	7.6L
Low bass driver (2x)	30.7L

The entire wooden cabinet is assembled at Multidesk, where each part is laser cut for maximum accuracy. Next, the panels are glued using PVC wood glue. Internal studs are positioned using 5mm deep hollowed-out ridges in the plywood, as shown in Figure 61. This way, the position of each wooden plank is more straightforward, and there is more surface area to glue the parts together. Where possible, miter joints are used for corner connections as recommended by multidesk. Also, dowels and 5mm cavities are used at perpendicular multiplex connections for better glue bonding and accurate part fitting. Finally, the thread inserts necessary to install the front baffle, rear panels, speaker stand, and speaker drivers are also installed by Multidesk.

The front baffle, rear cover, and stand

The front panel is one part made using composite marble. This material is also called cultured marble or artificial marble. It looks and feels similar to marble, but it is less heavy. Cultured marble parts are made by mixing marble pieces with resin composite. This mixture is then cast in the desired shape. The process results in a marble-like product that can have multiple finishes and looks. For now, a matt white without marbling is used to work with, but in Chapter 9, other colors and finishes are presented. This technique of casting cultured marble is primarily seen in the bathroom environment for making sinks, showers, and bathtubs.

The front baffle will stretch over the speaker's entire almost 1.5 meter-long height. It also bends over to the side of the speaker at the top. With a density of 2.1 g/cm^3 (Demartini et al., 2018). The front baffle would have a total weight of almost 15kg, making it quite heavy but handleable by one person. The front baffle is connected to the structural body using nut inserts and is then bolted from the inside of the speaker. In total, 12 bolts are used, as shown in Figure 60.

The speaker has two 2mm thick aluminum rear panels. The top part covers up the low-mid driver, electronics, and top of the speaker, and the lower panel covers up the low bass woofers. They have a brushed look with a satin gloss. Both panels are laser cut to shape, attached to the wooden body using a threaded nut insert in the multiplex, and damped using sealing gaskets. The top part is cold-rolled into the desired bend.

Speaker stands

The speaker is placed on a custom-designed stand. The stand is made of cultured marble, just like the front baffle. At its sides, it is curved outwards to provides a stable and large surface on the floor for the speakers to rest on. The composite marble's weight will ensure that the center of mass of the

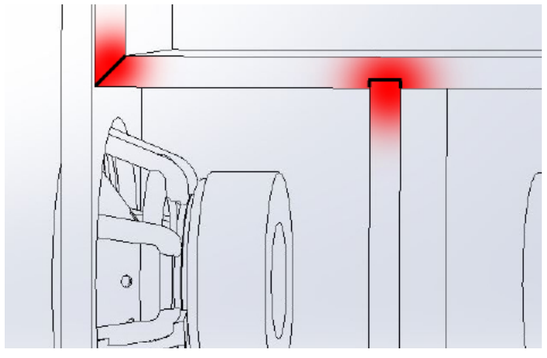


FIGURE 61. MITER SAWS AND 5MM-CAVITY CONNECTIONS

FIGURE 62. IMPRESSION OF THE CURRENT DESIGN STATUS OF THE SPEAKER STAND

entire speaker is closer to the ground. The solid piece of cultured marble will weigh slightly more than the front panel, around 20kg.

Speaker drivers

The specific models for each speaker driver were determined by Dutch & Dutch and are similar to the drivers used in the current design of the 8C's. The newly designed speakers' low bass and low-mid channels house the same speaker driver, the Wavecore SW223BD03. In total, eight of the 8¾" drivers are present in one speaker. These drivers have an aluminum cone (Wavecore, 2020) making them highly stiff, resulting in low distortion levels. They are so-called long-throw driver units, meaning the conus can move back and forth over a relatively long length. The length between the minimum and maximum extension is 10.7mm. The low bass and low-mid woofers are connected to the multiplex structure using threaded inserts installed into the plywood, as shown in Figure 63.

The mid driver producing the passive cardioid radiation pattern is the Seas H1252-06. An 8" driver capable of producing a flat frequency response over a broad frequency range. Like the Wavecore Woofer, it also has an aluminum conus. The manufacturer recommends using the speaker between 25 and 2,500Hz (S.A.Solutions, 2022). However, it will only be producing sound between 200 and 1,250 Hz due to the inefficiency caused by its open box design, which is needed for the passive cardioid character. Furthermore, the bass demands of the new design and the 8C are too high to let this single driver do all the work. The dedicated Wavecore woofers are better suited for the job. By limiting the frequencies played by a single driver, conus breakup happens at louder volumes resulting in a higher maximum SPL and less overall distortion. The mid driver is bolted into threaded inserts in the multiplex wood.

The tweeter used is the Seas H1212-06, a 1" Aluminium/magnesium alloy dome tweeter; it will produce frequencies from 1,250 up to 20,000Hz. The tweeter is attached to the custom-designed waveguide, similar to the one used in the 8C. Dutch & Dutch designed this waveguide precisely to match this tweeter. It has a hexagonal protective cap to make it less vulnerable to damage caused by touching the outside of the diaphragm. The tweeter is mounted directly onto the front baffle by bolting into inserts placed in the cultured marble part. This way, a tight fit between tweeter and waveguide is ensured.

Each speaker is connected to an amplifier with two cables: a signal cable and a ground cable. See Figure 64 for the electrical circuit of the speaker where each ground and signal wire is displayed as one wire. This is done because these wires will also be within one cable sleeve within the speaker, as shown in Figure 66.

FIGURE 63. THREAD INSERT MOUNTED IN CABINET TO CONNECT SPEAKER DRIVER

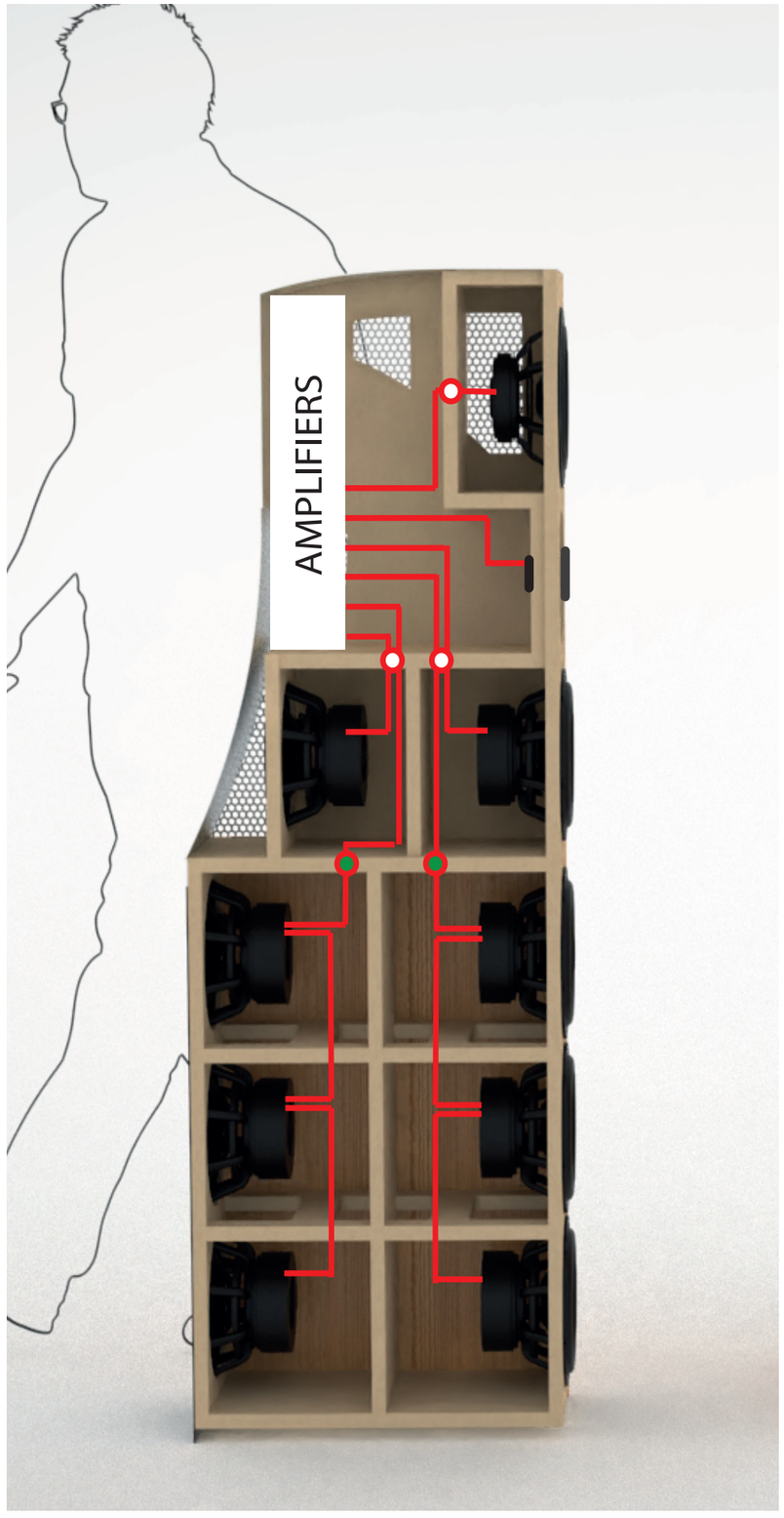


FIGURE 64. INTERNAL WIRING CONNECTING THE SPEKAER TO THE AMPLIFIERS

Connections - internal wiring

The speaker has six different speaker channels that need to be connected to one of the six amplifiers in the top part of the speaker, behind the mid driver and the tweeter, see Figure 64. Per channel, a positive signal wire and a ground connection between the amplifier and speaker drivers are necessary. Each positive and negative cable is bonded with a rubber enclosing, as shown in Figure 66, meaning that 12 wires housed in 6 cables are needed to provide each channel with a signal and a ground connection. However, the two low bass channels have three speaker drivers with the same input signal and ground connection to their dedicated amplifier. In total, ten drivers need to be connected with six amplifiers. For the connection of these three speaker drivers to their amplifier, only one cable is leaving the low bass speaker drivers' enclosure. This cable connects to the positive and negative terminal of one speaker, then piggyback connectors are used to loop this connection through to the other two speakers. See Figure 65 for a piggyback connector; it is a connector that turns one male connection into two male connections, making it possible to add another cable and loop the signal through to another speaker. The benefit of using these connectors is that only one cable must leave the airtight enclosure instead of three.

An overview of the location of the amplifier and the cable connections can be seen in Figure 64. The tweeter connection is most straightforward as the tweeter's back is in the same space within the speaker cabinet as its amplifier. The mid driver is located in its dedicated enclosure, and a hole in this enclosure will be covered up with a metal plate and rubber air seal -as shown in Figure 68. This accommodates the cables to connect the mid driver and amplifier without air leaks.

The low-mid drivers will be connected using the same principles. However, two cables will be entering.

Connections - external wiring

There are also connections to the speaker's exterior that is reachable by the user. These connections are needed to provide the speaker with power, an ethernet cable connection, and to make it possible to connect additional digital and analog sound sources to the speaker using AES connectors. The ethernet cable is not needed for connection to the internet as the speakers include wi-fi. However, when making changes to the speakers' settings, the software requires the speaker to have a physical ethernet connection. In total, the speaker will have the following connections:

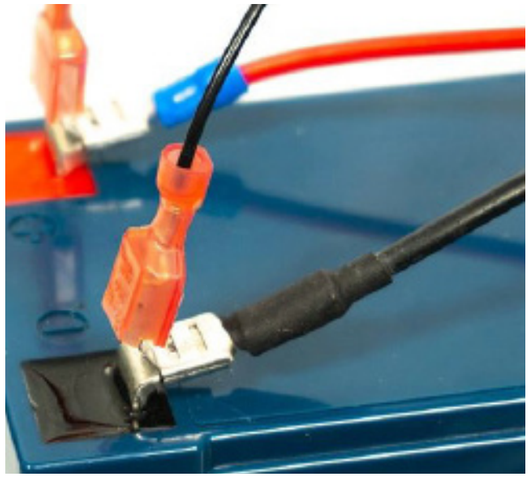


FIGURE 65. PIGGYBACK CONNECTING TWO WIRES TO ONE TERMINAL

FIGURE 66. POSITIVE AND GROUND CABLE IN ONE SLEEVE

FIGURE 67. REAR CONNECTIONS ON 8C

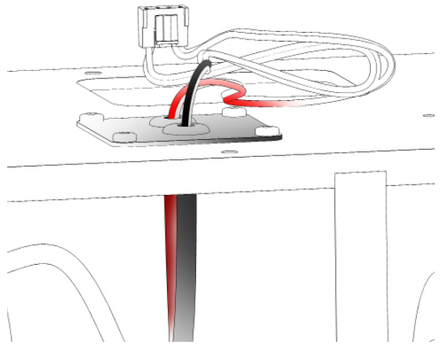


FIGURE 68. METAL PLATES TO PROVIDE AIRTIGHT CABLE CONNECTIONS

- Standard mains power cable with IEC C13 connector
- Ethernet cable connection with RJ45 socket Digital input using AES connector
- Balanced analog input using AES connector
- Audio throughput with XLR

The connections will not be at the same place as the electronics; this would mean that the cables must be connected at the back of the speaker at 1m height. Cables hanging out of the speaker are undesirable as the weight of the cables will cause stress on the connectors and would distract from the overall aesthetics of the design. So instead, the cables will be led from the electronics to connectors located at the speaker's bottom behind the metal rear covers. This way, all external cables are located outside each airtight speaker compartment but within the visual body of the speaker. More connections through the inner bodies could result in air leaks and make servicing more difficult.

Amplifiers

The six amplifiers are necessary to provide each speaker channel with a sound signal and accommodate the requirement of 115db at 1m SPL as stated in the Program of Requirements in Appendix F.

It is essential to mention the low impedance of the two subwoofer channels because each channel consists of three parallel connected subwoofers. The impedance of 8 ohms per speaker driver results in a nominal load of 2.7 ohms. Impedance is resistance for alternating current, and in a parallel circuit, the total resistance/impedance is calculated using:

$$R_{parallel} = \frac{1}{\left(\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}\right)}$$

The speaker driver is also available in a 4 ohm version, but this would result in an even lower impedance (1.3 ohms), being harder to drive than 2.7 ohms for the amplifiers. None of Pascal's amplifiers are suited for loads under 2 ohms. The high current draw from a low-impedance speaker can overheat an amplifier that is not suited for the job. With impedances below

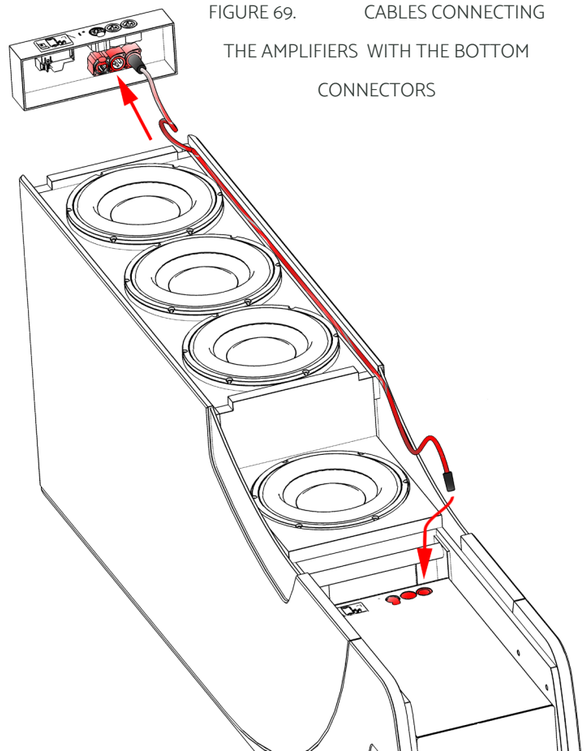


FIGURE 69. CABLES CONNECTING THE AMPLIFIERS WITH THE BOTTOM CONNECTORS

Driver (altern, configuration)	Efficiency (dB/W)	Total Impedance (ohm)	Max Power peak handling (W)	Power needed for 115db @1 meter (W)	Can requirements be met?	If not: Actual max SPL: (dB @1 meter)
Tweeter	91.5	8	220	**220**	YES	
mid	88	8	300	**500**	**NO**	113.6dB
Low-mid	86	4	2500	**800**	YES	
Subwoofer 3x8ohm	81+4.8+3= **88.8**	2.7	2500	**420**	YES	

TABLE 1 OVERVIEW OF SPEAKER DRIVER AND SPEAKER CHANNEL PERFORMANCE

4 ohms, the thermal management of an amplifier should be engineered with great care.

The goal of a peak SPL of 115dB at a 1-meter distance resulted in the second criteria for choosing the optimal amplifier. The efficiency of each speaker channel was calculated to see how much power the amplifier must have for it to reach 115dB SPL. Efficiency describes the speaker driver's sound pressure with an input of 1 watt, which can be used to derive the theoretical amplifier power needed to reach 115dB SPL; see Table 1 for the overview per speaker channel.

The lowest frequencies are handled by the two subwoofer channels, each consisting of three parallel connected 8-ohm Wavecore drivers that have an efficiency of 81dB/W per speaker. More drivers increase the efficiency of a system. Having two drivers doubles the amplitude, meaning an increase of 3dB as the decibel scale is logarithmic. Using three drivers adds 4.8db/W to efficiency, resulting in an efficiency of 85.8dB/W. However, the two subwoofer channels work together, and the rear cardioid subwoofer channels add up 3dB/W to this on-axis SPL, resulting in an 88.8dB/W efficiency.

Two important notes should be made when looking at Table 1. First, the low-mid driver cannot accommodate the set peak SPL of 115dB at 1 meter. The required power (500W) would be more than the max-rated handling power of the Seas speaker driver. The theoretical maximum SPL at one meter is 113.6dB.

The second note is that this calculation is overly simplified and insignificant below a speaker driver's resonant frequency (Fs). Woofers typically start 'rolling off' (having a 12dB/octave highpass filter) below each speaker driver's unique Fs. Dutch & Dutch compensates for this roll-off by applying a compensation filter. However, this significantly increases the energy the system has to deliver below the woofer's Fs, making the calculation shown in table 1 not applicable. The resonant frequency of the Wavecore speaker drivers is 25Hz, but if not mounted in a theoretical ideal cabinet, the system's resonant frequency will become higher. The ideal cabinet should have the equivalent volume of three times 28L as specified by Seas. However, the volume of the subwoofer compartment is only 31.5L. Using the software WiniSD, the system was modeled, showing that the resonant frequency will increase to 48.6Hz instead of 25Hz. WiniSD was also used to calculate the amplitude boost necessary to archive a flat frequency response, which means that the frequency should not deviate more than 1dB above or below the 0dB reference between 30Hz and 20kHz. Secondly, the -3dB point should be at 20Hz or lower. Applying the filter that fulfills these requirements shows that a +12dB gain boost is needed. Therefore, the efficiency of the entire subsystem with filter equals 88.8-12=76.8dB/W.

For the speaker to reach an SPL of 113dB at one meter, a 4200W amplifier is needed. This amount of power is not realistic, and an iteration of the set requirements is necessary at this point. First, the Pascal amplifier offerings are researched further.

The Pascal amplifiers were first filtered on their ability to drive 2.7-ohm loads. The X-pro -the most powerful amplifier series- has a rated minimal load impedance of 4 ohms and is thus unsuitable for the task. The second most powerful L-pro2S series can drive 2.7-ohm loads and deliver 1200W into 2.7 ohms and has a second channel that can produce 800W into 4 ohms and 400W into 8 ohms. An additional L-A2 board can be linked to the L-pro2S, adding 800W into the 4-ohm amplifier channel.

This maximum of 1200W power is used to iterate upon the design requirements and get an SPL level that is reachable with the L-pro2. The new requirements are a flat frequency response (+/- 1dB) between 30Hz and 20kHz and a -3dB point at 25Hz, which means that the amplifier will have to boost the signal at 25Hz with 8.5dB to get a -3dB frequency response. Therefore, the maximum peak SPL for this system with 1200W input is 111.1dB.

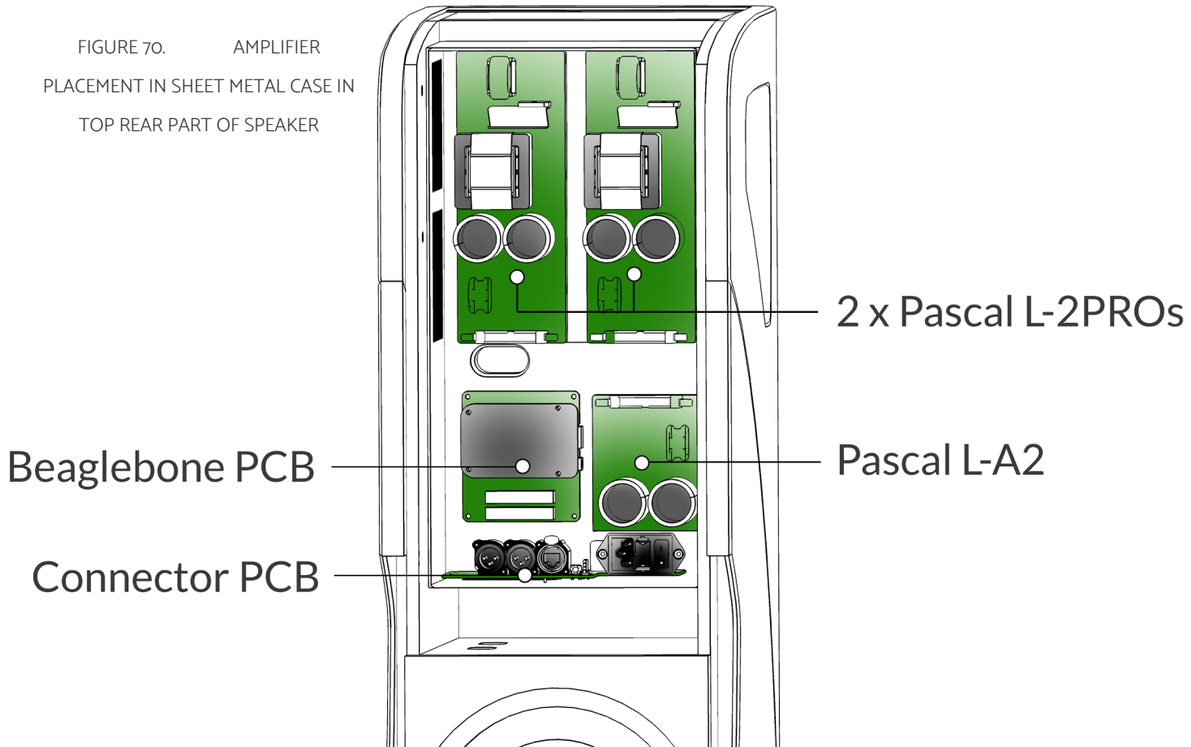
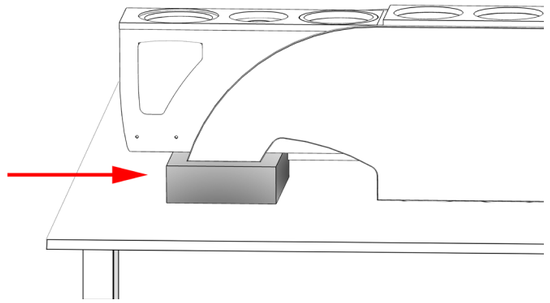
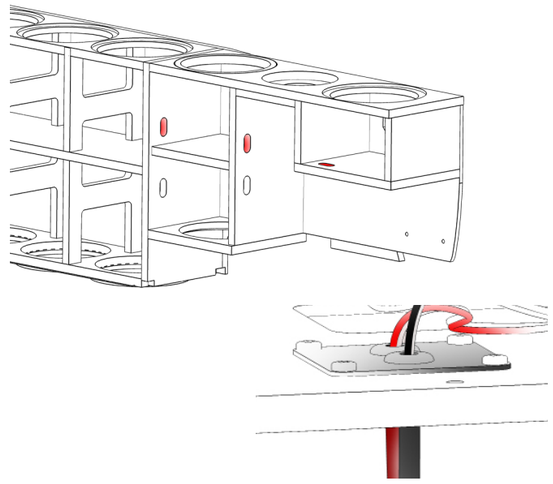


FIGURE 70. AMPLIFIER PLACEMENT IN SHEET METAL CASE IN TOP REAR PART OF SPEAKER

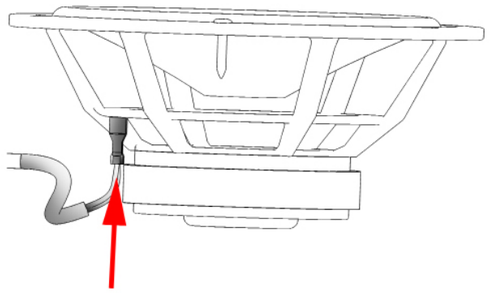
8.4 ASSEMBLY PLAN

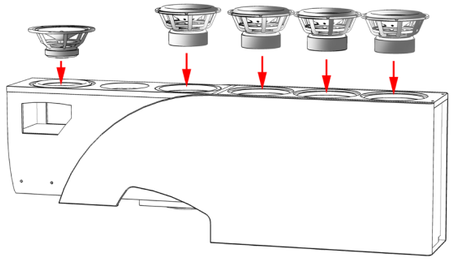


1. The cabinet is laid on its backside on a workbench; the rear top part is supported by custom-made wooden support.

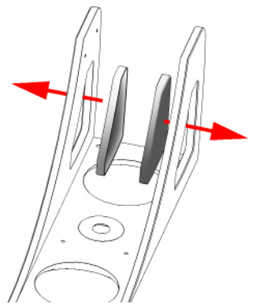


2. Cable plates for the front sub and low-mid compartment are screwed into the cabinet. The cable for the mid-driver is put through the plate not yet fastened.

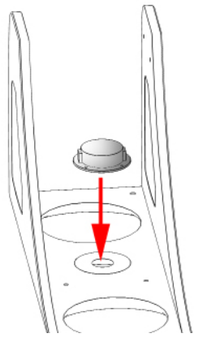




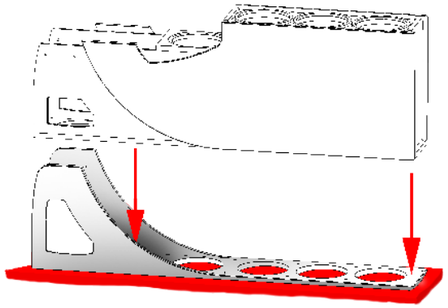
3. All front speaker drivers -except the tweeter- are connected and bolted onto the cabinet.

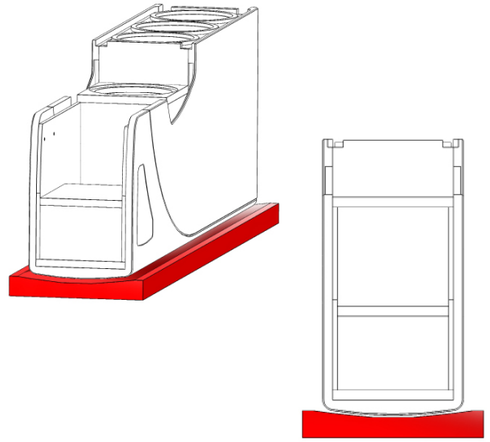


4. Two roasters are installed in the front baffle by bolting them from the inside of the front baffle.

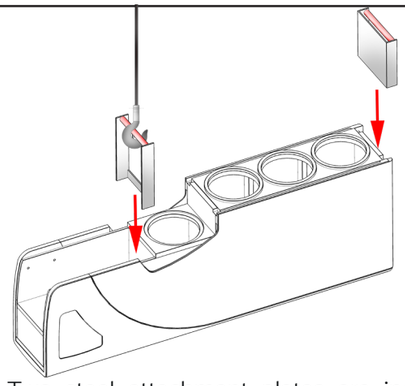


5. The tweeter is connected to the front baffle by four bolts.

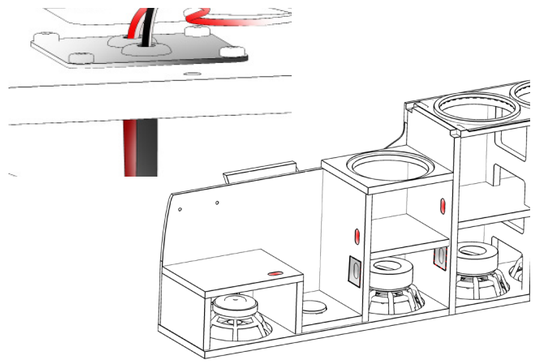




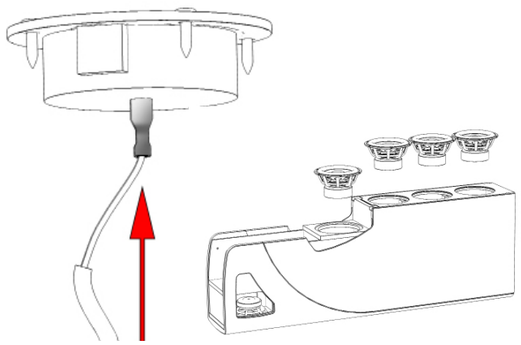
6. The front baffle is then placed flat on a second workbench. Positioned upon another support structure to divide the forces on the curved front baffle. The cabinet is then rotated and placed upon the front baffle. The ten bolts are then fastened to secure the front baffle to the cabinet.



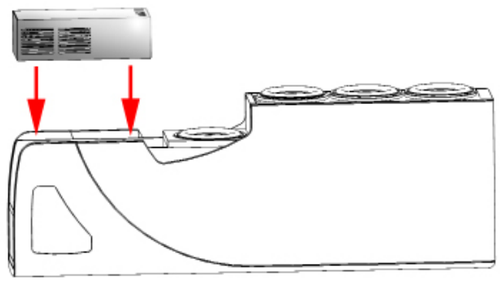
7. Two steel attachment plates are installed to accommodate lifting the body with a roof-mounted pulley.



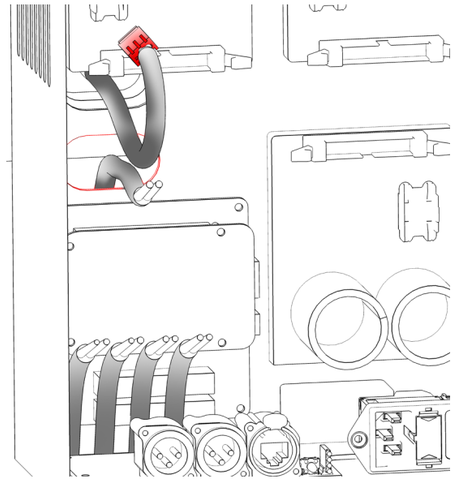
8. Metal speaker connection plates arefastened for the rear-sub, low-mid, and mid-driver.



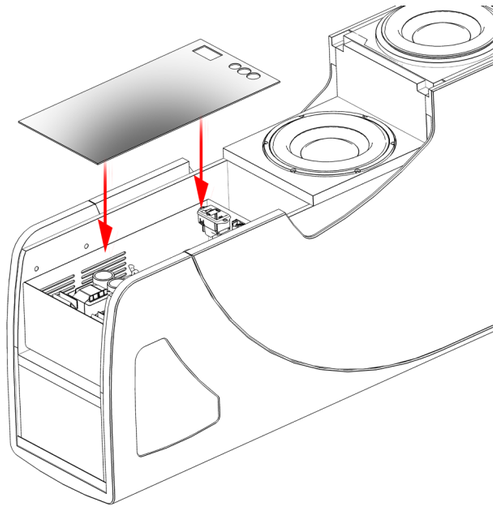
9. Rear speaker drivers and tweeter are connected to the cable and bolted into the cabinet.



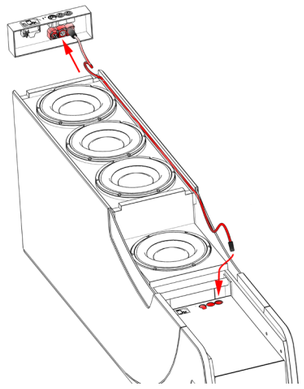
10. The electronics housing is installed into the cabinet.



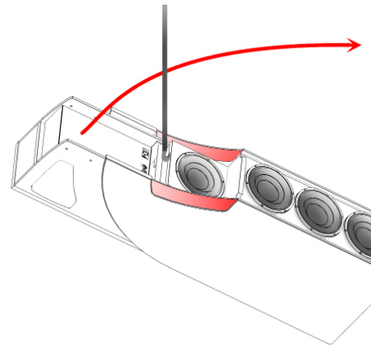
11. Speaker cables are led through the electronics housing and connected to the amplifiers.



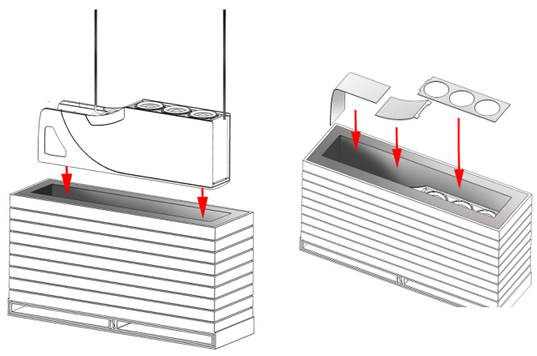
12. Electronics housing is closed using bolts.



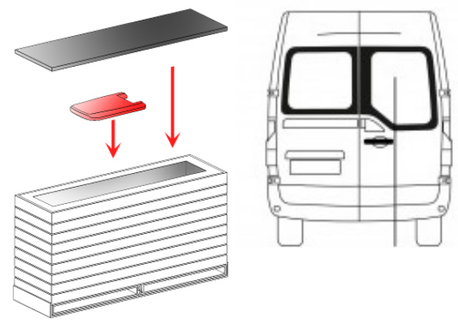
13. The connectors at the bottom of the speaker are connected to the electronics.



14. The speaker is tilted using the top pulley connection and the side roasters are mounted. The speaker is ready for performance tests.



15. If the speaker passes all test, it is packed for trasnportation and the back panels are mounted.



16. The stand is added as it will be installed at customers, the speaker is ready for delivery.

8.5 KEY FINDINGS

- Carton mockups were made to optimize the aesthetics of the chosen concept. Mark Sypensteyn, an expert on design drawing, was consulted during this process. The looks of the design have further been optimized by looking at the nine principles of design.

- The final aesthetics were implemented in an embodiment prototype. The prototype served to evaluate aesthetics and optimize part assembly.

- The proposed parts, part-materials, and dimensions are presented.

- The proposed amplifiers are two Pascal L-2PROs and one L-A2 extension board. A maximum linear SPL at one meter of 111,1dB. Limitations for not reaching the targeted goal of 115dB are discussed.

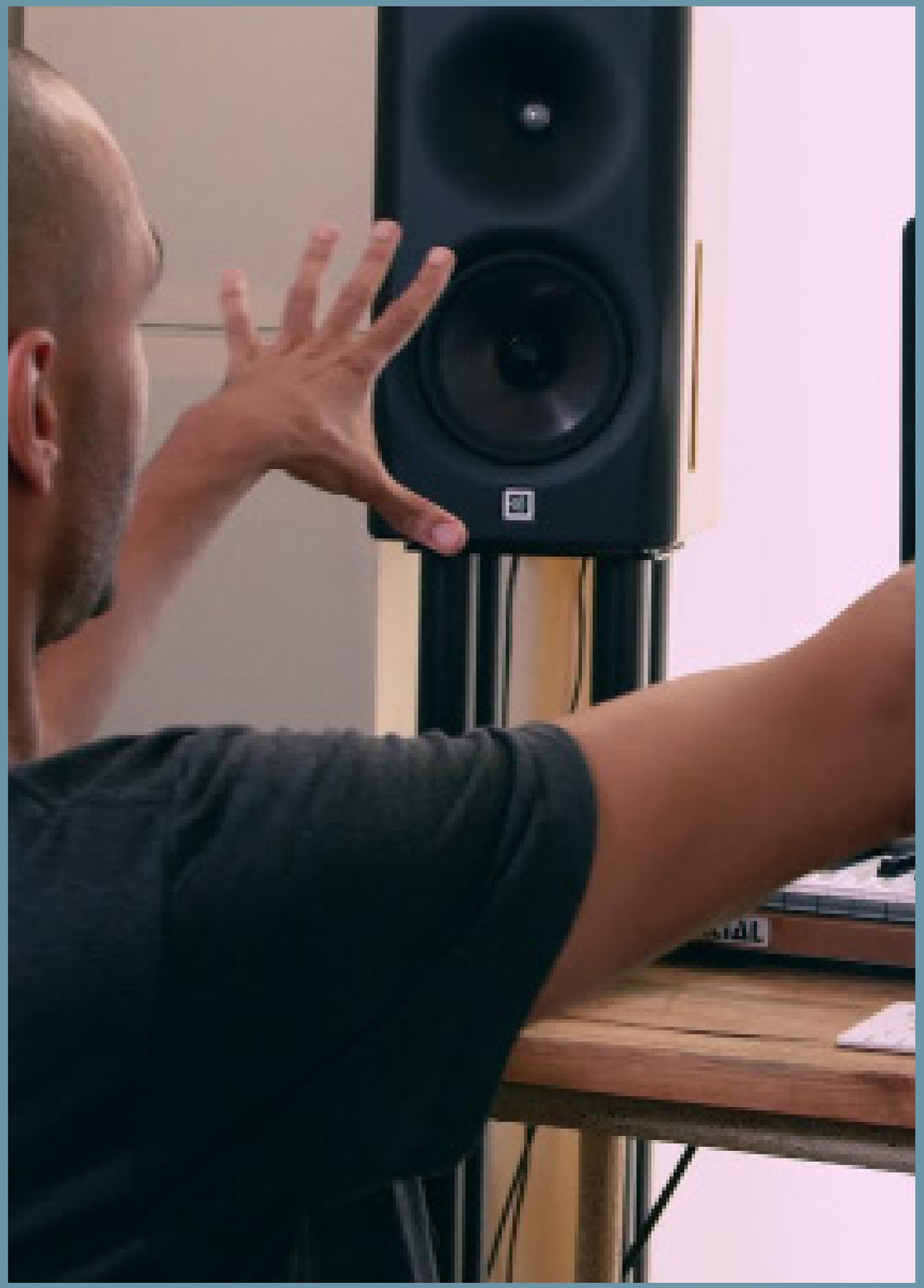


FIGURE 71. PATRICE BAUMEL ABOUT MAKING MUSIC AND BEING A MUSICIAN

9 EVALUATION

9.1 EVALUATION OF AESHETICS

A second questionnaire was sent out to verify if the new design reached its intended goals, as determined in Chapter 6.

The Beolab A90, the Wilson Sacha DAW, and the KEF ls50 that were also present in the first questionnaire regarding aesthetics were included in this second research. They were added as a reference, so it could be seen in which way the respondents of this survey share the same preferences as the first questionnaire's respondents. The Dutch & Dutch 8C was not added as the company wants the development of this new speaker to be kept discreet; not associating the new design with the 8C speaker will make sure the design is not directly linked to Dutch & Dutch.

In total 43 people filled in the questionnaire, of whom 42 (97.7%) were male and 1 female; this is comparable to the 95.7% male respondents of the first questionnaire. The largest group of 19 people (44.2%) was between the ages of 60 and 69, and the second largest group of 12 respondents was aged between 50 and 59. Remarkable is that the second largest group of 12 people between the ages of 40-49 was not at all present in the first survey. Respondents were younger in this second questionnaire. Only 1 participant said to have an interest in audio lower than 5 on the 7-point scale- giving it a score of 2.
The ratings of the three reference speakers (Beolab a90, Kef LS50, and the Wilson Sasha DAW) differed much from the first questionnaire. Average differences between the two questionnaires smaller than 0.5 points were neglected as this could be due to the small sample size.

Compared to the 8C, the speaker scored worse on the ugly to beautiful scale, with a 4,3 average compared to 5.1 on the 8C. The sound quality people would guess from the looks is also rated lower, 5.1 versus a 5.6 for the 8C speaker. The average traditional-modern score increased from 4.4 to 5.3. The design was also rated as more unique (a higher score) with a rating of 5.2 compared to the 4.5 given to the looks of the 8C.

The goal was to make the design look modern and score 1,0 points higher on the 7-point scale. In total, the respondents rated the speaker 0,9 points higher, close to the targeted 1.0 points. A more modern design was also achieved, although less convincing. The average score for the new design was 0.7 points higher than for the 8C. Not there yet, but a step in the right direction.

Thus, the aim to make a more modern and unique-looking speaker is reached. However, the speaker is also regarded as uglier, and the sound quality is rated lower. The aim was to get at least a similar result regarding the general acceptance of the looks and sound quality perception. An explanation

for lower scoring sound quality could be that the new speaker was introduced as a design by an Industrial design student rather than a new product of the professional company Dutch & Dutch. For this reason, the amount of engineering work and elaborate testing of Dutch & Dutch is not communicated, as the speaker is maybe more seen as a DIY project of yet another forum member. It is expected that the perceived sound quality will rise when the product is seen in the context of a professional company like Dutch & Dutch.

The fact that it is perceived as more ugly does not have to mean too much, as one prototype image was shown together with several renders. Moreover, it has less detail than the 8C, which is already fully developed and optimized as it has been on the market for several years. Still, it is something to look into when discussing the prototype's aesthetics. Further research is necessary to get better insights into the acceptance of the esthetics among the target group of the new speaker.

Average scores:

Ugly beautiful:	4.3
Poor-high quality	5.1
Traditional-modern	5.3
Cold-warm	4.3
Ordinary-unique	5.2

Physical prototype evaluation

Pictures and renders of a prototype and CAD model are one way to assess a speaker's looks. However, the ability to touch and walk around a product adds another dimension to evaluating its looks. The prototype was shown to multiple students and co-workers of the faculty. It was qualitative research where the prototype was located in the IDE faculty and students passing by were asked multiple questions. The form used can be seen in Appendix D. In order to obtain the most relevant feedback, questions were used as a guideline for discussing the prototype and design rather than a static questionnaire. Also, the technical working principles as described on the form were told to the participants in person. Seven people joined for a discussion, of which 2 were not students but workers at the faculty without a design background.
The oak wood side panels were often mentioned as a likable part of the design. People liked the 'natural' look of the oak and mentioned it as being 'traditional' in contrast to the 'modern' white front baffle. Nobody mentioned the oak as being a negative aspect of the design. The white baffle had people disagreeing with each other. Some mentioned it as looking modern and sleek and liked this combination. Others mentioned it having too high a contrast with the black speaker drivers.

Almost everyone agreed to dislike the side roasters. They were often described as too rough and industrial-looking compared to the rest of the design. Most people also mentioned the large dimensions as a downside of the design. The prototype's roasters had a rough square grid different from a round grid as was intended. This was because a better matching roaster grid could not be found easily. Although the roaster is not entirely representative, it is still important to note that the roasters are a prominent part of the design. Therefore, it is important to be aware that the pattern can be a distracting part of the product if not designed right. Furthermore, because of its looks, people said it must be a speaker for real audio fanatics and that it would not be something they would typically place in their living room.

People had much input when asked about aspects of the speaker they would like to see customizable. Suggestions were given to make the speaker look more personal:

- A black baffle would result in a less busy-looking design font view
- More high gloss finish
- Option to have a transparent roaster
- More fine roaster pattern
- More round roaster pattern
- Black roaster
- Option for different wood types.
- 'Air' between stand and speaker
- Leave white space between roundings around the woofers to create a less busy-looking front baffle.
- The front baffle wraps around the sides, 3cm front baffles before the wood begins at the sides.
- Release a smaller version of the speaker.

The discussions provided feedback that can be separated into two types; Feedback related to the (lack of) quality of the prototype and feedback about overall design decisions. It is essential, although sometimes difficult, to differentiate these two. Feedback related to the quality of the prototype can be marked as less relevant as the final product's material, manufacturing, and assembly quality will be on another -much higher- level. The second type of feedback -regarding the underlying design choices of the loudspeaker- is the most interesting type as these negatively perceived aspects will not change when the product is manufactured perfectly. Furthermore, only trends that are mentioned more often should be considered.

An iteration on the stand is made to give it a less busy -more calm- look. The current shape is too complex to minimize this complexity to achieve a less obtrusive look. As mentioned, the grid pattern of the prototype was different and of less quality than intended, and most negative feedback on the roaster could be traced back to the square shape of the prototype's grid pattern. Therefore, only minor adjustments to the roaster's dimensions were made to improve its balance with the front baffle and side panel.

To further improve the product experience, the 'free space between the speaker drivers is increased by reducing the size of the roundings around the lowest four speaker drivers. This way, the roundings around the woofers do not touch each other, creating a more calm look. Different color combinations for the front baffle and roasters are experimented with. The wood type has remained the same for now. The adjustments were implemented, and renders were made of the final design.

FIGURE 72. SIMPLIFIED OVERVIEW OF APPENDIX E

9.2 COST PRICE

First, a Bill of Materials (BoM) was made that could be used to determine a cost price. The BoM can be found in Appendix E, which includes the price of each part and labor costs necessary for the final product. A simplified version can be seen in Figure 73. The determined price estimates the price Dutch & Dutch has to spend for one fully assembled speaker. For the buyer, additional transportation costs, the profit margin for Dutch & Dutch, and optional reseller/ dealers will be added to that price.

The BoM is divided into six subsystems: the structural cabinet, front baffle, rear panels, electronics & speakers & electronics, the stand and packaging & assembly. For the structural body, the pricing was determined using the current price of wood at the material shop of the faculty IDE, together with looking into the current price of the 8C-cabinet. the overview of natural oak and black baffle configuration of the 8C can be found. The current manufacturing cost price of this assembled 8C-cabinet is €390. The new speaker is way larger but has relatively less solid oak wood than the 8C. Therefore it was estimated that the cost price should be around 1.0 to 2.0 times higher. The calculated material price was around €175, and the labor costs needed for additional engineering, machining, assembling, and transportation were determined to be around €240. The speaker cabinet assembly would cost Dutch & Dutch 415 euros per speaker.

The front baffle price was determined by asking advice from Howan Lau, CEO of Hamwells bv and responsible for most of the company's material sourcing. They source composite marble parts in China for their products, and the price for the front baffle and the stand was based on Hamwell's current part cost prices. In total, the baffle material and production price were determined to be around €300. However, the front baffle needs much post-processing to get the cut-outs and screw inserts into place. Howan calculated that this would lead to additional expenses of around €90 per front baffle. Therefore, including transportation, the total price for Dutch & Dutch was determined to be €420 per front baffle.

The stand has similarities to the front baffle as it is produced using the same production method. However, it is made of slightly more material, but less post-processing is needed than for the front baffle. Therefore, the total price will be lower than the front baffle; the cost, including transportation, was determined to be €285. It is essential to consider that one mold used for casting composite marble can only produce one cast part per workday. This means that around 260 products can be produced within one year using one mold. Dutch & Dutch expect sales numbers to be below 260 per year. Still, it is important to consider this bottleneck as it can become a problem if there is a sudden peak in demand, for example, just after the product is launched. Buying extra molds would cost around €5,000 per mold. As the front baffle and stand each have a separate mold, an amount of around €10,000 would have to be spent to double the production capacity.

The electronics are mostly from third parties. The cost price was determined using the current pricing of Pascal electronics (for the amplifiers) and the current prices Dutch & Dutch pays for speaker drivers, cables, and connectors. Total pricing was determined to be around €1,820. This will be the most significant part of the budget, which makes sense as it includes all speaker functionality.

For the packaging costs, a global estimation is made for a custom-made wooden transport crate fitted with interior foam to protect the product during transport. Total packaging costs have been estimated to be around €300.

The total manufacturing price per speaker is estimated to be around €3,700 per speaker. The 8C manufacturing price is around €2,000 per pair and sells for €11,800 (Dutch&Dutch, 2022). Applying this multiplier of three to the cost price of the new speaker means that the estimated selling price would be €22,200 a pair.

The product proposition has been evaluated multiple times during the project leading to adjustment of the design or in the case of new insights, into re-evaluation of the Program of Requirements as seen in Appendix F.

Subsystem		Costs
1	Structural cabinet	*€414.60*
2	Front Baffle	*€420.60*
3	Rear aluminium panels	*€39.20*
4	Speakers and Electronics	*€1,820.91*
5	Stand	*€285.25*
6	Packaging and assembly	*€330.00*
	10% Unforeseen Expenses	*€289.60*
	Manufacturing cost price	***€3,885.41***

FIGURE 73. MEASUREMENTS MIC POINTED AT SEAS DRIVER

9.3 EVALUATON ON PROGRAM OF REQ.

Some aspects are not met yet, such as requirements regarding the software, user interface, and maintenance of the loudspeaker. These requirements have been discussed in the report but not yet validated. Looking back at the making of the Program of Requirements, it becomes clear that the requirements envisioned a product that is market ready at the end of this report. However, this is not the case and was never considered possible within the given time. Many steps have been taken during the product development in this project, but the final design remains far from market ready.

As the project continued, the scope was slightly adjusted, resulting in the canceling of sound tests. At the start of the project, sound tests were part of the project, but along the way, it became clear that it would take much time, and Dutch & dutch could more efficiently perform these tests themselves at the end of the project; therefore it was removed from the scope of the project.

The maximum manufacturing cost price of €12,500 is way higher than the eventual calculated cost price, and looking back, this maximum was set too high. Dutch & Dutch had no clear goal in mind, and this goal was set without having a complete overview of the current costs of manufacturing speakers.

Goals regarding the sustainability of the product are only partially met; an evaluation -like a Life Cycle Assessment- has not been done yet, and therefore it is not possible to make realistic claims about meeting the goals regarding the impact of the product on the planet. Chapter 10 describes the recommended next step to take.

Overall, the proposed design offers a solution to the embodiment of a full-range cardioid loudspeaker that is directional across its full frequency response and can play as loud as 111.1dB, having a flat frequency response. Furthermore, the solution is in line with the Dutch & Dutch's product portfolio, and only a few adjustments to the assembly line are necessary to accommodate the manufacturing of this product.

9.4 KEY FINDINGS

- The aesthetics of the design were evaluated by audio forum members via a digital questionnaire. The aim to make a more modern and unique-looking speaker is reached. Goals regarding overall appeal and high-quality appearance were not yet met. Solutions for iterations are proposed.

- Prototype aesthetics were also evaluated in discussion with students and employees of the IDE faculty; this proved fruitful for new iteration ideas.

- The manufacturing cost price was calculated to be €3,700 per speaker, and the retail price was €22,200.

- Not all requirements as stated in the Program of Requirements are met yet; further detailing of material sources and software optimization was outside this project's scope.

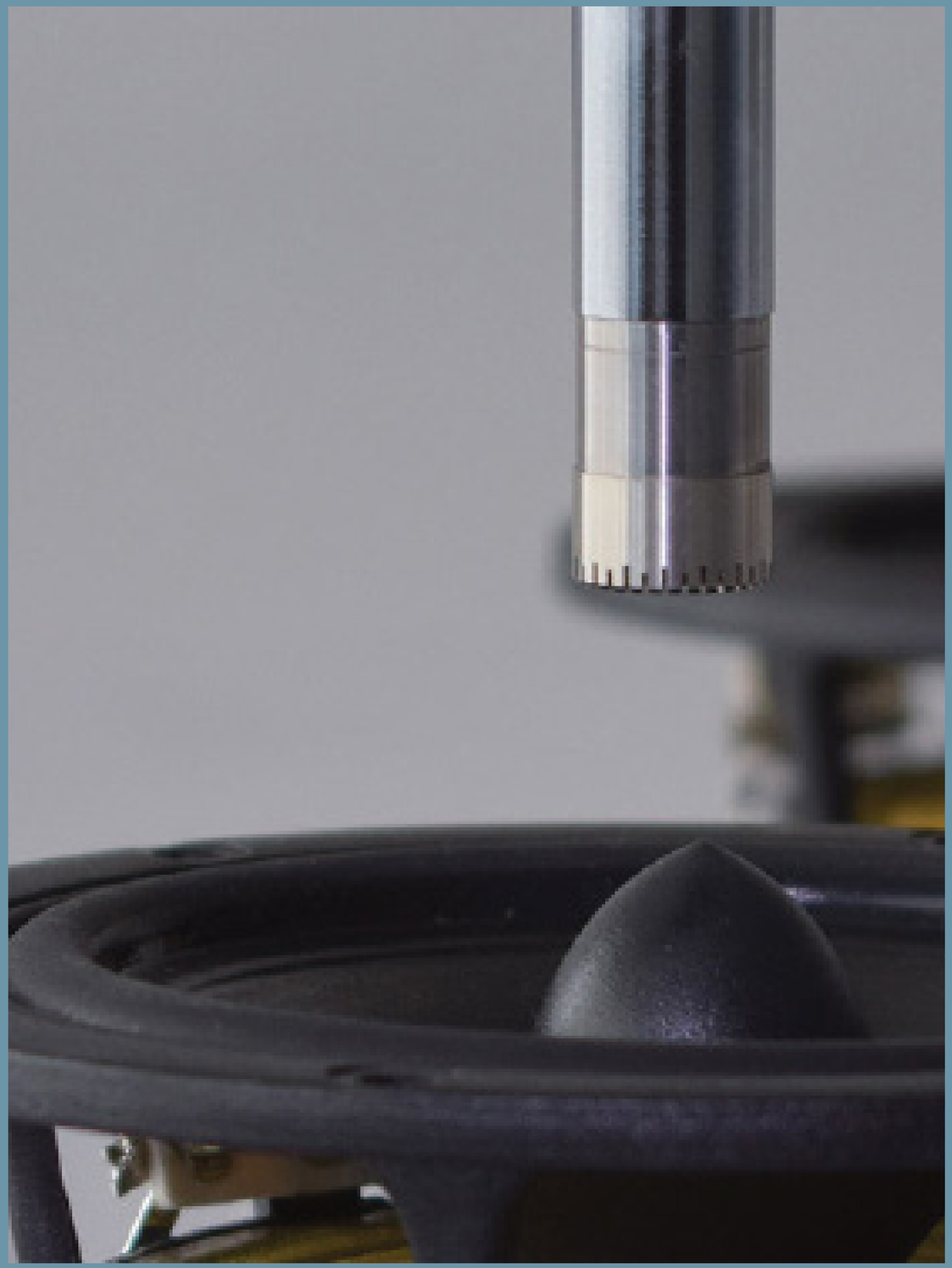


FIGURE 74. RENDER OF FINAL DESIGN WITH BLACK DETAILS

10
RECOMMENDATIONS

10.1 NEXT STEPS

Acoustics
The acoustics of the final design have been based on a previous technical prototype, but have not been verified with measuring tests. Acoustics have been evaluated using theory as advanced optimising of the sound performance was out of the scope of this project. However, making the prototype functional to perform listening tests and response measurements will likely identify challenges that will not be found otherwise.

Some problems are already identified and should be addressed before performing the measurements. The dampening of the aluminium back panels should be further looked into as it is expected that they start vibrating when music is reproduced, resulting in unwanted noise. To be most effective, the material used for damping should be targeted at reducing vibrations caused by the aluminium panels' vibration at their resonant frequency. Moreover, the space between the back panels, roasters and the low-mid driver mounted at the rear of the speaker should be simulated. This small encores visually hides the rear low-mid driver and although it is designed to be acoustically open,it is a small compartment and pressure build up can happen. This aspect is taken into account with the design of the roaster and curve dimension, but further evaluation is necessary. Evaluating the pressure build-up in this compartment is also useful for assessing vibrations of the rear aluminium panels.

Parts, assembly, and transportation
Connections of threaded inserts are proposed for connecting the stand to the speaker cabinet. However, the exact position and dimensions can be further optimized to improve ease of assembly and make installing the speaker stands at customers' homes more straightforward. Furthermore, the roaster's connections to the cabinet and the front baffle can be optimized for better fixation, improving the overall product experience.

The heat created by the amplifiers is not quantified yet, and adding a large heat sink is proposed. The dimensions of this heat sink and the necessity of active cooling are not further researched. Overheating amplifiers will have a shorter lifespan and can even result in dangerous situations. Therefore, amplifier heat-up should be taken seriously when continuing with a fully functional prototype.

The initial Sound Pressure levels are not reached because of multiple limitations. The setup must be optimized if it is still desired to reach the initially set SPL. A subwoofer channel with a higher load impedance means a more powerful amplifier can be used. For the mid-driver, the maximum power rating is a bottleneck for a higher SPL. Choosing a more efficient driver that can cope with higher power levels is necessary for reaching a higher max SPL.

It is recommended to do a Life Cycle Assessment of the product to map the impact of each stage of the product's lifetime. Optimizations can then be made to reduce the product's impact on the planet. For example, the speaker's parts are made of materials that can be difficult to obtain, require much energy to process, and are not all recyclable. Therefore, optimizing the product's lifespan can lower the product's footprint. In addition, using standard parts where possible, offering repair, and having spare parts in stock are suggestions to maximize the product's lifespan.

The packaging has yet to be designed, and it is recommended to contact packaging manufacturers/ experts to develop the product's packaging further.

Aesthetics
The roasters and the stand are a prominent part of the design, but during this project, only limited time is spent optimizing their looks. Making the roasters a custom-made part with a unique grid pattern can elevate the product experience. A concept for the stand is proposed but lacks advanced detailing.

Furthermore, personalization options are proposed but not further explored. Experimenting with different colors and wood types can lead to new combinations that can make the design appeal to more customers. Furthermore, personalizing a product can increase customers' product attachment, making it more likely that they handle the product with care and postpone its replacement (Mugge et al., 2008).

10.2 FINAL RENDERS

FIGURE 75. DIFFERENT VIEWS OF FINAL DESIGN, BOTH BLACK AND WHITE VERSIONS ARE SHOWN

as

10.3 KEY FINDINGS

- Sound tests are necessary to evaluate the final design's acoustic performance.

- Further detailing of different part connections is needed to reduce vibrations during product use and make assembly more straightforward.

- Aesthetics of roaster and stand must be further optimized and detailed.

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A
Appendix
QUESTIONNAIRE RESULTS

Questionaire

In order to get insights into preferences regarding looks of audiophiles and their perception towards Duch & Dutch in relation to competitors, a questionnaire was made and distributed via hi-fi fora audiosciencereview.com (international audio forum) and hififorum.nl (Dutch audio forum). The questionnaire started with questions regarding the background of the respondents and their speaker setup(s) at home.

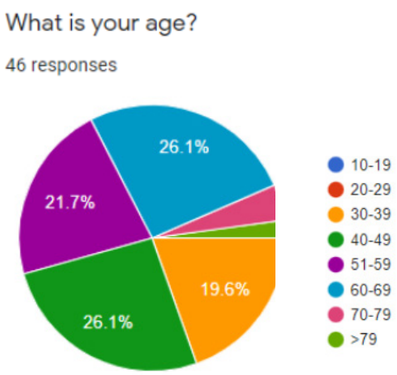
In total 46 people responded in the one week the questionnaire was online. 95.7% of the respondents were male (44 in total), the other two preferred not to disclose their gender. 93.3% of the respondents were aged between 30 and 69, all respondents were older than 30. The bottom left Figure shows the age distribution of all respondents.

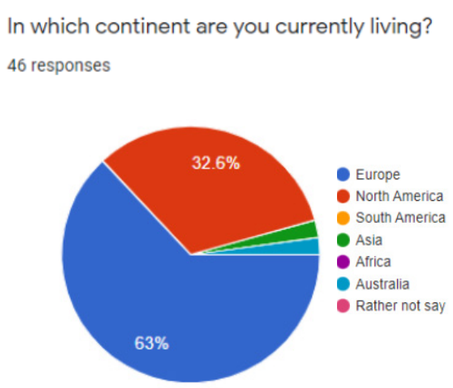
Demographic information is shown in the bottom right Figure. 29 respondents were from europe and 15 from North America, furthermore both from Asia and Australia there was one respondent.

All respondents were highly interested in hi-fi with an average of 6.3 on a 7 point scale from 'no interest' to 'very interested'. 37 people (80.5%) had a stereo setup without a subwoofer, which is the same category the 8C would be in. Two people with a stereo setup also owned a surround type setup. Seven people (23.9%) had a home theatre style surround setup with 3 or more channels and a separate subwoofer (3.1 setup or higher) and three respondents had a stereo setup with one or more separate subwoofers. 32 respondents (69.6%) had a passive setup of which one person also had an active setup. 11 of the 46 people had an active system which was either completely wireless or with different 'wired' sources attached to it. Three people (6.6%) listened mostly to headphones at home.

Knowing the speaker brand or even the specific model could have an influence on how people would rate the speakers. Most people at least knew the brand and often they also recognised the specific model shown. The brands B&O and B&W were known to every respondent. The KEF LS50 had been listened to the most, 32.6% of the respondents said to have listened to the speaker in real life. Grimm was the most unknown speaker, with 30.4% of the respondents not knowing about either the speaker or brand. Every speaker was once listened to by at least 3 respondents.

First question asked to all respondents was to rate the general looks of the speaker. The Dutch & Dutch 8C and the KEF Ls50 got the highest average ratings, they both got a score of 5.09. The Bowers & Wilkins was rated the most ugly with an average of 2.5. The total average score of all speakers was 3.8 and only the 8C and the Kii Three scored higher than the midpoint of 4.0, meaning they were regarded closer to beautiful than to ugly, even though it is only marginal. Respondents were divided about general looks on most speakers with standard deviations as high as 1.3 to 1.8 for all speakers except the Dutch & Dutch 8C, which had the lowest SD of 1.0. People were thus most uniformly pleased with its design.





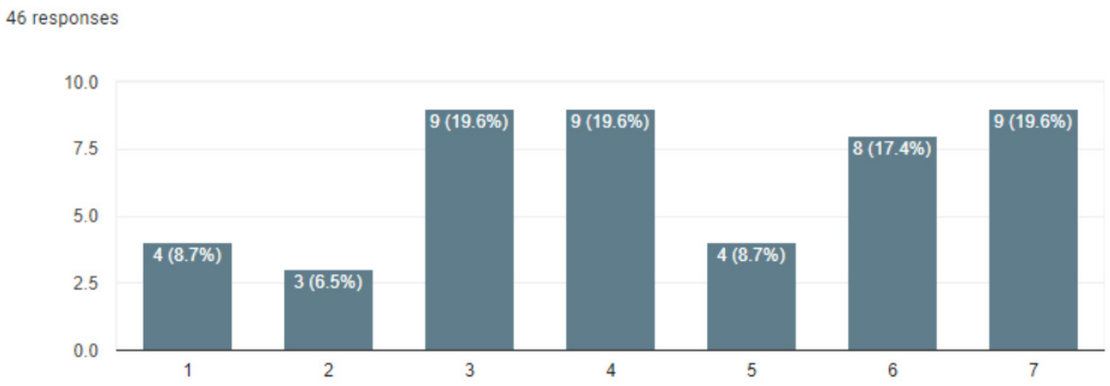
The second question of the interview was about the quality of the speakers. A difficult question as looks do not have to say anything about the quality of a speaker, but it can of course play a part in people's perception when -for example- expensive materials are used in a speaker cabinet design. 3 respondents commented that it was nonsense to ask about quality just based on looks. Answer to this question was not too different for all speakers with the Dutch & Dutch rated highest wth 5.6 and Wilson being lowest with a score of 4.6.

All speakers were on average more rated towards modern looking with an average of all speakers of 5.11 where 7 was described as modern and 1 described traditional looking. The B&O Beolab 90 was rated as the most modern looking speaker with a score of 6.1. Followed up by the Kii and the KEF, both scoring a 5.5. The Wilson and Dutch & Dutch scored low on the traditional to modern looking axis - 4.3 and 4.4 respectively-meaning that they were perceived as the least modern looking speakers of this selection.

When asked about whether a speaker's design was more toward a cold and clinical look or a warm and embracing look, the answers were far less uniform than most other questions. Exceptions being the 8C which is rated with an average of 4 -thus slightly towards the warm side- and the Wilson with a score of 2 -thus being more towards the cold looking side of the spectrum.

On average the speakers were rated as more unique and distinctive than common and indistinctive with an average of 5.0, higher meaning more distinctive. Again, the Beolab 90 was scoring highest on the 7 point scale with a 5.6, meaning it was perceived as the most unique design of all. The Dutch & Dutch 8C was rated as the most common type of speaker with a score of 4.5.

The last question was about the environment for which the speaker was designed. Respondents were asked to rate if they thought the speakers looked more as if they were only designed for professional studio use or more for a domestic living room environment. Again, the 7 point scale was used. The B&O got a score of 5.6 and was thus rated as the most domestic looking speaker. The Wilson Sascha DAW looked the most studio-like with an average score of 4.4 which is still more towards the domestic side than towards the studio side. However, the answers were not uniform, as can be seen in the Figure presented below The 8C's got a rating of 4.8 where most respondents (20 out of 46) gave a rating of 4, and thus looking at home in both astudio and a domestic environment. Interesting is that B&W has a close collaboration with the famous Abbey Road studios in London. The 800 D(iamond) series being the main speakers for the studio's sound engineers. This seemed to have little influence on the ratings.



B
Appendix
NEXT-GEN ANALYSIS

See confidential appendix x1.e

Differences compared to the design of 8C
See confidential appendix X1.f

JBL Charge
The same is done for the iconic JBL charge, the JBL charge. At the moment of writing, the fourth generation of JBL charge is on the market and to make the difference bigger, the latest JBL charge is compared to the Charge 3.

1. Less contrasting side woofer, not silver anymore, but in the same colour as body.
2. Thinner 'hard' plastic edge' and changed from hard plastic to rubber material
3. Cloth surrounds instead of hard plastic.
4. Interface simplified, focus on on/off switch and bluetooth connect button, volume controls more subtle, Usage has moved towards changing volumes on mobile phone
5. Cloth hole sizes are bigger, a coarser look.
6. Logo changed from orange square to outlined text in colour of the product.
7. Outer shape is more curvy and forms a more coherent whole. The silhouette of the speaker is one smooth line.
8. Outer edge of the harder plastic material has gotten a less smooth shape
9. Harder plastic material and cloth are flush, more smooth transition making the cylinder shape one surface.

B&W Headphones

1. Leather headband replaced by cloth
2. Metal shiny hinge changed to matte hinge that is visually more similar to bottom part of headshell attachment
3. Headshell attachment is also changed to matte plastic
4. Shape is oval instead of a rounded rectangle
5. Leather on headshell is also replaced for cloth
6. No stitches/seams visible, smooth headband
7. Headshell attachment is made out thick and solid material instead of thin metal tubes
8. Simplified ear pad surface instead of double rounded it is now chamfered.
9. Transition from square shaped to round shapes also applied at the ear padding, it is a more round tube at the inside of the headphones
10. Less small details in total, more calm look and simple shapes used.

Logitech Master series computer mouse

1. The front side of the two main buttons on the mouse are flat with rounded edges instead of the more pointy first gen model.
2. The sharp looking edges are also removed at the side of the product, here Logitech has also chosen to make a more curvy and round line.
3. The third generation is not divided by a midline anymore at the topside. In the newer model, the top surface is one smooth surface
4. The transition area between top and side is more simplistic with a half round shape instead of the more complex shape of the older model.
5. The pattern on the side has changed. The geometrical complex pattern is gone and the new Logitech mouse just has straight lines at its side.

Logitech Master MX 1

Logitech Master MX 3

C
Appendix
HARRIS PROFILE

Dutch & Dutch design
As all speaker renders show the design in similar materials, seeing to what degree the designs are' 'typical Dutch & Dutch' is possible. Concept 1 differs a lot compared to the looks of the 8C and 6C designs mainly because of the different-looking front baffle in combination with the large wooden side panels that bend towards the front. Concept 2 has an overall shape that is close to 8C and 6C. The square main body is in line with the looks of these speakers. The shaped top curve, together with the remarkable rear vent, differs from what Dutch & Dutch is currently doing. Concept 3 has a front baffle that curves towards the sides at the top of the speaker. This is a detail that is also present on the 8C, but it is exaggerated in this concept. The smooth back line is unique and not directly derived from current Dutch & Dutch designs.

High-end / luxurious looks
This criterion is subjective; however, the overall shape and detailing determine this mostly at this point. The shape of concept 1 is most basic, and detailing as the spacers and wooden panels bend around the front side were added to give it a distinctive look. However, distinctiveness did not result in a high-end or luxurious-looking product in this case. Concept 2's bent top line is subtle and adds complexity to the overall shape that leans more towards luxurious than concept 1. The detailing is a bit too rough at this moment, but when done properly, the rear vent can be a stylish aspect of the aesthetics contributing to a luxurious look. Concept 3 is aesthetically the most elegant of the three and is distinctive and high-end looking, in my personal opinion. The detail of the rear curve and the unique front baffle make this concept score highest on this criteria.

Ease of assembly
The large wooden parts in concepts 1 and 2 will be heavy and, therefore, more difficult to handle during the assembly. Concept 1 has smaller wooden panels, but the front baffle requires caution when handling, making its assembly also more complex. The large front baffle can also be slightly more difficult to connect, and that is why this concept scores slightly lower on ease of assembly.

Ease of parts production
Concept 1 is the easiest one to produce, the large wooden panel will probably not be a problem, and the baffles are easier to manufacture than the ones from the other two concepts. Concept 2 will give some difficulties regarding the larger front baffle; the rear baffles can easily be divided. The bent wooden top will be more challenging to produce, making it score lower than concept 1. Concept 3 has a very difficult front baffle, although the smaller wooden panels, the straight-forward rear side, and the top cover will not provide many difficulties regarding manufacturing.

Expected difficulties with tolerances
Larger parts have more tolerance difficulties. Wood can be especially difficult to work with as it is a natural product that can expand and shrink in changing environments. This has mainly to do with humidity levels. The large wooden panels of concepts 1 and 3 can cause problems regarding the perfect fitting of components. This is an important aspect of such a luxurious product as the product price thus does not

allow for cheap-looking faults caused by too high tolerances.

Accessibility of critical parts
The first concept has a smaller front baffle that can also be split into multiple parts, making it the easiest one of the three to access the speaker drivers at the front. On the backside, the same is true, although it is similarly easy to access the rear driver in concept 2 and even easier in concept 3 because no rear baffle is present in this design. The electronics in all designs can be placed at the bottom, which is most convenient for the exterior cable connections, or in the cavity behind the tweeter. Accessibility, when placed at the bottom, can be given an equal score for all three of the concepts if the electronics are placed at the bottom of the speaker. When placed behind the tweeter, this is also the case as all concepts have a rear baffle that needs to be removed in order to access this part of the body via the back of the speaker.

Transportation of the 8C now happens via euro pallets. This is not cheap, but a good way to ensure the speakers survive international transport without damage. The dimensions of a euro pallet are 1200x800mm, and the maximum height of transported product can be 2200mm. The height of all speakers is about 1400mm and includes parts that are vertically larger than 1200mm. In concepts 1 and 2, these are the wooden side panels. In concept 3, the front baffle has the total height speaker. These parts will have to be transported vertically as the speakers will have been sold as stereo pairs. Two speakers per pallet are desired. With a floor surface of around 300x500mm, this must be possible for all speakers if 200 mm per axis is added for stuffing and packaging. The total space per speaker, if transported as one piece, will be 500x700x1600mm. Two speakers standing next to each other -with facing side panels will add up to 1000x700x1600. This definitely fits onto a euro pallet. Leaving space on the pallet (at least 500x1000x2200) to add speaker stands onto the pallet. Speaker 3 makes the most efficient use of the space, which makes it easier to create correct packaging within the given space. Concept 2 is the least space efficient, and concept 3 is somewhere in between the other two concepts. The concept all has parts that require special attention when transporting. For example, the wooden panels in concept 1 need special care, just like in concept 2. Although the large baffle of concept 2 is also critical. In concept 3, it is mainly the front baffle, as the wooden panels are slightly smaller compared to concepts 1 and 2.

Possibility for personalization
Details matter for a costly product like this, and having a choice in the materials, colors, and finishes are important for offering a customer exactly what he or she wants. Customization is possible for each concept, but the baffles will probably be the easiest to give a specific look by changing materials and finish. The wooden panels can be made out of different wood or finish, but the possibilities are limited. The baffles are easier to personalize. Concept 3 has a large baffle that makes changing its overall appearance effectively easy. The vents at the rear side that are present in concepts 2 and 3 also provide a good detail that can be changed according to the user's preferences.

Expected cost price
Speaker drivers and electronics will be similar for all concepts. The difference in cost price will be determined because of difficult parts.

D

APPENDIX
EVALUATION FORM PHYS. PROTOTYPE

DUTCH & DUTCH

This is a prototype of a new high-end speaker concept designed for the Rotterdam-based company Dutch & Dutch. It is an all-in-one active speaker, meaning that after plugging in the power chords, you can immediately start listening to your favorite music using wireless streaming. It can also be connected to your other audio gear, like for example a turntable.

Before diving into the innovative technology of this speaker, which element of its looks catches your attention first?

TECHNOLOGY

This speaker is a directional speaker, making use of cardioid technology. This means that the speaker reproduces sound in a focused manner as most of the sound's energy is directed straight to the listening position. This way, you are only listening to direct sound and not to the room boundary reflections. The focused cardioid radiation pattern is achieved by making use of delayed anti-phase noise that is reproduced at the four rear-mounted speaker drivers. Because of the long wavelengths of mid- and especially low frequency-sounds, these frequencies radiate omnidirectional through a room. In fact, you hear these frequencies equally loud no matter if you are positioned in front or behind a traditional speaker. These non-focused soundwaves bounce against the front and side walls of a room and will reach the listeners ears milliseconds later than the direct sound. This new speaker-concept eliminates the soundwaves that 'bend around' the cabinet by using anti-noise, resulting in a much more directional sound at all frequencies.

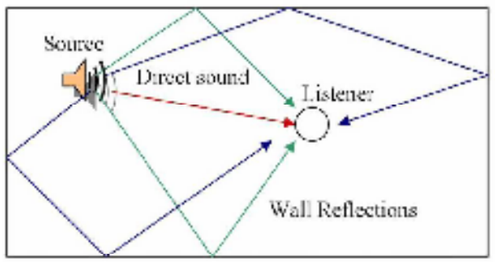


Figure 2: When listening to conventional speakers, you listen to the direct sound together with all in-room reflections

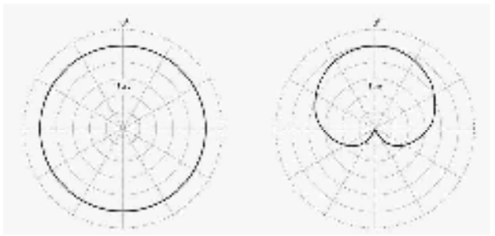


Figure 1: Omnidirectional radiation (left) versus Cardioid radiation (right) pattern of sound

Which design aspect(s) of the speaker do you <u>like</u> most?

Which design aspect(s) of the speaker-prototype do you <u>dislike</u> most?

Which words do you associate with/would you use to -describe the looks of this speaker?
(+/- 2-5 words)

You have seen the prototype and heard about its technological working principles, What would be your estimate on the price of a pair (thus in total two) of these speakers?

For whom do you think this speaker is designed, what is the target group like?

There will be customization-options offered to customers to make the speaker more according to their personal preferences. If every aspect regarding the looks could be adjusted/ personalized, what would you change or add to this setup?

Is the stand in line with the rest of the design?

UGLY O O O O O O O **BEAUTIFUL**

E

APPENDIX
BoM & COST PRICE CALCULATIONS

DUTCH & DUTCH

2022 Graduation Pepijn Gerritsen BoM new speaker design Dutch & Dutch
Bill of Materials

Item	Description	Material	Source	#	Unit Price	Total Price
Subsystem 1: Structural cabinet	Side panel left	Solid european oak	Multidesk	1	€50.00	€50.00
	Side panel right	Solid european oak	Multidesk	1	€50.00	€50.00
	Sub bottom panel(hor.)	Multiplex Birch	Multidesk	1	€3.50	€3.50
	Sub stiffnes suport panel (hor.)	Multiplex Birch	Multidesk	4	€3.50	€14.00
	Low mid bottom panel (hor.)	Multiplex Birch	Multidesk	1	€3.50	€3.50
	Low mid top panel (hor.)	Multiplex Birch	Multidesk	1	€3.50	€3.50
	mid bottom panel (hor.)	Multiplex Birch	Multidesk	1	€3.50	€3.50
	mid top panel. (hor.)	Multiplex Birch	Multidesk	1	€3.50	€3.50
	Sub partition panel (vert.)	Multiplex Birch	Multidesk	1	€3.50	€3.50
	bottom front panel w/woofer cutout (vert.)	Multiplex Birch	Multidesk	1	€3.50	€3.50
	Back panel w/woofer cutout(vert.)	Multiplex Birch	Multidesk	1	€3.50	€3.50
	Low mid partition panel (vert.)	Multiplex Birch	Multidesk	1	€3.50	€3.50
	tweeter support panel (vert.)	Multiplex Birch	Multidesk	1	€3.50	€3.50
	mid rear panel (vert.	Multiplex Birch	Multidesk	1	€3.50	€3.50
	Top front panel with woofer cutout (vert.)	Multiplex Birch	Multidesk	1	€3.50	€3.50
	Top inner side panel with cardioid cutour (vert.()	Multiplex Birch	Multidesk	2	€3.50	€7.00
	Threaded inserts			58	€0.20	€11.60
	Glue			1	€10.00	€10.00
	Labour CAD drawing/machining/assembly	(hours)	*Multidesk*	5	€40.00	€200.00
	Transport to Dutch & Dutch			1	€30.00	€30.00
					Subtotals:	€414.60
Subsystem 2: Front Baffle	Front baffle	composite marble		1	€300.00	€300.00
	threaded insert m8	Stainless steel		12	€0.20	€2.40
	M8 bolts	Stainless steel		12	€0.05	€0.60
	Washer	Stainless steel		12	€0.05	€0.60
	Logo assembly			1	€5.00	€5.00
	Metal roasters with wool			4	€3.00	€12.00
	Labour by front baffle manufacturer			10	€5.00	€50.00
	Transport to Dutch & Dutch			1	€50.00	€50.00
					Subtotals:	€420.60
Subsystem 3: Rear panels	Rear panel	Aluminum		1	€5.00	€5.00
	low-mid panel	Aluminum		1	€5.00	€5.00
	top panel	Aluminum		1	€5.00	€5.00
	threaded inserts	Stainless steel		12	€0.20	€2.40
	m6 bolts	Stainless steel		12	€0.15	€1.80
	Labour by aluminum manufacturer	(hours)		1	€20.00	€20.00
					Subtotals:	€39.20
Subsystem 4: Speakers and Electronics	Wavecore woofer	-	Wavecore	8	€54.00	€432.00
	Seas mid driver	-	Seas	1	€47.00	€47.00
	Seas tweeter	-	Seas	1	€32.00	€32.00
	Airtight cable guiding plate	Stainless steel		3	€1.00	€3.00
	Airtight cable connector PCB	-		2	€2.00	€4.00
	Sleeved signal and GND cable long F-spade	Copper + rubber		5	€2.00	€10.00
	Sleeved signal and GND cable short F-spade	Copper + rubber		5	€2.00	€10.00
	Sleeved signal and GND cable short Piggyback				€2.00	€0.00
	Gasket per three speakers	foam		3	€1.00	€3.00
	L-pro amplifiers 2 x	-	Pascal	2	€225.00	€450.00
	La-2 amplifier ext. module		Pascal	1	€70.00	€70.00
	Acoustic delay material	Foam	Akotherm	2	€250.00	€500.00
	DSP electronics	-		1	€170.00	€170.00
	Beaglebone			1	€60.00	€60.00
	Metal casing for electronics anti-EMI	Aluminium		1	€15.00	€15.00
	Bolts	Stainless steel		58	€0.15	€8.70
	Ethernet cable short	Copper + rubber		1	€1.30	€1.30
	Ethernet cable long	Copper + rubber		1	€1.85	€1.85
	XLR short	Copper + rubber		1	€1.00	€1.00
	Power cable short	Copper + rubber		1	€1.00	€1.00
	Power cable long	Copper + rubber		1	€0.86	€0.86
	Ribbon calble			1	€0.20	€0.20
					Subtotals:	€1,820.91
Subsystem 5: Stand	Casted Stand	Composite marble		1	€250.00	€250.00
	Labour			2	€5.00	€10.00
	Transport to D&D			1	€25.00	€25.00
	M8 inserts	Stainless steel		1	€0.20	€0.20
	M8 bolts	Stainless steel			€0.15	€0.00
	Washer	Stainless steel		1	€0.05	€0.05
	Connectors case				€0.00	€0.00
					Subtotals:	€285.25
Subsystem 6: packaging and assembly	Wooden body			1	€150.00	€150.00
	Foam material			1	€20.00	€20.00
	Steel plates for roof pulley mounting			2	€5.00	€10.00
	Assembly labour hours			5	€30.00	€150.00
					Subtotals:	€330.00
Unforeseen Expenses	10%					**€289.60**
Manufacturing cost price					**Totals:**	€3,885.41

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APPENDIX
PROGRAM OF REQUIREMENTS

	#	REQUIREMENT	VALIDATION METHOD	VALIDATED?
Sourcing				
	1	If wood is used, it should be sourced from FSC suppliers.	Ask multidesk	
	2	Collaboration with local companies should be preferred, and at least 50% of the parts should be from companies in the Benelux.	Not possible now - include recommendations	
	3	Plastic parts should be of at least 50% recycled material.	Not possible now - include recommendations	
	4	Metals used in the exterior of the product should be 100% recycled. Electronics are thus not included, as the influence of Dutch & Dutch on their suppliers is only small.	Not possible now - include recommendations	
Manufacturing				
	5	Wooden cabinet must be evaluated and optimized by Multidesk	Talk with Multidesk	
	6	Manufacturing processes should be suited for small batch production quantities, suited for 100 up to a 1000 pieces (50 to 500 stereo sets)	Check sources and experts on possible manufacturning processes	
Assembly				
	7	Two persons should be able to assemble the speakers in such a way that it is ready for delivery.	Verify with prototype	
	8	Subassemblies that need lifting for assembly can way 30kg maximum as this is the maximum to lift by a person according to EU norms.	Scales / SolidWorks	
	9	Customization of colors and material looks should be possible, at least five different possible combinations f colors should be possible for buyers.	Include recommendations	
Distribution & installation				
	10	It must be possible to transport and install the loudspeaker with two persons, using standard transportation/logistics tools and machines.	Verify with prototype	
	11	The manufacturing cost price of the product should be lower than €12.500,-	Elaborate BoM and recommended sourcing	
	12	Transportation should be possible on a euro pallet. 1200x800mm	Come up with concept/recommendatons for packaging	
	13	Buying the speakers should mean that they are delivered to any address, unpacked, installed, and set up in cooperation with someone from Dutch & Dutch and even adjusted/tweaked afterward according to the buyer's preferences, all included in the buying price.	Include recommendations	
	14	Custom packaging should ensure the speaker can be shipped anywhere in the world without damaging the speakers both functionally and aesthetically.	Come up with concept/recommendatons for packaging	
Maintenance				
	15	The speakers should be built to last; all hardware components should survive 30 years of use with occasional service and maintenance.	Ask device of D&D experts	
	16	There should be a lifetime warranty for first buyers; exceptions are when speakers are transported or mistreated.	Include recommendations	
	17	It should be possible to change each part individually. If parts fail, spare parts should be available for the entire lifetime of the product (30 years)	look at BoM and Prototype	
	18	Cleaning should be possible by the user, and it should be described in the manual how to clean and maintain the speakers.	Include recommendations	

Use			
	19	(Active) cardioid sound pattern implemented for the frequencies lower frequencies (<200Hz)	proven by acoustical prototype
	20	The product should be a six-way speaker with crossovers around 100Hz, 200Hz, and 1250Hz. The Woofers and low-mid channels will both have an anti-phase duplicate to accommodate the cardioid pattern.	proven by acoustical prototype
	21	Passive cardioid sound pattern for mid-frequencies (200-1250Hz) should work according to the same principles as in the 8C.	proven by acoustical prototype
	22	At low frequencies (<200Hz), the SPL should increase with at least >6 Db (4 times louder)	proven by acoustical prototype
	23	-	proven by acoustical prototype
	24	Waveguide and tweeter should work similarly to the 8C, resulting in a constant directivity pattern.	proven by acoustical prototype
	25	The speaker must be active, meaning it has built-in amplifiers (class-D), DAC, and streaming options.	proven by acoustical prototype
	26	The product should have a linear frequency response from 20Hz up to 20kHz with a max deviation of +/- 1.5 dB	Theoretical analysis using WiniSD
	27	Materials/colors should be able to be changed according to customers' preferences.	Already proven by acoustical prototype
	28	The new product should fit in Dutch & Dutch current product portfolio and match the look & feel as determined in the design language.	Enquete v2
	29	The new design should not be an enlarged version of the 8C	Enquette V2 - physiscal
	30	Looking at the design should be enough to guess its high-end nature	Aesthetical eval. of prototype.
	31	The product should be optimized for use in domestic environments	Aesthetical eval. of prototype.
	32	The product should be controllable from the listening position (Volume control, input switching)	Make it compatible with controller and software
	33	The product must accommodate digital and analog inputs	SolidWorks model
Reuse			Already proven by acoustical prototype
	34	Online product registration should be promoted, for example, with an extended warranty. To keep insight in the location and owner of the speaker.	Include recommendations
	35	Keeping in contact with the customers - for example, by giving them a yearly call- is necessary to ensure the customers are still satisfied with the speaker and to limit the number of speakers that are thrown away or kept in storage because of a defect. Dutch & Dutch buying the speakers customers want to get rid of should also be an option. Reselling these speakers refurbished is a way to ensure minimal precious materials are thrown away.	Include recommendations
Disposal			
	36	Staying in contact with users is essential to ensure the speakers stay in good working condition.	Include recommendations
	37	It must be possible for users to register the product to keep track of the products all over the world.	Include recommendations

KEY FINDINGS