Why hide it?

Reimagining the role of urban edge computing in an AI-inspired, human-embodied manner.

Anya Pozniak | Master Thesis | September 2024
Integrated Product Design | Delft University of Technology

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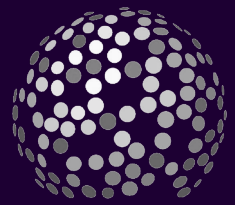


Anya Pozniak

Graduation Master Thesis

Discover Phase

Design Phase

Supplements

Abbreviations

CAPEX | Capital Expenditure

EMDC | Edge Micro Data Center

JBTD | Jobs to be done

MEC | Mobile Edge Computing

MCO | Mechanical Components Outline

LHP | Loop Heat Pipe

OPEX | Operational Expenditure

PEaaS | Powerful Edge as a Service

STP | Segmentation, Targeting, Positioning

USP | Unique Selling Proposition

Introduction

The title of this graduation thesis, “Why hide it? Reimagining the role of urban edge computing in an AI-inspired, human-embodied manner,” reflects the main focus points and results of this project. The client, HiroEdgeMicroDataCenters B.V. develops software and hardware solutions for edge micro data centers (abbreviated EMDC), came in with a speculative idea of rethinking the role of edge infrastructure in the environments they are placed in. Current technical infrastructure (Figure 1, left most) contributes to visual ‘pollution’ reinforcing discomfort and stress. The public is calling for alternative solutions to integrate technical infrastructure, focusing on enhancing the aesthetics and functional aspects of community environments. This call is timely and pressing as various technological developments necessitate large-scale introduction of edge equipment into data-generating hotspots, such as city centers. Hiro was in search of a timeless EMDC enclosure design that would not be perceived as visually disturbing technical pollution, but rather enhance the aesthetics and appeal of buildings and public spaces they are placed in while also serving as a statement of their brand identity.

The project consisted of two major parts: the Discover and Design phases. In the Discover phase, research activities pertaining to the original project brief led to reframing it into a problem and vision statements. Initial research also included an analysis of internal hardware, product interaction, and client brand identity, resulting in a comprehensive list of preliminary performance and aesthetics requirements. The project then moved into the Design phase, which consisted of two main design moments. The first moment focused on defining the macro form factor that would create a timeless design that reflects the identified brand identity. Perhaps the most distinctive element of the search for the desired macro form factor was its co-creation with the generative AI tool, MidJourney. The first moment resulted in down-selecting an inspiration image for the desired macro form factor aesthetic. During the second and final design moment, the shape from an inspiration image was put against various requirements and feasibility constraints to detail it and turn it into a Hiro EMDC. The result, consisting of a concept board and the CAD model, presents the first embodiment and iteration of the Hiro EMDC enclosure concept, accounting for its aesthetical and functional aspects respectively. Figure 1 showcases snapshots of the major outcomes along the design process.

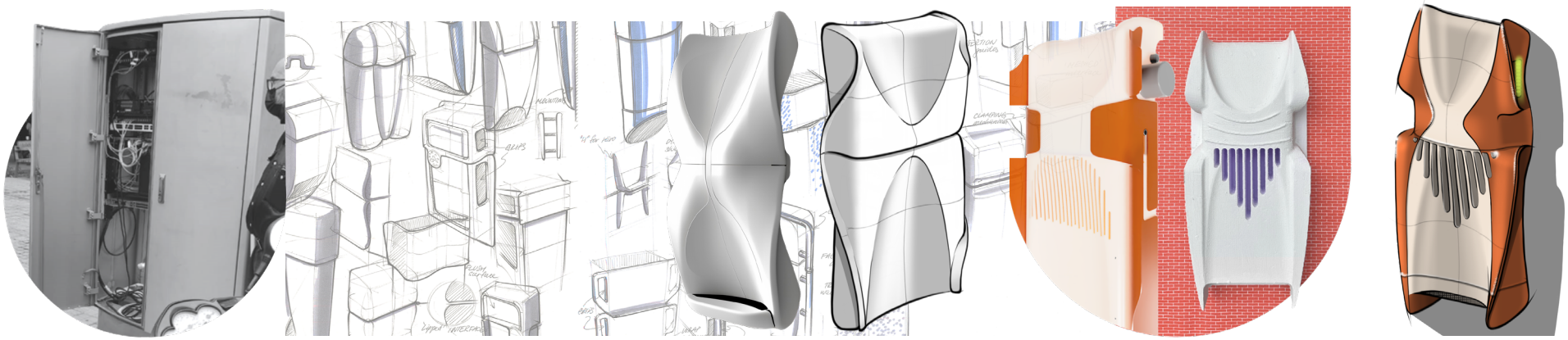


Figure 1 - Snapshots of the major outcomes along the design process.

Anya Pozniak | Master Thesis

Discover Phase
Stage 1.0

Why hide it? Reimagining the role of urban edge computing
in an AI-inspired, human-embodied manner.

Data centers, their main components, and the role they play

What do ongoing developments such as smart cities, autonomous driving, and smart energy grids have in common? They will have many intelligent devices collaborating, exchanging data, and using AI to act on it. That amount of data and interaction requires nearby cloud services support that runs on powerful computing hardware. Data centers can be compared to the central nervous system of the Internet as they provide centralized computing resources in the form of hardware and software for data storage and application hosting required by modern technical systems. Data centers range from rooms of a few square meters in office buildings to facilities that take up hundreds of thousands of square meters (the largest data center to date, Figure 1, measures around 1 million square meters (or 223 soccer fields) in its land use (CadLan, 2023)).

Figure 1 - Inner Mongolia Hohhot Cloud data center zone, aerial view (NewWIT Blog, 2016).

The main components of a data center are as follows (Sunbird DCIM, n.d.):

- **Servers** | Servers act as primary computing devices that process and store data. Servers bundle up CPU, RAM, hard drives and SSD, networking components (NICs and switches), and other cores based on client workload requirements.
- **Storage systems** | A component that is responsible for storing vast amounts of data.
- **Networking equipment** | This component comprises of routers, switches, and firewalls that facilitate communication between servers and clients.
- **Cooling and power systems** | These systems deliver the electricity that data centers need for their operation and ensure that the components operate at the same temperatures.
- **Security measures** | This component includes access controls, encryption, and surveillance systems.

While centralized computing resources like data centers are the backbone of modern computational needs, several drawbacks call for alternatives, such as localized edge data processing (Sharma, 2024), (Sunbird DCIM, n.d.-a):

- **Data latency** | Data latency refers to the delay or lag in the transmission and processing of data within a computer system or network, caused by the distance between the receiver device and the centralized data center. Data latency is especially detrimental for applications requiring real-time processing or low-latency responses, such as IoT, gaming, and autonomous vehicles. Edge computing brings computing resources closer to the point of data generation and consumption, thus reducing latency.
- **Bandwidth consumption** | Centralized data centers rely on network connectivity to transmit data between the user and the centralized servers. High volumes of data transmission can strain network bandwidth and increase costs. Edge computing offloads data processing and storage tasks to local edge servers and edge data centers, reducing the need for extensive data transmission to centralized data centers. This conserves network bandwidth and lowers operational costs.
- **Reliability & redundancy** | Centralized data centers can essentially become single points of failure (as in a recent Microsoft Azure outing that caused disruptions in airline, bank, and stock exchange operations worldwide, Figure 2 on the next page), where a disruption in one location can impact the entire system. As a mitigation strategy, centralized infrastructure often has high availability and redundancy, which is often complex and costly. In contrast, edge computing distributes computing resources across multiple edge nodes, increasing resilience and fault tolerance.

- **Data privacy & compliance** | Centralized data centers have raised concerns over data privacy and compliance, especially when sensitive data is transmitted and stored in a centralized location. To mitigate this risk, in some cases, regulatory requirements restrict data residency or impose data sovereignty requirements. Edge computing allows for localized data processing and storage, keeping sensitive data closer to its source and minimizing the need to transmit data over public networks.

- **Scalability** | Centralized data centers are often built at scale, requiring significant upfront costs and infrastructure (electricity, water, land) upgrades and have substantial lead times. Edge computing provides a more scalable and fine-grained hardware architecture by distributing and embedding smaller data centers across the edge of the network close to data-dense environments. New edge data centers can be deployed incrementally to meet growing demand, providing a more agile and cost-effective approach to scalability.

The client company

Hiro MicroDataCneters B.V. (Figure 3) was founded in Voorburg, the Netherlands in 2017 by Fred Buining when he foresaw the necessary transition of computing away from centralized facilities to edge-cloud computing infrastructure, specifically EdgeMicroDataCenters (EMDCs), that allow big data and AI applications to be supported locally. Hiro is currently a company of 19 software developers and designers who primarily focus on developing innovative edge-cloud services and EMDC hardware. Their hardware development is done by specialized 3rd parties in Europe. Hiro is currently engaged in 8 European R&D funded projects (total value 64M

Figure 2 - July 2024 Microsoft Azure outting caused chaos across many travel modes; air passengers worlwide were stranded in airport with their flights being canceled or delayed (Corfield, 2024).

Figure 3 - Hiro company logo.

Euro) in which innovative software and hardware are being developed with industry (Dell, Intel, Micron Technology, Broadcom) and academic partners, including various leading universities and research centers. Hiro is regarded as the leading European innovative edge-cloud computing company with a technology strategy that fully aligns with Europe's vision of digital sovereignty.

Big Cloud providers' success is based on providing cloud computing services and hardware 'as a service.' Hiro's strategy is to develop a similar offering that they coin 'Powerful Edge-cloud Computing as a Service' (PEaaS) that will now be designed for the typically distributed edge environments. PEaaS is a fully portable and complete 'turn-key' solution of hardware and software that does not require a server room for installation or trained personnel to maintain them. The company's entry-level EMDCs capacities range from 1.8 to 5.6 kW, an equivalent of a containerized rack of legacy servers that has been packed into a thin mini-fridge-sized form factor through an innovative approach to hardware design. EMDCs' compactness and energy efficiency are based on small form factor industrial servers (Com Express and Com HPC, Figure 4) allowing simple installation on walls and masts, while the solution being solid state (no moving parts) implies that it requires little to no maintenance. Scalability is software-enhanced, meaning that when more capacity is needed another EMDC is shipped to a client and installed by them, while the capacity is automatically absorbed in the edge cloud services. According to Hiro, obtaining computing resources through PEaaS provides the following advantages over centralized computing resources:

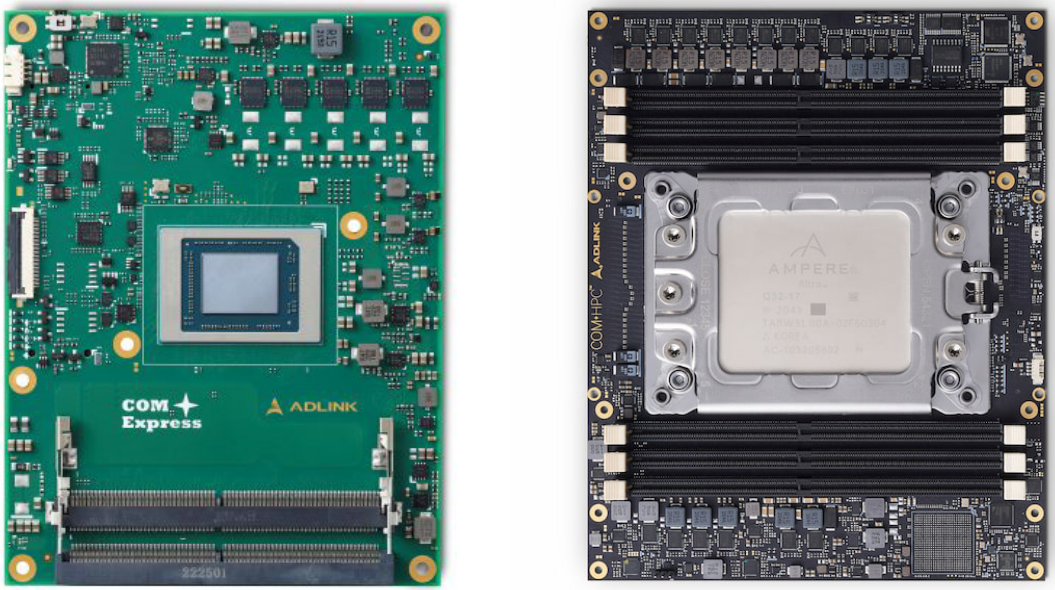


Figure 4 - ADLINK COM Express (left) and COM-HPC (right) servers (ADLINK, n.d.).

- **Decreased CAPEX** | Low start-up costs, grow as you go, buy or lease
- **Decreased OPEX** | Subscription-based support services
- **Increased resilience** | EMDCs in a mesh have no single point of failure
- **Increased deployment** | Fast deployment and scaling
- **Increased security** | Modularity and compartmentations
- **Digital sovereignty** | Over Data, AI, Applications off-premise cloud

Innovation for sustainability, modularity, and customization are at the heart of Hiro's offering. Hiro will first help their clients assess their computing needs and offer an optimal compute node combination (CPU, GPU, etc.) and capacity. After purchasing or leasing Hiro's EMDCs, the company will be monitoring their performance remotely, catching any issues ideally even before the client notices them.

WWWWWH

I've been tasked with the challenge of desig-

ning a customizable data center enclosure that reflects Hiro's innovative spirit and that adapts to various environments it'll be placed in, while also serving as an aesthetics statement. The initial project brief asked me to focus on complying with various requirements posed for the enclosure by the internal electronic components while keeping the solution at a conceptual level when it came to requirements coming from the data center environment outside.

To create a holistic problem overview, I utilized the WWWWWH framework.

WHO |

Who has the problem?

Figure 5 presents a list of stakeholders involved in the problem. Stakeholders that were believed to have a stronger, more immediate interest were placed on the top, and the problem's importance for stakeholders diminished towards the bottom of the table. The stakeholder interests and problems are further discussed below.

Hiro

Companies/industries with computing needs
- IT leadership
- IT specialists

Hiro's competitors
- Public cloud providers
- Companies developing various edge solutions

General public/citizens

City minicipalities (integration of edge)

Legislators

Figure 5 - Problem stakeholder list.

- **Organizations with high computing needs** | Industry 4.0, smart cities, healthcare, autonomous driving, smart grid, and telecommunications.
    - Applications that require real-time insights such as autonomous driving
    - Organizations that manage sensitive data as "cybercrimes cost an average of $4.35 million in 2022 for data breaches." (Stagnitto, 2024)
- **Public cloud providers** | Problems with their offerings have pushed more and more businesses to move to 'hybrid cloud' and use their offerings less.
- **General public** | While companies with computing needs are one important stakeholder, another important stakeholder is regular citizens. Currently, there's already a high number of infrastructure, especially in dense areas, that ensures connectivity, such as antennas and 5g small cells. Arguably, the aesthetics and visual appeal of these products are close to non-existent (see section 'Urban adoption of 5g equipment' below). As we move into the age of smart cities, autonomous mobility, and other computationally intensive developments that require real-time insights, the amount of edge computing infrastructure will have to grow at very high rates. Hiro estimates that we might need an edge data center as frequently as every two blocks in cities. As this infrastructure makes it into our daily city environments, citizens would have to face it daily.

Who has an interest in finding a solution?

The primary stakeholders that have an interest in finding a solution are companies and industries with high computing needs. Public cloud providers are interested in finding solutions to issues with their current cloud offerings to keep their clients using the public cloud and not continuing to shift to the private cloud. Hiro and their competitors are interested in solving the problem using an alternative way of edge computing. Municipalities are interested in finding a solution that would integrate into cityscapes seamlessly and improve people's lives. Legislators are also interested in finding solutions that offer better security.

WHAT |

What is the problem?

Every year sees an exponential increase in the computing power required by such developments as smart cities, increasingly complex IoT systems, and, most recently, AI-powered applications. Currently, there are two primary ways for an organization to store and process their data and run their applications: public cloud and private cloud.

Public cloud | Offered by big tech companies, such as Google, Amazon, and Microsoft

Benefits:

- low to none CAPEX

- relatively low OPEX (maintenance is done by the providers)
- easier scaling/upgrades

Drawbacks:

- poor data security (multi-tenant infrastructures)
- low resilience (one point of failure, especially for single cloud operations)
- high latency (especially detrimental to applications that require real-time insights such as autonomous driving)
- no digital sovereignty (data stored in public clouds can be distributed across various locations worldwide and may be stored in a country with different privacy laws, potentially exposing businesses to legal risks)
- poor workload distribution (underlying infrastructure's ability to handle sudden spikes in demand)
- variable nature of pricing models across different clouds makes budgeting difficult for businesses as unexpected charges can arise
- vendor lock-in (overreliance on a single cloud, its provider's technologies and services, can make it challenging and costly to switch to another provider or transition to hybrid or multi-cloud operations)

Private cloud | Companies have their own computing equipment that enables them to have a private cloud

Benefits:

- higher data security
- higher resilience (especially when companies have mesh infrastructure)
- low latency (computing is much closer to the data generation source)
- digital sovereignty (having full control over one's data and computing resources)
- better workload distribution and bandwidth

Drawbacks:

- comparatively very high CAPEX (floor space, necessary IT equipment)
- high OPEX (power for computing and cooling, skillful IT staff for operations and maintenance)
- current edge data center infrastructure has lower deployment and scaling capabilities compared to the public cloud

The majority of businesses nowadays rely on the public cloud, which implies having to face its notorious downsides such as poor security, low latency, poor workload distribution, and no data sovereignty. Decentralized infrastructure and private cloud, a.k.a. edge computing, solve many of the issues with using a public cloud. To be effective, however, edge equipment needs to be placed in a mesh around the area where data is generated, meaning around the city centers, potentially as frequently as every other block. However, current edge offerings (such as IP65 Server Platform by Supermicro, Figure 6) are purely performance-focused and are not designed to be introduced into the cities at scale but rather be hidden away like the current centralized server rooms. So the problem becomes how to merge this new equipment into cityscapes organically, promoting public acceptance, and perhaps even appreciation, towards them.

What has been done to solve it?

- **Organizations** have been adopting a 'hybrid cloud,' an orchestration between public

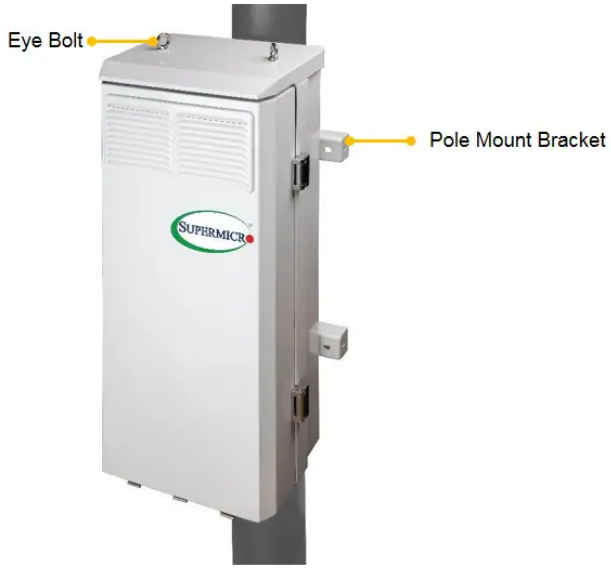


Figure 6 - One of Supermicro's IP65 Server Paltform configurations (Super Micro Computer, Inc., n.d.).

and private clouds, that gives extra security advantages (Kerner, 2019). Using a private cloud implies that an organization has a local data center.

- **Public cloud providers**, including Google, Amazon, and Microsoft, have participated in the Cloud Security Alliance to promote best practices in cloud computing (Farrell, 2023).

- For its security and low latency advantages, edge computing, and data center equipment required for it, has received much attention in recent years with the investments expected to be at $274 billion in 2025 (~64% increase compared to 2022) (Bangalore et al., 2023).

    - Companies like HPE, Dell, and Supermicro have been developing edge infrastructure starting in 2010s in response to emerging issues with public cloud.

WHERE |

Where is the problem? Where is the possible solution?

The epicenter of both the problem and the solution are city centers. They both generate a vast amount of data and computing needs, including the real-time insights requiring low latency computing discussed before. The current most feasible solution is placing computing resources closer to data generation (city centers), which is known by the term edge computing.

WHEN |

When did the problem occur?

The rise of the commercial internet in the late 1990s and early 2000s and the relatively high computational needs it required at the time marked the transition to centralized data center infrastructure for the benefits, such as service reliability. Public cloud originated in 2006 with the launch of Amazon Web Services (AWS), which was followed by Google Cloud and Microsoft Azure. Such issues with this technology as data security, regulations compliance, and vendor lock-in have surfaced shortly after. Ever-tightening regulations (GDPR and HIPAA, for example) and ever-increasing, both in number and sophistication, cyber attacks throughout late 2010s and early 2020s have continued to put pressure on organizations to find alternative solutions to their computing and data storage needs.

When should it be solved?

Pressing issues such as data security and sovereignty and certain predicted futures and concepts, such as smart cities and autonomous driving, necessitate widespread edge introduction as soon as possible. Until then, these developments would be facing significant development and implementation roadblocks.

WHY |

Why is it a problem?

- People have higher and higher standards and requirements for the cities they live in, including landscape aesthetics, telecommunication quality, access to green spaces, smart infrastructure, etc.

- These increased requirements extend to the visual appeal and aesthetics of cities as well. People expect architecture and its elements to be “beautiful, innovative, contextually sensitive, and create a sense of neighborhood identity and ownership” (Pobiner, 2020).

- A failure to adopt edge infrastructure will very likely slow down initiatives such as smart cities and autonomous driving as well as have more explicit implications on telecommunications quality and data security and sovereignty.

Why is there no solution?

- A vast array of different environmental challenges of edge deployment, including being exposed to harsh weather conditions and unwelcoming human behaviors towards them Satariano & Alba, 2020) to name a few, make designing integrated (servers, cooling, etc.) edge hardware a very complex task

- Edge computing infrastructure hasn’t yet been introduced into urban environments at a scale large enough that necessitates considering how to organically incorporate them into those environments.

- In their aesthetics and interaction, integrated edge hardware offerings by players such as HPE, Cisco, Dell, and Supermicro, seem to largely be adoptations of server racks for the edge. These solutions emphasize performance and don’t seem to acknowledge or consider the complexity that comes with introducing this equipment into people’s daily environments.

- There's a lack of innovation and imagination about how edge infrastructure can fit into and enhance public environments.

HOW |

How did the problem come about?

The problem originated with the rise of the commercial internet. This application required more advanced data storage and processing to ensure service reliability, which marked the transition to a centralized data center infrastructure. After the introduction of the public cloud, the companies started transitioning to this solution due to the benefits it offered, such low to no CAPEX costs and easier scaling. However, such issues with this technology as data security, regulations compliance, and vendor lock-in have surfaced shortly after. Seeing these developments, companies such as HPE, Dell, and Supermicro started developing edge hardware that was largely derivatives of centralized data center racks and servers. Ever-tightening standards (GDPR and HIPAA, for example) and ever-increasing, both in number and sophistication, cyber-attacks for the past 10 years have continued to put pressure on organizations to find alternative solutions to their computing and data storage needs, with many of them opting out for 'hybrid' cloud in the recent years. Finally, recent technology developments, such as autonomous driving, and modern telecommunication protocols put further emphasis on the widespread adoption of edge that provides low latency and better workload distribution benefits for these technologies.

How did the stakeholders try to solve the problem?

- **Hiro's competitors** have been launching various edge solutions; servers and micro data centers by HPE, Dell, and Supermicro among the most relevant examples (hardware) (Figure 7).

- **Public cloud providers**, including Google, Amazon, and Microsoft, have participated in the Cloud Security Alliance to promote best practices in cloud computing (Farrell, 2023).

- **Businesses** have been investing in their own computing infrastructure and transitioning to a 'hybrid' cloud, with 71% of businesses reporting using this strategy in their operations in 2023 and 4% of companies using private cloud only (Stagnitto, 2024).

- **Legislators** have been tightening data privacy regulations and standards for data storage and processing.

Figure 7 - Examples of edge offerings by HPE (Micro Datacenter, left) and Dell (MDC Micro 415, right; Dell presents the product alonside a person to showcase its size) (Revista Cloud, 2017; Dell Modular Data Centers, n.d.).

Hiro brand identity

The Brand DNA framework (van Boeijen et al, 2020) (Figure 8) was coupled with the “Brand identity platform: defining a brand’s program” framework (Kapferer, 1997) to get to the essence of Hiro’s identity as a brand. The frameworks were used during an interview on the topic with the client.

Appendix B provides the specifics of the branding identity interview with the client through the “Brand identity platform: defining a brand’s program” framework lens. In consultation with the client, 5 keywords were selected to reflect the brand identity:

pioneering

elegant

professional

empowering

assertive

The keywords were seen as North Star for the desired ‘semantic fit’ (Karjalainen, 2004) during the design process as well as for eventually narrowing down on the concept that communicates the right message (Crilly, 2005).

STP

The enclosure of a Hiro EMDC is arguably its business card and can be a powerful marketing tool when designed with the target audience in mind. The STP (Segmentation, Targeting, Positioning) framework is one of the fundamental tools in branding and marketing that helps companies tailor their offerings to chosen market segments. In the context of this project, STP framework was utilized to get a greater resolution on the exact market segments that the enclosure design will be targeting and to make sure that it appeals aesthetically within those segments.

Segmentation

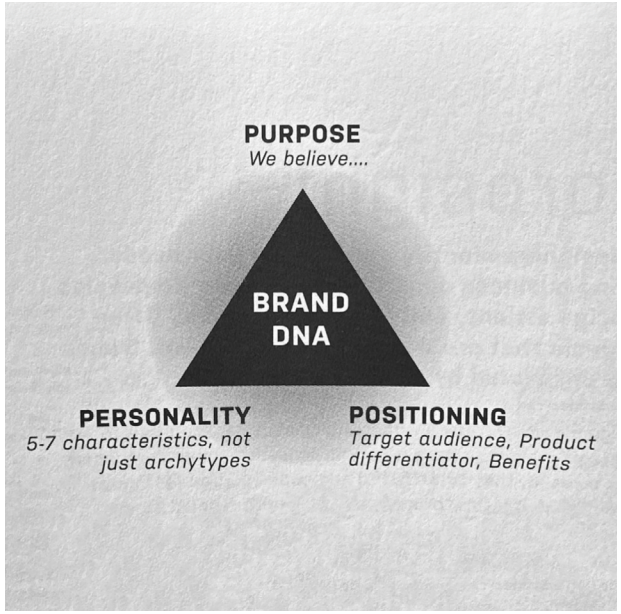


Figure 8 - Brand DNA framework (van Boeijen et al, 2014).

The first step of the framework is segmenting the overall market. To do so, the JTBD (‘Jobs to be done’) framework was utilized. Harvard Business School professor Clayton Christensen coined what is now known as the framework in the 1990s. The framework revolutionized customer segmentation through its approach to understanding why people make (purchasing) decisions they make not through demographic-based analysis, prevailing strategy at a time, but rather by looking at the ‘job’ that people needed to get done and what they ‘hired’ to achieve desired outcomes.

Arguably, the overall job customers are trying to accomplish when hiring any computing equipment is to receive, process, store, and send data efficiently and securely. Issues with the currently available computing options outlined in the WWWWWH section created a relatively new market segment with the following characteristics (outlined through the job description, the context it’s done in, and the success criteria):

- **Description** | Seamless, pain-free adoption of one’s own computing resources on or near the premise
- **Context** | Companies that are working in the domains of manufacturing, healthcare, smart cities (smart energy grid, smart traffic regulation, autonomous transportation systems (AV, UA, ATO)), and telecommunications
- **Success criteria** |
  - **Technical** | Low latency, high bandwidth, enhanced security/digital sovereignty, high resilience

- **User experience** | Seamless integration into client's existing systems; easy to use and troubleshoot; accessible and understandable system monitoring; ease of upgrades

- **Design aesthetics** | Seamless, non-disruptive integration into the client's environment and/or enhancement of aesthetics of the client's environment

In addition to the more functional description of the job to be done above, the job has the following emotional and social dimensions:

- **Emotional** | Relieving anxiety/having peace of mind, being in control, having a sense of pride.

- **Social** | How does a customer want to be seen by others/fit into social contexts? A customer would hire an edge piece of equipment to create an image of success and a progressive company. With this decision, they might also want to communicate that they are a responsible brand that prioritizes data security.

From the overall job to be done described above, different industries mentioned above can be further segmented based on their varying contexts (see details below). Figure 9 presents a context example for each industry. For each of the industries that will be described below, the 'Design aesthetics' dimension was broken down further into three categories that are explained below. All of these categories would be relevant for the customizable EMDC parts.

1. **Specific customer identity** | This category refers to the specific branding elements that a client is using, such as logo, color palette, graphics, etc.

2. **Immediate environment customization** | This category encompasses customization of certain EMDC parts to synthesize with the specific wall design that the EMDC is mounted on (brick Vs concrete wall, for example).

3. **Segment identity** | This category acknowledges the difference in aesthetics that exists across various industries. For example, industry 4.0 might be characterized by metallic elements and straight lines, while for healthcare organic form factors and nude color pallets might be more appropriate.

Figure 9 - Context examples for the 3 industries of interest (left ro tight): manufacturing, healthcare, city centers (with the focus on historic centers) (Ahmedabad | Asia Manufacturing Review., n.d.; Terminologie uit de Medische Sector, n.d.).

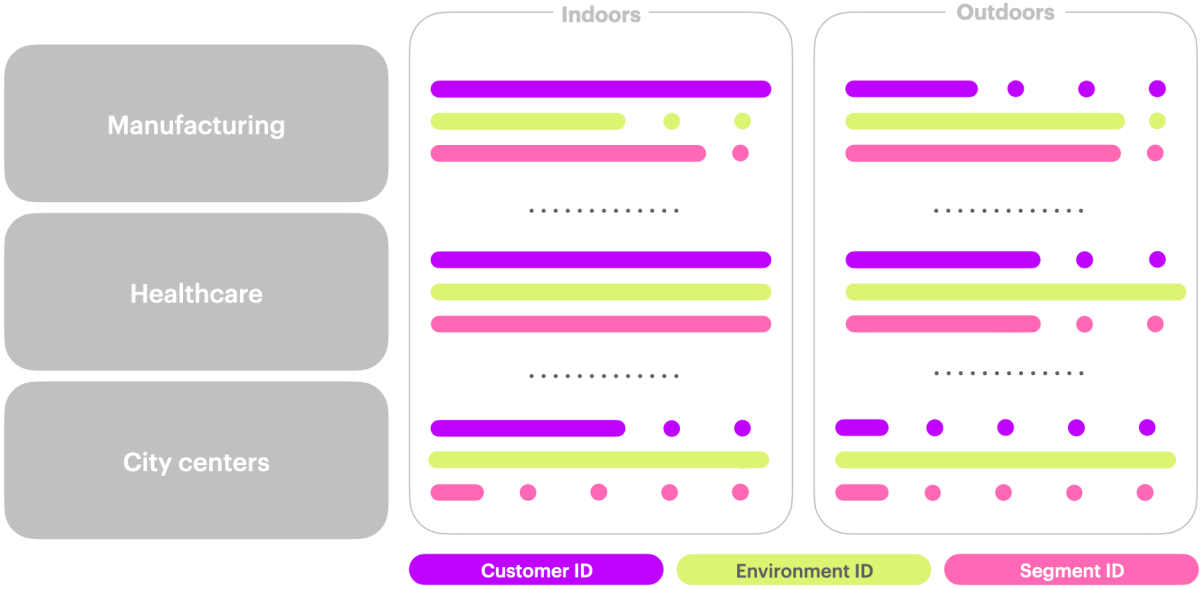


Figure 10 - Design aesthetics categories and their rankings.

Figure 10 presents the ranking of the three design aesthetics categories across industries under consideration on a scale from 1 to 5, with 1 being low and 5 - high importance of each category for a particular industry. Categories were ranked for indoor and outdoor settings as differences across design aesthetics categories' importance across these 2 settings were expected. The rankings were given based on the discussion on the topic with the client, with their intelligence being based on marketing research and ongoing conversations with potential customers. Consultation with a branding and marketing expert Erik Roscam Abbing also influenced the rankings. Appendix C presents a further explanation of the rankings given.

Manufacturing

Description | Seamless, pain-free integration of computing resources for manufacturing/ industrial processes

Context | Industrial manufacturing facilities

Success criteria |

- **Technical** | Low latency, high bandwidth, enhanced security/digital sovereignty, high resilience
- **User experience** | Seamless integration into client's existing systems; easy to use, monitor, and troubleshoot; ease of upgrades
- **Design aesthetics** | 'Clean' and sleek design aesthetics appropriate for the manufacturing floor and/or the factory's wall outside. See Figure 10 for the expected importance of the three design categories.

Healthcare

Description | Seamless, pain-free integration of computing resources for medical operations

Context | Medical facilities (hospitals, doctors' offices, etc.)

Success criteria |

- **Technical** | Enhanced security/digital sovereignty, high resilience, low latency, high bandwidth
- **User experience** | Seamless integration into client's existing systems; easy to use, monitor, and troubleshoot; ease of upgrades; user-friendly experiences/ interactions that don't require IT specialists
- **Design aesthetics** | Seamless integration, 'blending-in' into the client's environment. Design aesthetics that resonates with this segment's identity that involves such elements as safety-first, organic form factors and nude color palettes, for example. See Figure 10 for the expected importance of the three design categories.

City centers

Description | Seamless, pain-free integration

of computing resources for facilitating smart city features, such as smart energy grid, smart traffic regulation, autonomous transportation systems (AV, UA, ATO)

Context | Cityscapes

Success criteria |

- **Technical** | Low latency, high bandwidth, enhanced security/digital sovereignty, high resilience
- **User experience** | Seamless integration into client's existing systems; easy to use, monitor, and troubleshoot; ease of upgrades; user-friendly experiences/ interactions that don't require IT specialists

Design aesthetics | Design aesthetic that adds to the visual appeal of the neighborhoods without creating additional visual clutter; enclosure design that prioritizes immediate environment customization over tailoring it to the customer or segment identity (Figure 10).

Targeting

While Hiro plans to target all of the above-mentioned industries with their offerings, given the time limitation of this project, selecting one target segment to focus the enclosure design on is necessary. Given the conceptual, provocative nature of the design brief that is meant to put Hiro in the spotlight and showcase an alternative role that edge infrastructure can play in our environments, it was determined that the industry that would allow the assignment to unfold to its full potential is City centers/outdoors setting. The following reasons led me to such a targeting focus:

- More straightforward design aesthetics categories application - focus on immediate environment customization.
- Less reliance on third parties for inputs, such as customer identity elements of their organization, and feedback.
- Focusing on Dutch historic city centers in particular, testing and feedback sessions with such stakeholders as Delft municipality and the general public are expected to be easier to arrange.
- Personal and client research points to city centers as the most challenging case of edge equipment design and integration. While edge infrastructure might feel more appropriate in cities' modern neighborhoods, (stylistically) fitting it into historic city centers presents a greater challenge, the concern that has been highlighted in local media sources (Wood, 2019).
- Personal interest in the cityscapes of the future as well as the role and place of smart technologies, and the equipment needed to facilitate them.

While the enclosure design will be focused on the 'City centers' segment in the outdoors context, specifically focusing on the 'Immediate environment customization' category, it would be beneficial to consider the appropriateness of the design for the other two industry segments of interest somewhere along the design process.

Positioning

Two key elements of enclosure design and aesthetics that play a role in positioning a Hiro EMDC enclosure for the selected 'City centers 'market segment are as follows:

- **Hiro timeless, 'signature' enclosure design base** | The core, standard parts of the enclosure will serve as a 'signature' design base, reflecting the Hiro brand identity discussed earlier. As a signature design, the enclosure will already provide a degree of synthesis with its environment, serving as a strong base for customizable features.
- **Immediate environment customization** | As determined to be the most relevant customizable design aesthetics category within the selected segment, customizable enclosure parts will focus on customizing the EMDC to the immediate outdoor wall environment it is put in.

Before looking at the USPs (Unique Selling Points) of targeted enclosure aesthetics Hiro can offer this segment, it is important to understand the relevant competition. Hiro's competition can be broken down into 3 main groups.

Group 1 - Direct competition | The client considers Supermicro, a Bay Area-based company that provides a comprehensive range of advanced server, storage, and networking solutions, as their most direct competitor. IP65 Server Platform mentioned several times earlier is perhaps the most relevant example from their edge computing portfolio. However, it can be seen that Supermicro doesn't extend their innovative thinking to enclosure design, offering a mere

Figure 11 - An example of a MEC enclosure (Great Lakes Data Racks & Cabinets, 2023).

metal box.

- **5g MEC** | 5g MEC (Mobile Edge Computing) devices can be described as micro data centers for telecommunications use and can considered to be simplified versions of an edge micro data center developed by Hiro. In that sense, Hiro is competing with offerings from Nokia, Ericsson, Cisco, and Huawei. As can be seen in Figure 11, the current MEC enclosure designs are the same standard metal boxes.

Group 2 - Server providers | Companies such as HPE, Dell, and Lenovo offer computing equipment from stand-alone servers to entire racks. Especially when it comes to the servers, after the purchase these companies leave it up to their customers how they integrate this equi-

Figure 12 - Room controls demand more attention than Knoll's interior design work.

pment into their environments. A result of this approach can be seen in Figure 12. With this picture, Knoll meant to highlight a slick conference room for which they customized their furniture. Sticking out like a sore thumb, not quite a micro data center, but room controls draw as much attention within the picture as Knoll's work, showcasing the impact that technical equipment in an environment is not designed with the context in mind.

Within the focus of this project, rack offerings by HPE and Dell present an interesting case study. HPE Micro Datacenter (Figure 13) is a wheeled black box that is well-equipped to be tucked away in a locked room. Notably, this enclosure design features some elements (front grille and rectangle side graphics) from HPE's design language. In a

Figure 13 - HPE Micro Datacenter (top) and Dell Micro 415 (bottom left) and 815 (bottom right) (Revista Cloud, 2017; Dell Modular Data Centers, n.d).

similar vein, Dell's EMC Modular Data Centers Micro 415 and 815 (Figure 13) resemble steel industrial fridges with servers inside.

Group 3 - Equipment concealment providers | If Hiro is to include an element of equipment concealment as one of their product features, it's important to consider companies in this industry as their non-direct, yet competitors. Valmont Industries (Valmont Telecom, n.d.), ConcealFab (ConcealFab, 2023), and Reycap (Raycap Industrial Surge Protection, 2024) are the most notable players, currently focusing on 5g equipment concealment. A particularly noteworthy example by Raycap is shown in Figure 14, where the enclosure blends in with the building facade.

Of less interest, yet still worthwhile considering are the manufacturers of the industry-standard metal enclosures by players such as Delvalle (Delvalle, n.d.). While excelling in technical specifications to protect equipment inside from harsh weather and vandalism, these solutions don't consider how cityscapes are going to look with the coming mass adoption of edge computing. Figure 15 showcases one of those metal boxes in Barcelona, Spain. It is not hard to imagine a detrimental visual impact on such an architecturally significant city as Barcelona if such boxes were placed every other block.

As the reader might have concluded already, none of Hiro's direct competitors offers viable enclosure solutions for the coming mass integration of edge computing within cityscapes. This brings us to discussing the competitive advantage and USP (Unique Selling Proposition) that doing so would bring to Hiro.

Competitive advantages & USP with regards to targeted enclosure design and aesthetics | Hiro's strongest competitive advantage and USP is perhaps their aim to provide stress-free edge integration and deployment across both their hardware and software offerings. The way this goal is reflected in the enclosure design is by offering a solution that would solve the challenge of cityscape integration for Hiro's clients. For the City centers/outdoors setting segment, this will be achieved through a combination of the 3 key design elements mentioned above. Serving as a baseline, the signature design of the standard enclosure parts described previously will reflect Hiro's identity. Unlike any of the options currently available on the market, the very form factor of the enclosure will speak for its creator. In their turn, customizable parts are expected to be the most instrumental in explicitly blending the enclosure into its urban environment through design elements such as color, texture, etc. that will be specified later in the design process.

Overall, such an approach would allow Hiro to synthesize the strengths of their competitors mentioned above. Hiro EMDC would provide a powerful hardware solution that competes with or even outperforms Group 1 and 2's solutions while incorporating Group 3's USP into their offering.

Finally, thinking of consistency in the brand image, while offering a customizable solution, the signature enclosure design would still express Hiro's identity (that of a pioneering, elegant, professional, empowering, and assertive brand). That way Hiro's brand image is consistent across all customizable enclosures out in a city. From a high-level perspective, speculative enclosure design that challenges the role of edge equipment in cityscapes is consistent with and will help to further strengthen Hiro's brand image as a highly innovative company that confronts established norms, empowering their customers.

Figure 14 - Raycap concealment enclosure blending in with the wall (top right corner of the image) (Raycap Industrial Surge Protection, 2024).

Figure 15 - Standard metal box edge equipment enclosure in Barcelona (Lenovo Press, n.d.).

Urban adoption of 5g equipment - a case study for EMDC enclosure design

As pointed out earlier, cityscapes present arguably the greatest challenge for edge equipment design and integration and it was deemed necessary to analyze what has been done within the scope of this challenge to date. In this regard, the introduction of 5g infrastructure into cityscapes presents a relevant case study when thinking about installation practices and enclosure aesthetics of Hiro EMDCs. The large-scale adoption of 5g networks over the past decade (Nin, 2020) has prompted the spread of the infrastructure necessary to facilitate this technology. This infrastructure includes 5g small cells (Figure 16), base stations that extend network coverage and signal strength, and Mobile Edge Computing (MEC) devices (Shao, 2021), arguably micro data centers for a telecommunications use case. The benefits of low latency and high bandwidth that edge MECs provide were required to ensure that the promise of 5g technology, faster data transmission speeds from a greater volume of devices, would be achieved.

While both infrastructure types facilitate 5g connectivity, the differences in their functionalities, and, as a result, the physical size, have prompted contrasting requirements and approaches in terms of integration of both device types into the cityscapes. Due to their simpler functionality, 5g small cells have a smaller form factor compared to 5g MECs. 5g radio signals are also more easily blocked by various objects and materials, which necessitates small cells to be incorporated into a city environment as frequently as possible (Kelly, 2021). Given this fact, city government bodies and the public felt strongly about having a say in how these infrastructure pieces, which might be appearing as frequently as every other block, would look and fit into cityscapes. The common thread across the expectations of the aesthetics for 5g small cells has been the expectation for them to have an 'unobtrusive' nature, to be something that "blends in with the communities" (Wood, 2019), (Kelly, 2021). Cities

Figure 16 - Concealed 5g small cell on a light pole (ConcealFab, 2023).

like New York are also organizing design reviews and public consultations to engage the public in decision-making and collective maintenance of the city's visual standards. As a result, 5g infrastructure has been largely incorporated with existing city furniture, such as streetlight poles, bus stops, and traffic lights.

Around three decades ago, Valmont Industries created camouflaged pine tree tower in the Denver market, and the equipment concealment industry has been on the rise since then. Figure 17 on the next page presents an array of notable concealment solutions by Valmont alongside two more significant industry players, ConcealFab and Reycap, organized by the extent to which they hide the equipment versus how aesthetically pleasing these solutions appear. Currently, available concealment solutions seem to be following a linear relationship between the extent of concealment and aesthetics, where little concealment tends also to be less aesthetically pleasing and vice versa. Along this trajectory, Hiro EMDC enclosure finds its place in the upper right corner as a solution that would add to the visual appeal of its environment and also serve an alternative purpose that way.

Concealment solutions in Figure 17 are customized to their different environments through factors such as color (brown cases for a wooden pole, for example), choice of the subject appropriate for the context(a palm tree, a boulder, and a water tower), and form factor (an angular tower that matches typical stadium style). It can be argued that there are two main kinds of concealment strategies present:

1. Using objects typical for the environment, such as rocks, trash bins, and information

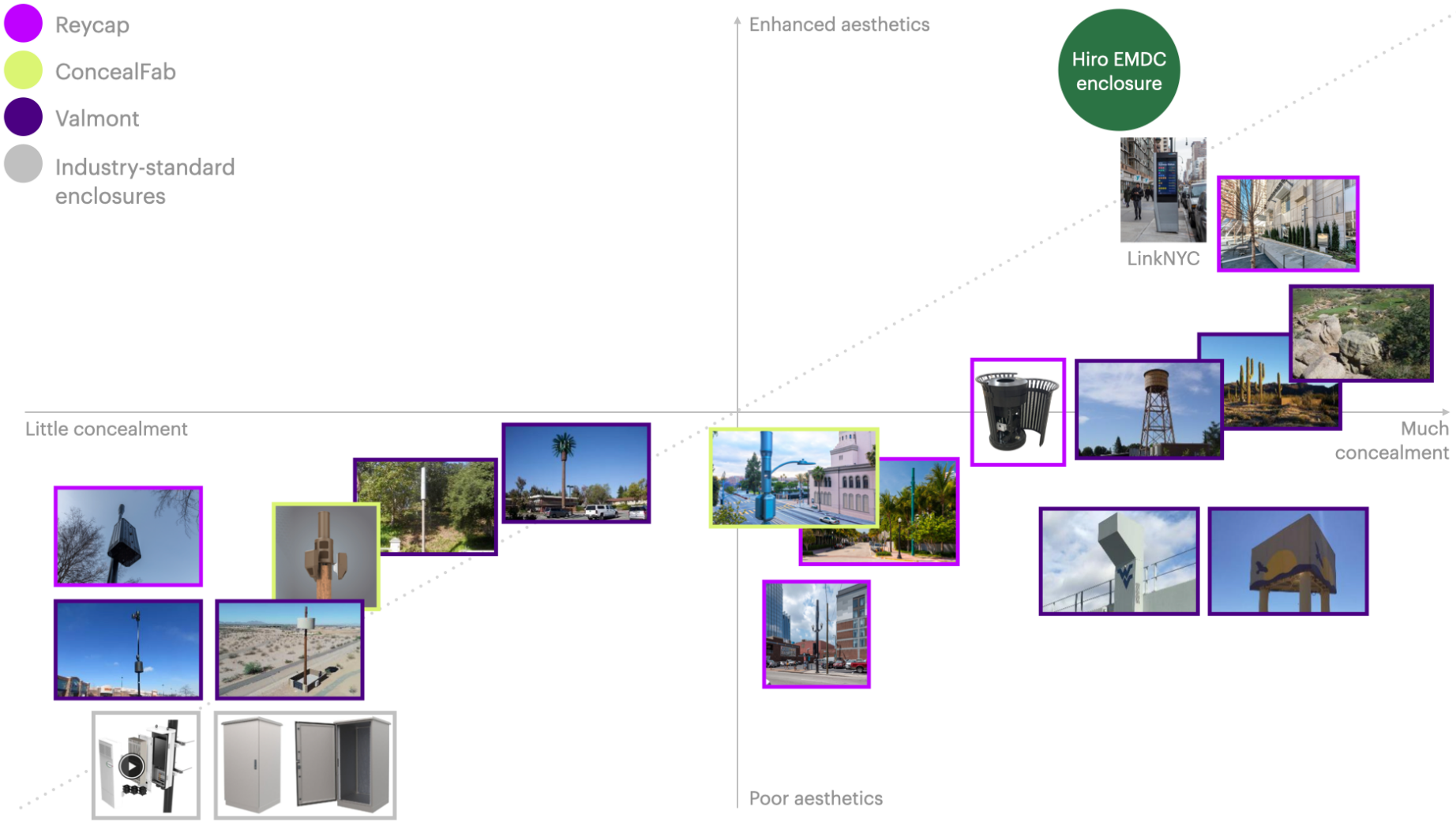


Figure 17 - Notable concealment solutions organized by the extent of their degree of concealment and aesthetical appeal (ConcealFab, 2023; Raycap Industrial Surge Protection, 2024; Valmont Telecom, n.d.)

screens, to hide the equipment. Arguably, this strategy is more successful as it conceals the equipment and seamlessly blends with its surroundings to a greater extent, often hiding the equipment inside completely. At the same time, this strategy also must be more costly and time-consuming.

2. Masking equipment onto existing infrastructure, such as streetlight poles and building walls. While arguably less effective in the concealment of the equipment, this strategy requires less financial and time investments.

As has been discussed earlier, with the continuously growing amount of data generated and applications that require real-time data analysis (take autonomous driving as one example), the pressure for local data processing will increase, pushing for large-scale adoption of edge data centers. This implies that micro data centers will have to emerge from their current hideaways and enter the cityscapes likely as frequently as 5g small cells currently. This presents an incorporation aesthetics challenge similar to the current one with 5g small cells with an extra layer of a larger form factor (at least for the foreseeable future) of EMDCs compared to cells.

MAYA principle

This project's objective is to introduce an innovative, ground-breaking enclosure design for an edge micro data center. Such design would take a 180-turn from the currently established norms for data center racks and enclosures as purely functional entities, often hidden from the public eye. While introducing such a high degree of novelty is at the center of this assignment, it's important to consider the possible implications of such design in the real world.

MAYA, the Most Advanced Yet Acceptable, principle helps to shine some light on this question. Coined by Raymond Loewy in the 1950s, this design principle states that a product's innovative features (also referred to as novelty) must be balanced with its familiar ones (or typicality) to appeal to consumers (Dam, 2024). Notably, Hekkert et al. (2003) found that the combination of both a high level of typicality and a high level of novelty leads to higher aesthetic preference among consumers.

Mulder-Nijkamp et al. (2022) found that when designing an appearance of brand extensions (which in the case of this project can be viewed from the lens of the enclosure being an extension data center product category as a whole, influenced by the brand identity of Hiro), three determinants play an important role: "product typicality (does the design look like the archetype product), novelty (how novel is the design) and brand fit (does the design refer to the brand characteristics)." When thinking about brand fit, Hiro brand identity described above would need to be embodied in the enclosure through a careful choice of physical design features and visual cues such as macro form factor definition, materials, etc, a process that is known as 'semantic fit' (Karjalainen, 2004). If well executed, 'semantic fit' ensures that the target group receives the right message that is aligned with the desired brand identity (Crilly, 2005).

It can be further argued that two determinants, novelty and brand fit, are particularly influential in this project. Data centers are currently hidden from the public eye and also not part of the 'consumer,' 'public 'product category, so a great part of the population doesn't have a mental image of what these products look like. So can we we argue that a Hiro EMDC enclosure design will be setting typicality standards for edge infrastructure? A question then arises of how novel can an enclosure design appear to be accepted not just by Hiro's clients, but specifically by the public, facing edge infrastructure in social settings, such as historic city centers? And how such design will be perceived by the clients and the broader public? Engagement with the client and/or the public will be necessary throughout the design process to keep a hand on the pulse of novelty tolerance and perception of enclosure concepts considered.

The influence of premium product standing on the enclosure design

Hiro's positions themselves as a premium brand, with EMDC offerings starting at around 150 thousand euros. For such an expensive price tag, the company offers innovation across not only the technical aspects of a data center design but the aesthetics as well. The client is looking for a speculative enclosure design that would differentiate itself from the 'metal boxes'

offered by competitors and reflect Hiro's innovative spirit.

Such outlook of the client on the enclosure design has been challenged, yet the literature review supported it. At this point, there has been overwhelming evidence that enhanced product aesthetics and attractive design can "enhance product liking (Hoegg, Alba, and Dahl 2010; Reimann et al. 2010), inform inferences of value (Sevilla and Kahn 2014), luxury (Hagtvedt and Patrick 2008) ... as well as convey product and firm value (Brasel and Gips 2014; Townsend and Shu 2010)" (Patrick et al., 2019). Crolic et al. (2019) showcased the strong influence of design aesthetics when consumers evaluate and choose products, specifically focusing on consumer products such as smartphones and kettles. Across the studies they conducted, consumers tended to expect superior performance in unmentioned functional attributes for products that they perceived to be more aesthetically pleasing, even when other products excelled in functional aspects that were presented to the participants.

Even though Hiro's sales pertain to the B2B domain, the call to focus on aesthetics in B2B products can be found as early as 2013 (Busse, 2013). Even if Hiro's EMDCs will be sold to other businesses, being an edge infrastructure implies that EMDCs will be seen by hundreds if not thousands of eyes when placed in urban settings. In a large-scale study conducted in the UK Seresinhe et al. (2019) explored the relationship between "beautiful environments and everyday wellbeing." Their research concluded that people experience more positive emotions in more scenic "built-up environments." In addition, the Attention Restoration Theory claims that scenes that don't demand our full attention make people less fatigued, which could lead to experiencing less irritability as well (Kaplan, 1995). This points to the importance of creating a speculative enclosure design that is not perceived as 'visual clutter.'

Previous instances of vandalism towards smart city infrastructure, such as 5g equipment (Satariano & Alba, 2020), raise similar concerns for Hiro EMDCs, especially as they become more prominent given their enhanced aesthetics. However, enhanced aesthetics itself might play a role in deterring vandalism through this quality. Cozens and Love (2015) provide a comprehensive review of the Crime Prevention through Environmental Design (CPTED) strategy that has shown how beautified environments that are well-designed and maintained are less likely to suffer from vandal attacks as they evoke community pride, discouraging damaging behaviors.

Customization as a premium product feature in other industries

As discussed earlier, environment customization is a popular feature in the one group of Hiro competitors - companies specializing in 5g infrastructure concealment. It was decided to carry out further analysis on products with environmental customization features, specifically focusing on those pertaining to the premium/luxury sector. Figure 18 on the next page presents relevant and notable examples that have been collected in the domains of product and interior design.

- **The Frame TV by Samsung** | This TV embodies a strikingly simple, yet elegant solution to the problem of having a black box on one's wall whenever the TV is not on. This product adjusts its screen display settings to enable its owners to turn it into artwork or photograph of their choice when the device is idle (The Frame TV (2024) - Highlights | Samsung NL, 2024).

- **Knoll furniture** | Producing and selling such iconic furniture pieces as Wassily Chair and Barcelona Chair, the company offers its clients to customize such details as upholstery, material finishes and colors, and furniture configuration to match their space perfectly (Knoll - Modern Furniture Design for the Office & Home, n.d.).

- **Bowers & Wilkins Nautilus speaker** | Not only the speaker has an intriguing form factor form factor, but B&W offers their clients an option to customize its color to match their environment (Nautilus, n.d.).

- **Planika fireplaces** | The manufacturer offers customization of dimensions of existing fireplace designs (Sadowski, 2021).

- **Architectural Grille** | The company offers a variety of grille tiles that can be customized in terms of color and material, for example, to match the client's space. The company can also create fully custom designs if requested (ARCHITECTURAL GRILLE, n.d.).

Customization offerings in these products provide further evidence for the relevance and even importance of including customization possibilities when marketing one's product in the premium/luxury market.

Figure 18 - Notable examples of customization features found in premium products. Clockwise starting from 12h position: Frame TV by Samsung, customized Knoll's Wassily chair, B&O Nautilus speaker, Planika fireplace, Architectural Grille (The Frame TV (2024) - Highlights | Samsung NL, 2024; Knoll - Modern Furniture Design for the Office & Home, n.d.; Nautilus, n.d.; Sadowski, 2021; ARCHITECTURAL GRILLE, n.d.).

Now that various research topics pertaining to the original design brief have been considered, the original assignment can be reframed into a problem statement and subsequent design vision using the knowledge obtained.

Problem statement

Now that various research topics pertaining to the original design brief have been considered, the original assignment can be reframed into a problem statement and subsequent design vision using the knowledge obtained.

I WANT

urban edge computing infrastructure

TO

contribute to the visual appeal of a cityscape

BECAUSE

current offerings prioritize performance over aesthetics, inhibiting the integration of this infrastructure into society at a necessary scale.

Vision statement

While the problem statement addressed edge equipment as a whole, the vision statement was created to guide the design process of the Hiro EMDC enclosure specifically within this problem space. This statement was meant to serve as a North Star for key decisions regarding enclosure design uncertainties.

I envision a Hiro EMDC that contributes to the visual appeal of a cityscape, blending in yet standing out with its design, broadening the view on the role of edge equipment in public spaces and carving a unique niche for Hiro offerings.

Now that the high-level picture has been painted, it is necessary to analyze known hardware and interaction elements which will be laid out in the sections to follow. EMDC hardware and interaction analysis allowed digesting specific performance criteria for the to-be-embodied enclosure. A list of preliminary requirements that resulted from this activity can be seen in Appendix D and specific requirements will be mentioned using their IDs (consisting of letters and a number) whenever appropriate in the sections to follow. A few requirements and wishes that will be specifically referred to in the sections to follow are presented in Figure 19.

Requirements/Must-haves	Wishes/Nice-to-haves
Enclosure interaction (I)	
IR 15 | Enclosure must provide basic system status updates.	
Overall enclosure (E)	
ER 6 | Enclosures must have appropriate features to ensure pleasant, safe, and ergonomic insertion of DC unit into the Cooling unit • Alignment features	
ER 7 | Units' enclosure must protect internal hardware components from damage during shipment and installation.	
ER 8 | Enclosure must include basic assembly features • How internals are going to be placed/fixtured inside them	
Cooling unit enclosure (C)	
CR 1 | Cooling unit enclosure must incorporate features that facilitate passive cooling and leverage chimney effect.	
CR 3 | Enclosure internal cross sectional shape must facilitate smooth airflow throughout the chimney.	
	CW 4 | Enclosure walls should possess insulating properties.

Figure 18 - Select requirements and wishes.

Main internal hardware components and their functions

Internal hardware can be broken down into two main parts: computing equipment and the cooling solution. The paragraphs below share more information about internal hardware with Figure 19 showcasing the components mentioned. It must be noted that a limited amount of information can be shared about the internal hardware as some of the knowledge is proprietary.

Computing equipment | Computing equipment is a complete data center in a box, consisting of different kinds of server nodes: servers (CPU, GPU, FPGA, etc.), power, and dual fabric switching (Ethernet, PCIe, Peripheral Component Interconnect Express) that are all connected via a passive backplane. The server nodes are organized in rows (this project is focused on the one-row EMDC configuration) with 11 servers comprising one row. Depending on the number of rows and servers, Hiro mountable EMDC capacity ranges between 1.8 and 5.4 kW, which is comparable to a 42U rack. In the context of the assignment the overall space take-up, rather than the exact representation of the parts mentioned above, was more pertinent, so the compute nodes were modeled in CAD as simple

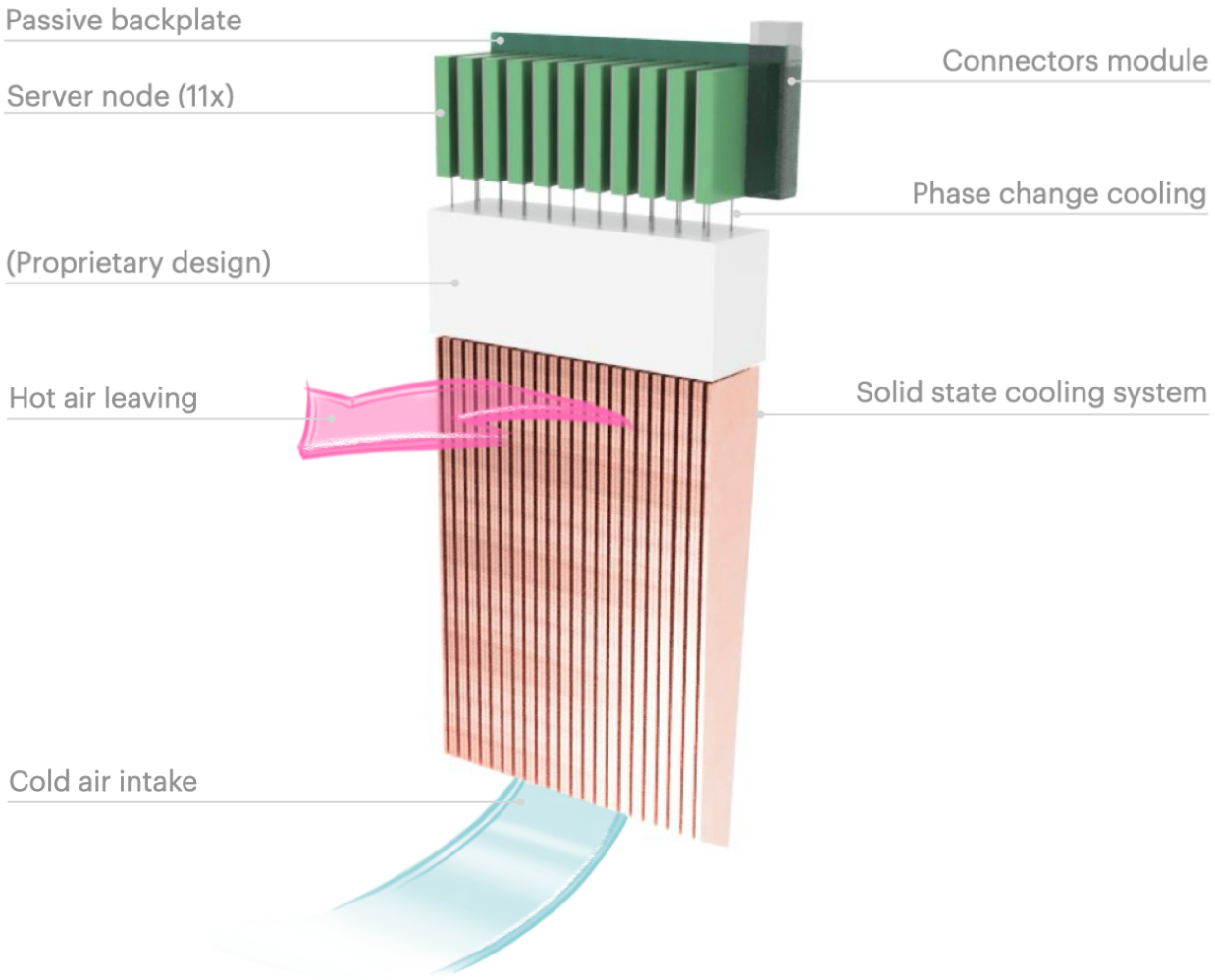


Figure 19 - Internal hardware components.

blocks with appropriate dimensions (Figure 19).

Cooling solution | Hiro aims to remove at least 70% of generated heat passively (phase change cooling, without fan support) using rising-heat or chimney effect (Figure 20). In short, the stack/chimney effect occurs when there's a significant temperature difference between the inside and outside of the system. Hot air rises, creating a pressure difference between the top and bottom that drives air movement. As warm air exits the chimney (and the building in the case of a chimney in a house) at the top, it creates a suction effect, drawing in colder air from the outside through openings at the lower levels of the system. The cooling solution uses highly efficient phase change cooling incorporated in loop heat pipes (LHPs). Refrigerant evaporates with the heat generated by the servers and condenses in the condenser plates. This LHP technology is also used for satellites and gravity has little to no effect on its efficiency. The heat gets carried away by the cold air running through the cooling system.

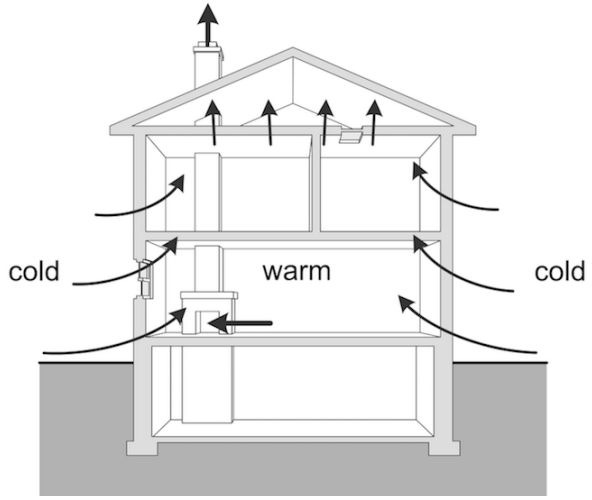


Figure 20 - Stack/chimney effect in an example of a residential house (Professional Remodeler, n.d.).

Main enclosure parts, their inputs, and constraints

The two main parts of the internal hardware also define the two main parts of the enclosure: the Data Center (DC) unit and the Cooling unit. In addition to the main parts, several subsystems ensure and facilitate the connection between the Cooling and the Data Center units, including mounting, clamping, and enclosure close-off.

Figure 21 highlights the units and the subsystems. Dimensions of the internal hardware components described above were the primary guidance for the overall enclosure sizing. It must also be noted that these dimensions are preliminary and were defined to the best of the client's knowledge at the time and are subject to change as computing and cooling components get optimized for performance. Appendix E provides relevant dimensions for the enclosure parts.

Before diving into the parameters that define the units and the subsystems, it's important to understand how they interact with one another on a high level.

High-level interaction between units |

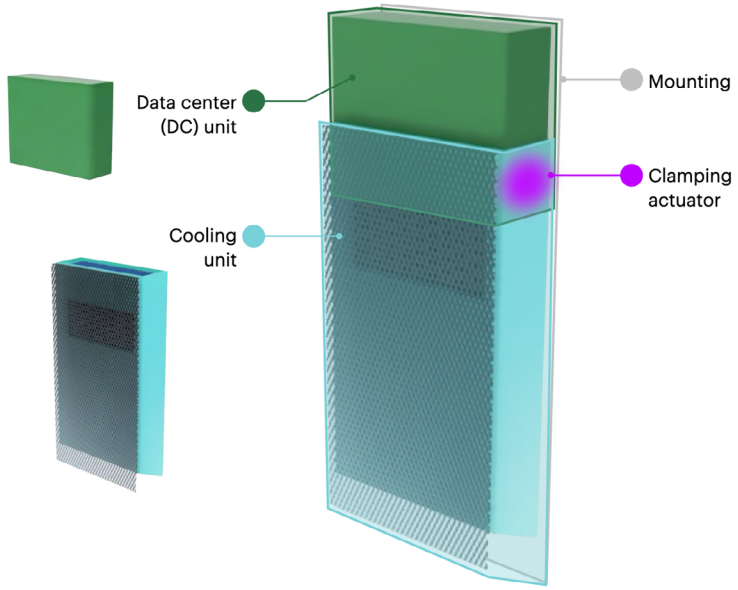


Figure 21 - EMDC main units and subsystems.

1. The Cooling unit is mounted on a wall surface. Here it's important to note that in case of outdoor placement, the equipment is mounted on the 1st floor level or higher. Thus, a scissor lift (or similar means) is necessary for the EMDC installation outside.

2. Next, the DC unit is slid on top of the Cooling unit. Such relative positioning of the units was chosen to leverage passive cooling capacity, as placement of the Cooling unit on the bottom facilitates cold air take-in.

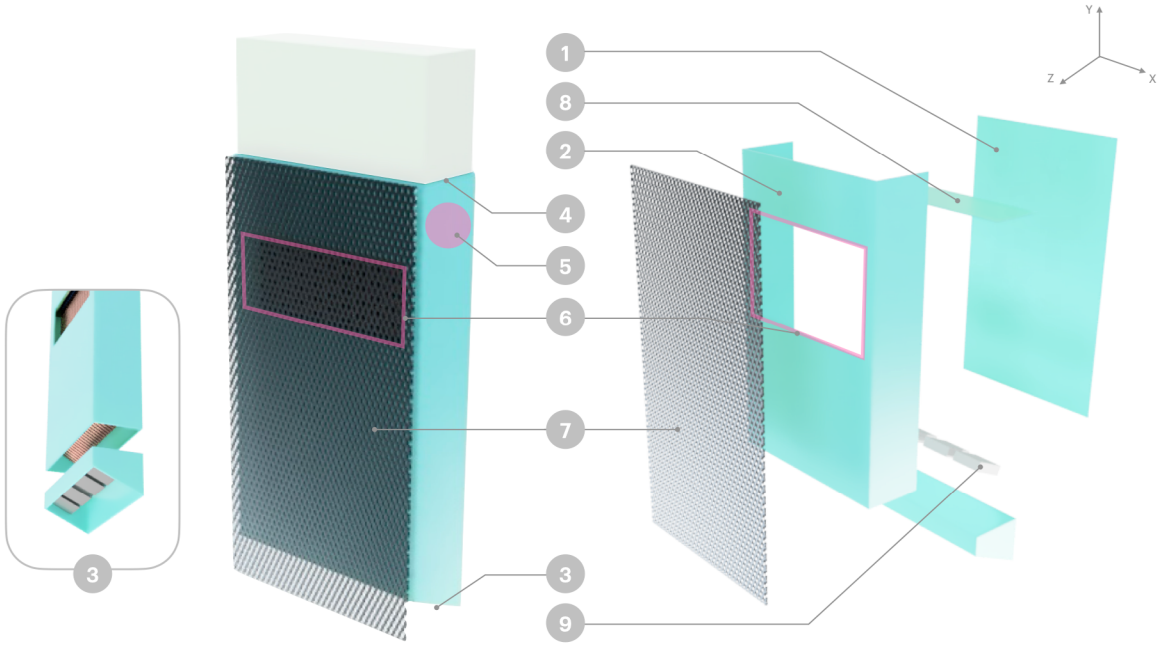
3. The two units are then connected with a clamping mechanism that also activates a passive cooling solution.

4. Finally, the EMDC is powered on and the enclosure is closed off.

EMDC interaction will be discussed in more detail and visualized in the next chapter.

Cooling unit

The Cooling unit enclosure part houses the passive cooling solution hardware. Figure 22 summarizes all relevant design parameters and considerations for the Cooling unit with more details discussed below. The main parameters of the Cooling unit were driven by the performance requirements that this part of the enclosure needs to meet, with details outlined in the paragraphs below. The parameters are grouped thinking about their role and place in the Cooling unit enclosure design. Figure 22 points out these parameters on the Cooling unit's preliminary CAD model, while Appendix E provides various relevant dimensions.



External design features	
Design constraints	**Design freedoms**
x-dimension as least 420 mm	Overall form factor | (1) Back lid and (2) front cover
y-dimension at least ~853 mm	(3) Bottom cold air intake
Front opening area = ~1.5x of the top opning area/enclosure cross section	(4) DC unit interface
	(5) Clamping actuator interface
	(6) Front opening | shape and space take up
	(7) Trombe wall
	DC unit alignment feature(s)
	Mounting grips
Internal design features	
Internal cooling elements fixture in space	
(8) Chimney close off	
Chimney airflow | Air guiding ribs on the back wall	
Chimney airflow | Smooth, uniform chimney cross-section	
Chimney airflow | Airtight shaft	
Off-the-shelf items	
Dust filters	
(9) Fans	
Instalaltion considerations	
Cooling unit moutning on the wall	
Trombe wall/Cooling unit attachment	
Front cover to back lid attachment	

Figure 22 - Relevant Cooling unit design parameters.

(CR 1) Stack/chimney effect | Perhaps the primary role of the Cooling unit is facilitating passive cooling for the EMDC. Several chimney variables affect chimney performance (The Theory of How a Chimney Works — Action Chimneys Are Specialists in Residential and Commercial Chimney Repair and Chimney Relining., n.d.), as a result also influencing the Cooling unit design and dimensioning.

- **Chimney height** | The greater the chimney height, the more air suction it creates for the chimney effect. The vertical (y) dimension of the solid-state cooling system in Figure 19 is the most crucial variable in determining the overall height of the chimney with an estimate for it provided by the client.

- **(CR 3) Cross-Sectional Area and Shape of the Chimney** | The x-dimension of the chimney was set by the industry-standard 3U 19" server rack (Figure 23). Z-dimension was obtained by summing the dimension along the same axis of the proprietary internal hardware components, and a necessary clearance between the hardware and the enclosure internal wall. As the 'Internal design features' section from Figure 22 points out, during the final stages of enclosure design, the internal wall should be detailed to ensure that it facilitates smooth passage of the airflow.

- **Ventilation openings** | The Cooling unit design features two openings that facilitate the chimney effect, the bottom cold intake and the front hot air exhaust (refer back to Figure 19 and Figure 22). As having a more traditional chimney top opening was not possible due to hardware components blocking the way, the top opening was moved to the front. Per the client's advice, the area of the front opening was made twice bigger compared to that of the top opening to compensate for a less streamlined airflow compared to the simpler bottom-to-top configuration. The bottom opening is slanted to increase the surface area of the cold air intake (Figure 22).

- **(CW 4) Insulation and material selection** | Insulating surfaces of the chimney helps increase the temperature differential between air inside the chimney and outside in the surrounding environment, which, in its turn, facilitates the chimney effect. While Hiro assumes wall insulation to be one of the less impactful properties in aiding passive cooling, adding insulating properties to enclosure walls would be a nice-to-have feature. For example, having a material with some air bubbles present within it can help with the enclosure's insulation properties. At the same time, it is also important to keep the weight requirement (IR 5) for the Cooling unit when selecting a material for its construction.

Figure 23 - An example of an industry-standard 3U 19" server rack (Amazon, n.d.).

While not an explicit chimney variable, in an outside setting, the Trombe wall component of the Cooling unit (Figure 22) helps the chimney reinforce the natural airflow through the cooling system as well as prevent the Cooling enclosure front surface from heating up. By absorbing the heat from the environment, the Trombe wall creates an airflow driven by the temperature difference between the wall-enclosure air and the environment air. The hot air between the wall and the outside of the enclosure rises, driving the suction of cool air on the bottom and facilitating the hot air leaving the Cooling unit on the top.

According to the client's estimations and simulations, the passive cooling solution would be sufficient for 80% of the EMDC lifecycle. However, during the remaining 20%, in extreme situations involving high ambient temperatures and high hardware utilization levels, fans would be activated to drive the airflow. This fact stresses the importance of designing an enclosure that prioritizes the facilitation of the airflow to ensure that the passive cooling promise can be met (CR 1).

(ER 7, 8) Protection and fixture in space of internal cooling hardware | The enclosure covers the internal cooling hardware fully, protecting it from physical damage during shipment and installation; it also fixtures the components

in place inside. To account for assembly considerations, it was decided to split the enclosure into the front cover and the back lid, with internal hardware being secured on the back lid and the front cover would be resting on top of that.

(IR 10) Appropriate grip features for mounting | It must be ensured that the Cooling unit provides a way to securely raise and mount it on the desired surface.

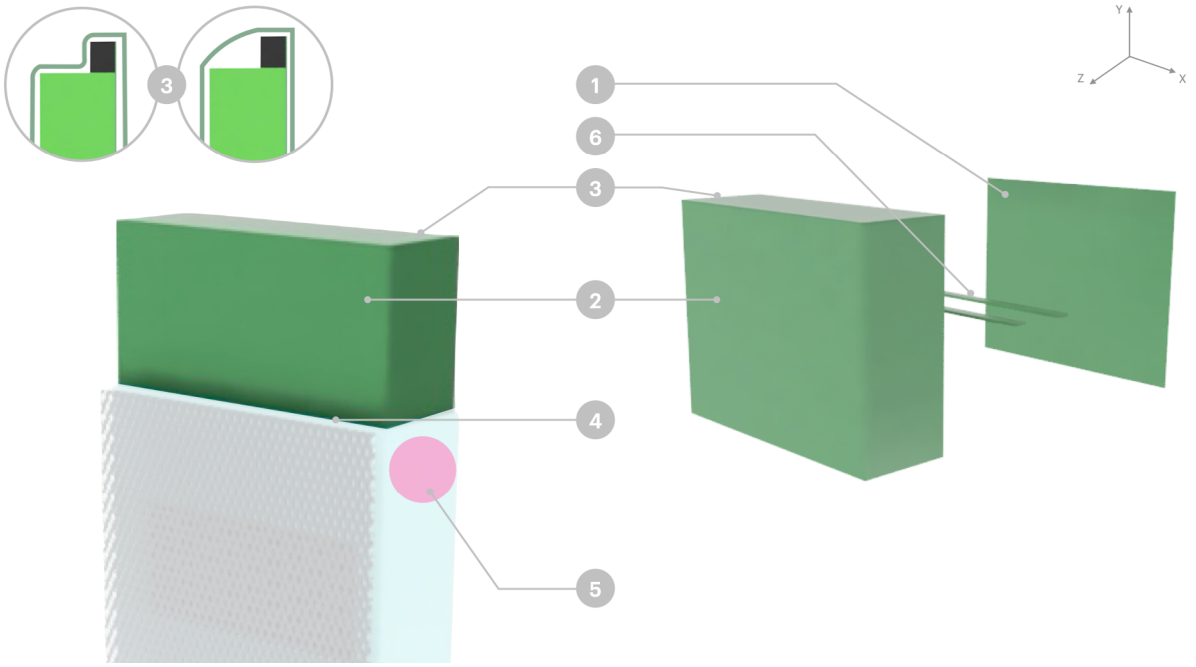
(ER 6) Facilitating alignment of DC unit during its insertion | The Cooling unit has to incorporate alignment features that ensure a smooth and ergonomic experience when inserting the DC unit on top of it.

Data center (DC) unit

The primary role of the DC unit is to house computing equipment. Figure 24 summarizes all relevant design parameters and considerations for the DC unit with relevant details being further discussed below. The parameters are grouped thinking about their role and place in the DC unit enclosure design. Figure 24 also points out these parameters on the DC unit's preliminary CAD model, while Appendix E provides various relevant dimensions.

(ER 7, 8) Protection and fixture of internal computing hardware | The main function of the DC unit enclosure is the protection of internal hardware during shipment and installation. This requirement also includes fixturing the hardware in place.

(IR 10) Appropriate grip features for insertion | Similar to the Cooling unit, the DC unit needs to provide a way to securely raise and insert it into



External design features	
Design constraints	**Design freedoms**
	Overall form factor | (1) Back lid and (2) front cover
	(3) DC unit top design
	(4) Cooling unit interface
	(5) Clamping actuator interface
11 LEDs (1 per compute node)	Hardware status indicators (LEDs)
	EMDC powering
	Insertion grips
Internal design features	
Internal cooling elements fixture in space	
(6) Servers close off	
Off-the-shelf items	
Cable connectors	
LHP rubbers (in between 2 servers close-off planes)	
Instalaltion considerations	
Front cover to back lid attachment	

Figure 24 - Relevant DC unit design parameters.

the Cooling unit.

(IR 15) Internal hardware status indication | The outside of the DC unit needs to incorporate features, such as LED lights, that allow for physical monitoring verification of hardware status.

(ER 1) DC unit top design | The design of the top surface of the DC unit is expected to be highly influential in its ability to withstand its environment, especially when thinking about dust accumulation and bird perching. This design freedom needs to be carefully considered to ensure that the desired performance for this requirement is achieved with the proposed concept for it.

The subsystems

In addition to the two main enclosure units discussed above, several subsystems account for the units' interaction with their environment and link these units together.

Mounting | The Mounting subsystem ensures that EMDC stays on the designated surface securely. While primarily relevant for and part of the Cooling unit, there's a possible design option where mounting becomes part of the DC unit as well.

Clamping | Within the context of this project, clamping will imply designing its external features, including selecting a clamping actuator that delivers a force in the desired ballpark and specifying clamping interactions and UX as well as clamping interface with the units. The scope does not include the internal mechanical system that clamps internal hardware.

Enclosure close-off | Enclosure close-off implies preventing unauthorized tampering. This part is meant to protect features such as EMDC powering, the clamping actuator, and other critical parts of EMDC operation.

Figure 25 summarizes some of the uncertainties about the subsystems mentioned above as well as the Cooling unit described earlier.

Standard Vs. customizable parts

As discussed in the aesthetics and branding section earlier and reflected in the design vision, enclosure customization is seen as a USP of Hiro premium EMDCs, planned to be offered at no additional price by the client. Figure 26 on the next page provides a proposal for the parts of an EMDC that would be appropriate to be kept standard (in terms of their overall form factor) and those that will be customizable to each client/industry/environment. The selection of EMDC parts to be kept standard was driven by considering which parts need to meet stringent performance requirements as well as which ones would be most appropriate for expressing Hiro brand identity. In addition, the PEaaS leasing scheme for EMDC distribution played a role in standard Vs. customizable parts selection as to prevent waste accumulation as EMDCs change their owners.

Unit/subsystem	Uncertainties
Cooling unit	•**DC unit alignment features**	Part of the Cooling unit or an entirely separate part? •**Bottom cold air intake**	Separate part or part of the Cooling unit?
Clamping	•Is clamping actuator left on EMDC at all times or is it a portable part?
Enclosure close off	•Which elements of EMDC need to be closed off (power, clamping actuator, etc.)? •How does it lock/prevent tampering? •Part of one of the units or an independent subsystem? •Can Trombe wall be extended to act as an enclosure close off?

Figure 25 - Uncertainties about the subsystems and the Cooling unit.

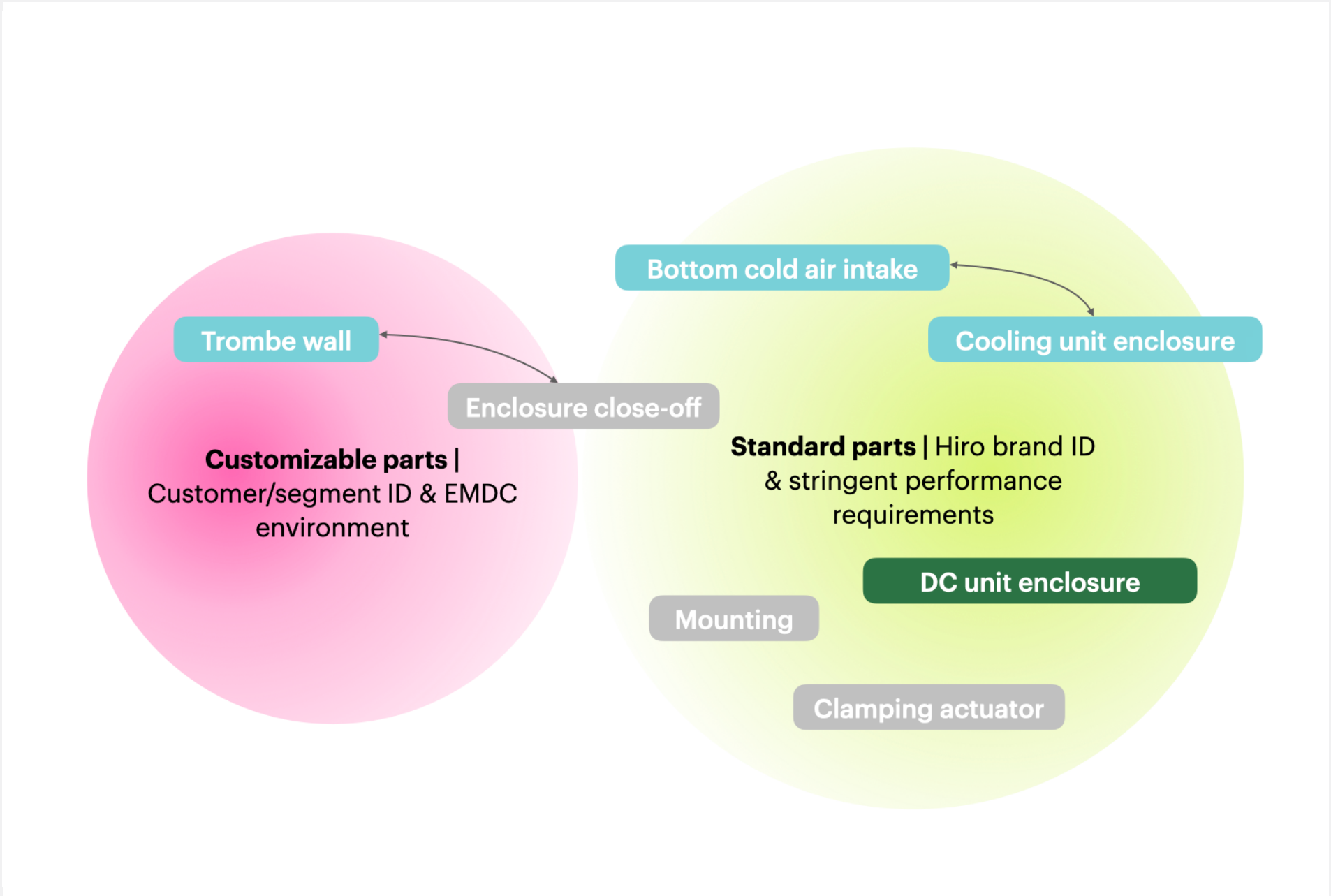


Figure 26 - Summary of standard and customizable EMDC parts.

Influencing context parameters

Figure 27 maps the main groups of context parameters that impact Hiro EMDC as well as the kind of influence that various parameter groups are expected to have on the enclosure design.

Placement context | Placement context involves such attributes as location, setting, industry and architecture types, and mount surface. Standard EMDC parts need to be designed to fit in across as many placement contexts as possible. However, for the customizable enclosure parts, these context parameters will serve as inputs for their designs. Overall, the 'Placement context' group is expected to have the greatest effect on the enclosure aesthetics, which, in its turn, will define the public perception of Hiro as a brand.

Physical environment | 'Physical environment' context parameters consider various influences that EMDC's immediate environment surrounding it would place on the device. These parameters are expected to have the greatest impact on passive cooling effectiveness and overall enclosure integrity. In addition, visibility would be important during the 'Monitoring' stage of the envisioned interaction scenario (described below) in cases when a user would need to be able to see hardware status physically via the LED lights.

Humans | 'Humans' context parameters account for the considerations over public perception of the speculative EMDC enclosure design with regards to the desired Hiro brand identity expressed in the problem and vision statements earlier. It also acknowledges the fact that a lack of public acceptance, which can emerge in the form of vandal actions toward EMDCs, can compromise enclosure integrity.

The Interaction subgroup will be discussed to a greater extent in the next section.

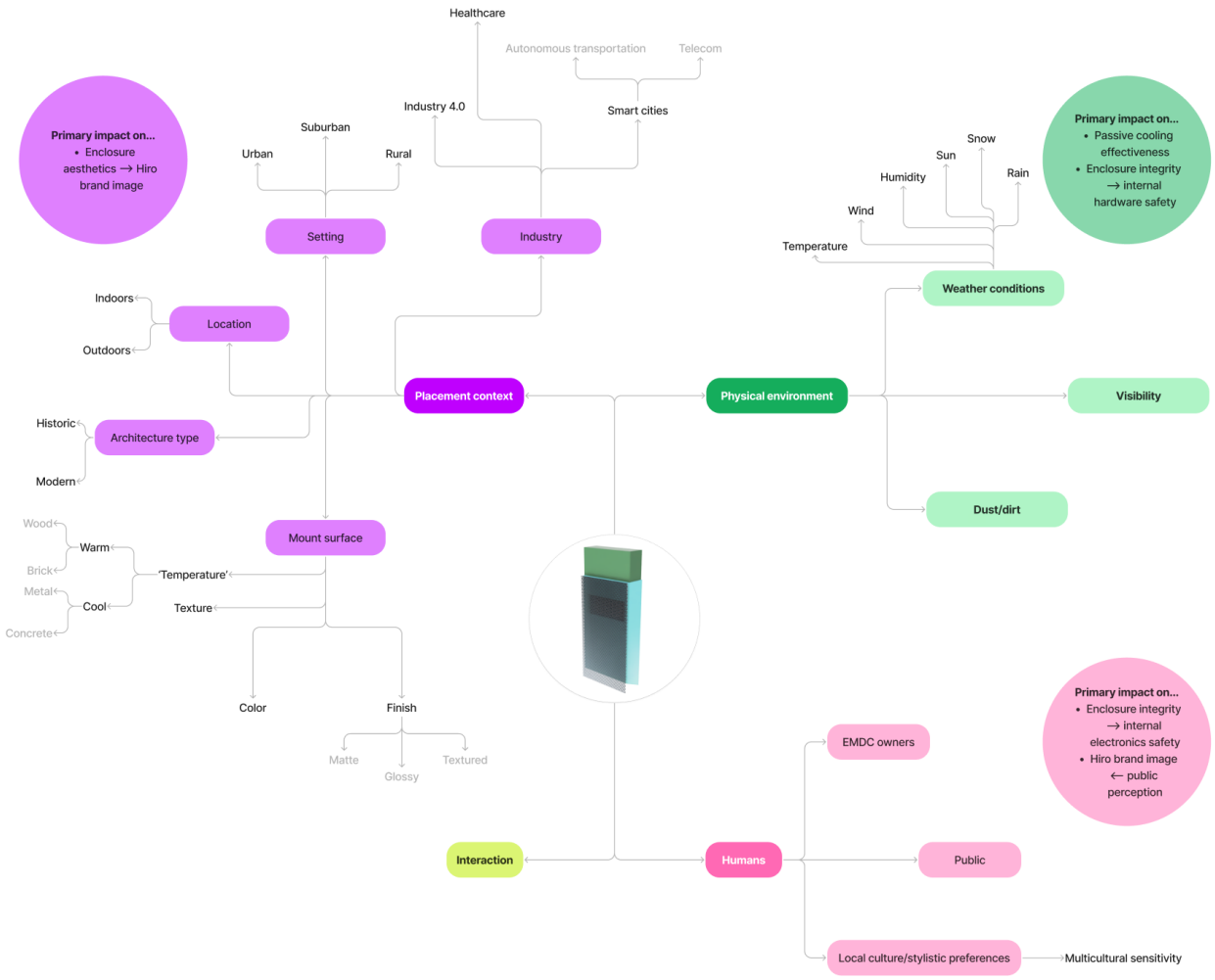
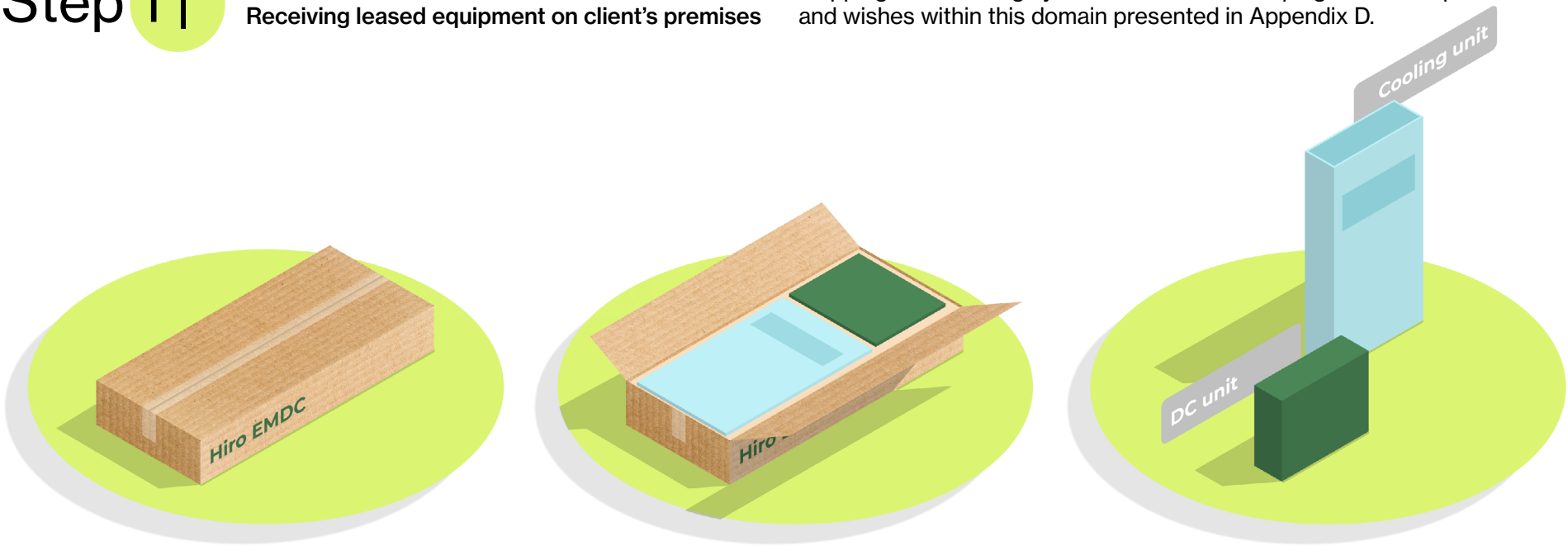


Figure 27 - Context parameters impacting Hiro EMDC.

Envisioned interaction with Hiro EMDC

Knowledge obtained from the client with regards to the PEaaS leasing/ distribution framework they envision and hardware and context parameters analyses described above led to the creation of a comprehensive overview of the envisioned EMDC interaction. The interaction, spanning the stages from receiving the first hardware shipment to decommissioning the equipment, is laid out visually in the pages to follow. It is important to note that Hiro aims for all interaction procedures to be appropriate and safe to be handled by an electrical engineer, removing the necessity of specialized data center staff. Appendix F presents various considerations and uncertainties that have been identified in the process of interaction mapping and that largely contributed to developing a list of requirements and wishes within this domain presented in Appendix D.

Step 1 | Receiving leased equipment on client's premises

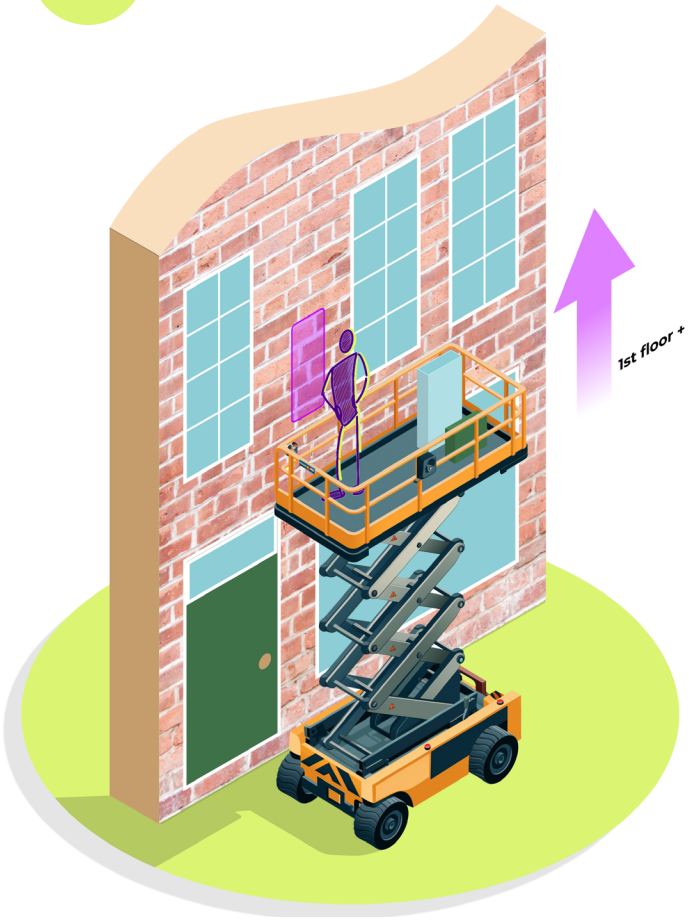


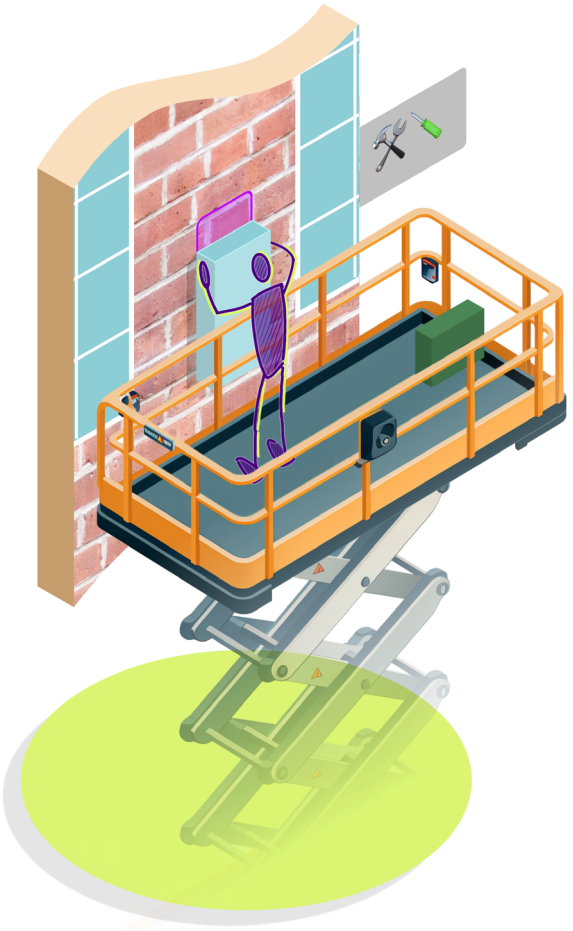
1.1 | A client configures their EMDC online and Hiro sends the EMDC to their premises location via secure shipping.

1.2 | An authorized electrical engineer from the client company opens and unpacks the shipment.

1.3 | The 2 units are safe to be handled by authorized staff. No data center knowledge is needed, only electrical installation qualification.

Step 2 | Installing the Cooling unit

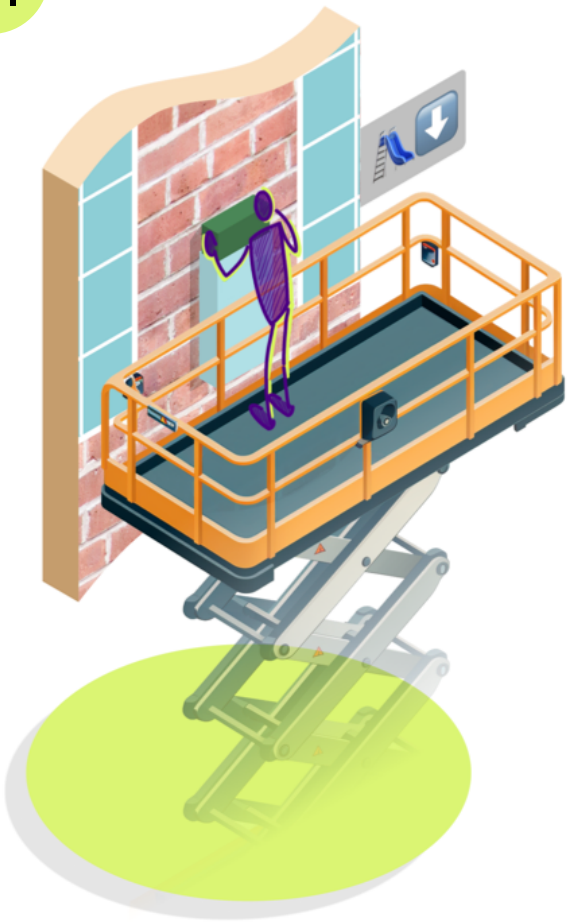


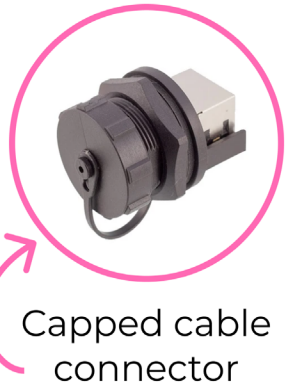


2.1 | Installation personnel uses a scissor lift (or other means) to take the units and necessary tools up to the desired level of the EMDC mounting (1st floor or higher).

2.2 | Installation personnel mounts the Cooling unit on the building surface. This unit stays on the wall permanently unless a client decides to move or decomission their EMDC.

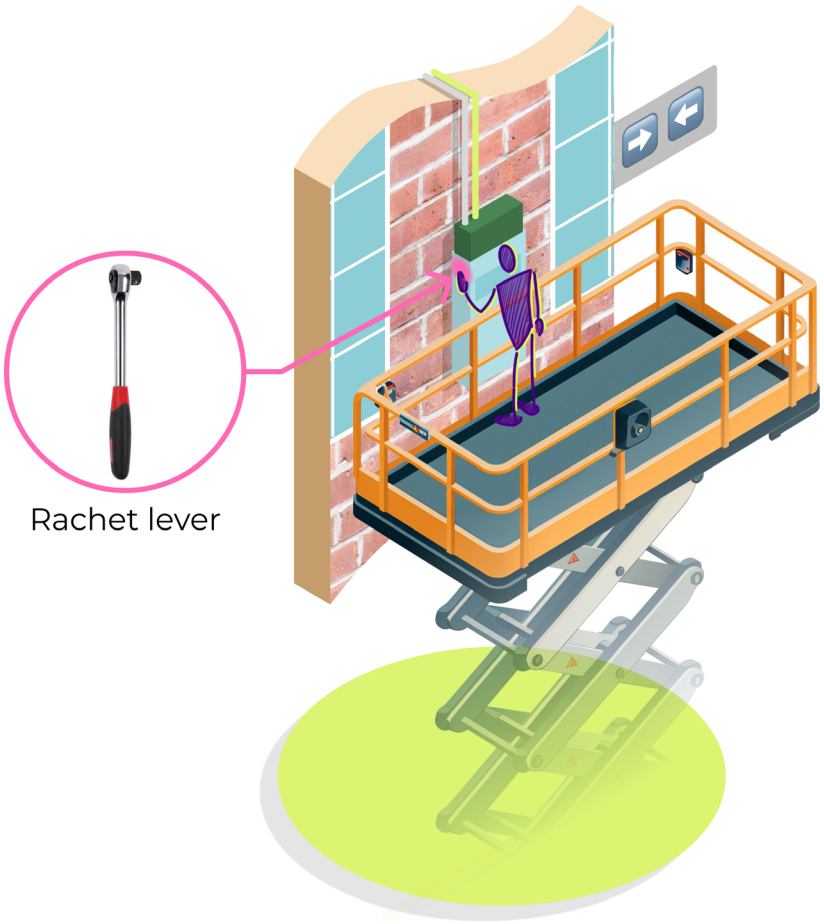
Step 3 | Setting up the DC unit





3.1 | Installation personnel inserts the DC unit into the Cooling unit from the top.

3.2 | Installation personnel adjusts cable length as necessary and connects the cables (8x Ethernet, 1x power) to the DC unit with appropriate capped cable connectors.



3.3 | Installation personnel uses a ratchet lever to clamp and secure the DC unit with the Cooling unit.

3.4 | Installation personnel turns on the data center and verifies via LEDs and online app the proper functioning of the hardware.

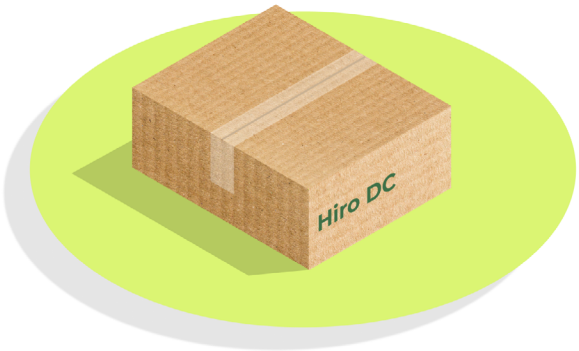
A cleint monitors EMDC status using digital platforms (1) and/or physically (2, status LED lights).

Minatenance personnel replaces consumables (dust screens and fans) when necessary. Hiro monitors the component status and ships replacement parts when it's time for a replacement.

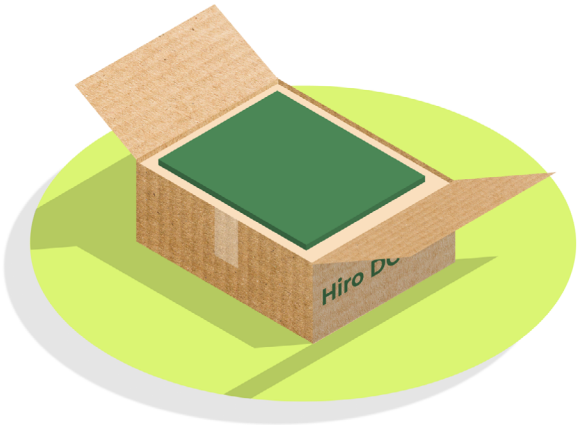
1st time installation

While in use

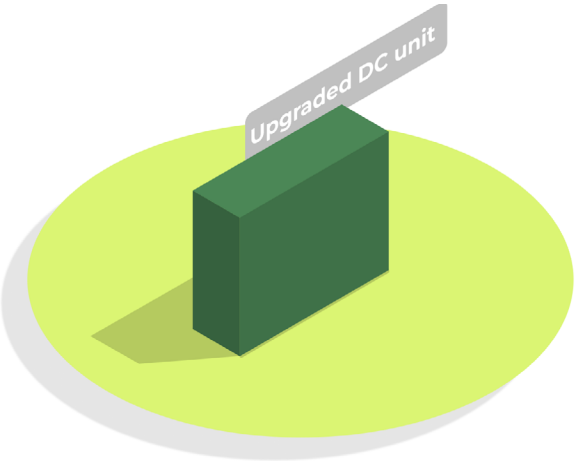
Step 1 | Receiving upgraded equipment on client's premises



1.1 | A client receives a box from Hiro at their premise with an upgraded DC unit.



1.2 | A client opens the box.



1.3 | A client unpacks the new unit.

Step 2| Uninstalling the old DC unit

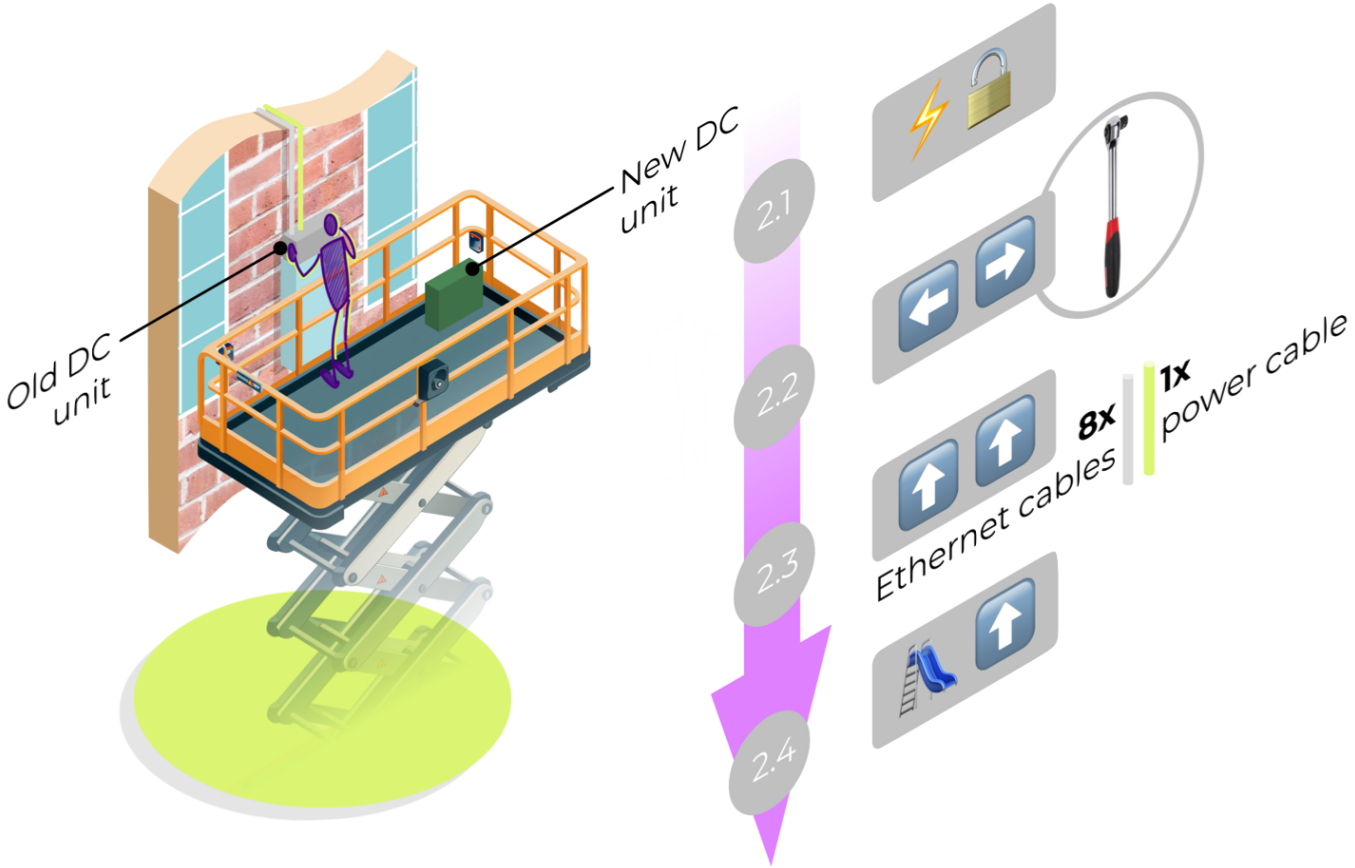
Installation staff carries out the **reverse** sequence of actions of the '1st Time Installation' on the **old** DC unit:

2.1 | opens up and powers off the EMDC.

2.2 | unclamps the old DC unit from the Cooling unit.

2.3 | unplugs the cables.

2.4 | removes the old DC unit from the Cooling unit from the top.



Step 3|

Re-installing upgraded DC unit

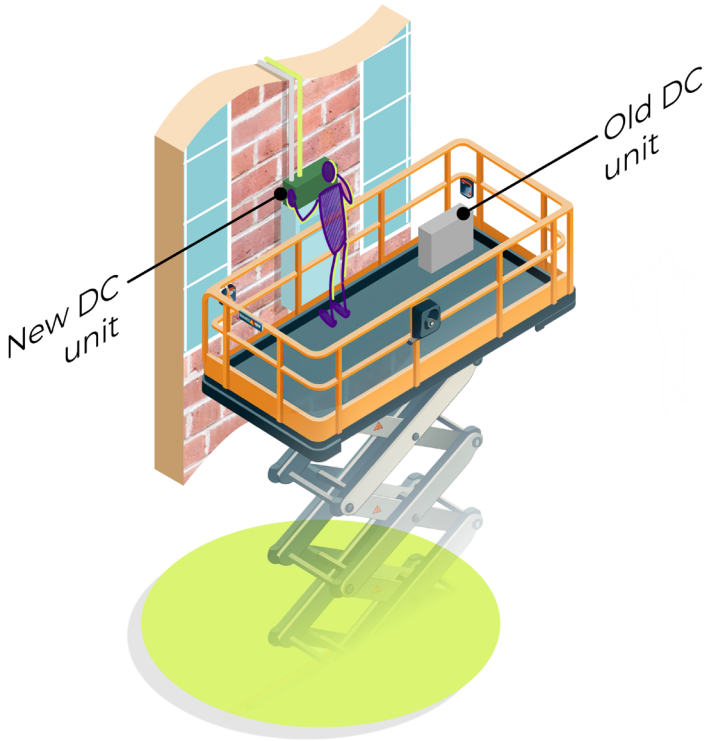
Installation staff carries out the **same** sequence of actions of the '1st Time Installation' on the **new** DC unit:

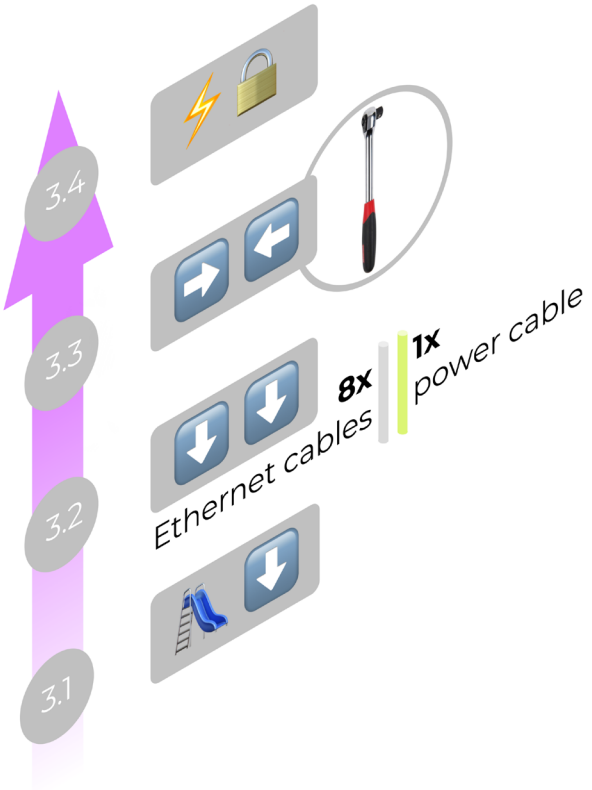
3.1 | inserts the new DC unit into the Cooling unit from the top.

3.2 | plugs in the cables.

3.3 | clamps the new DC unit with the Cooling unit.

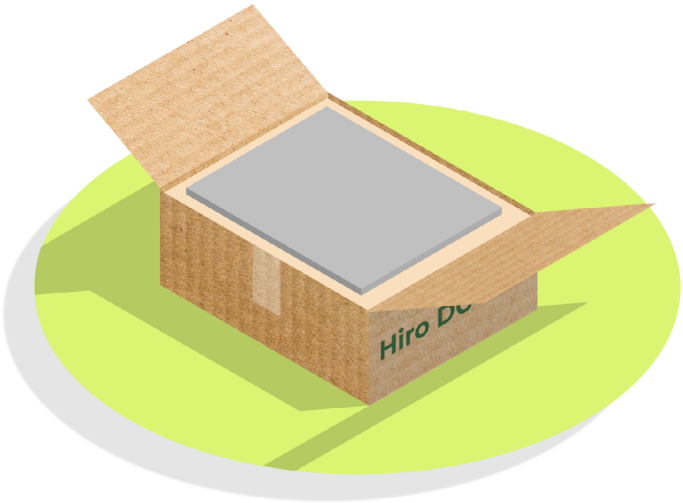
3.4 | powers on and closes off the EMDC.





Step 4

Shipping old DC unit back



4.1 | A client packages the old DC unit in a shipment box provided by Hiro.

4.2 | A client ships the box with an old DC unit back to Hiro.

Step 1| Uninstalling the DC unit

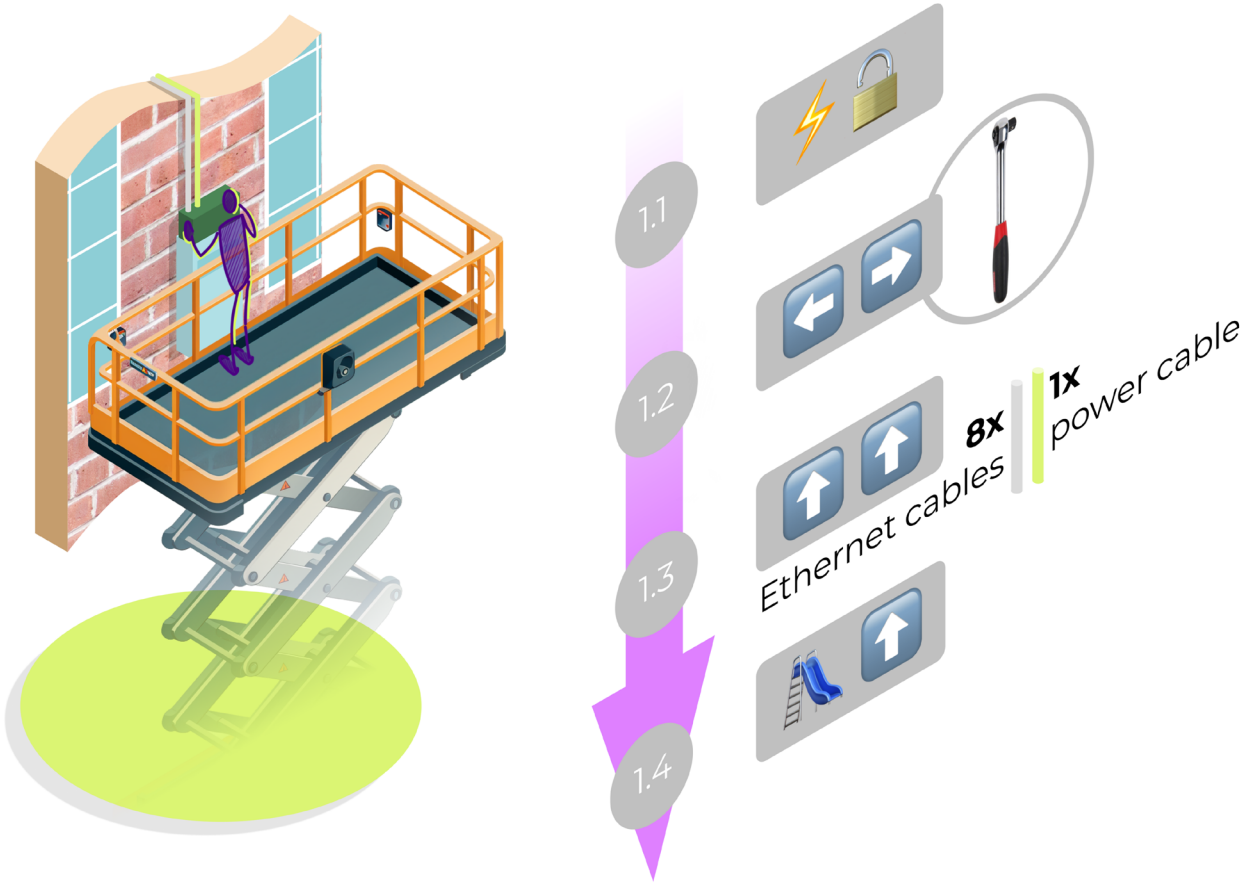
Installation staff carries out the **reverse** sequence of actions of the '1st Time Installation' on the DC unit:

1.1 | opens up and powers off the EMDC.

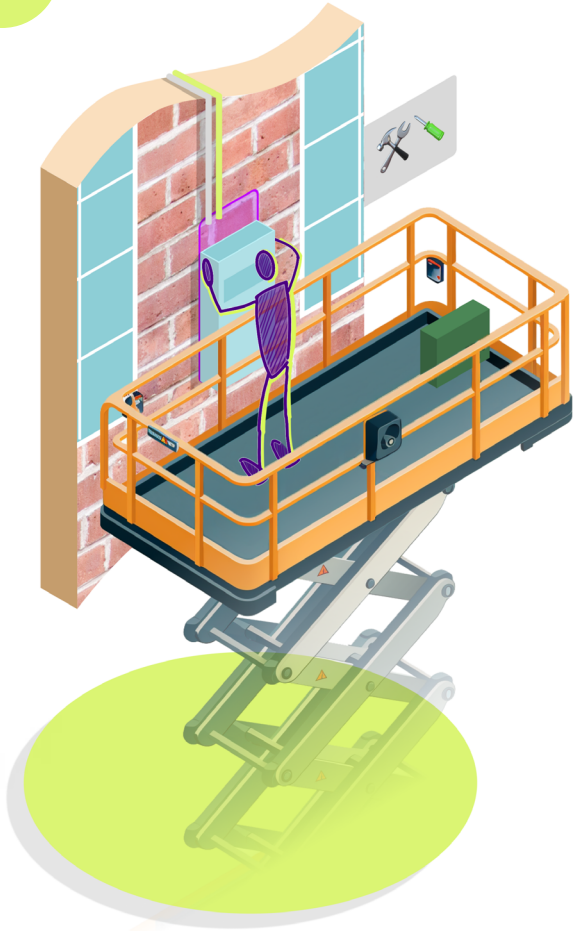
1.2 | unclamps the old DC unit from the Cooling unit.

1.3 | unplugs the cables.

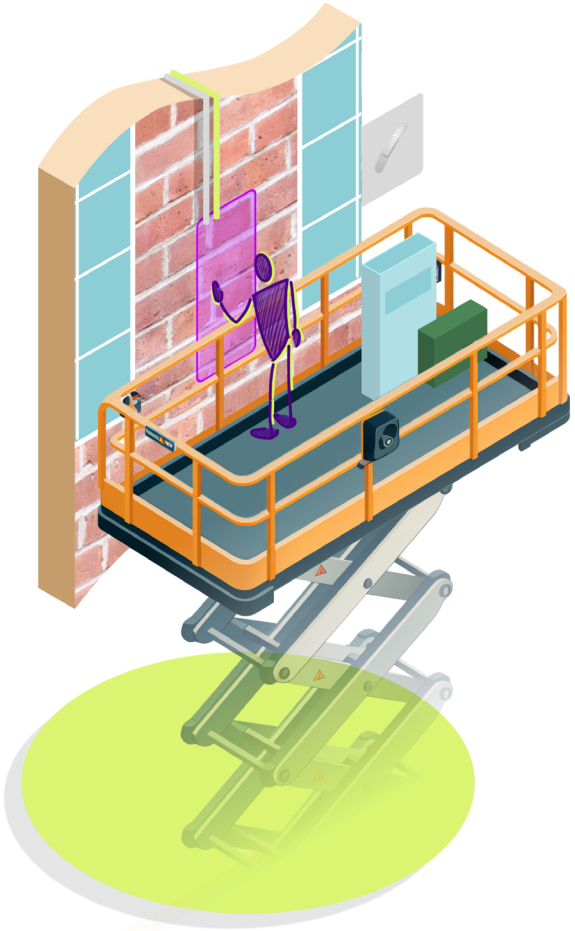
1.4 | removes the old DC unit from the Cooling unit from the top.



Step 2 | De-mounting the Cooling unit

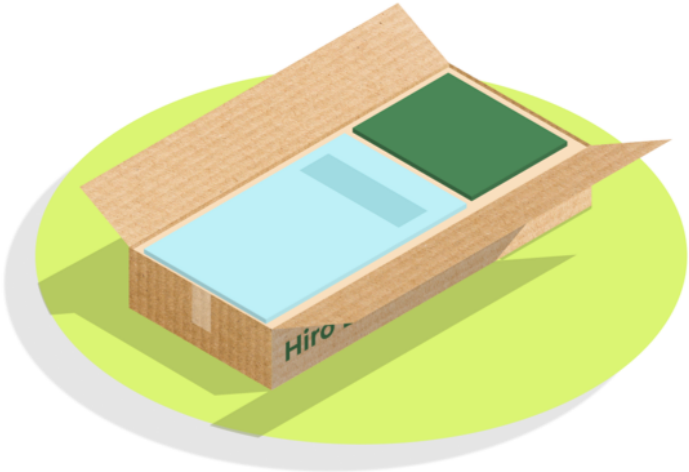


2.1 | Installation personnel demounts the Cooling unit from the wall.

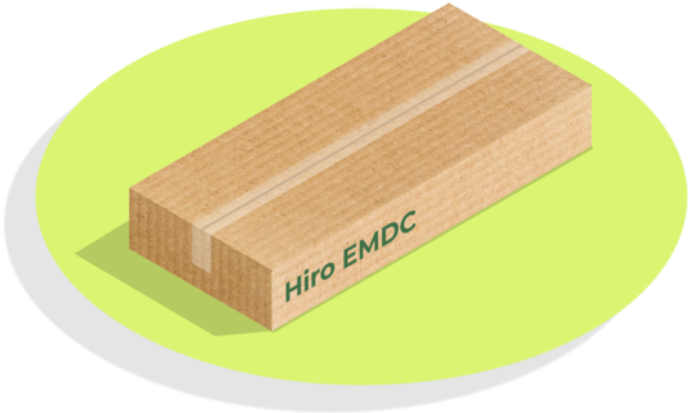


2.2 | Installation personnel fixes up any any defects that Cooling unit mounting might have caused to the wall.

Step 3| Returning the EMDC to Hiro



3.1 | A client packages the two units in a shipment box provided by Hiro.



3.2 | A client ships the box with equipment back to Hiro.

After obtaining a comprehensive outlook on the problem space and understanding of the hardware and interaction elements involved, it is time to envision a design process that would enable synthesizing these findings into a tangible Hiro EMDC enclosure concept design.

Design process outlook

Design sequence planning

The design of the EMDC enclosure is expected to be carried out in two main stages (Figure 28):

Stage 1 | During stage 1 the focus will be on focusing on the DC and Cooling units timeless, core design that includes such features as macro from factors, the units' interface, and other features specific to each unit. As these core elements are considered to be the strongest expressions of Hiro brand identity, it is deemed most important to detail them first. Core elements design will also help with defining micro features during the second stage of design development.

Manufacturing analysis | During this intermediate step between stages 1 and 2, manufacturing methods and corresponding materials for the selected units' designs will be looked into. While manufacturing methods will not be considered during stage 1 to avoid limiting ideation scope, manufacturing feasibility needs to be considered in the final enclosure concept design proposal. Based on this analysis, macro form factor adjustments will be adequate if necessary. Manufacturing method(s) and material(s) choices will also feed into the second stage of development to understand design possibilities and limitations for micro features design of the units.

Stage 2 | During this stage, the DC and Cooling unit designs will be flashed out with the missing features given the manufacturing analysis takeaways. Customizable parts of the enclosure will also be developed during this stage. Finally, the remaining subsystems, such as the mounting and the clamping actuator, will be detailed and finalized.

Detailing extent

The time limitations of this project necessitate determining the extent to which various elements of the EMDC would be developed and detailed. Figure 29 on the next page points out three levels of development and detailing. For the items in the 'Detailed design' category, flashed-out CAD models and a detailed explanation of all the features and choices that led to them are planned to be delivered at the end of the project. Items in the 'Recommendation/concept design' category will rely on existing solutions and/or provide conceptual solutions. Finally, units' internal features and off-the-shelf items

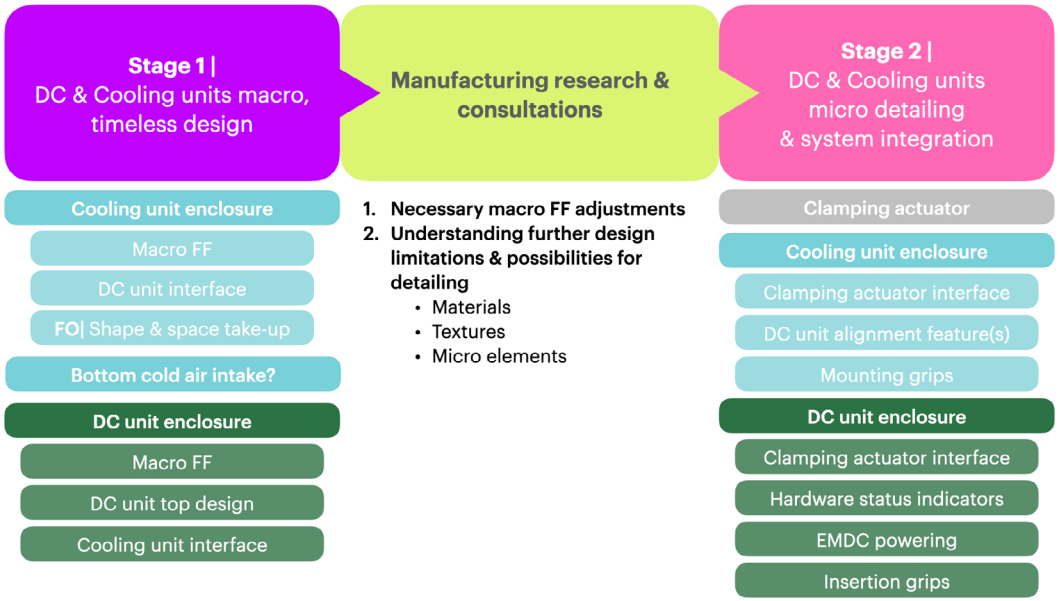


Figure 28 - Stages of development of the EMDC parts.

will be incorporated into detailed models if time allows.

Generative AI in the design process

The decision to incorporate generative AI tools into the design process was primarily driven by personal interest in this domain as well as also being supported by Hiro's strive to bring innovation into various aspects of their company operations and offerings. When deciding on how to incorporate AI in the design process, the two primary questions of 'why?' and 'how?' to use it were considered.

In his Master's thesis, Theijse (2024) investigated AI image generators in the context of bike frame design, concluding that "lack of control" is one of the greatest roadblocks to using state-of-the-art tools in the design process. However, on the flip side, he also pointed out that "AI is mainly suitable for inspiration and early ideation, it performs best when there are no strict requirements, constraints, or overly complex ideas" (Theijse, 2024). Theijse's conclusions are consistent with other research efforts on the topic that increasingly look at investigating AI tools as a means to "support human divergent creativity during the early-stage concept design process" (Paananen, et. al, 2023).

While the literature review presented a theoretical overview of the possibilities and limitations of AI usage in the design process, a recent conceptual footwear design by Nike presented a successful real-world application of the technology (Designboom, 2024). Leading up to the Paris 2024 Olympic games, Nike designers sat down with 13 world-class athletes to create conceptual shoe designs that reflected each athlete's personality. The process involved using Midjourney (Midjourney, n.d.a) to co-create extensive mood boards with the athletes (Figure 30) (Nike, n.d.). The mood boards were then used by designers to make 2D sketches, from which selected designs were converted into 3D models through computational design and then 3D printed for presentation in Paris. A

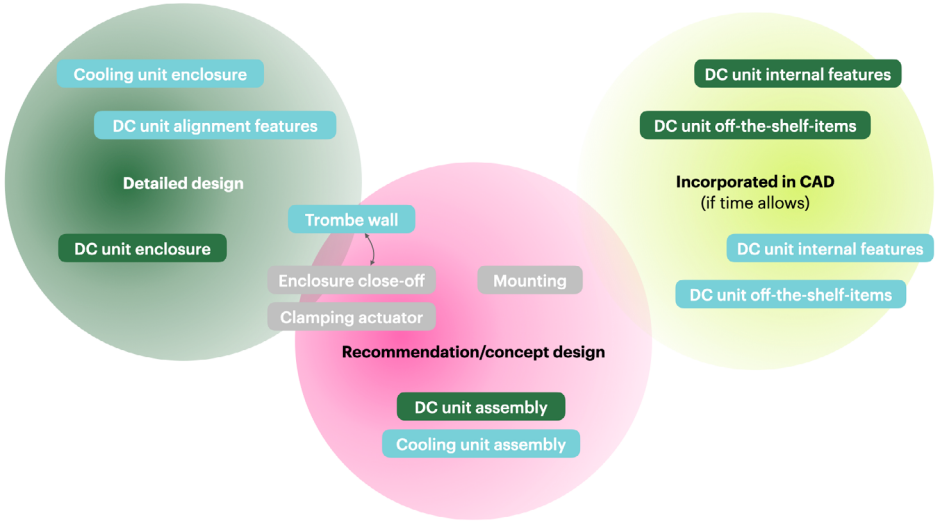


Figure 29 - Various extents of expected EMDC parts development.

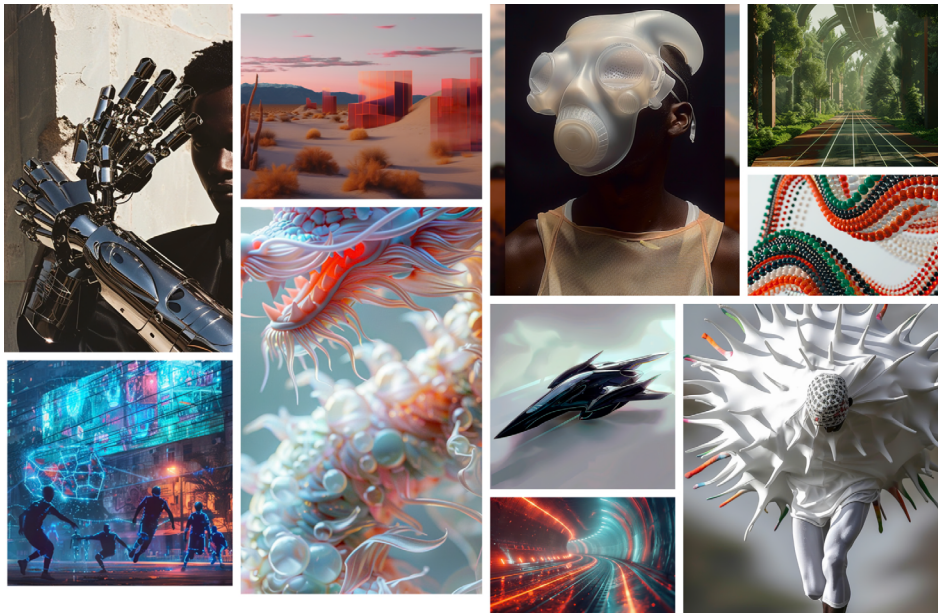


Figure 30 - A few image examples from Nike mood boards (Nike, n.d.).

conversation with one of the designers involved in the project also revealed that Vizcom (Vizcom AI, n.d.) was utilized in the detailing stage of the design process.

Findings from the literature review and AI application in the design process of the Nike conceptual footwear led to the decision to incorporate AI tools in the 'fuzzy front end' of the enclosure design process, specifically during the ideation stage. The Nike project also led to narrowing down AI tools to be used in the process to Midjourney and Vizom, primarily driven by the evidence of their successful application in the industry. More details on the specific usage of these tools will be described in the next section.

A quote from Simone Rebaudengo, a co-founder of the creative studio Oio that has been experimenting with AI tools in their speculative work, served as an inspiration and a North Star in guiding the usage of AI in the future design process: "We see the results of this new synthetic process as a starting point for unimaginable products, rather than the final step" (Figure 31) (Gorny, 2023). Considering that quote, the aim of using AI tools in this project would be for "exploration and imagination, rather than pure efficiency" (Gorny, 2023).

Outlook on selected AI tools usage in the envisioned design process

As Lee and Chiu (2023) pointed out "AI-generated visual stimuli have a positive effect on product design, but it does not mean that they are superior to online search visual stimuli, they are complementary to each other." This finding is consistent with the envisioned role of using selected AI tools, Midjourney and Vizcom, in the project as supplemental to traditional ways of searching for visual stimuli, such as Pinterest. Midjourbey is seen as most instrumental during Stage 1 of the design process described above, where its boundless imagination is seen as incredibly beneficial to the ideation process. Vizcom is expected to come more into play during Stage 2, where its rendering capabilities could be utilized to brainstorm detailing of the macro form factor. However, in all AI use case scenarios the aim is to keep the designer in the 'driver's seat,' responsible for concept selection and further development.

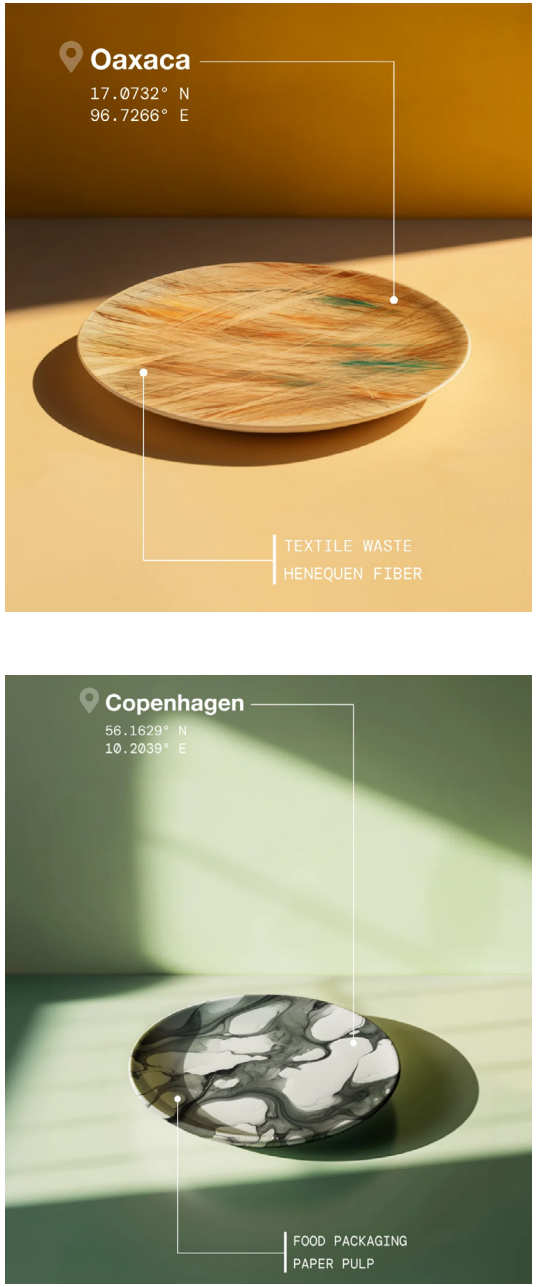


Figure 30 - Two plate sampels from Space10/Oio collaboration project 'Products of Place' (Gorny, 2023).

Anya Pozniak | Master Thesis

Design Phase
Stage 2.0

Why hide it? Reimagining the role of urban edge computing
in an AI-inspired, human-embodied manner.

Ideation divergent/ convergent stages

Macro from factor ideation and selection consisted of two major divergent/convergent stages (Figure 31). During Divergence 1.0, a mood board of classic designs was co-curated with the client and used as an inspiration source for self- and AI-powered ideation. After a wide range of ideas was developed, a public survey was leveraged to scope ideation down to several personal and AI-generated designs that were organized along a MAYA scale. Next, during the Divergence 2.0 stage survey feedback on the designs was taken into account in the next round of ideation with the selected designs on the MAYA scale serving as inspiration and starting points. Finally, Convergence 2.0 encompassed a focus group that led to zooming in on three enclosure concept directions and the selection of one to proceed with.

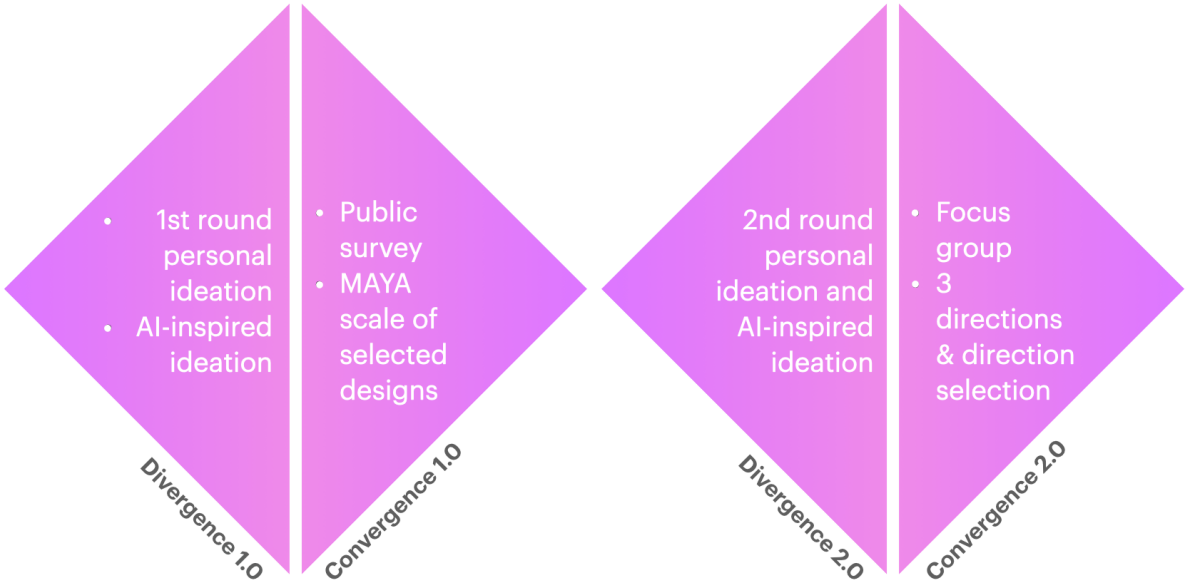


Figure 31 - Major divergent/convergent stages and the activities performed in them.

Classic designs mood boarding

The first step in designing the macro form factor of the EMDC enclosure was putting together a mood board of classic designs. Phaidon (2020) was referenced as a starting point for accumulating the designs. The designs were added to the board based on the personal opinion of whether or not they fit Hiro brand identity keywords (pioneering, elegant, professional, empowering, assertive) identified during the first stage of the project. Designs from various categories, from furniture to automotive, were considered for the board.

Next, ChatGPT was utilized to further broaden the scope of categories of products considered by asking the model to come up with design icons that can be described as pioneering, elegant, professional, empowering, and assertive. ChatGPT was prompted to think across a broad spectrum of product categories, from domestic appliances to automotive. The product type was then further specified for products that are wall-mounted and/or wall-hung. The final mood board with designs added through co-researching with ChatGPT can be seen in Figure 32 on the next page.

The next step in the mood boarding activity was to align with the client on the perception of design icons accumulated. As a result,

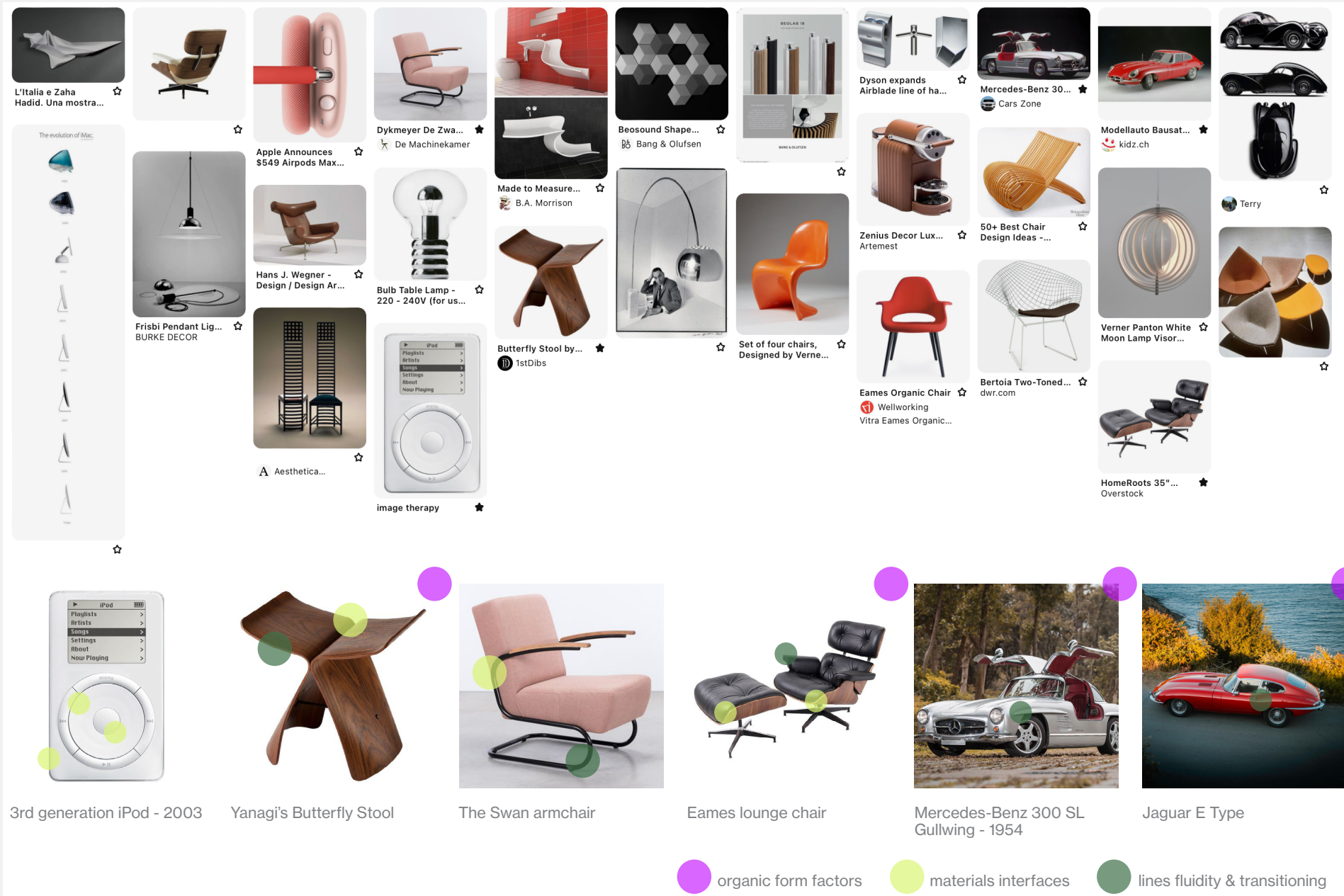


Figure 32 - Extensive classic designs mood board (top) as well as 6 down-selected designs with their interest features pointed out (bottom) (De Zwaan Buisframe fauteuil zwart / prairie stof 27 roze, n.d.; BedBath&Beyond, n.d.; Zegalba, 2022; Yanagi, n.d.; Unknown, 2014; CALVENDO, n.d.).

some designs were removed, while others were added. In addition, certain designs were identified as being of particular interest. The final mood board that was referenced during the first ideation round can be seen in Figure 32 on the previous page.

As can be seen from the five selected classic designs, the majority of them (except for the iPod and, arguably, the Swan armchair) are or gravitate towards organic form factors, defined by a curvilinear and fluid nature. When selecting the designs, a particular point of interest was the way two kinds of surfaces from different materials 'meet' one another. To give some examples, this can be observed between the plywood bases and leather seating cushion of the Eames Lounge chair, the way that the metal tube frame of the Swan armchair meets and supports its seat part, and the interplay between aluminum back and white plastic front in the iPod. The Butterfly Stool presents a case study for the two symmetric, mono-material pieces, where the two stool sides meet and bend away from one another, creating a smooth crease. Across the automotive classic designs, the fluidity of lines and their transitioning into various functional elements, such as windows, was a major point of interest.

First-round ideation

The first-round ideation was kicked off with an outside-of-the-box thinking exercise. During this activity, the objective was to set aside notions and requirements accumulated about the EMDC enclosure during the first part of the project and explore what other purposes these devices can serve in an urban environment. Figure 33 presents the ideation results from this activity. As can be seen, some additional roles that an EMDC enclosure can offer to its environment include shading and an engaging visual effect by utilizing acrylic sheets and their cast shadows.

First-round ideation was then continued more explicitly. The classic designs mood board was utilized to extrapolate possible EMDC enclosure designs from them.

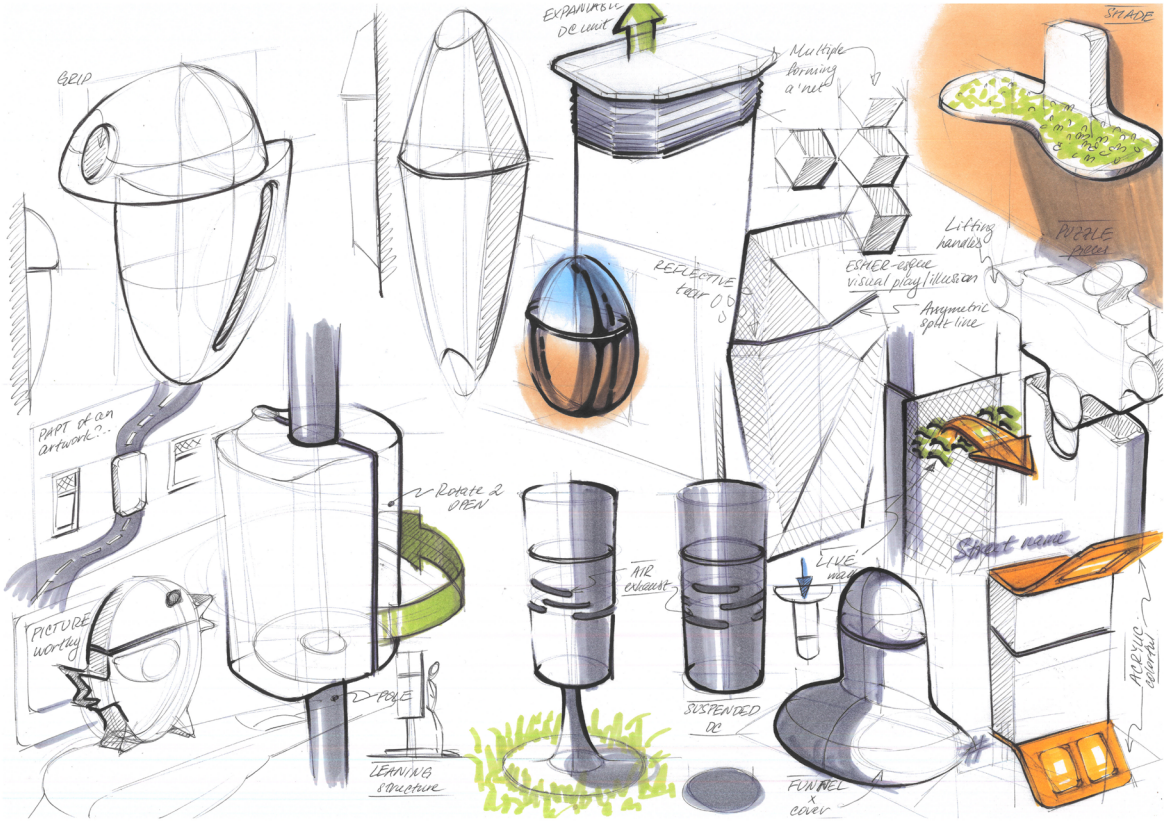


Figure 33 - 'Out-of-the-box' ideation activity, where alternative EMDC roles and possibilities were explored.

Midjourney-powered ideation

Once the flow of personal ideas slowed down, the ideation process turned to MidJourney (MidJourney, n.d.)to further expand on how a data center enclosure might look based on classic designs. The style reference (--sref) parameter within MidJourney was the key to this ideation activity. Combined with the prompt text, this parameter allows one to use images as a style reference to influence the aesthetics of the generated images (MidJourney, n.d.). After some trial and error, a prompt was devised that yielded satisfactory and inspiring results. The base prompt used for Midjourney ideation goes as follows:

ideas for a redesign of a wall-mounted air purifier, keyshot render --style raw --v # --sref [URL to the image of a desired classic design as a style reference]

The base prompt was supplemented with the following optional parameters, and their combinations, explained in greater detail below:

- --seed #
- --iw # (0.25 or 0.5)
- --w # (4 or 10)

Further prompt explanation is presented further.

Main prompt body | Perhaps the most important element of the main prompt body ("ideas for a redesign of a wall-mounted air purifier, keyshot render") is the "air purifier." Early unsuccessful attempts at utilizing MidJourney involved using generic terms such as "electronic device" in prompting. It led to the realization that the model needed a concrete object that it could work off of based on its training data (Kuchur, 2024). An air purifier was selected since it has similar dimensions and form factor to a Hiro EMDC. In addition, this product category has certain structural elements, such as fans, that could be inspiring in this ideation process. The "wall-mountable" property was specified as context in the prompt as this feature is an important attribute of the design sought after. "Keyshot render" was added as one of the "Magic" words (Kuchur, 2024), suggesting the desired image output style (a slick, realistic product render) to the model.

Base prompt parameters |

- **--style raw |** This parameter ensures that less generic AI 'beautification' is applied to the output images, which typically yields a better output when a specific style is added to the prompt (such as "keyshot render," for example) (MidJourney, n.d.).
- **--v # |** Even though MidJourney utilizes the latest version available by default, having the version parameter included allowed for an additional level of confidence about which version of the model is being utilized for the generation (MidJourney, n.d.).

Supplemental parameters | Whenever deemed necessary, three parameters were added to the base prompt and their values were varied:

- **--seed x |** This parameter was utilized when other parameters were varied for the same set of prompts to ensure that all images were generated from the same 'fog' within the model (MidJourney, n.d.).
- **--iw # (0.25 or 0.5) |** When working off base images in Midjourney (the image is uploaded in the thread and its URL is pasted before the base prompt), --iw # parameter determines how much influence the image has on the prompt for the final output (MidJourney, n.d.b). Within the context of this project, screenshots of the preliminary enclosure CAD were utilized to test the model's ability to produce meaningful results given the form factor, dimensions, and such prominent details as the front opening, in the base image. Figure 34 on the next page presents some examples of the preliminary enclosure base image alongside the outputs of different --iw # values. Through trial and error, it was determined that setting this parameter at 0.25 or 0.5 yielded the most satisfactory results (as a reference, in MidJourney version 6 utilized at the time when these activities were carried out, --iw 0 was the smallest possible value, --iw 1 - the default, and --iw 3 - the greatest possible value).

ideas for a redesign of a wall-mounted air purifier, keyshot render --style raw --v 6 --sref [Swan chair] ***--iw 0.25***

ideas for a redesign of a wall-mounted air purifier, keyshot render —seed 11 --style raw --v 6 --sref [Swan chair] ***--iw 0.5***

Figure 34 - Increasing the --iw parameter value tended to decrease the 'creativity' of the output as the model got more constrained by the CAD screenshot.

- **--w # (4 or 10)** | As described by MidJourney themselves, using the weird parameter yields "unconventional aesthetics" and "introduces quirky and offbeat qualities" to generated images (MidJourney, n.d.c). The interest in incorporating this parameter into the base prompt was primarily in further expanding imagination and inspirational visual material in unexpected ways. Through experimentation, it was determined that weird inputs of 4 and 10 yielded satisfactory, 'weird-enough' results (accepted values are between 0 and 3000). Figure 35 presents some examples of this parameter in action.

Once four images were generated for each prompt, designs of interest were varied, resulting in four more images based on the selected design. Out of original generations and their variations, designs to be considered in ideation were picked based on personal judgment of relevancy and interest to the EMDC enclosure design. A full summary of selected images and prompts that yielded them can be found in Appendix G. This appendix also presents examples of generations that were less successful or bizarre.

To remain focused, generated MidJourney images were downselected further (Figure 36 on the next page) with the macro form factor in mind. The selection was done based on personal preference as well as consultation with the client, using their input on which generated images resonated with the company's identity and their vision for the enclosure design. First-round ideation sketching continued with selected MidJourney-generated images to spark ideas. Figure 36 also presents first-round ideation results.

ideas for a redesign of a wall-mounted air purifier, keyshot render --style raw --v 6 --sref [Moon Lamp] --seed 17 ***--weird 4***

ideas for a redesign of a wall-mounted air purifier, keyshot render --style raw --v 6 --sref [Moon Lamp] --seed 17 ***--weird 10***

Figure 35 - Increasing the --w parameter value tended to deviate more from the expected style reference image as well as include more context in the ouput (Panton, n.d.).

[CAD screenshot] ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[B&O Beolab]* --style raw --v 6 --iw 0.5 + Upscale (C)

[CAD screenshot] ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[B&O Beolab]* --style raw --v 6 --iw 0.5 + Upscale (C)

ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[modernist architecture]* --style raw --v 6 + Upscale (C)

ideas for a redesign of a wall-mounted air purifier, keyshot render --style raw --v 6

ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[Moon Lamp]*--style raw --v 6 --w 10 + Upscale

ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[B&O Beosound]*--style raw --v 6 + Upscale (C)

[CAD screenshot] ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[Swan chair]*--style raw --v 6 --iw 0.25 + Upscale (C)

ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[B&O Beolab]* --style raw --v 6 + Upscale

ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[B&O Beolab]* --style raw --v 6 + Upscale

ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[modernist architecture]* --style raw --v 6 + Upscale (C)

ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[modernist architecture]* --style raw --v 6 + Upscale (C)

ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[Moon Lamp]*--style raw --v 6 --w 10 + Upscale

ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[Moon Lamp]*--style raw --v 6 + Upscale

ideas for a redesign of a wall-mounted air purifier, keyshot render --sref *[Jaguar]*--style raw --v 6 --w 4 + Upscale (C)

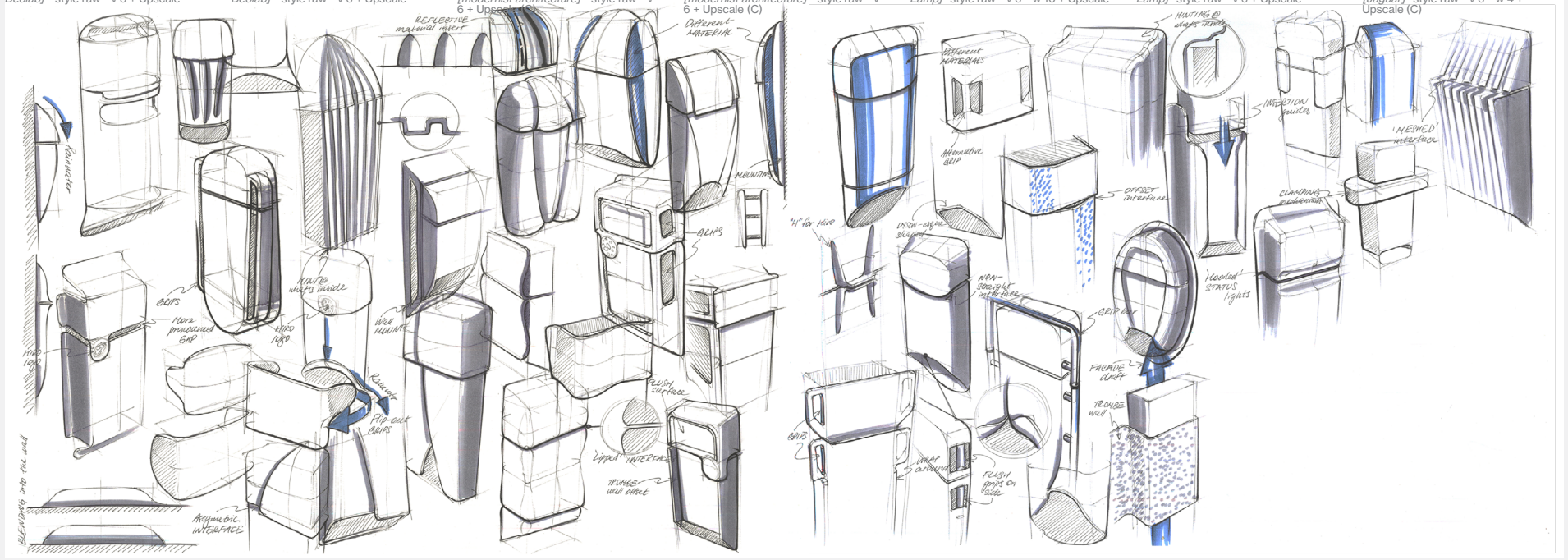


Figure 36 - Downselected MidJourney inspirational designs alongside their prompts and first-round ideation results.

User survey to scope down macro ideation

After the first round of unbound ideation on the macro form factor, it was necessary to gain greater focus on the second round of ideation, narrowing down the scope of inspiration references and desired form factors. As the public had not yet been involved in the design process, this moment presented an opportunity to reach out to an independent audience for their opinions. While those more closely involved with the project had preferences in terms of directions to take the design, carrying out a survey would provide a check on whether that intuition matched that of broader society. As the enclosure design will be placed in public settings, aligning with the public perception is a crucial step in ensuring it is successful and well-received. In addition, it was expected that this survey would provide a glimpse into how a potential client would perceive Hiro EMDC aesthetics.

The survey consisted of 3 sections as outlined below. Survey questions from each section can be accessed in Appendix H.

1. **Classic Designs section** | The objective of the questions in the Classic Designs section was to get into public perception of several designs selected from the mood board curated with the client concerning the five Hiro brand identity traits: pioneering, elegant, professional, empowering, and assertive. Four classic designs (Figure 37) were selected that were found to be the most useful and influential during the first round of ideation. Survey participants were first prompted to select 3 traits that spoke to them to the greatest extent in that design and then narrow it down to the top 1 trait. It must be noted that the 'professional' brand identity trait was replaced with the adjective 'refined' for the survey (it was believed that the adjective 'refined' embodied the desired trait more understandably, reflecting the implied well-crafted nature of a design). They were then asked to provide one design detail related to the form factor to back up their selection of the top-ranked trait for that design. It was expected that insights from this section would yield more specific information and direction in terms of which designs (and their specific details) express which trait.

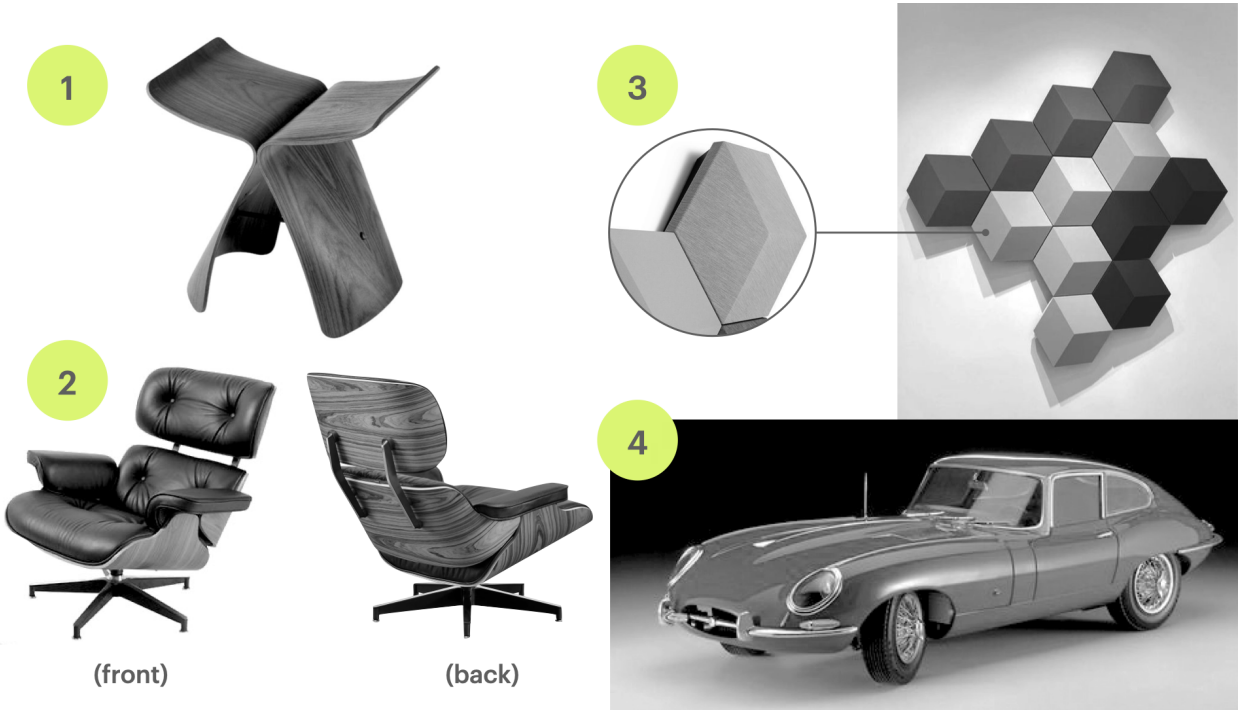


Figure 37 - Classic designs presented to the participants: 1 - Butterfly Stool, 2 - Eames lounge chair, 3 - B&O Beosound, 4 - Jaguar E Type.

2. **AI Inspiration from Classic Designs section** | Next, participants were asked about the selected AI-generated groups of designs (3-4 designs per group) (Figure 38 on the next page). The selection of designs for the survey was made based on personal preference based on the designs that were most influential during the first round of ideation.

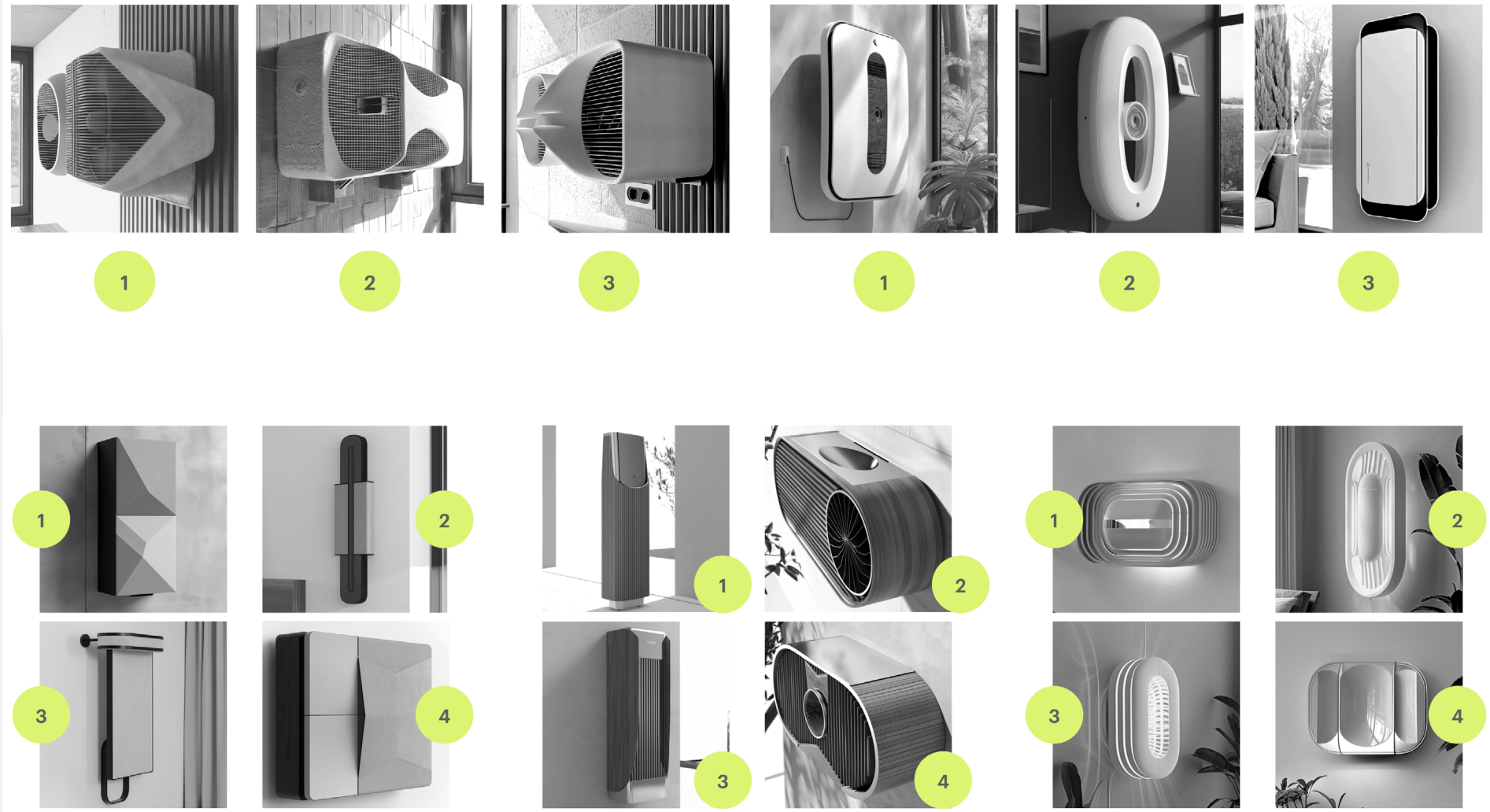


Figure 38 - Five groups of selected AI-generated designs.

For each design, participants were asked to pick one trait that, in their opinion, embodied that design to the greatest extent. Participants then picked their favorite design out of the group and reflected on which form factor details, related to the trait they selected for it or not, drew them to that design. The goal of this section of the survey was to continue distilling which designs resonate with each Hiro identity trait and which design elements make the public feel that way.

First-round Ideation section | In this section, survey participants were presented with the groups of sketches done during the first ideation round (Figure 39). Sketches were shown to the participants in 3 groups, with 2 groups being united by a common theme across sketches (Wrapping Planes and Visual Illusion). The third group, the Incidents, was composed of personally selected sketches that were deemed to be of interest to be presented to the public, yet we were not unified by a specific theme like in the first two cases. The questions in this section were focused on prompting participants for their favorite designs/form factors as well as the reasons for their preferences. A point of interest was whether certain ideas would gain a significant lead over others in the public's positive perception, which could be taken into account for the second ideation round.

Survey results

When analyzing the results, the following survey limitations were discovered:

- The first two sections of the survey featured black and white images with the idea that a monochrome color scheme would help participants focus on the overall macro form factor as opposed to going off-topic and commenting on such details as materials and finishes, for example. However, the idea behind black and white images should have been pointed out explicitly as it seemed to puzzle some participants.
- The limitations of AI image generation should have also been pointed out more explicitly as several participants were puzzled by the 'incompleteness' of some images.
- It was also observed that limited rendering of sketches led to misunderstandings in some cases.

The survey was conducted anonymously and gathered a total of 18 responses, *n = 18*.

Classic Designs and AI Inspiration from Classic Designs sections | Figure 40 on the next page presents combined results from the first 2 sections of the survey. For each of the 5 traits, classic designs and the crowd's AI-generated favorites are presented. In addition, common themes in people's free responses were also investigated to identify why certain designs communicated a particular trait to them. For example, as can be seen in Figure 40, assertive designs' form factor was described as bold and

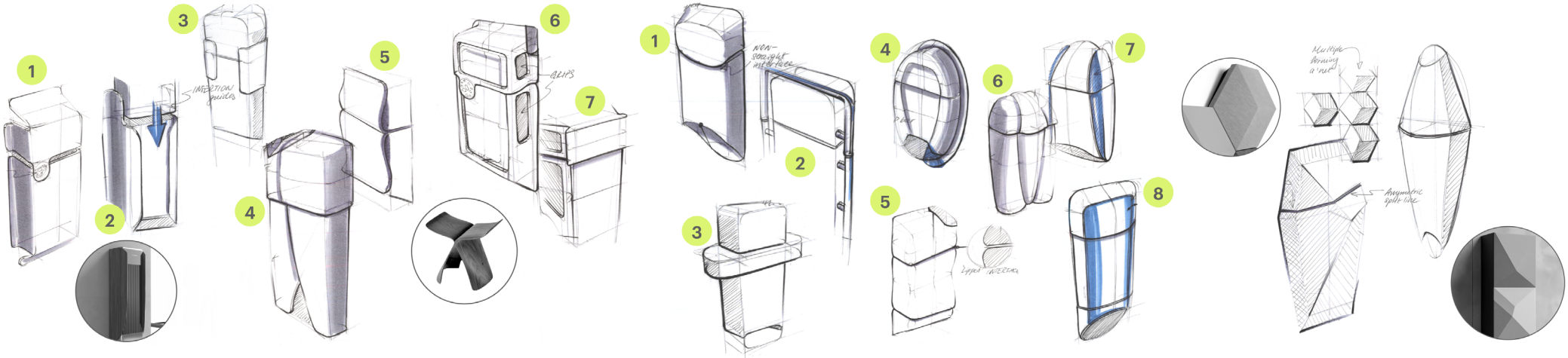


Figure 39 - Three groups of sketches from the first ideation round presented (left ro right): Wrapping Planes, Incidentals, Visual Illusion.

geometric, with one participant also using adjectives such as ‘strong’, ‘solid,’ and ‘tough.’ Overall, assertive designs were perceived as noticeable and powerful. In contrast, adjectives that were predominantly used for elegant designs included ‘organic,’ ‘flowing,’ and ‘minimal, clean.’ While the traits of assertive, elegant, and refined were easy for participants to perceive and comment on, the traits of empowering and pioneering seemed to be more challenging. Perhaps these traits are more related to the overall concept and the benefits it delivers. For example, the pioneering brand identity trait is expressed in the overall concept of an innovative edge equipment enclosure that adds to the visual appeal of its environment. Hiro EMDC empowers its users by providing them with private cloud and computing services. Analyzing the results of the first 2 sections of the survey, it was decided to pay particular attention to further expressing the ‘assertive’ and ‘elegant’ traits in the second round of ideation on the macro form factor, narrowing down on the designs from Figure 40 and their overlapping themes and comments.

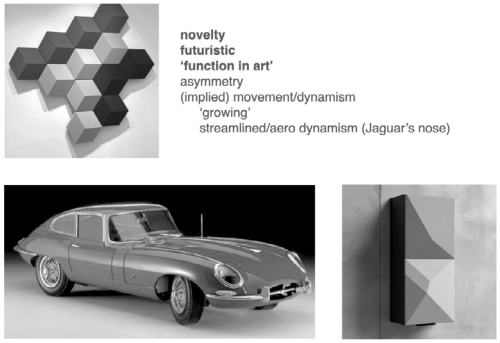
First-round Ideation section | Figure 41 on the next page presents the crowd’s favorites (alongside ‘like’ counts and corresponding percentages of the total number of responses per group) across the 3 sketch groups presented in the survey. Some of the details pointed out about the designs in the ‘Wrapping planes’ group were their organic form language (including details such as rounded features) and symmetry. Interestingly, without being explicitly prompted to think about features in the designs that might have any environment blending potential, one participant noted about design 1: “1 looks like it could blend with the wall.” Speaking of design 8 from the ‘Incidentals’ group, its simplicity and unobtrusive aesthetics were pointed out with one person even calling it ‘brutalist.’ Perhaps the simple nature of this form also led it to be perceived as what people would expect from a data center enclosure.

Overall, the ‘Wrapping planes’ and ‘Visual illusion’ groups scored the highest among the 3 groups presented (receiving 12 ‘likes’/66.7% and 11 ‘likes’/61.1% respectively). Noteworthy comments for these 2 most popular groups included people’s concerns over organic form factors potentially breaking up buildings’ predominantly geometric lines. In addition, people were concerned about adding visual clutter into the urban tissue, expressing their wish for the enclosure design to ‘blend well’ and come across as ‘more subtle and maybe even hidden.’

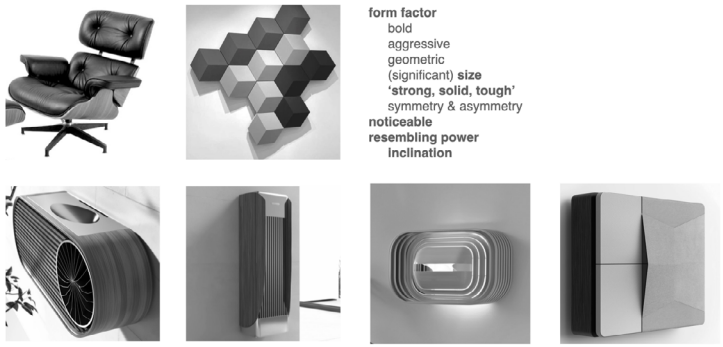
A more detailed analysis of the survey results can be seen in Appendix H.

Empowering

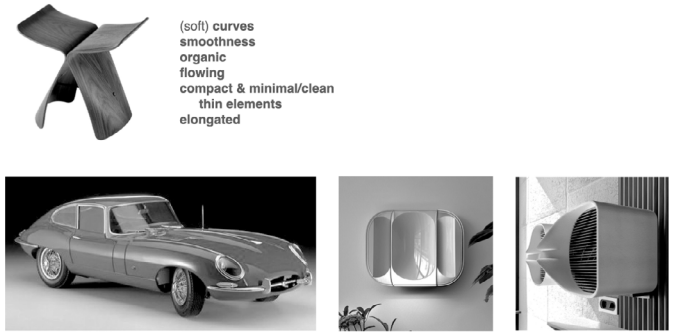
Pioneering



Assertive



Elegant



Refined

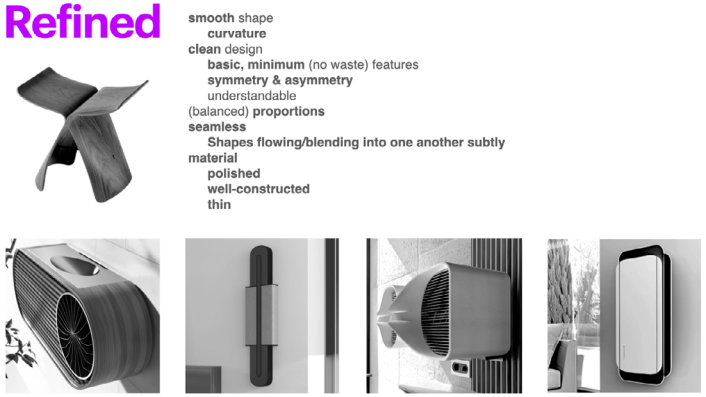


Figure 40 - The results of the ‘Classic Designs’ and ‘AI Inspiration from Classic Designs’ sections.

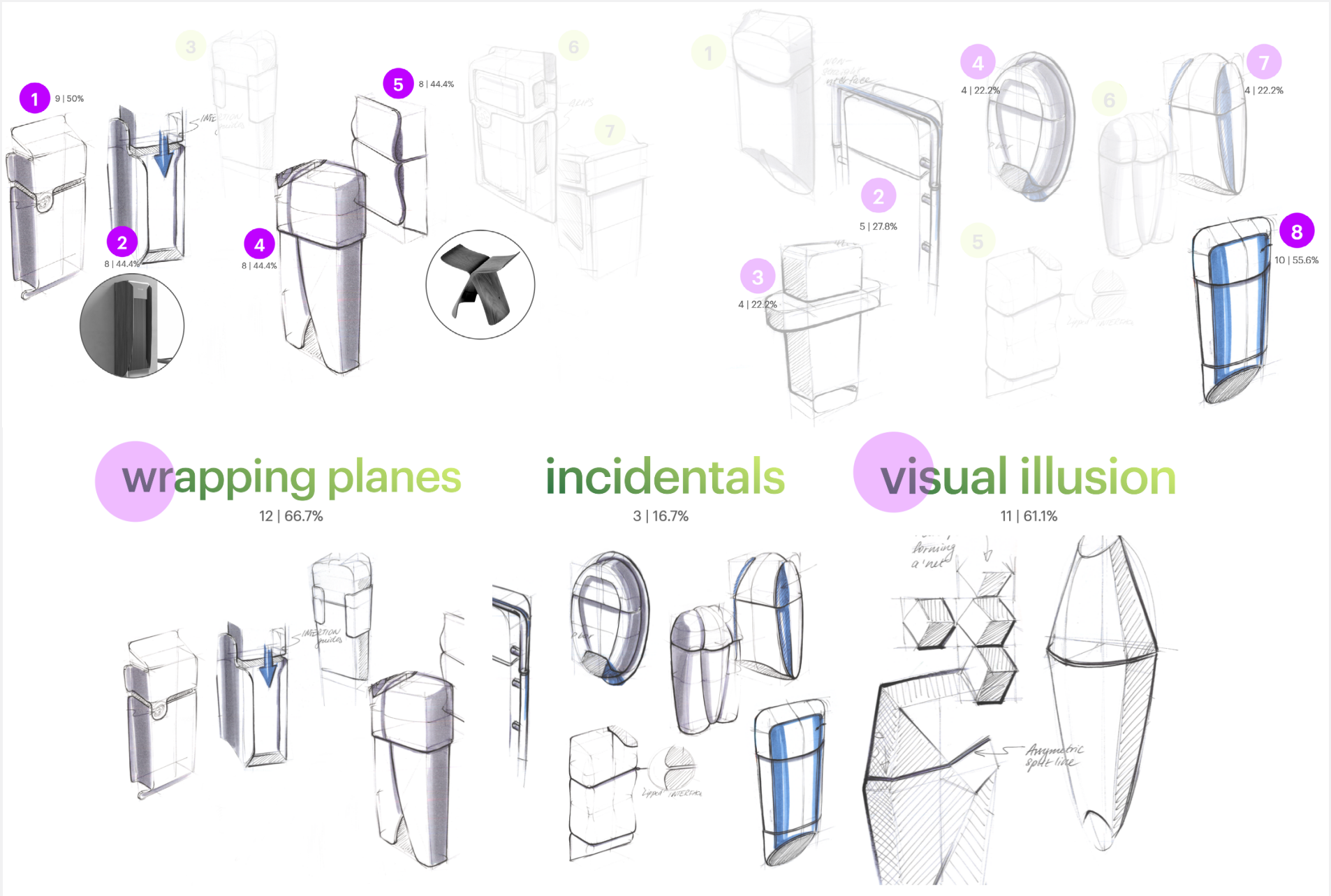


Figure 41 - The results of the First-round Ideation section.

Second-round ideation

Survey outcomes were further digested by organizing down-selected AI-generated and first-round ideation sketches along a MAYA continuum (Figure 42). Designs and sketches were organized between the 2 extremes of “I can recognize this as some kind of electronic device/data center” on the left to those that would be perceived as more functional pieces of art on the right. Next, the second round of ideation was conducted, including both personal ideation and AI-aided ideation (see Appendix I for designs generated during this round). Ideation was carried out across 3 main groups along the spectrum: left-most, middle, and right-most sections with some designs in between the sections being re-imagined for multiple sections. Figure 43 on the next page presents ideas generated across the 3 sections.

While the idea behind ideation across 3 sections was down-selecting each of them to one or 2 designs that would then be placed along the presented MAYA spectrum, it was quickly seen that the amount and richness of ideas in each group was beyond this simplification. As a result, the 3 sections were holistically assessed for underlying themes across all the sketches. In addition to the familiar ‘Wrapping planes’ and ‘Visual illusion’ themes, 2 new themes were identified: ‘Hat on’ and ‘Concave/convex.’ For each theme, 3-4 designs were selected on an increasing MAYA scale. Figure 43 presents the selected ideation sketches for each theme as well as a characteristic feature(s) that define that group of designs.

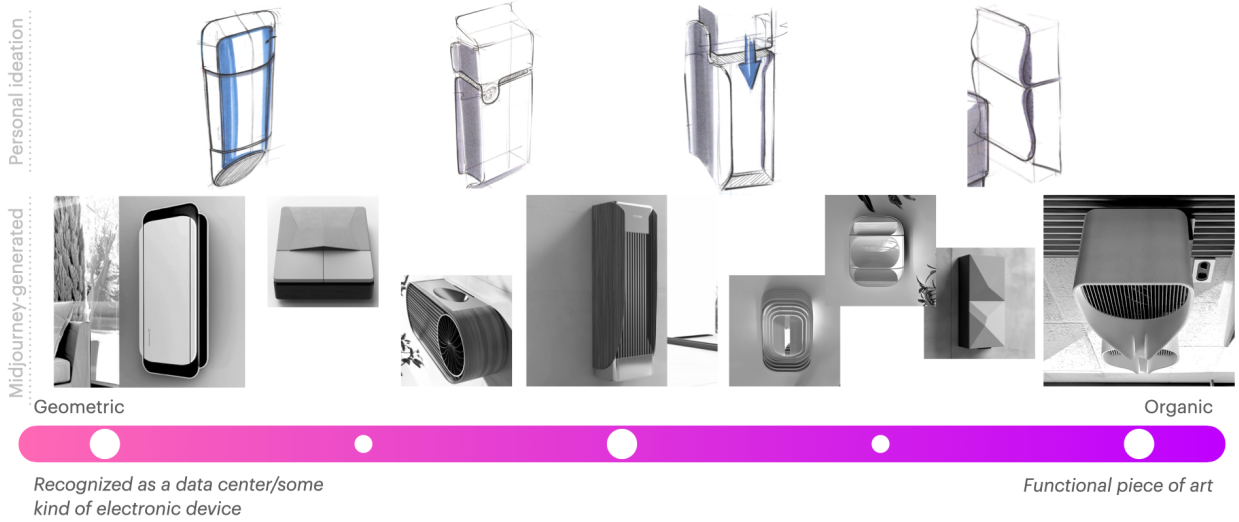


Figure 42 - Mapping of survey results on a MAYA scale.

For each theme, initial sketches were thought through and finalized, resulting in 2-4 concepts per theme. Figure 43 on the next page presents refined concepts across the 3 themes alongside the most influential AI-generated inspiration for them. It was decided that the ‘Hat on’ theme acts more as a detailing opportunity for the DC unit rather than a distinctive enough theme of its own. The sketches were again organized following the MAYA spectrum with more ‘acceptable’ designs on the leftmost side and more ‘advanced’ designs to the right.

Figure 43 - Second-round ideation sketches along MAYA continuum, selected second-round ideation sketches across the 4 themes, and refined concepts across the 3 themes alongside their most influential AI-generated inspirational images.

Second-round ideation

Narrowing down the scope of the second-round ideation was used as an opportunity to directly engage with the public and consider the context of interest (Dutch historic city centers) for the first time. An online focus group/co-creation session (Figure 44) was carried out with 3 participants, Zahra, Yaël, and David, who were engaged based on their expressed interest in staying involved with the project in the previous user survey. Participants formed a diverse group based on place of origin (Europe and Asia) and background (arts/design and engineering/technology disciplines), which was desired to reflect the multi-national public that is found in Dutch historic city centers.

Focus group stimuli included a short introductory presentation that went over background information about the EMDC that would be helpful for participants to know to engage in the session. A short paragraph was created and read to participants out loud to help them get into the desired frame of mind (Figure 45). After the introductory presentation, visual stimuli were presented in 3 series, starting with concept sketches on a white background, which were then presented on a brick wall typical for Dutch historic city centers, moving on to a presenting the design on one of the historic buildings found in Delft as it could be seen from the sidewalk. The last kind of visual stimulus featured stock images of manufacturing and healthcare environments that were used to help participants

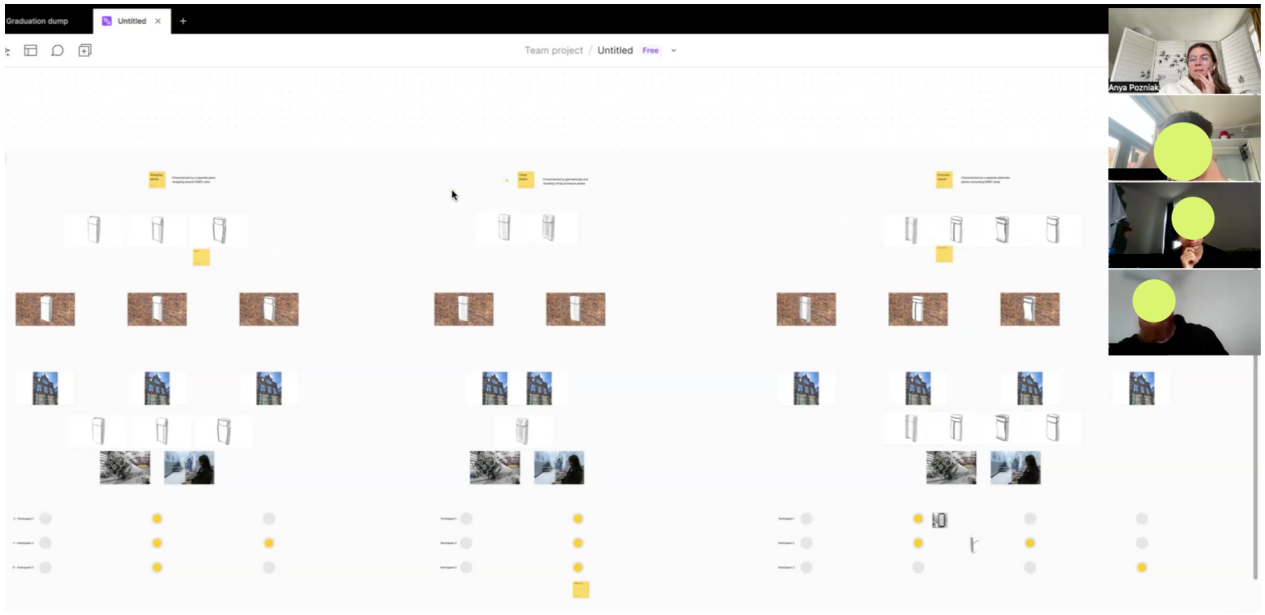


Figure 44 - Online Zoom focus group in session.

Imagine...

We're in 2030. You live in Delft. You are out on a walk in the city center. The city really transformed over the past few years, enhancing the life of its inhabitants with smart infrastructure. Self-driving cars make their way past you, with smart traffic regulation you barely need to wait to cross a street and 6G network took your connectivity to the next level.

Something else that is new is wall-mounted objects that have been popping up on building facades in Delft city center. You have heard that these are the devices that enable all of the smart features that you have been enjoying. But you'd have barely guessed that looking at them. You like how they kind of blend with the architecture in the historic city center and add to its visual appeal. They look like...

Figure 45 - Mood-setting paragraph for the focus group.

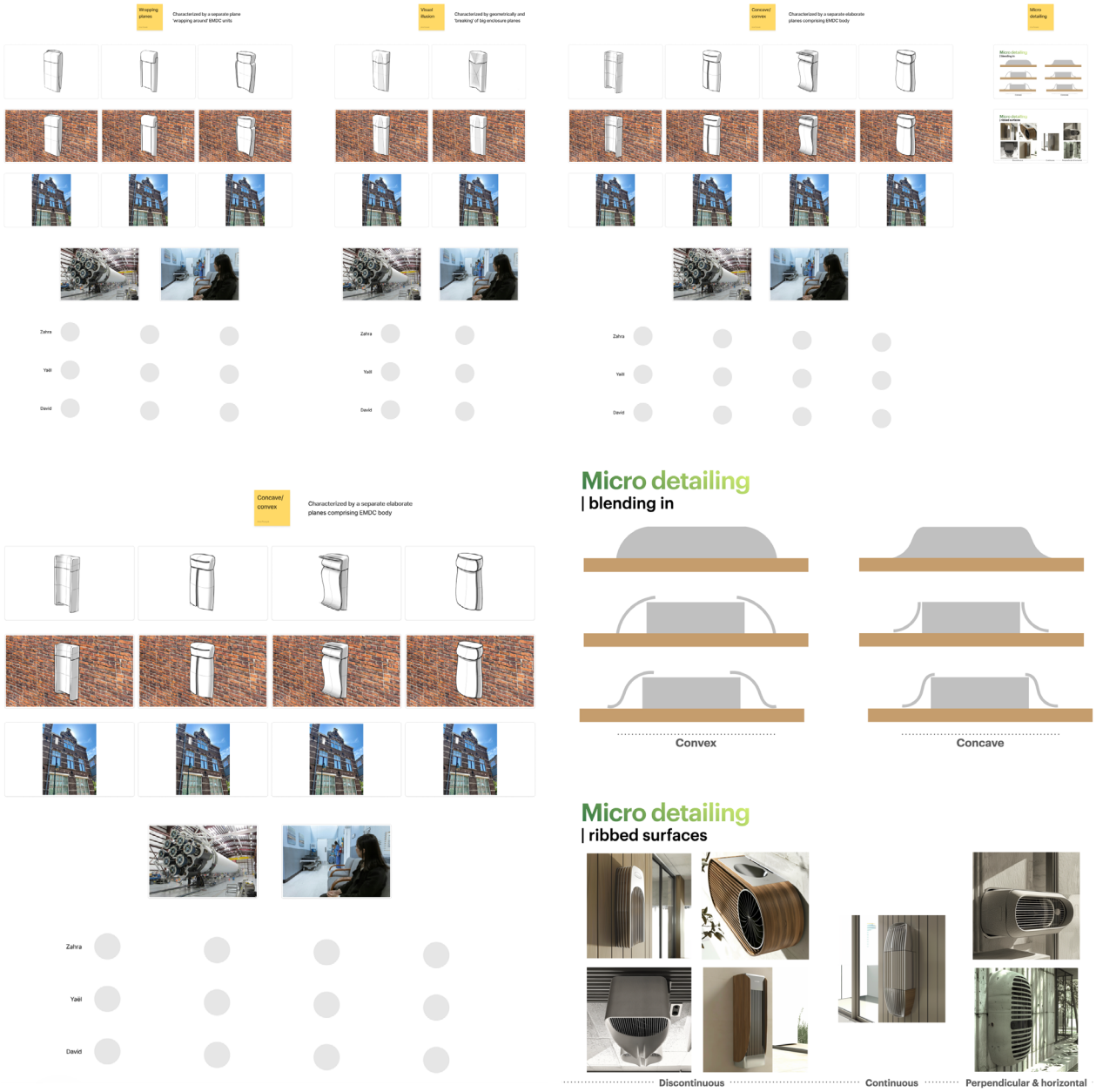


Figure 46 - Figma FigJam board set-up used for the focus group with 'Concave/convex' theme section and 2 micro elements topics highlighted on the bottom.

imagine presented concepts in those settings. The themes were also presented in increasing order of 'advancedness' with 'Wrapping planes' determined to be overall more 'acceptable,' while the concepts in the 'Concave/convex' group were assumed to be perceived as more advanced by participants. Visual stimuli were arranged and shown to participants on the Figma FigJam board (Figure 46).

Concepts in each theme were introduced to participants as points on a MAYA scale, going from a design that was assumed to be more 'acceptable' in the public eye on the left to a more 'advanced' one on the right. For each of the 3 themes, participants were first asked to review the 3 kinds of enclosure concepts presentation (sketch on white background and 2 in-context examples). Interestingly, participants repeatedly asked to see the first simple monochrome concept presentations, while in-context presentations did not seem to be as insightful as expected. This phenomenon might have been due to the detail overload in the in-context presentations while participants were trying to grasp the features of each design in a relatively short time. As they were considering each concept, participants were asked to imagine each concept and speak their minds about how they felt about and perceived each if they were to imagine seeing these designs while walking around Delft, for example. Once it seemed like each participant made up their mind with regards to the city center setting, 2 new settings – manufacturing and healthcare – were presented and a similar discussion with regards to each concept's appropriateness in the environments presented was carried out. At the end of each theme's discussion, each participant was asked to select one to two concepts that

they personally preferred across the 3 settings of interest. Their rankings were ultimately used as indicators of where they stand on the MAYA spectrum for a given design theme.

In the last section of the focus group, participants' perception of the 2 groups of micro design detailing elements was questioned. The 2 main groups of micro design elements presented featured 'Blending in' and 'Ribbed surfaces.' The 'Blending in' group (Figure 46 on the previous page) of designs presented various ways that a unit's enclosure or a wrapping plane around it could create an illusion of physically going into the wall and merging with it. The 'Ribbed surfaces' group (Figure 46 on previous page) presented various possibilities for decorating the Cooling unit with ribs, including ribs that went along one unit only or both of them as well as those that went in a less intuitive direction, such as perpendicular to the longest edge of the enclosure. The goal of this section of the focus group was to check assumptions on the perception of these microelements and whether the public was leaning towards any particular microelement type and the reasons behind it.

No quantification of data (such as asking participants to rank concepts) was carried out as this section was focused on obtaining qualitative data on participants' perceptions of microelements presented as well as any existing preferences among them.

The paragraphs below provide a summary of the feedback and concept ratings (Figure 47) for each of the 3 design themes as well as microelements.

1. **Wrapping planes** | As can be seen, design 2 was considered the most advanced yet acceptable. Design 1 did not receive much attention or comments overall, while design 3 was mentioned to be an example of "personification," being perceived as a robot or a creature that might be watching people. However, design 3 received positive feedback from Yaël with the suggestion of bringing the plane on the sides to the front to unify the 2 units.

2. **Visual illusion** | Unexpectedly, design 2 in this theme was an easy pick for the crowd's favorite. This theme also received a majority (2) of votes for the theme to be pursued for the final design. However, as pointed out by Yaël, the sharp angular form factor might look like certain military equipment to some parts of the general public. Alongside this comment, participants agreed that the sharp edges of the proposed concept could be smoothened to achieve a more fluid, inviting form factor.

3. **Concave/convex** | It was expected that as a theme with the most varied concepts, this group of designs would receive the most mixed rankings and feedback. At 2 votes, design 2 was overall most liked. While its highly personified nature was pointed out by multiple participants, the design was also perceived as giving off a "high-tech feeling" as voiced by Zahra. Yaël suggested that design 2 could be somehow combined with design 3 to tone down its personification. Design 4 received positive feedback for its biomimicry reference to the leaves wrapping the EMDC.

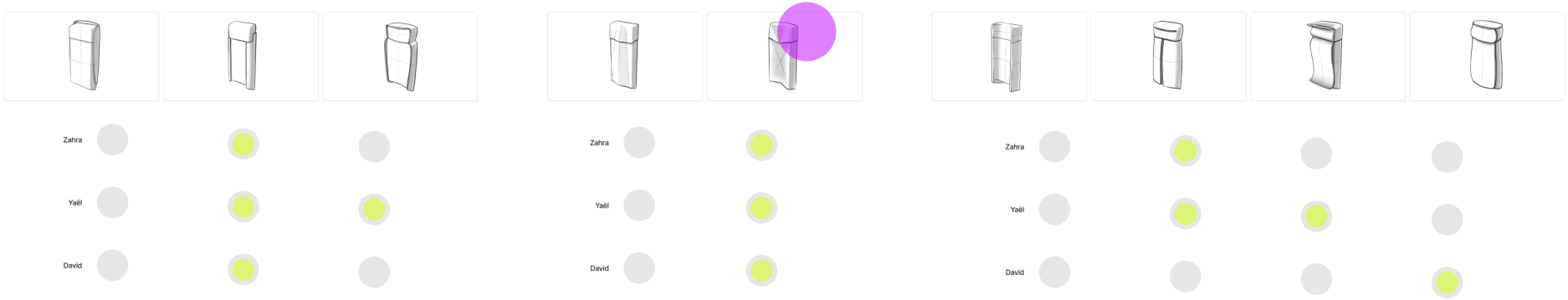


Figure 47 - Concept ratings for each of the 3 design themes. Visual Illusion theme ended up being crowd's favorite.

4. **Micro design detailing elements** | Participants' perception of the microelements presented was overall positive. Within the 'Blending in' group, participants expressed more appreciation for convex designs, using adjectives such as 'snuggly' to describe them, while the concave group was called 'bulky.' For the 'Ribbed surfaces' group, participants expressed the strongest preference towards the 'Discontinuous' group of design options whereas the 'Continous' group was perceived to be too visually overwhelming. In contrast, 'Discontinuous' ribs created a pleasing visual contrast between the smoothness of the top unit with the texture of the bottom one. As an overall comment for the 'Ribbed surfaces' group, it was interesting to hear that the public associated a ribbed surface with a cooling function, which they would expect from electronic devices that they know generate heat, making this detailing option a highly acceptable, perhaps even unconscious detail for the public eye.

As a final remark, it was interesting to note that while the respondents of the initial survey voiced the desire to know what these wall-mounted devices were, focus group participants didn't express that need when asked directly during the session. Such behavior was perhaps caused by the fact that focus group participants received explicit explanation about the EMDC with an opportunity to clarify any questions they had (a brief introduction to the EMDC concept was included in the survey as well, yet it might not have been clear or might have been overlooked by respondents), so that information was already in the back of their minds.

Macro form factor selection

Taking the feedback from the focus group into account, the last rounds of ideation around the 3 themes were performed and 3 final concepts were distilled and detailed. It must be noted that the three concepts that will be discussed and presented below are 'instances' of each design theme, showcasing key direction characteristics. The macro form factor that will be selected eventually is subject to change based on the demands presented by further enclosure development and integration of such details as microelements. Figures 48, 50, and 52 on the following pages present the final proposition for direction instance alongside inspiration images generated with MidJourney and other possible designs from the ideation activity. Figures 49, 51, and 53 present each concept direction placed in context.

Selection process

Design vision and aesthetics and enclosure requirements (AR 2, 4, 6-9, AW 3, 10 and EW 5, see Appendix D) served as the main drivers for developing criteria for macro form factor selection. The client was consulted for any additional criteria that needed to be added, which resulted in adding the 'Potential for future application scenarios' criterion. It must be noted that feasibility criteria, such as manufacturing complexity, have been left out at this stage. Since arriving at the desired macro form factor that expresses Hiro brand identity and expands EMDC role is at the core of this project, it was decided that it is of utmost importance to select the macro form factor that meets these criteria to the greatest extent. It was assumed that every concept could be made to meet technical criteria during the detailing stage of the project. Necessary decisions will then be made to account for such feasibility considerations as water tightness, impact resistance, etc.

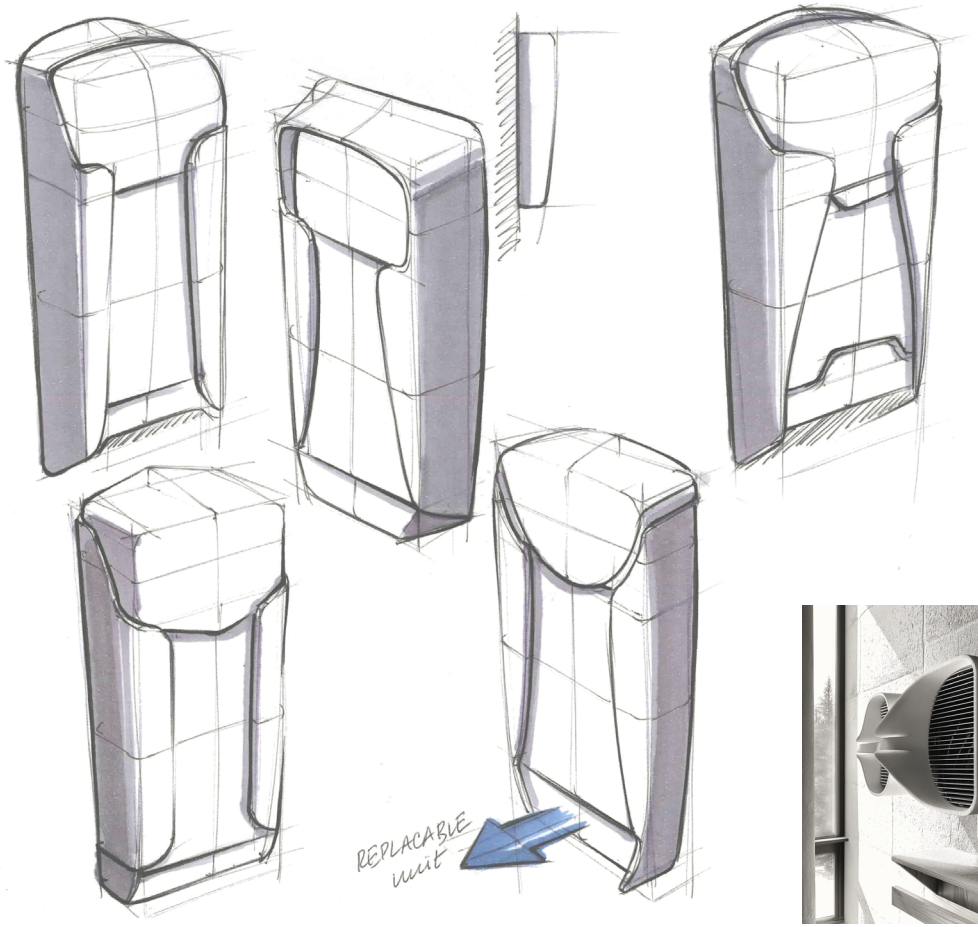
Figure 54 (after direction presentation figures) presents a list of criteria and their Harris profile rankings for the 3 designs considered. Appendix J describes the definition of each criterion and conditions to be met to receive a certain ranking (-- to ++). As visual inspection was determined insufficient to make a selection between designs 1 and 2, a weighted criteria matrix was utilized to obtain greater resolution on the concepts' performance (see Appendix J). As a result, the Light & Shadow direction (design 2) emerged as the strongest ranked option, with Wrapping planes (design 1) following closely. Such a result was also consistent with the most advanced, yet acceptable concept pointed out by focus group participants.

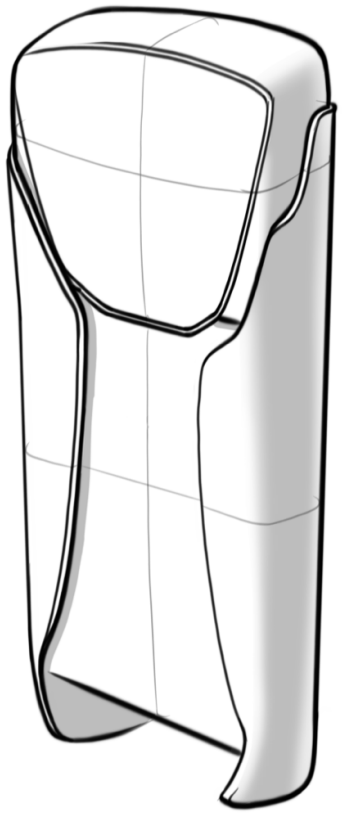
The best of both worlds

In addition to the concept selection activities described above, feedback from a Delft municipality was obtained to define the macro form factor. Such feedback was sought to incorporate the perspective of a government body that might be involved in implementing EMDCs in historic city centers into the selection process. The feedback was collected using Google Forms (Appendix K) and was aimed at determining which concept would be perceived as a non-disruptive part of the historic urban environment. The results of the survey pointed at design 1

Design 1 | **Wrapping Planes**

The defining characteristic of this direction is the wrapping plane feature that ‘hugs’ the Cooling unit and provides insertion guidance for the DC unit.





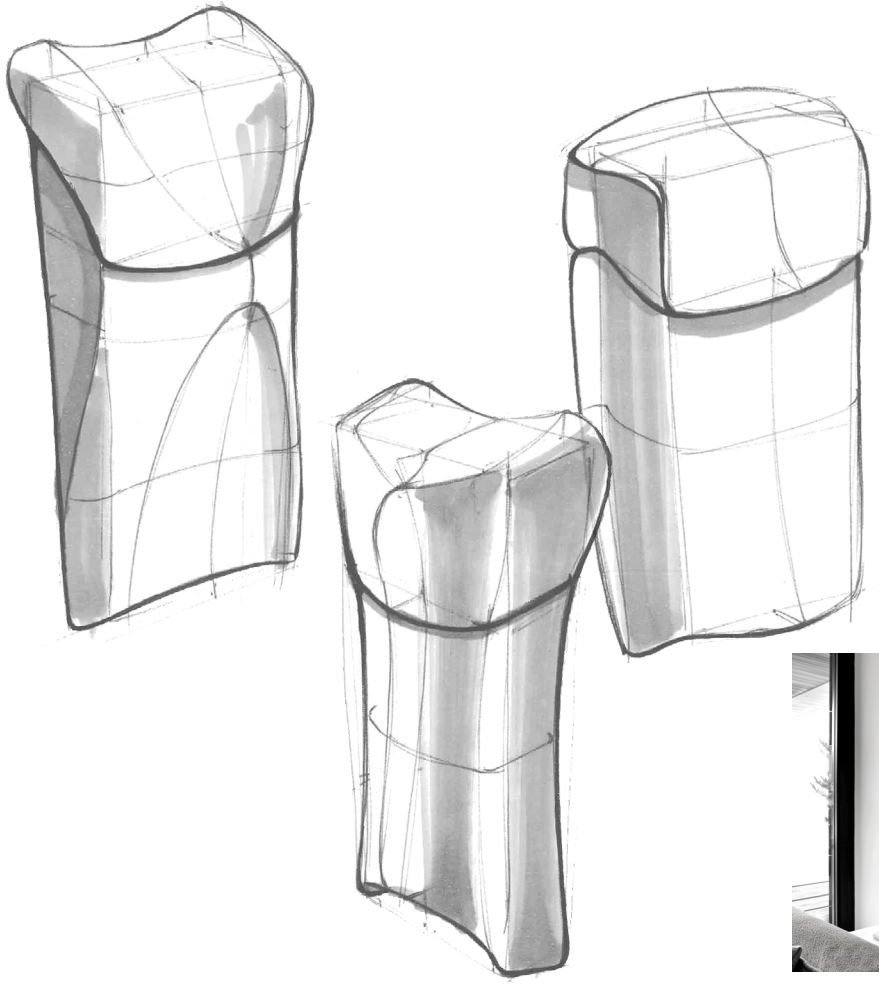
2D ‘footprint’ on the wall

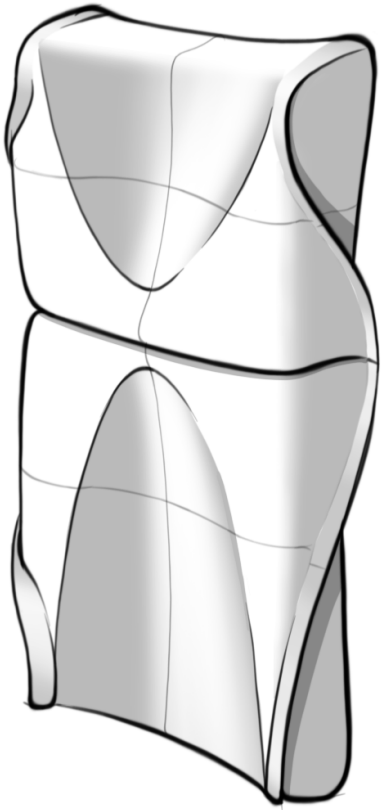
Figure 48 - Wrapping Planes direction possible designs, MidJourney-generated inspirations, and the final proposition for the direction instance.

Figure 49 - Wrapping Planes direction instance in context of interest (Dutch historic city centers). Dimensions and proportions not perfectly to-scale.

Design 2 | **Light & Shadow**

The characteristic that sets this direction apart is areas of contrast between light and shadow that are created by alternating convex and concave surfaces.





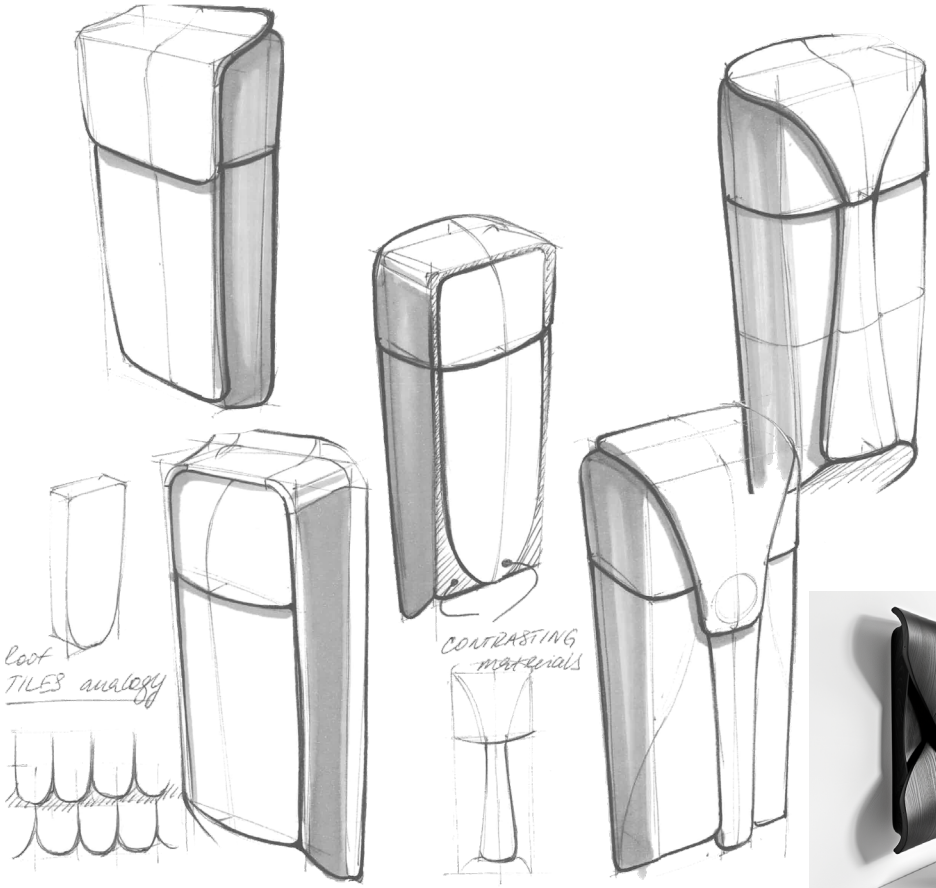
2D ‘footprint’ on the wall

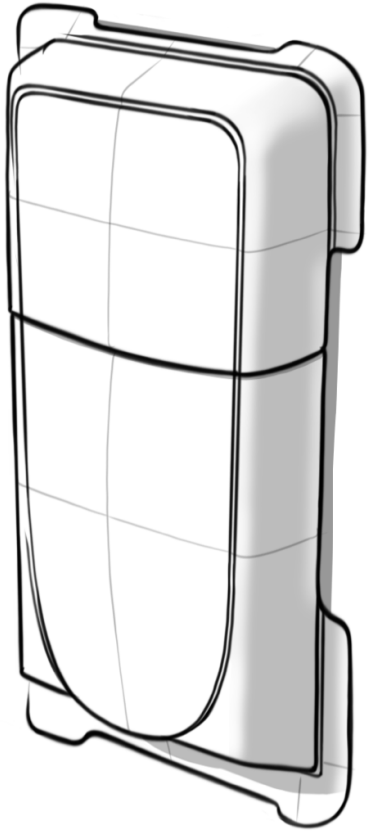
Figure 50 - Light & Shadow direction possible designs, MidJourney-generated inspirations, and the final proposition for the direction instance.

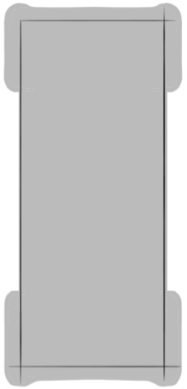
Figure 51 - Light & Shadow direction instance in context of interest (Dutch historic city centers). Dimensions and proportions not perfectly to-scale.

Design 3 | **The Stack-up**

This direction was dedicated to the exploration of design opportunities related to multiple EMDCs co-existing on a wall. The defining design element of this direction is a roof tile-type shape on the front of the enclosure.







2D 'footprint' on the wall

Figure 52 - The Stack-up direction possible designs, MidJourney-generated inspirations, and the final proposition for the direction instance.

Figure 53 -The Stack-up direction instance in context of interest (Dutch historic city centers). Dimensions and proportions not perfectly to-scale.

as the most non-disruptive direction due to the geometric nature of its form factor and more practical considerations such as allocating space from the masonry for wall preservation purposes. Design 2 was described as having a strong “will to form” that made it hard for the representative to describe it as non-disruptive if placed in a historic city center.

Such feedback led to the idea of merging the strengths of the 2 highest-scoring concepts which resulted in the addition of a wrapping plane, which will be referred to as ‘sleeve’ in the rest of this report, to design 2. A quick visualization of how design 2 might look with this addition was created (Figure 55). It was reasoned that adding the sleeve component to design 2’s core would yield a ‘cleaner’ EMDC enclosure design and expand its possibilities by adopting the following functions:

- **Customization** | Specifically thinking about color, the sleeve would enable easy customization for the 3 scenarios described earlier in this report (environment and client, and industry identities).
- **DC unit alignment features** | The sleeve would act as an aligning tool for the DC unit when inserted into the Cooling unit.
- **Feature concealment** | The sleeve could conceal features that might not be desirable to be seen by the public eye, such as power button and cable connectors.
- **Blending with the wall** | A sleeve can help ensure that EMDC is distanced from the wall (for preservation purposes) in a manner that can still be perceived as blending in with it.
- **Trombe wall fixturing** | The sleeve can also help with decoupling the function of Trombe wall fixturing from the Cooling unit.

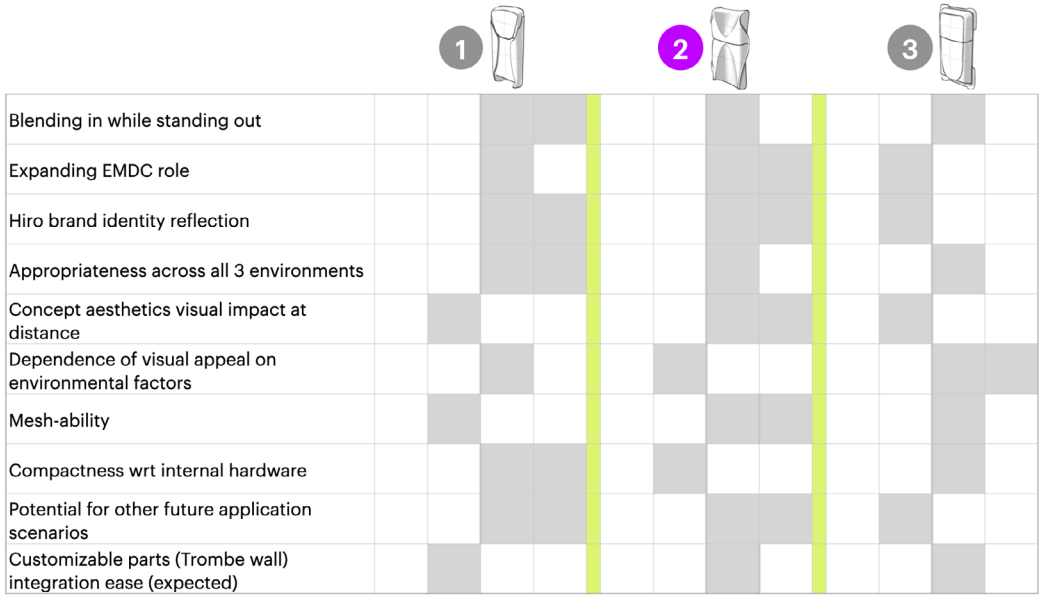


Figure 54 - List of criteria and their Harris profile ranking for the 3 designs.

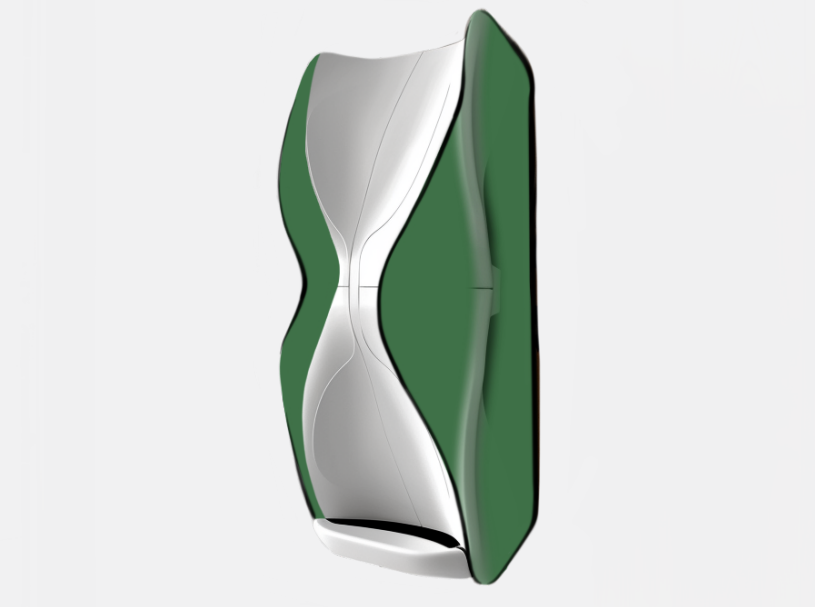


Figure 55 - Quick visualization of the sleeve components added to the Light & Shadow (design 2) concept.

Subparts review

The embodiment and detailing stage was kicked off by reviewing the subparts mapping from the first half of the project. The subparts map was updated given additional information obtained during the macro form factor ideation and selection stage, Figure 56 presents the updated map. This map was referenced throughout this stage to check whether all important aspects and design elements were accounted for. As can be seen, the map accounts for both specific design elements that needed to be accounted for, such as mounting and insertion grips, as well as broader considerations, such as aesthetics of the DC unit for the 2nd or 3rd rows of nodes. While the majority of subparts were placed in one of the three core enclosure buckets, it was left for future determination where subparts marked in light green would belong.

Going into the detailing phase, an initial list of requirements was updated to account for the greater resolution required in this stage. The next section goes into more detail on whether and how certain requirements were accounted for during the initial detailing phase.

Initial detailing

The initial detailing stage served the purpose of diverging and, whenever deemed appropriate, already converging on the design of and/or off-the-shelf items selection for the subparts described above. During this activity, the requirements were further elaborated on whenever appropriate, an updated list can be seen in Appendix L. The requirements and wishes were given an ID consisting of two capital letters and a number by which they are referenced throughout the following sections.

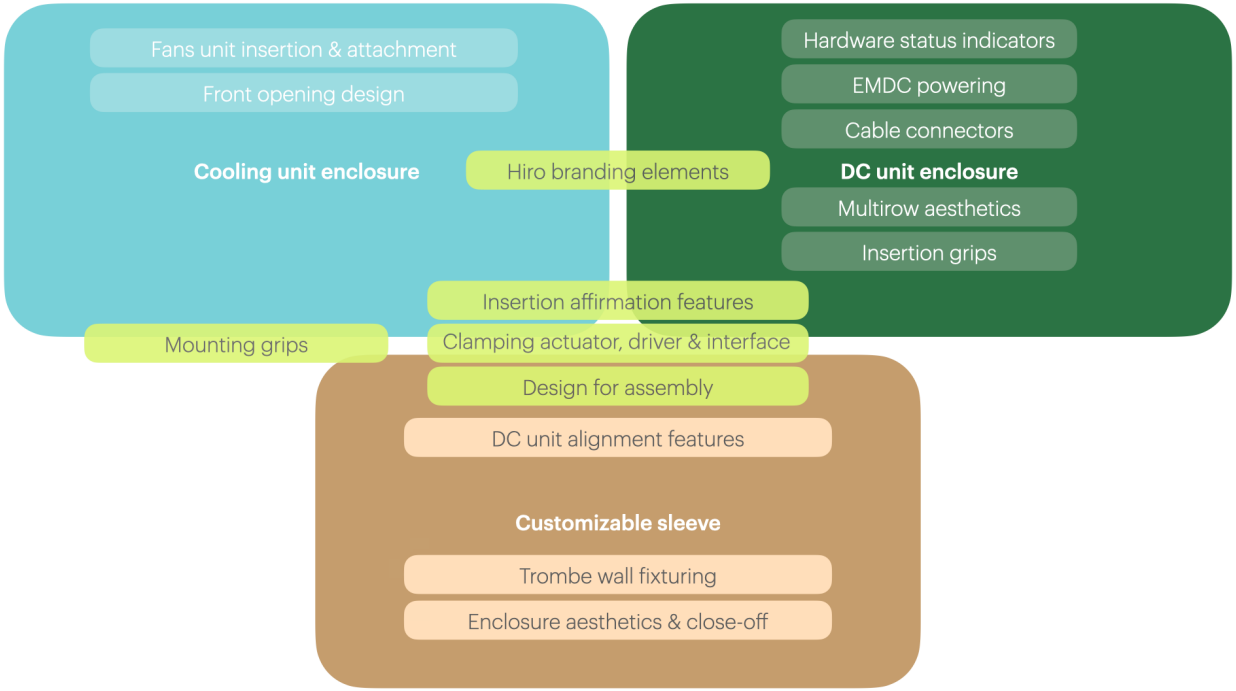


Figure 56 - Updated EMDC subparts mapping.

Cooling unit enclosure | In addition to the requirements that were carried over from the first half of the project, a greater resolution was obtained on performance requirements in terms of water and dust ingress and impact resistance. Standard telecom stainless steel rack, Delvalle STORM SERIES specifically (Figure 57), was analyzed (Delvalle, n.d.). It must be noted that meeting as demanding of performance requi-

Figure 57 - Delvalle STORM SERIES rugged enclosure (Delvalle, n.d.).

rements as industry-standard racks was not the goal of this project. Required performance metrics selected as requirements were based on what was deemed theoretically possible with the recommendations provided in the embodiment/detailing stage given the scope of this project.

- **Solid objects and dust ingress IP5X protection standard requirement** | IP (Ingress Protection) rating system specifies protection level against solid objects (first digit, 0-6) and liquids (second digit, 0-9K), the higher the digits the higher the protection level (Ingress Protection (IP) Ratings, n.d.). As an example, Delvalle STORM SERIES rack is IP66 rated, meaning that such enclosure is dust-tight and is “protected against powerful water jets from any direction” (Ingress Protection (IP) Ratings, n.d.). It was decided that level 5 of solid foreign objects protection will be set as a requirement, meaning that some dust might enter (especially thinking about the front opening in the Cooling unit) but it doesn’t interfere with the device’s operation (ER 1).

- **Liquids ingress IPX4 protection standard requirement** | IP level 4 of liquids protection (“water splashed against the enclosure from any direction shall have no harmful effect” (Ingress Protection (IP) Ratings, n.d.)) was deemed as appropriate to aim for (ER 1). The ‘Design for assembly’ section below outlines suggestions concerning achieving water tightness at various EMDC interfaces. In addition, water entrance through the front opening will be accounted for (EW 6, OW 3). It must be noted that in consultation with the client, it was determined that water and dust tightness is more important for the DC unit enclosure, but not of paramount importance for the Cooling unit enclosure. The passive nature of the cooling solution implies its exposure to the outside environment and necessitates its hardware to be able to withstand such environmental factors as humidity and dust by definition.

- **IK10 Resistance** | As the EMDC will be placed in an outdoors, public setting, accounting for vandalism and possible violent actions is important. Delvalle STORM SERIES rack claims maximum IK10 resistance, meaning that this enclosure successfully withstands 20 joules of impact energy or 5 kg weight dropped from a height of 400 mm (What Is the IK Impact Resistance Rating? | Apem Blog, 2024). To account for this enclosure protection aspect, when selecting materials and manufacturing, benchmarking will be performed to access criteria under which considered options would meet an IK10 impact test (MR 5).

- **Temperature gradient** | Delvalle STORM SERIES rack claims temperature resistance between -40°C and +100°C. While it is outside of the scope of this project to make definitive claims about the temperature range designed enclosure can sustain, a check consisting of online research must be carried out to ensure that the proposed materials/manufacturing combination would be suitable for outdoor conditions in terms of common temperature gradients (MR 4).

Fans unit attachment | A front-to-back sliding insertion was envisioned for the fans unit. Such a choice was made due to the ergonomic and user experience considerations as front-to-back sliding was determined to be advantageous in both of these aspects compared to the alternative of down-up attachment. It was reasoned that such an alternative would yield a worse experience due to limited visibility and insertion space accessibility (FR 7) and the possibility of dropping the unit in case of partial and/or unsuccessful insertion. The fans unit should also be designed to have hand grips that would help to aim and slide the unit in (FR 6). An off-the-shelf solution must be picked for the sliding and attachment method of the fans unit (FR 8), however, the selection of a specific hardware solution was left for a later moment after getting a better resolution on materials and manufacturing of the enclosure.

Front opening design | OR 1, 2 summarize key performance requirements for the front opening design. The selected front opening design must be stylistically appropriate for the selected macro form factor (OR4) and it should ideally preserve the ‘monolithic’ nature of the macro form factor (OW 4). Figure 58 on the next page presents inspirational images that were collected on Pinterest for the front opening design. As can be seen, the inspiration was centered on the idea of non-disruptive, ‘blending in’ designs. Plasteline was utilized to prototype some designs to get a better grasp of their physical implementation and resulting aesthetics (Figure 59 in two pages). Again, the selection of a specific front opening design was left for a later moment after the materials and manufacturing selection.

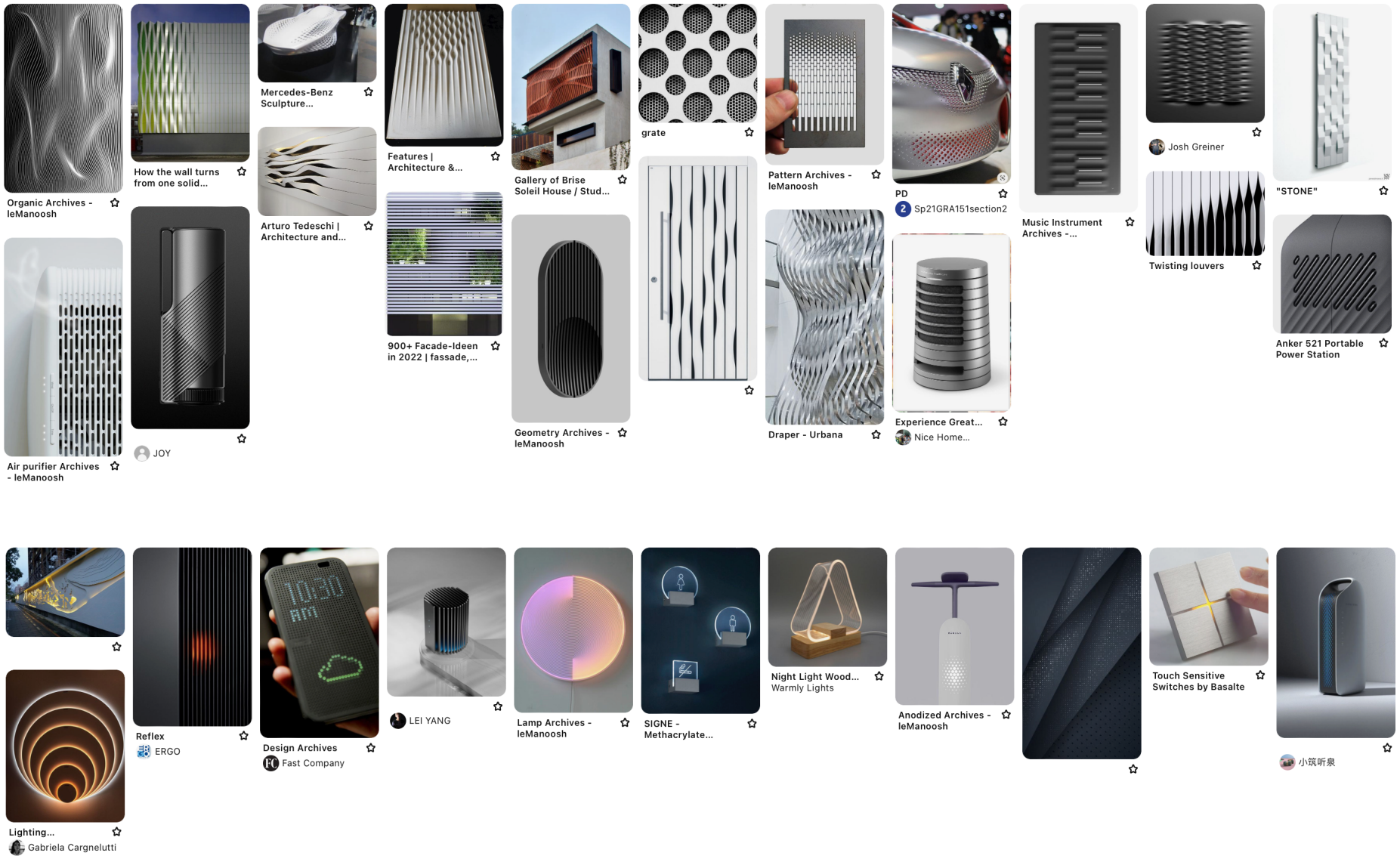


Figure 58 -Inspirational designs for the front opening (top) and status indicators (bottom) collected on Pinterest.

DC unit enclosure | The same three performance considerations described for the Cooling unit's enclosure apply to the DC unit. While this project focuses on the DC unit enclosure design for 1 row of nodes, it should be advised how selected macro form factor aesthetics would extend to the 2nd row of nodes (DW 1).

Hardware status indicators | Similar to the front opening design, a board of inspirational designs was created for LED status indicators (Figure 58 on previous page). A diverging approach was utilized, also considering solutions outside of the electronics domain, such as using clear acrylic or glass with engraved or etched icons. Similar to the front opening, hardware status indicators must fit in with the macro form factor (IR 10, IW 10). Thinking of the desired performance, ultra-bright or high-intensity LEDs with luminous intensity ratings around 5000 millicandela (roughly equivalent to a luminous intensity of five 'standard candles' for comparison) would be necessary to ensure visibility in bright sunlight and viewing distance requirements (IR 5) (Choosing Correct LED Mcd for Outdoor Indication, 2011). However, to mitigate light pollution concerns (IW 9), measures such as light diffusers and environment-responsive LEDs (that adjust brightness based on the readings of a light sensor, for example) should be incorporated. While choosing a specific LED is outside of the scope of this analysis, consideration described above should be considered for this subpart selection. Further detailing

EMDC powering | It was deemed appropriate to select a specific embodiment for the EMDC power button at this stage. Popular

Figure 59 - Plasteline mock-ups of selected front opening designs.

across applications from consumer electronics to the ones in aerospace and defense industries, a polycarbonate overlay with embossed buttons (Figure 60) was selected due to the good weather resistance properties (PR 1) and high degree of customization (PW 3) that such panels provide (Bowie, n.d). It must be noted that LEDs can be incorporated into such panels (take note of a diffuser circle on the left of the panel in Figure 60), which provides a design opportunity for the status indicators described above.

Cable connectors | Specific cable connectors were considered at this stage to get

Figure 60 - Polycarbonate overlay with embossed buttons (Bowie, n.d.).

an idea about their sizing for CAD model development at a later stage (CaR 3) (Figure 61). In consultation with the client, Eaton RWQ M22 provided a good reference for understanding the general sizing of Ethernet cable connectors (Elektramat, n.d.). AMPHE - 309 WATERTIGHT IP67 was selected for the power connector (Amphenol, n.d.). Its 120V dimensioning was considered as it corresponds to Hiro's short-term, immediate client base in Europe (CaR 5). Appendix M provides further information on the sizing of the selected cable connectors.

Hiro branding elements | Hiro branding element(s), specifically thinking about Hiro logo, should appear on the core enclosure parts of the EMDC (EW 7). The exact appearance and location of branding element(s) were to be determined later.

Mounting and insertion handles | Considering HR 2, a critical decision was made for detachable handles on both units. This decision was made due to the following considerations:

- Detachable handles decouple ergonomics from aesthetics and enable focusing their design on an optimal ergonomics experience (HR 2, 4).
- Detachable handles would provide an extra level of protection against undesired behaviors (such as trying to get EMDC off the wall) as the means of grabbing the enclosure would not always be present.
- Detachable handles would yield a 'cleaner,' more minimalistic final design.

To enable detachability, a quick-release stainless steel pin with a pull-release mechanism was selected given cost and ease of use considerations (Figure 62). A pull release was chosen over a push release (such as a button) for reliability reasons (HR 3). Pull was considered to be more of an intended activity compared to pushing a button which can happen accidentally during mounting and insertion activities. The sizing of the pins will be determined after a greater resolution is obtained on the expected unit's weights, given the selected materials and manufacturing.

Sleeve | As described earlier, the sleeve subpart was added to the core enclosure to detach some functions from the core enclosure. The meaning and partial embodiment of these func-

Figure 61 - Eaton RWQ M22 capped Ethernet connector (left) and AMPHE - 309 WATERTIGHT IP67 capped power connector (right) (Elektramat, n.d.; Amphenol, n.d.).

Figure 62 - Quick-release stainless steel pin with a pull-release mechanism (Exact Tooling, n.d.).

tions are outlined below:

- **DC unit alignment features** | A preliminary sketch of the sleeve design was created with two types of alignment features incorporated (Figure 63). Firstly, side guides limit the movement of the DC unit towards an installer. Secondly, combined with the rib on the back of the DC unit, the back slit limits the sideways wiggle of the DC unit and ensures precise and timely insertion of the DC unit (SR 1, 2). A V-shaped top of the slit ensures initial ease of alignment with the rib.

- **Enclosure aesthetics & close-off** | Another function of the sleeve was to hide enclosure functional elements (SR 3) and perhaps even provide means of 'closing off' such subparts as the clamping interface. Wing-like flaps were envisioned as a way to embody the first requirement (Figure 63). It was, however, to be tested whether such a feature poses significant obstacles to DC unit insertion. Another envisioned function of the DC unit that was embodied in the sleeve was the 'blending in' with the wall (Figure 63) aspect of the design vision (SW 4).

- **Trombe wall fixturing** | The final function of the sleeve considered was its role in fixturing and supporting the Trombe wall. Such a decision was made due to the expected high weight of the Cooling unit, making it undesirable to add any further subparts to this component.

Insertion affirmation features | It was determined that further investigation through user testing was necessary to determine if additional features, affirming complete and successful insertion of the DC unit into the Cooling unit, were necessary (IW 13).

Clamping actuator and its interface | As already discussed in the Discover phase of the project, a removable ratchet lever (Figure 64) was selected as a clamping actuator due to this tool's strengths in amplified, yet precise force delivery (CIR 3, CIW 1, CIW 2) (Ratchet Mechanism: Understanding Its Function and Applications, 2024). Selecting a removable actuator was primarily driven by requirements driven by concerns over undesired (de)actuating scenarios (CIR 6, CIW 6). HEX bolt connector (Figure 64) was selected for driving the clamping mechanism over an alternative of square-shaped connection due to easier tool alignment and thus better

Figure 63 - Preliminary sketch of the sleeve design.

Figure 64 - Removable ratchet lever (left) and HEX bolt connector (right) (SIDCHROME., 2021; RS PRO Stainless Steel Hex Socket Cap Screw, DIN 912, M8 x 45mm, n.d.).

accessibility in tight spaces that it provides (CIR 8) (Hex Nuts Vs Square Nuts: What's the Difference? | Blog- Monroe Aerospace, 2022). M8 bolt size was deemed sufficient for the ease of actuator alignment. A female HEX driver was selected for aesthetics purposes as it would be flush with the surface of the enclosure and the sleeve. This implies that a HEX bit would need to be used with a ratchet lever to engage with the driver. Thinking of the interfaces, holes, and cuts would need to be made in the units' enclosures and the sleeve to accommodate sliding motions of the sleeve and the DC unit past the driver and ensure the driver's accessibility for the actuator.

Design for assembly | When thinking about the design for the assembly, it was considered how internal hardware components, including close-offs that the nodes and chimney require (Figure 65), would be placed inside an enclosure. It was decided to split the enclosure into front covers and back lids. The close-offs would be split as well, with one part attached to the front covers and another one - to the back lids (Figure 65). It is important to note that for better compatibility and contact when assembled, all close-off parts need to be made from the same material. In terms of the attachment method of the back lids to the front covers, threaded inserts (Figure 65) can be embedded into the front covers to be used with screw fasteners. To ensure water tightness of holes and interfaces (ER 1), the following mitigations can be put in place:

- **Front covers/back lids interface** | Continuous perimeter gasket can be placed at the interface. When compressed, such a gasket will prevent dust and liquid splashes from entering through the interface. Such gaskets come in materials like EPDM and silicone as well as U- or D-shaped profiles (Figure 65).

- **Fastener sealing** | Sealing washers and/or O-rings (Figure 65) can be utilized to ensure that no dust and/or liquids get into the enclosure through fastener holes. For an extra layer of protection, silicone sealant can also be applied around the screw holes before inserting the screws. However, it might negatively affect disassembly in terms of increased difficulty of removing screws and sealant residue. Similar measures can be applied to the interface between cable connectors and the DC unit enclosure.

- **Handle holes caps** | Whenever detached, mounting/insertion grips would leave holes in the enclosures. Snap-on plugs (Figure 65) can be used to cap the holes and prevent liquids and dust from entering the enclosures.

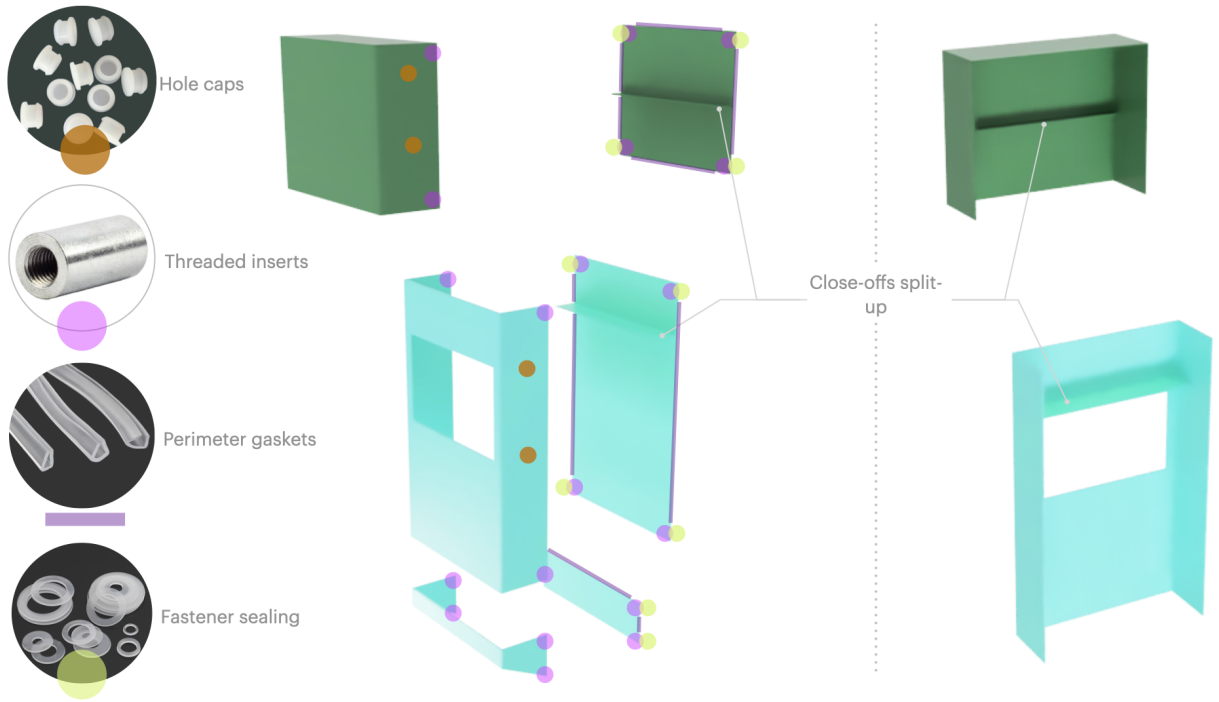


Figure 65 - Various considerations regarding design for the assembly and their expected locations on the EMDC preliminary enclosure CAD (Adeo Group, n.d.).

Design for physical ergonomics

Since the ergonomics of EMDC handling and interaction have always been considered a critical, 'deal-breaker' aspect of the enclosure design due to the expected heavy weight of the units, it was decided to tackle its detailing first. These design activities were primarily centered on getting greater resolution on the following EMDC subparts:

- Mounting grips
- Insertion grips
- DC unit alignment features

The first step of this process was estimating the weight of the internal hardware. Using the CAD model created during the first half of the project, the weight of custom metal cooling solution parts was estimated using the volumes and material properties obtained from the CAD software. The client advised on the weight assumptions for the remaining internal hardware components. With these calculations and assumptions, the Coolung unit's internal hardware has been determined to be 42.6 kg, while the DC unit's - 6.1 kg. Refer to Appendix N for further details on internal hardware weight estimation. The maximum lifting weight for 1 person in optimal conditions is 23 kg (Ergonomie Site, n.d.). This fact necessitates the Cooling unit being handled by 2 installers. It was decided to have installers face the sides of the Cooling unit as such positioning would also yield better visibility when it comes to aiming at the mounting bracket on the wall with the Cooling unit.

Next, one-to-one cardboard prototypes were created to get a better feeling of real-life units' sizing (Figure 66). The prototypes enabled the development of the first ideas for the design of the detachable handles (Figure 67) and the potential sequence of mounting and installation steps that would yield a maximally ergonomic experience. Richard Goosens, who is part of the Human-Centered Design group at IDE TU Delft with expertise in Applied Ergonomics and Design, was consulted to get feedback on preliminary handle designs and mounting and installation steps which resulted in the envisioned procedure for EMDC installers. This procedure was combined with the EMDC subparts analysis outlined in the previous section to revise the interaction analysis from the first part of the project, specifically focusing on the first-time installation activities (presented on the next few pages). The goal of this activity was to determine further gaps in knowledge, recorded as 'Remaining questions' and 'Design considerations,' regarding EMDC subparts. This analysis led to further elaboration on requirements and wishes from Appendix L. The analysis assumed that electrical engineers responsible for EMDC installation are already on the scissor lift on the desired mounting level. This updated envisioned procedure was utilized during ergonomics and interaction user testing (specifically focusing on Cooling unit lifting and mounting and DC unit insertion) that will be described shortly and is partly illustrated using photographs obtained during the experiment.

Figure 66 - One-to-one cardboard prototypes.

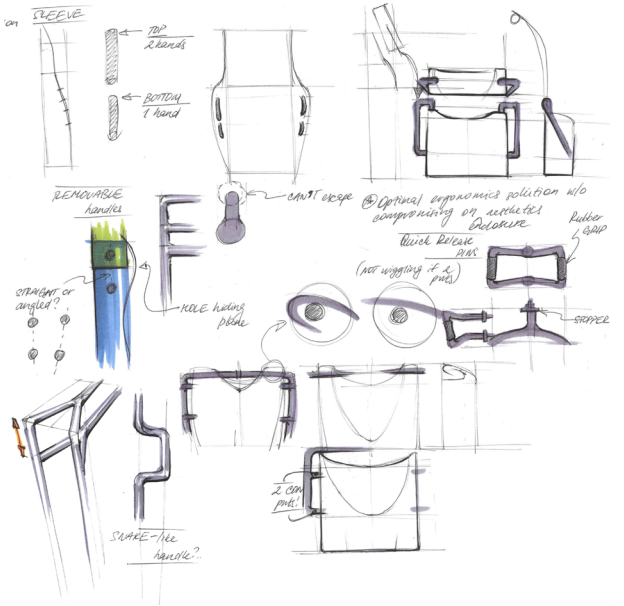


Figure 67 - First ideas for the design of the detachable handles.

Step 2 | Cooling unit lifting and mounting & sleeve insertion

2.1 | Attach custom-designed Cooling unit handles to the enclosure on both sides. For optimal ergonomics concerning force distribution in the wrists and arms, the following design elements are featured:

- Handle tilt towards the enclosure/away from the installer corresponding the the natural, neutral wrist position when arms are bent at 90 degrees
- Side-by-side position of the handles for the two hands
- Top finger dents for optimized stress distribution (not included in the prototype)

2.2 | Squat lift the Cooling unit from a 23.5 cm tall stand (part of the shipment packaging) that raises the units' handles to the optimal squat lifting height of 71.5 cm (DINED, Dutch adults, m+f 20-60, 2004, Elbow height, sitting + Popliteral height, sitting (mm), DINED (n.d)). Such optimal height was determined under an assumption of recommended squat lifting body form where the knees are bent at 90 degrees. Hands are positioned next to one another. Once standing, the elbows should be bent at about 90 degrees (Neudecker, 2023). If height difference is present among installers, a taller person should bend their knees until the elbows are bent at about 90 degrees for both installers.

Step 1 | Mounting hardware wall inspallation

Remaining questions |

- The exact hardware used to mount the units on the wall
- How would mounting on uneven wall surface work?

2.3 | Once standing, readjust the hands to grab the Cooling unit with the hand that is closer to the wall. Carry out this action one by one, communicating with your colleague regarding who goes first. Feel a small knob on the bottom inside the enclosure that is there to help you better control the bottom of the unit.

2.4 | Making sure you pass the unit over the scissor lift barrier, aim mounting hooks on the back of the Cooling unit at the bracket mounted on the wall. Communicate with your colleague to make sure both sides were mounted on the bracket successfully and let go of the Cooling unit that is now mounted on the wall.

2.5 | Detach the handles from the enclosure by pulling on a ring to release the pins.

Design considerations |

- Creating enough clearance to avoid fingers reaching internal hardware.

2.6 | Slide the sleeve over the Cooign unit, ensuring that it lands on its own mounting bracket. Rigidly attach the sleeve to the Cooling unit. Position the scissor lift at a level so that the top of the front opening is at the level of your hands when bent in elbows at 90 degrees.

Remaining questions |

- How does the sleeve get attachend to the Cooling unit?

Step 3 | DC unit insertion

3.1 | Attach custom-designed DC unit handles to the enclosure on both sides. For optimal ergonomics concerning force distribution in the wrists and arms, the following design elements are featured:

- Handle tilt towards the back of the unit/away from the installer corresponding the the natural, neutral wrist position when arms are bent at 90 degrees
- Top finger dents for optimized stress distribution (not included in the prototype)

3.2 | Facing the front of the DC unit (handles are tilted away from you), one person lifts the DC unit from the ground by using the handles on its sides.

3.3 | First, get the DC unit over the sleeve's sides and gradually lower the DC unit. Align the rib on the back of the unit with the back slit of the sleeve and gradually lower the DC unit onto the Cooling unit until you feel a solid connection between the two units.

3.4 | Detach the handles from the DC unit enclosure by engaging the quick-release pin mechanism through pulling.

Remaingin questions |

- Any additional (visual/audio) cues of successful insertion necessary?
- Does DC unit have its own mounting or does it rely on the same one as the Cooling unit?
- Ensuring liquids sealing between the units?

Design considerations |

- V-shaped top of the alignment slit for easier insertion start.
- Sufficient slit alignment length to ensure DC unit gets aligned sifficiently ealry.
- Ensuring insertion clearance: manufacturing method of sleeve and DC unit back lid have to have good tolerances.

Step 4 | Fans unit and cables connections

4.1 | Slide the fans unit on the bottom of the Cooling unit, front to back.

Remaingin questions |

- The exact (sliding) way/mechanism?
- Appropriate sizing for the fans unit hand grips (FR 6).

4.2 | Connect the cables (1x power, 8x Ethernet) via capped cable connectors.

Step 5 | Units clamping

4.2 | Connect the cables (1x power, 8x Ethernet)via capped cable connectors.

Remaingin questions |

- How long does a ratchet lever need to be due to space constraints?
- HEX connector: size, meale/female?

Step 6 | EMDC close-off

6.1 | Close off clamping outlet and handle attachment points.

Remaining questions |

- How secure does the close-off need to be (locking)?
- Can sleeve have a feature for the clamping outlet close-off?

Ergonomics and interaction user testing

Once a greater resolution was obtained on the desired handle design and installation procedure that should yield optimal ergonomics experience, it was deemed necessary to test these assumptions with real weights. A user testing moment was set up and carried out with the following research questions to clarify uncertainties in the envisioned designs and installation procedure:

1. What tilt angle (a, Figure 68) of the Cooling unit handles yields the least straining lifting and mounting experience?
2. How hard do participants find it to aim at the mounting bracket on the wall with the Cooling unit's mounting hooks with the proposed hand positioning on the Cooling unit?
3. What tilt angle (b, Figure 68) of the Data Center unit handles yields the least straining insertion experience?
4. Does the proposed sleeve design involving slated sides and a back rib provide sufficient guidance and affirmation of the successful insertion of the Data Center unit into the Cooling unit?

The experiment also served the purpose of testing the user experience of lifting, mounting, and insertion overall to determine the extent of physical strain and intuitiveness that the envisioned experience had.

The first step of creating prototypes for user testing was determining handle sizing by referencing and analyzing hand ergonomic measurements. Figure 69 presents dimensions that resulted from this analysis, while Appendix O goes into more detail about how they were determined.

A total of 3 stand-alone prototypes were created for testing: The Cooling unit, the DC unit, and the sleeve (Figure 70 on the next page). All prototypes were true to size and the selection of construction materials and methods was primarily driven by weight-bearing requirements for the 2 units. The two experiment set-ups that these prototypes were arranged in can be seen in Figure 70. During the first part of the experiment (research questions 1 and 2) participants were asked to squat lift the Cooling unit and aim with the hooks on its back at the mounting bracket on the wall. Participants were instructed to perform actions according to the desired

Figure 68 - Handle tilt angles under investigation.

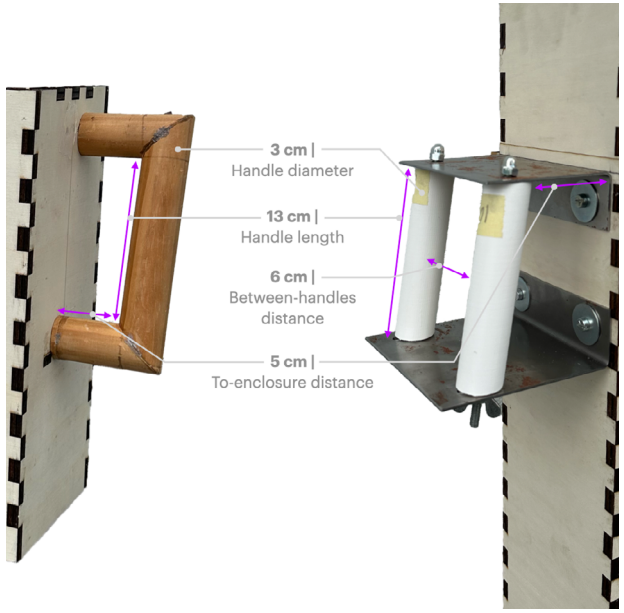
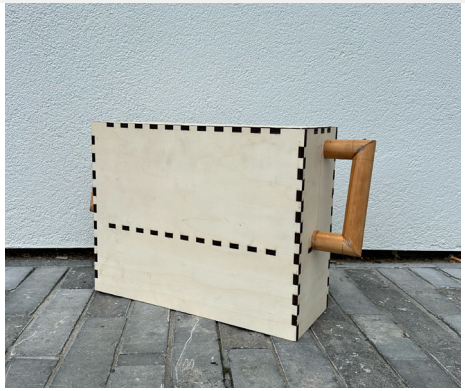
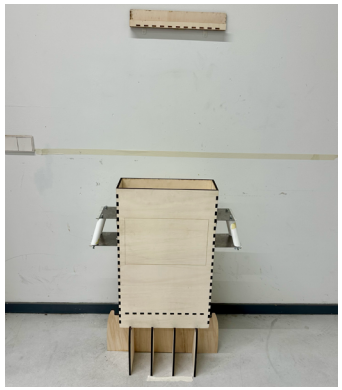
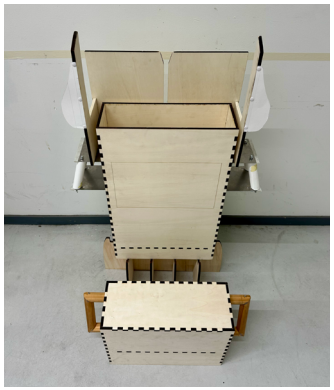


Figure 69 - Handle dimesions following hand ergonomics considerations.


1

Cooling unit
testing set-up

2

DC unit
testing set-up

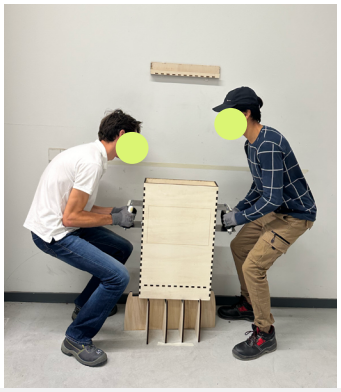



Figure 70 - Prototypes created (top row), the two experiment set-ups (middle row), and pictures of the main experiment activities and stages (bottom row).

lifting and mounting procedure described in the previous section (refer to Appendix P for further details on specific instructions given to participants). Three handle tilt angles (5, 10, and 15 degrees directed away from the participants) were tested, and participants recorded their feedback using Google Forms. For the second part of the experiment, which aimed to answer research questions 3 and 4, a sleeve was added to the Cooling unit that was left resting on the stand. Participants were asked to lift the DC unit from the ground and insert it into the Cooling unit, using sleeve sides and back slit as guides. Like in the first part of the experiment, participants were instructed to perform actions according to the desired insertion procedure described in the previous section (refer to Appendix P for further details on specific instructions given to participants). Again, 3 handle tilt angles (5, 10, and 15 degrees directed away from the participants) were tested and participants recorded their feedback using Google Forms. Figure 70 presents pictures of the main stages of user testing described above.

In addition to the four main research questions, additional questions that participants were asked to answer yielded the following design embodiment implications based on testing results (refer to Appendix P for the additional questions asked and elaboration on experiment results):

Cooling unit squat lifting and mounting procedure |

- **Cooling unit handles |** 5-degree tilt angle was preferred. Another handle section should be implemented for easier bottom grip reach. No changes to the spacing between handles with regards to one another or enclosure are necessary.
- **Bottom grip |** No changes to the size or position of the knob are necessary. A cue for the bottom hand placement on the sides of the Cooling would be beneficial.
- **Mounting hardware |** Selected brackets should protrude from the wall and the Cooling unit's back wall as much as possible.

Datacenter unit insertion procedure |

- **Initial position |** Having the step on the top of the Cooling unit slightly below the elbow position at 90 degrees is a recommended starting position for the insertion procedure (about 95 cm away from the floor of the scissor lift).
- **DC unit handles |** 10-degree tilt angle was preferred.
- **Sleeve design |** Rigid back piece for clear back slit guidance must be ensured. No significant changes to the wings, including the flaps, are necessary.

Subparts embodiment analysis

To bring together the findings obtained regarding EMDC subparts so far, a comprehensive diagram was created (Figures 71, 72, see next pages). This activity aimed at getting an idea about the locations of various features and subsystems on the units' enclosures. Thinking ahead to manufacturing and materials selection, enclosure modifications necessary to accommodate the elements were thought through. In addition, remaining questions about hardware features were recorded. A plasteline mock-up was created to give three-dimensionality to the analysis described above (Figure 72 in two pages).

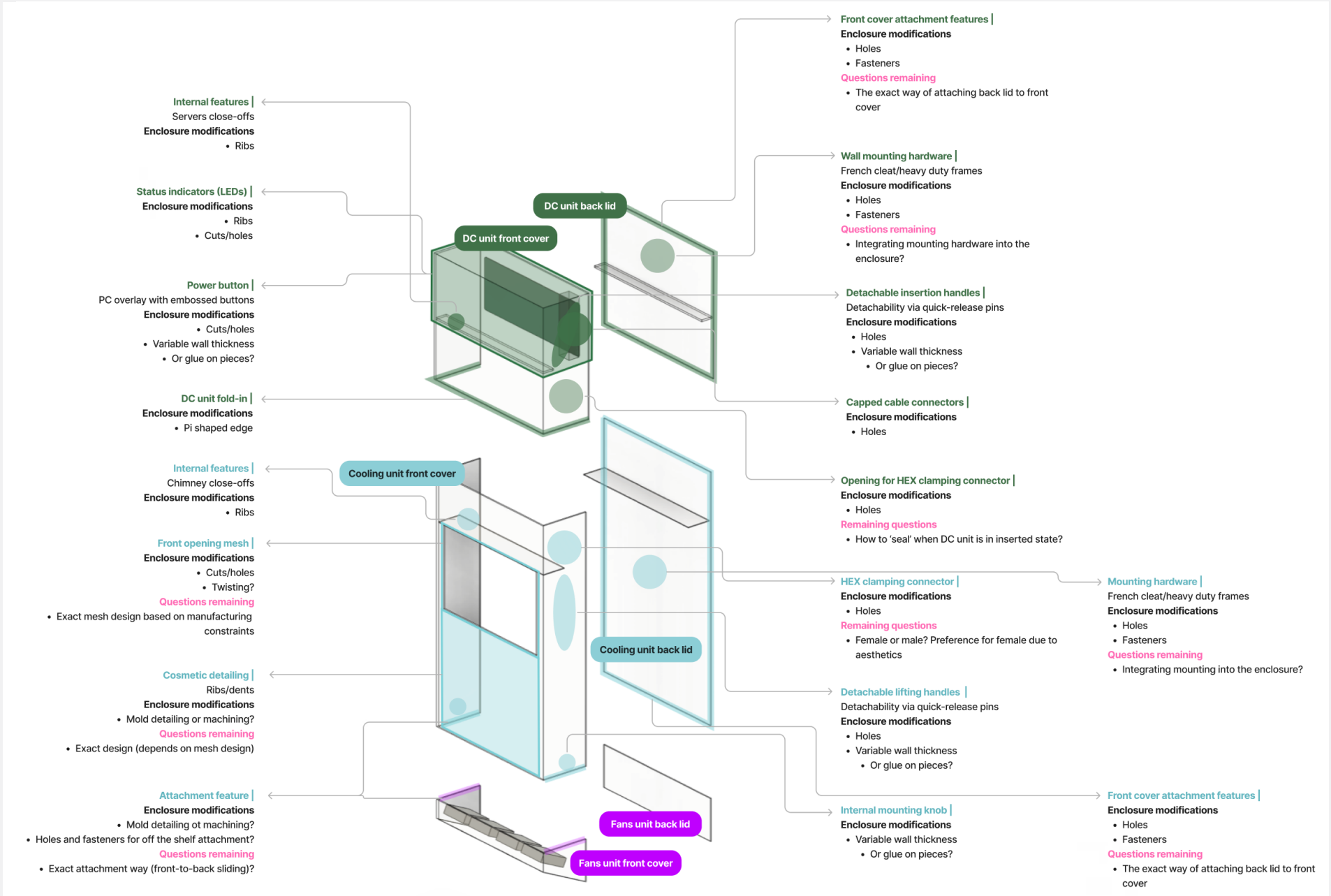
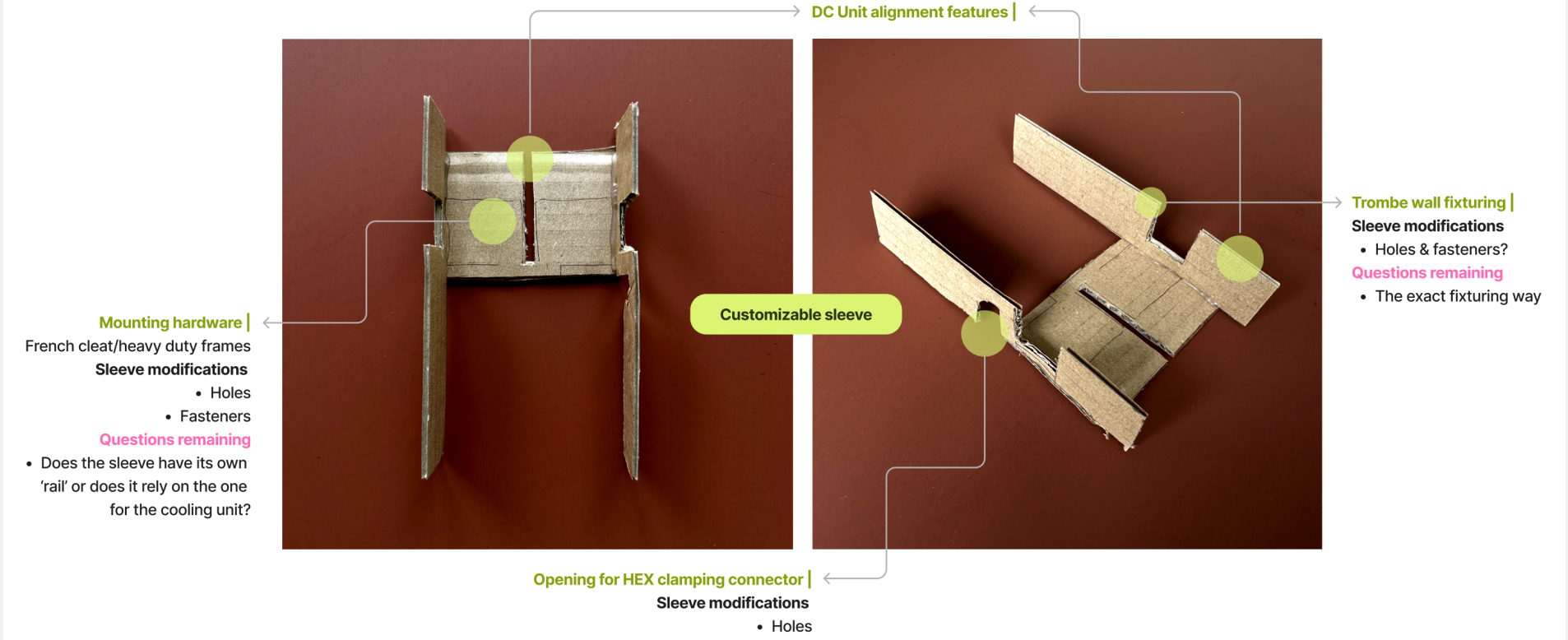


Figure 71 - Comphrehensive diagram of EMDC subparts, their locations, and expected enclosure modifications (Cooling, DC, and Fans units).



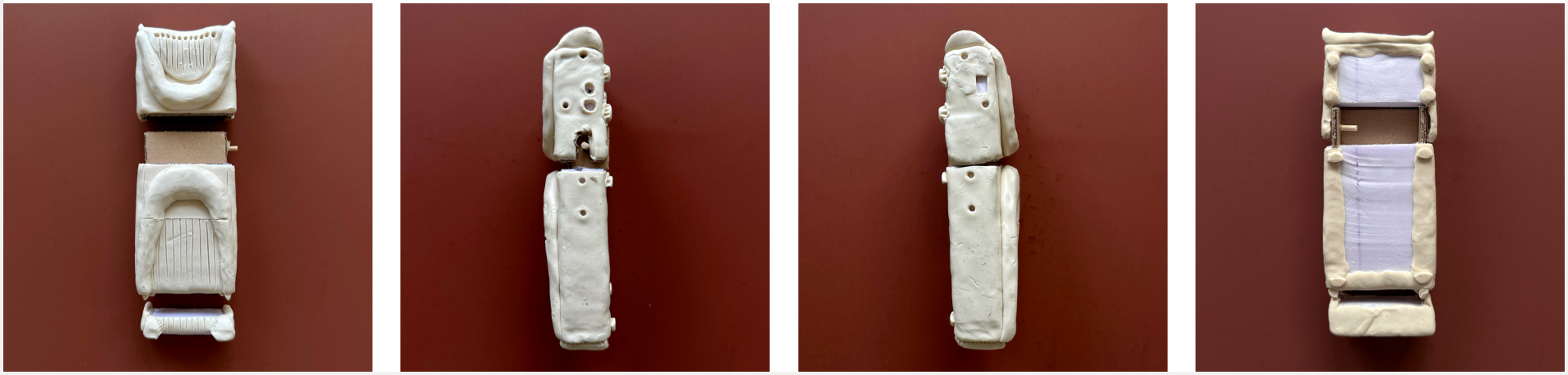


Figure 72 - Diagram for the sleeve (top) and plasteline mock-up (bottom).

Materials and manufacturing selection

Manufacturing technologies to be compared were first down-selected based on facilitating the desired organic form factor and being appropriate for relatively low production volumes (250-500 units/year) (MR 6). As a result, thermoforming, Resin Transfer Moulding (RTM), and large-scale FDM 3D printing were selected as manufacturing alternatives to be compared. Materials were selected based on mechanical strength requirements. For RTM, while glass and carbon fiber composites are popular choices given their superb mechanical performance and lightness, these options are also known to have negative impacts on the environment (Composites Construction UK, 2023) (Figure 73). Therefore, as a more sustainable alternative, Bcomp's flax reinforcement fabric (the company has showcased their solution's feasibility in industries from automotive to travel luggages) coupled with biobased resins (such as IB2 Epoxy Infusion Bio Resin (IB2 Epoxy Infusion Bio Resin - Easy Composites, n.d.)) is proposed and analyzed in this report (Figure 74). It must be noted, however, that the tensile strength of flax reinforcement fiber is about 5 times smaller than that of carbon fiber and 4 times smaller than glass fiber's (Natural Flax Fibre Reinforcement in Composites - Easy Composites, n.d.). However, if necessary flax fibers can be combined with carbon or glass fibers (ampliTexTM - Bcomp, n.d.), still yielding a more sustainable solution as part of the reinforcement would be naturally sourced. Polycarbonate was selected as a material for thermoforming and FDM 3D printing as this thermoplastic is known for its strength and impact resistance properties (International Polymer Solutions Inc., n.d.). These materials/manufacturing methods combinations were compared under the assumption that all of them provide adequate environmental resilience, specifically resistance to dirt and water. For large-scale 3D FDM 3D printing, this implied that the print would need to be treated post-production with an epoxy coating, for example, to make sure that the layers are fused together and don't let liquids and dust in.

A list of selection criteria was generated, primarily driven by requirements accumulated to this point (Appendix L), that materials/manufacturing alternatives were ranked against. Appendix Q elaborated on the meaning of each criterion. The sections to follow explain the material/manufacturing choices for the standard core, customizable sleeve, and back lids.

Standard core |

Figure 75 on the next page presents Harris profile for the standard core's selection of materials/manufacturing combination (see Appendix Q for the reasoning behind the rankings given). Backed up by an additional weighted criteria matrix check (Appendix Q), biobased composite/RTM emerged as an alternative of choice. In addition to the main criteria, the following considerations led to

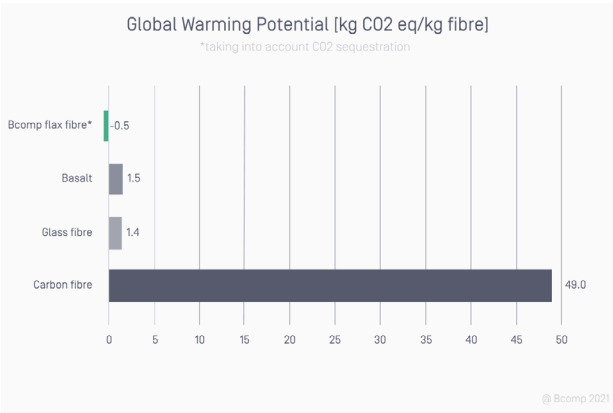


Figure 73 - Global warming potential of various composite alternatives (*Marine - Bcomp*, 2024).

Figure 74 - One of Bcomp's flax reinforcement fabrics (left) (ampliTexTM - Bcomp, n.d.), IB2 Epoxy Infusion Bio Resin (middle) (IB2 Epoxy Infusion Bio Resin - Easy Composites, n.d.), and an example of a flax reinforced composite chair fresh out of the mold (right) (Easy Composites Ltd., 2024).

selecting this alternative:

- Perhaps the most crucial factor that led to making this choice was the sturdiness that composite parts are known for. Thermoformed PC part would bend at impact, potentially reaching and hurting internal hardware. The stiffness of the composite enclosure would also be crucial for installation where a flimsy shell would make handling a heavy Cooling unit challenging and potentially even lead to injuries.

- The feasibility of using composites in outdoor settings has been proven in various industries and by various players. For example, Bcomp's flax reinforcement fabrics have been successfully implemented in the marine industry (*Marine - Bcomp*, 2024), while NPSP has created a building facade from biocomposite (NPSP, n.d.).

- Composite materials' tougher, more rugged aesthetic might also be beneficial in convincing clients of its superb performance as they likely will be comparing Hiro enclosure with the familiar steel boxes.

- As can be seen in Figure 75, RTM ranks poorly in the 'Start-up' criterion due to the expected high costs of molds as discussed in Appendix Q. However, if the client decides to opt for thermoforming for all or a part of the production, it might be possible to reuse RTM molds for thermoforming.

Customizable sleeve |

While the mechanical strength and the longevity it yields were some of the most important selection criteria for the core enclosure parts, different functionalities of and corresponding requirements for the sleeve rearranged priority of the selection criteria for this part (Figure 76). The core enclosure together with the hardware inside is expected to approach 60 kilograms on its own, so the lightness of the sleeve was determined to be of utmost importance for mounting reliability and sustainability (decreasing weight for transportation, for example) reasons. 'Desired aesthetics' moved up in importance slightly due to the assumption that having even wider color, finish, and texturing choices is beneficial for this customizable part of the EMDC. In addition, the fact that the sleeve is expected to be changed for every client, its longevity properties were deemed less important, with 'Sustainability' and cost determinant ('Start-up costs,' 'Post-processing requirements') criteria being pushed up instead. Finally, with the core enclosure designed for mechanical strength and impact resistance to protect

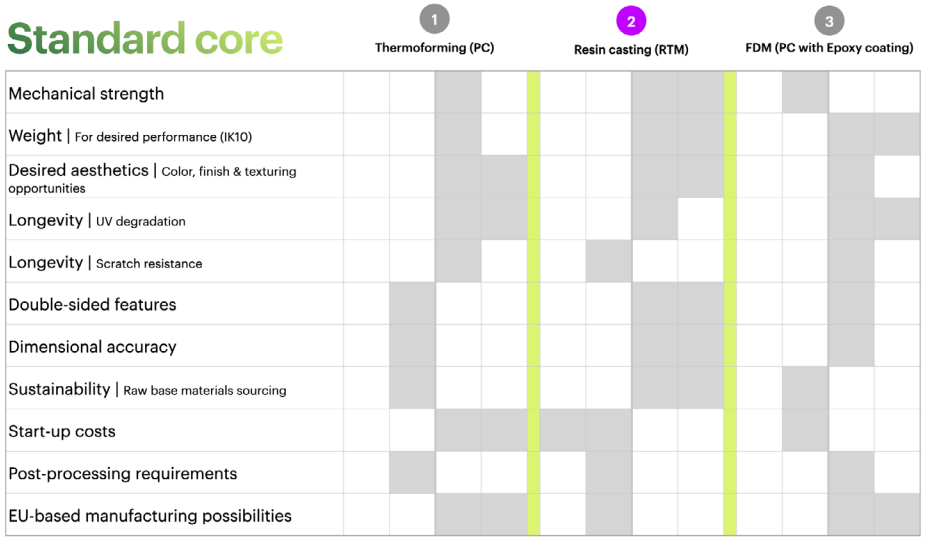


Figure 75 - Harris profile for the standard core's selection of materials/manufacturing combination.

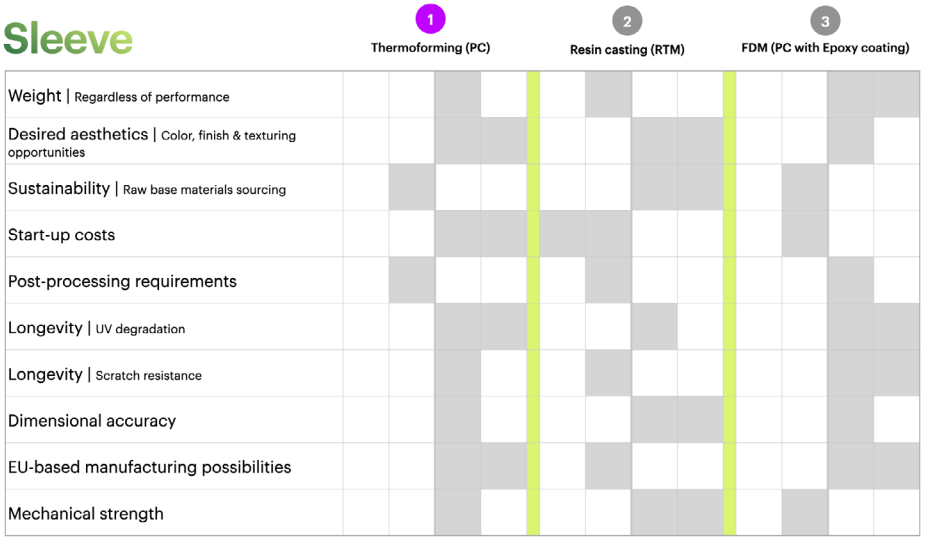


Figure 76 - Harris profile for the customizable sleeve's selection of materials/manufacturing combination.

the internals, this criterion became of much less importance for the sleeve.

As a result of rearranging the criteria and adjusting their rankings whenever appropriate, PC thermoforming was selected as a material/manufacturing combination for the sleeve. See Appendix Q for an explanation of the criteria and the rankings as well as the weighted criteria matrix.

Back lids and close-off planes |

Due to the hidden nature of the back lids (including the sleeve back plate) and close-off planes, factors such as cost-effectiveness, facilitation of necessary operations (such as drilling the holes and bending), sturdiness, and lightness were prioritized when selecting a material/manufacturing combination for these parts.

When thinking about a material that balances strength, lightweightness, and relative ease of manufacturing, aluminum comes to mind. Given the requirements and constraints described above, aluminum (6061, specifically) sheet stamping was selected as a material/manufacturing combination for the 3 back parts. This approach can also be utilized for creating the close-off planes. Considering the material thickness of standard steel data center enclosures (Data Centres EMI Shielded Enclosure for IT Equipment, n.d.), 3-4 mm sheet thickness would be recommended to bear the weight of the Cooling unit's hardware sturdily, while 2-3 mm sheet would be sufficient for the back lids of the DC and fans units.

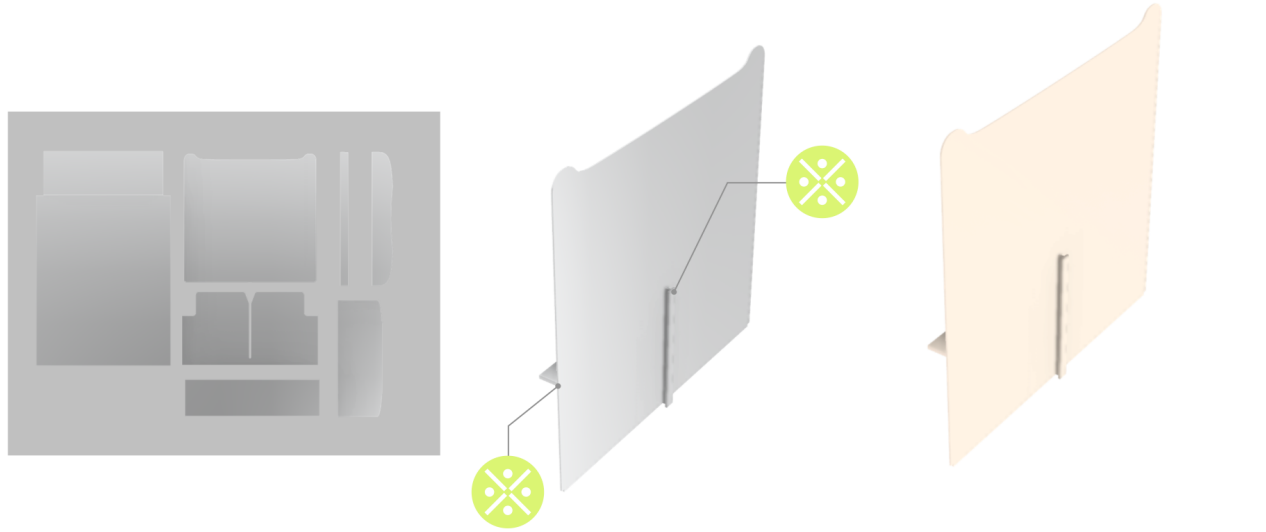


Figure 77 - Proposed manufacturing sequence for the units' back lids and close-off planes.

Carrying out anodization after the final shape of a part has been achieved would ensure not only that a part would have excellent weather-resistant properties, but also have the aesthetic benefit of color matching back lids to the front covers. Figure 77 presents presents proposed manufacturing sequence described above.

Using a CAD model to estimate the weights of back lids if they were made from aluminum 6061, it was determined that just on their own Cooling unit's back lid would weigh slightly short of 2.5 kg, and the DC unit's lid - almost 1 kg. If it was desired to optimize the weights further, ACM (Aluminum Composite Material) panels (Figure 78) could be considered as an alternative to aluminum sheets. ACM is a common material in architecture

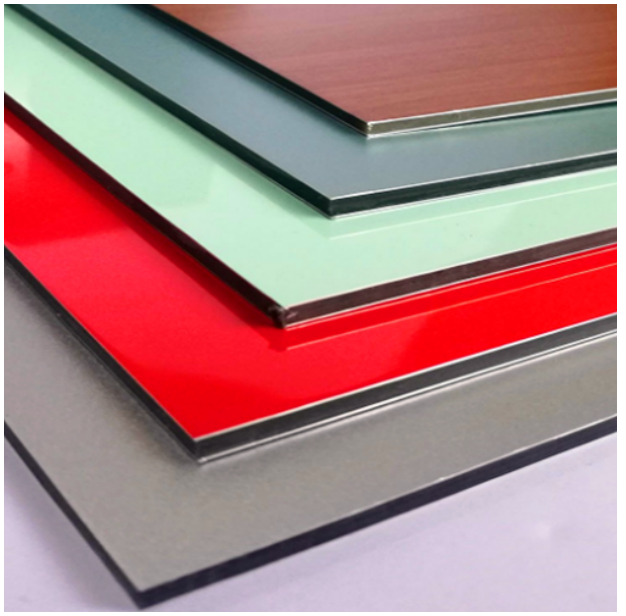


Figure 78 - ACM (Aluminum Composite Material) panels (Star Corporation, n.d.).

for cladding buildings, facades, and other exterior surfaces, highlighting its excellent weather-resistive properties (Sahand, 2023). As this material consists of two aluminum sheets bonded to a solid polyethylene core, it offers a lightness advantage over pure metal sheets. Some other subsequent advantages of ACM are lower material and tooling costs. However, the composite nature of ACM also poses questions regarding its rigidity compared to a pure metal sheet, which needs to be further mechanically analyzed and/or empirically tested to determine the appropriateness of this material for back lids manufacturing. Another weight-saving option would be manufacturing close-off planes from plastic sheets, however, in that case, their attachment to the back lids needs to be thought through.

Macro form factor CAD embodiment and final detailing

To embody all the detailing described above in the form factor of AI inspiration and clarify any remaining uncertainties, a CAD model has been created, Figure 79 on the next page presents the results. As a first step in this activity, AI-generated inspiration has been analyzed for elements that gave that form factor its distinctive character. Figure 80 presents this breakdown, and, as can be seen, the majority of notable details pertain to the organic, 'curvy' nature of the form factor. Figure 80 also shows how various parts of the AI shape were interpreted in the context of specific EMDC MCO and subparts. While visual analysis yielded important conclusions about the shape, the image is still a 2D representation from a single view, which limits the extent to which it can be analyzed. In particular, the behavior of the backward wing flap is unclear from the given perspective. While certain assumptions about its behavior can be made (it was assumed that the flap folds back merging with the side of the shape and perhaps slightly bending outwards from the mounting surface, see plasteline mock-up in upper right corner of Figure 80), it was decided to reach for other AI tools as a way to check the assumptions and gain further insights about a single view, 2D image. Vizcom (Vizcom, n.d.) was utilized to obtain a 3D interpretation of the AI inspiration image (Figure 81). Unfortunately, as can be seen, Vizcom was struggling with interpreting the sides of the wings as well, seemingly missing the backward side bend. However, analyzing the generated 3D model, including its cross sections, yielded several other useful observations. For example, model analysis was in agreement with an observation that the front of the object seems to be flat. More importantly, the generated 3D model pointed at an important discrepancy in the vertical center contour line

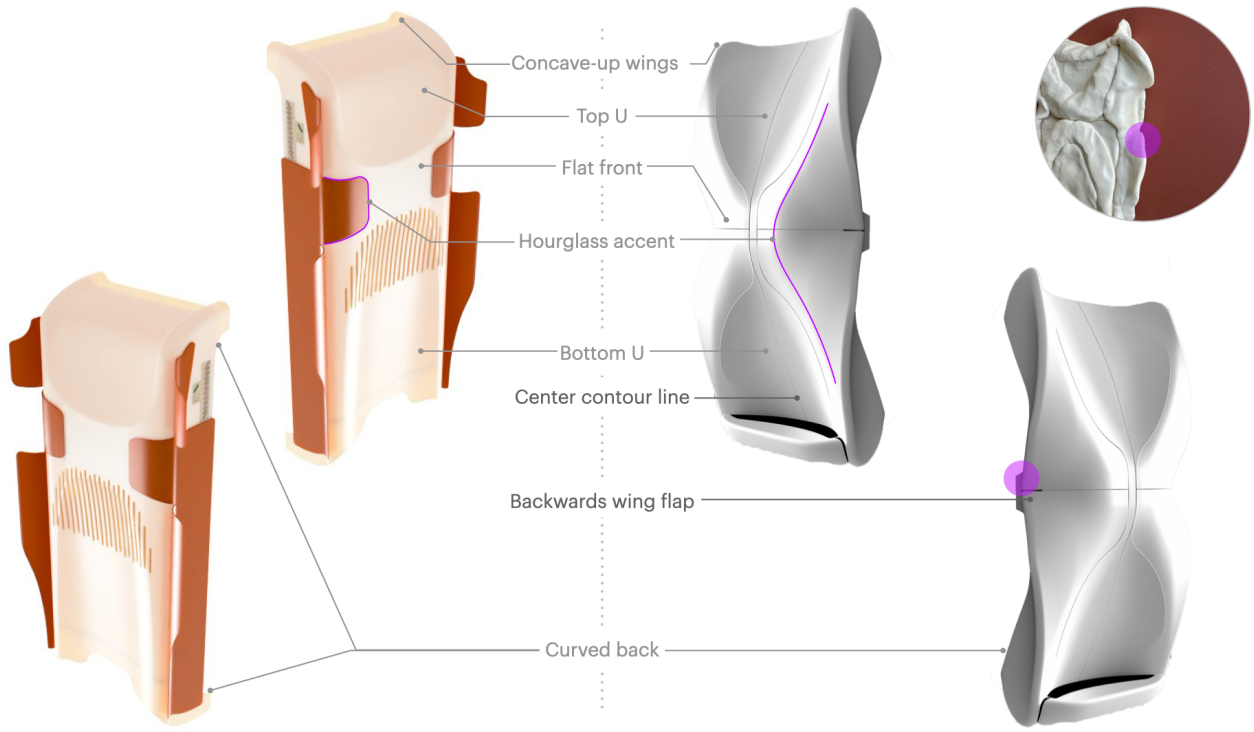


Figure 80 - AI-generated inspiration interpretation in the context of specific EMDC MCO and subparts contraints.

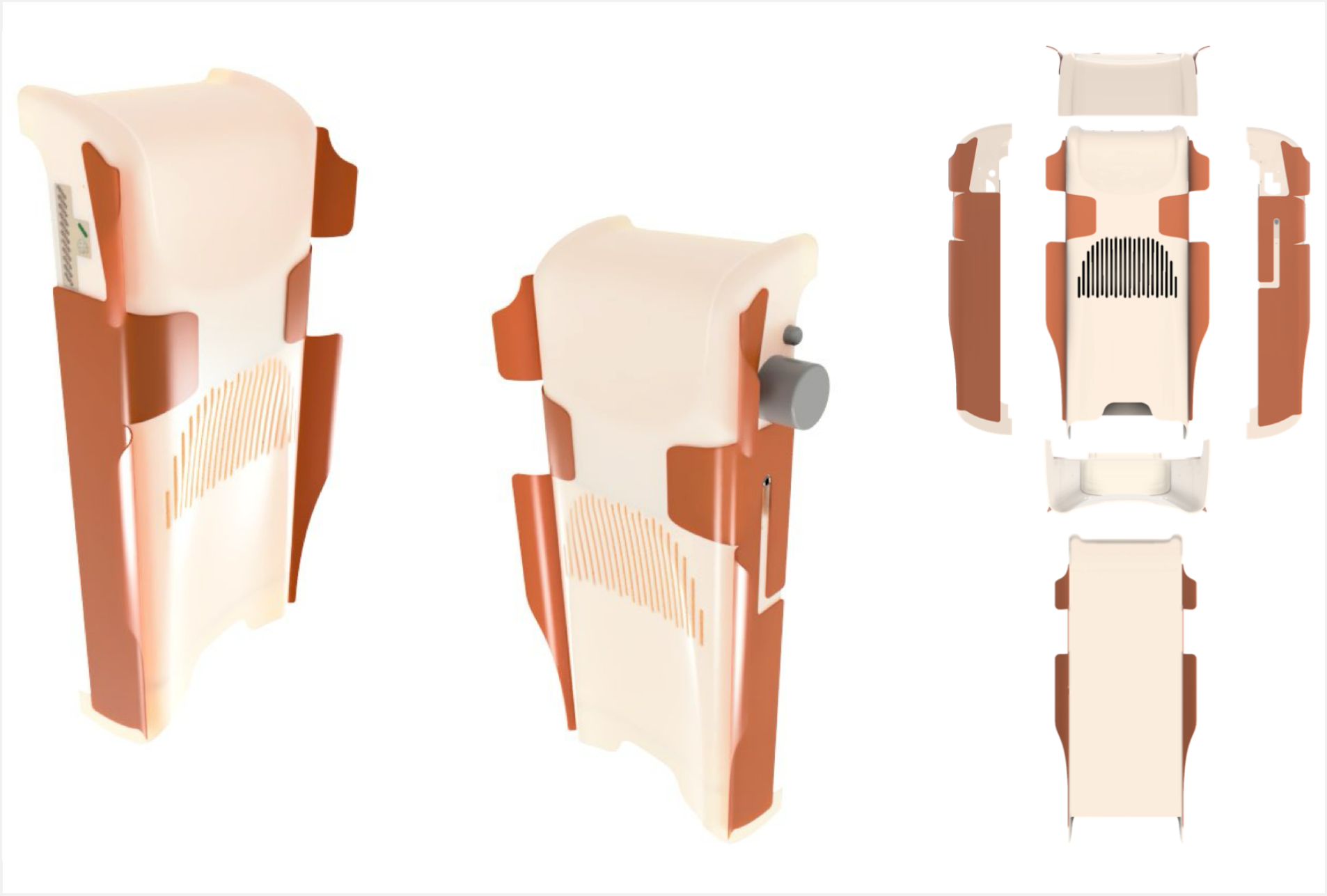


Figure 79 - CAD embodiment results.

of the AI image - the line should be concave based on visual inspection and intuition. Vizcom 3D model also served as primary guidance for the definition of DC and Cooling units' concave 'waves.'

To synthesize the analysis described above, a simplified sketch of the envisioned embodiment of EMDC core body was created and used in guiding the creation of the CAD model (Figure 81). The sleeve was then modeled to mimic the 'flaps' of the AI inspiration image with the majority of its aesthetics driven by limitations posed by various enclosure features (sleeve design will be described in greater detail below). The model has been created using a combination of parametric and T-spline modeling (Figure 81) in Autodesk Fusion 360 (Autodesk Fusion | 3D CAD, CAM, CAE, & PCB Cloud-Based Software | Autodesk, n.d.).

At this stage, the final detailing of different features, subsystems, and components has been performed with various choices described in the sections below. Appendix R provides drawings with relevant dimensions for the CAD model.

Final detailing

Cooling unit enclosure |

Front opening | A combination of airflow facilitation (OR 2) and preservation of the 'monolithic' nature of the macro form factor (OR, OW 4) considerations led to the proposed front opening design (Figure 82, see next page). Figure 82 also presents ideation that has been performed on the front opening alongside a few inspirational designs from the Pinterest board presented earlier (Figure 58) that were particularly influential in the creation of the proposed design. The curved nature of the top of the opening was driven by the intention of minimizing the amount of rainwater that gets inside the Cooling unit (EW 6, OW 3). Assuming that the majority of rainwater would have a top-down motion, it was reasoned that fitting most of the front opening within the cavity of the Cooling unit's bottom wave would be desirable and beneficial.

CAD software has been used to estimate that the proposed design yields about 63% of the front opening being fully open to the air, falling short of the desired 70% (OR 1). The slits can be further widened and exten-

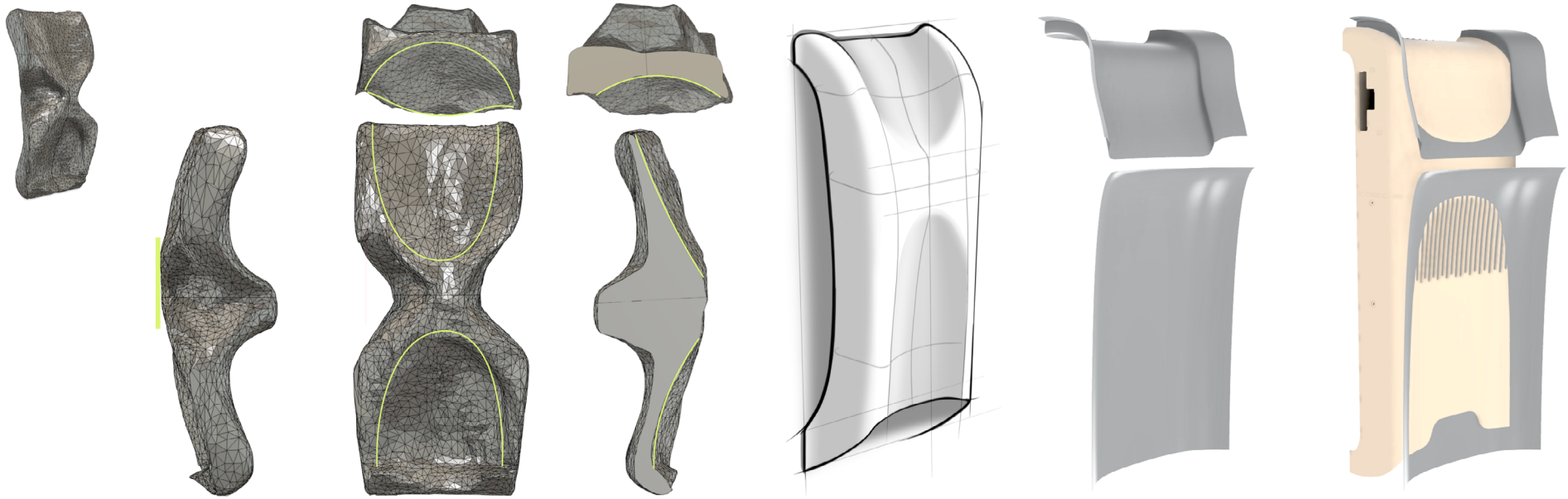


Figure 81 - Vizcom analysis (left), simplified sketch (middle), and and T-spline surfaces used to create top and bottom U's (right).

ded to reach the desired percentage with an option to also extend the openings to the sides of the Cooling unit enclosure.

To address desired levels of solids ingress protection (ER 1), inserting a dust mesh screen (Figure 83) behind the front opening is proposed. While providing a recommendation for a specific screen was determined to be outside the scope of this project, some considerations that need to be made when picking a specific design would be its weather-resistive properties as well as its ability to deform shape in case the screen needs to follow the curvy surface of the Cooling unit.

Fans unit attachment | Considering various requirements posed for the fans unit attachment, specifically FR 4, FR 5, FR 8, and FW 10, and the front-to-back sliding interaction envisioned earlier a Rollon MiniRail system (Figure 84, see next page) is proposed as an attachment solution between the Fans and the Cooling units. The manufacturer claims their compact, adaptive solution is resistant to corrosion and requires low maintenance (MiniRoller Rail: Compact Linear Guide - Rollon Group, 2024). If this proposed solution is to be further considered for implementation, an uncertainty that needs to be cleared is the amount of weight that the MiniRail system can support. In addition, watertightness considerations outlined earlier need to be implemented at the interface of the two units. Another uncertainty is the system's overlap with the mounting knob within the Cooling unit. While the knobs can be simply moved up above the rails, it can also be investigated whether the MiniRail system part mounted on the bottom of the Cooling can serve as a knob itself. The last feature to be highlighted in the design of the Fans unit are the hand grips (Figure 84) (FR 6).

Cooling unit mounting | As a result of the

Figure 82 - Front opening inspirational designs (bottom right), ideation (left), and design proposal (right).

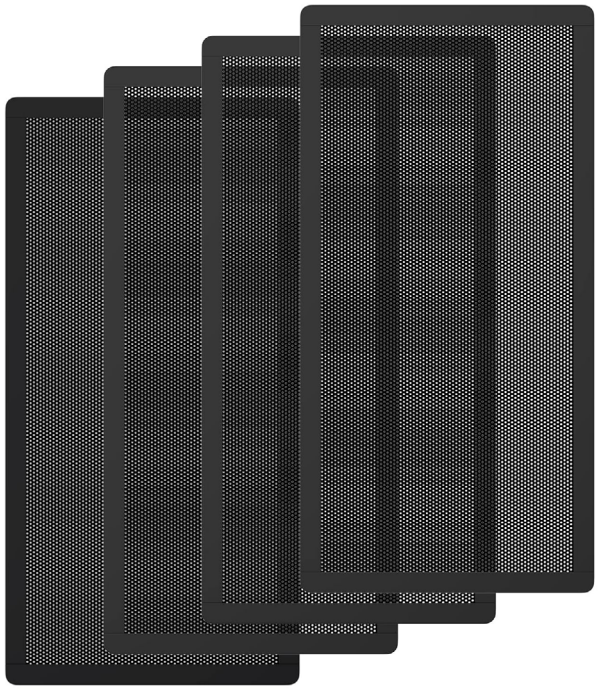


Figure 83 - Example of a dust mesh screen (MoKo, n.d.).

user testing, adding a use cue for hand placement on the bottom of the Cooling unit for its mounting procedure is recommended. A reverse, concave-down U-shaped channel is proposed. Due to time limitations, the channel was not implemented in CAD, Figure 84 presents its approximate size and location on the side of the Cooling unit. While initially concave/convex bending of the hand placement area was investigated, such design was deemed unfeasible given the desired Fans unit insertion and attachment as it presents significant challenges to the front-to-back sliding implementation.

DC unit |

Insertion back rib | An off-the-shelf T beam profile (Figure 85) is proposed as the back rib that would be welded to the DC unit's back lid as mentioned earlier. Such a shape would not only guide the unit along the vertical direction but also ensure another degree of constraint (the T-shaped profile would prevent the unit from wiggling towards the installer). However, such an additional degree of freedom constraint might not be necessary. In fact, ergonomics user testing was performed with a simple I-shaped beam, an interaction element that did not receive any negative feedback. Further user testing is recommended to make a final pick for the shape of the back rib.

Bird perching considerations | To ensure that the aesthetical appeal of the EMDC enclosure is not compromised, bird perching needs to be accounted for (DR 4). A 45-degree incline is recommended to prevent birds from landing on surfaces (Frequently Asked Questions About Birds, n.d.). Due to the preference for a tight MCO wrap-up (EW 4), a 25-degree incline was implemented with additional measures such as slippery composite material and an uneven surface of the top of the DC unit expected to compensate for the missing 20 degrees of incline (Figure 86 on the next page).

Hardware status indicators | Figure 86 presents the proposal for the implementation of hardware status indicators, where the indicators were made part of the polycarbonate overlay plate with the power button and placed on the side of the DC unit behind a sleeve flap. The rounded rectangle shape of the LEDs diffusers and the power button was inspired by the front opening slits design. Their size was maximized for visibility given the space that was available on the side of the DC unit for this component.

Side placement of status indicators originated from several requirements and considerations described below:

- **Visibility (IR 5) |**
    - **Due to bright sunlight |** Placing status indicators on the side is expected to be beneficial in terms of visibility due to bright sunlight as, with the light shining on outside wall-mounted objects predominantly from above, the sides of such objects outside tend to be shaded throughout the day. In addition, additional shading will be provided by the sleeve wings.

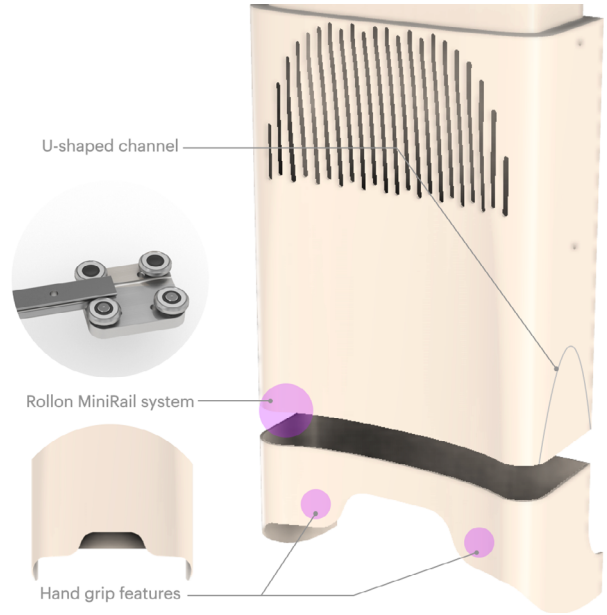


Figure 84 - Rollon MiniRail system (*MiniRoller Rail: Compact Linear Guide - Rollon Group*, 2024) and hand grip features.

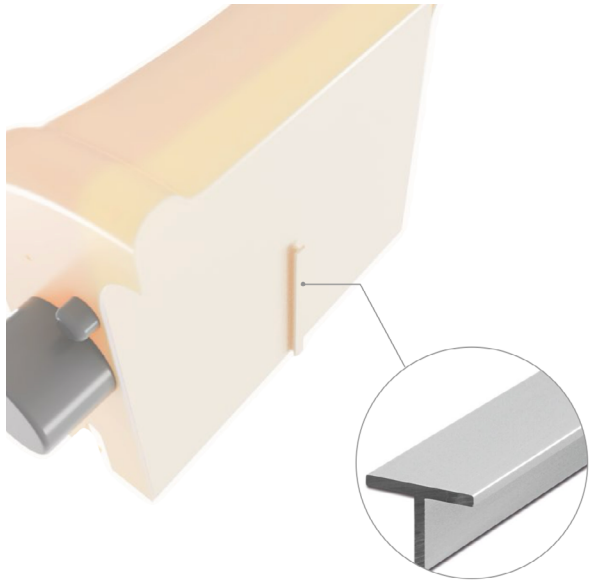


Figure 85 - T profile of the insertion back rib (*T-profielen Aluminium Online Kopen Bij OSTERMANN*, n.d.).

- **From the ground** | While the side placement isn't optimal for visibility from the front of the EMDC, it can still be argued, however, that LEDs placed on a side can be accessed from the same side of the sidewalk compared to those placed on the top or the front of the product (maintenance person might have to cross the street to extend their visibility angle in the latter case). In consultation with the client, it was determined that status LEDs are not a critical feature and the reliance and accessibility to it can be traded for other considerations.

- **Obstructions to water runoff (IW 7)** | Adding enclosure features such as protrusions and cuts to accommodate LEDs would inevitably lead to worse water runoff. This development also implies a greater dirt accumulation and decreased appeal of the 'face' of the EMDC. Placing LEDs on the side preserves the integrity and, ultimately, visual appeal of the front of the product.

- **EMDC 2nd row (IW 3)** | Ultimate product line extensions to 2 and perhaps even 3 rows of nodes were also considered when thinking about status indicators design and placement. It was determined that for ease of interpretation, each enclosure 'bulk' housing a row of nodes should have its own 11 status LEDs

- **Depersonification** | One of the main objections to placing status LEDs on the front of the EMDC was the 'personification' that such design direction is likely to bring along. Personification was given a negative connotation during the focus group conducted for the macro form factor ideation and selection. If interpreted as the 'eyes' of the device, status LEDs might lead the public to feel like they are being 'watched' by the device, an undesirable consequence in the public sector.

- **Information overload** | Information overload that the public might experience was also considered when deciding on the placement of status indicators (IW 9). Under the assumption that the lights would always need to be on for reliability reasons, side placement of the LEDs is expected to have more favorable consequences as the public will not be confronted with information they do not understand and need to know in their faces as in the case with front placement of the lights. However, such an assumption needs to be tested and verified through user testing. If the front placement of the lights is determined as the preferred option in the future, such information overload mitigation strategies as on-demand switching on and environment-sensitive brightness adjustments of the LEDs can be implemented.

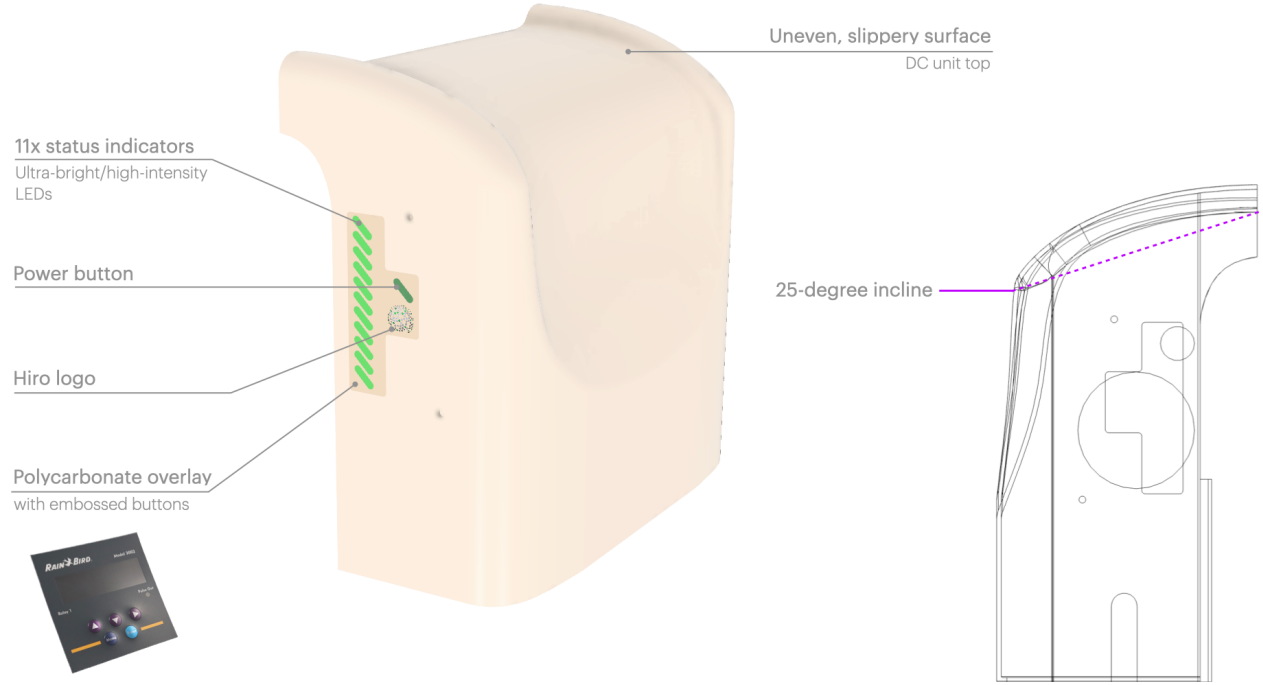


Figure 86 - Hardware status indicators design (left) and bird perching considerations (right).

- **Other considerations |**

    - Keeping the front clean from functional features maintains the appeal of the ‘uncluttered,’ ‘clean’ nature of the AI inspiration image

    - Not overwhelming the public with more information. People potentially freaking out if not all the lights are not green (‘Is it about to explode or something?’)

    One of the trade-offs made in the proposed status indicators design is the ease of interpretation (IW 6). Since the nodes are arranged horizontally inside the DC unit, the horizontal orientation of the status lights would yield a more straightforward correspondence of lights to their respective nodes. However, clear documentation and communication of the orientation of lights with respect to their nodes should not play a crucial role in the readability of hardware status.

Mounting/insertion handles |

Figure 87 presents the proposed final mounting (Cooling unit’s) and insertion (DC unit’s) handle designs, optimized for ergonomics (HR 2). As can be seen, user testing led to the updated design of the mounting handles, with an extra section added below for easier hand-switching during Cooling unit’s installation. This additional section allows for a mid-stop between the initial hand positioning during squat lifting of the unit and grabbing the unit on the bottom. The handles were extended along the sides of the Cooling unit to measure 30 cm from the bottom edge of the unit (difference between ‘Elbow height, standing’ and ‘Fist height, standing’ P50 measurements for Dutch adults, m+f 20-60, 2004 (DINED, n.d.)), ensuring easier reach. Appendix O provides the drawings with relevant dimensions for mounting and insertion handles.

At this stage, a recommendation for quick-release pin sizes was also determined. Assuming that both handles connect to each enclosure at 4 points, 10 kg weight for the DC unit (extra weight margin to account for enclosure weight) and 46 kg for the Cooling unit (maximum allowable weight for 2 people to handle), M6 and M8 pins are recommended for the sizes of the pins respectively (refer to Appendix O for calculations verifying performance). As can be seen, ‘stabilizing disks’ were added at the connections between handles and pins to increase the interface area between the handle and the unit’s enclosure to prevent handle wiggling.

While manufacturing detailing of the handles was determined outside of the scope of this project, bending and welding aluminum tube extrusions was envisioned as a possible route. Like back lids, handles serve more functional rather than aesthetical purpose, so minimizing the price of manufacturing while maintaining desired performance metrics (especially for the mounting handles that need to support the Cooling unit’s high weight) is a recommended approach for handles’ manufacturing. While off-the-shelf solutions with the desired ergonomics and mechanical performance were not found, the search was limited in time and further research and consideration of existing solutions is recommended.

Customizable sleeve |

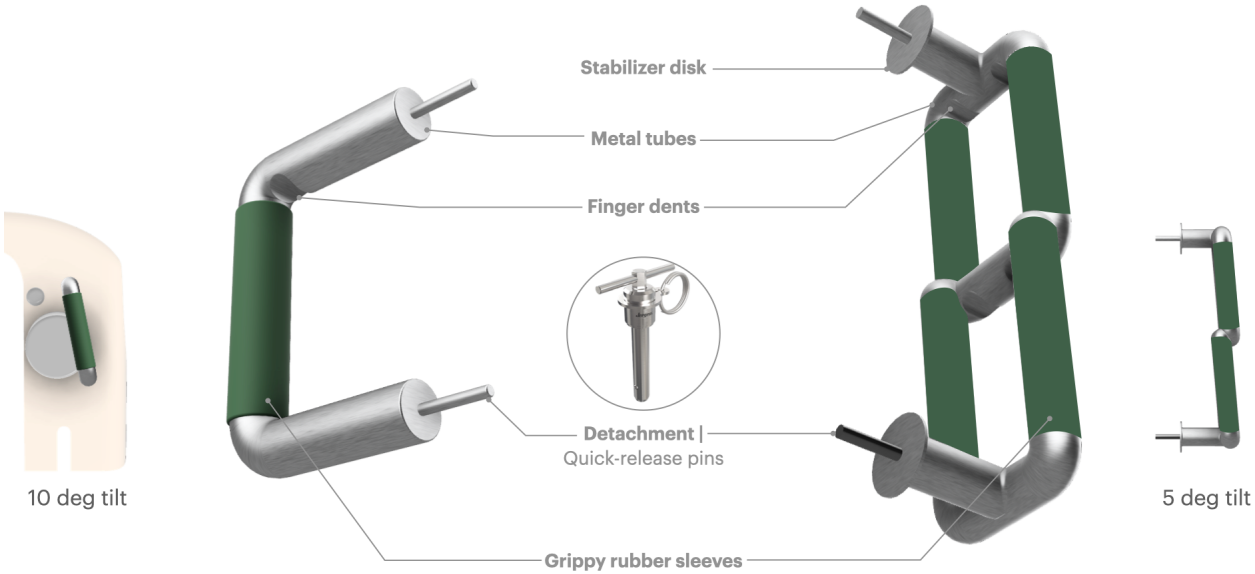


Figure 87 - Proposed final mounting (Cooling unit’s) and insertion (DC unit’s) handle designs, optimized for ergonomics.

Figure 88 presents the proposed customizable sleeve design. As can be seen, the extent of the wings was driven by the biggest (power) cable connector; the wings were made just big enough to conceal the connector when looking at EMDC up front (SR 3). On the left side, the sleeve features a channel that ensures its insertion past the HEX clamping driver. Several uncertainties that remain regarding sleeve design are as follows:

- In the current CAD model, the connection of the DC unit part of the sleeve to its middle 'hugging' part is insufficient. Increasing this connection, while keeping the limitations of thermoforming as a selected manufacturing method for this part, is necessary.
- The connection of the sleeve sides to its aluminum back plate requires further detailing. Alternatively, a thermoforming sleeve as one part from the PC can be considered, however, sufficient rigidity of the back plate for DC unit guidance during insertion needs to be verified.
- The rigid connection between the sleeve and the Cooling unit (SR 5) needs to be detailed.

Clamping actuator |

The sleeve allows about 19 cm of vertical space (Appendix R) for ratchet lever rotation, which is expected to be sufficient, especially given the precise nature of force delivery preferred in this interaction (CI 3). The center of the HEX driver is situated about 12 cm away from the outer front edge of the sleeve (Appendix R), requiring a ratchet lever longer than this dimension. The sizing of the ratchet lever needs to be chosen carefully, as longer levers yield greater torques (with torque being a product between lever length and force applied), which might result in less precision in force delivery and greater than desired torque values that might cause damage to the clamping mechanism.

Mounting solution |

Research into existing heavy-duty mounting solutions pointed at Multibrackets M Universal Wallmount HD (Figure 89) as a feasible solution given the requirements and constraints posed by this EMDC subpart. In such a solution, the rectangular part of the bracket is mounted on the wall, while the vertical brackets are atta-

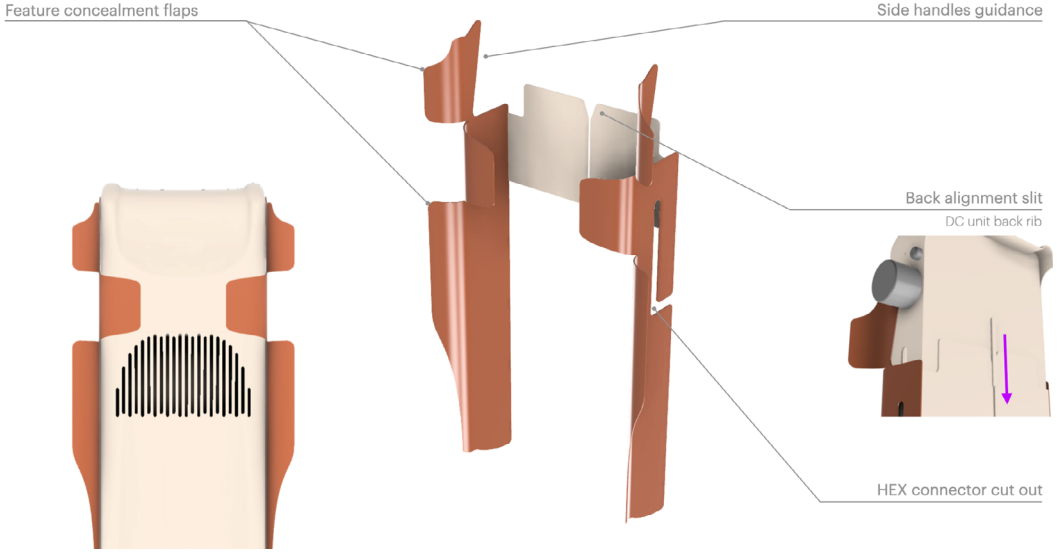


Figure 88 - Proposed customizable sleeve design.

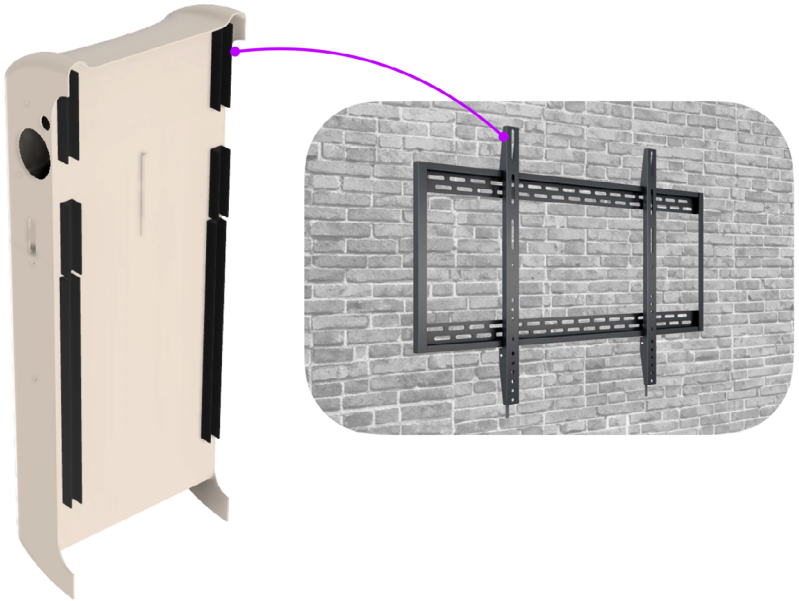


Figure 89 - Selected mounting solution highlight (MultiBrackets, n.d.).

ched to the back of the product to be mounted (Figure 89 on previous page). The manufacturer claims this heavy-duty bracket to be able to support up to 100 kg (MoR 4) (MultiBrackets, n.d.). However, it would still be recommended that the Cooling unit, the DC unit, and the sleeve are each supported by their own bracket to add an extra level of safety and not overload mounting hardware. If this proposed existing solution is to be considered further, weather-resistive properties (MoR 5) of Multibrackets M Universal Wallmount HD would need to be verified.

In the historic city center's context of interest, preserving the mounting wall surface is extremely important (MoR, MoW 2). At the same time, such an environment also introduces the challenge of uneven mounting surfaces (MoR 6). Mitigation strategies for the 2 considerations mentioned above include adjustable bracket spacers, rubber or plastic mounting blocks and shims, and rubber pads and gaskets that can be placed between the bracket and the mounting surface.

Figure 90 - HORIZON STUDIO/Bcomp luxury suitcase (left, Pillay (2023)) and the looks of various reinforcement fabrics with clear resin applied to them (right, *ampliTexTM - Bcomp.* (n.d.)).

Color, finish, and texturing detailing

In general, as a standard part, it is envisioned that the clients would be able to choose from a few hues, appropriate across the 3 contexts of interest (city center, manufacturing, and healthcare), for the core enclosure. In the immediate context of interest, Dutch historic city centers, a brick-inspired monochromatic color palette is proposed. Given such color harmony and the desired minimization of enclosure heating up from the sun (ER, EW 3), a light, nude beige hue is envisioned for the core enclosure. Such a hue is expected to be appropriate given the generally relatively light mortar in between the bricks and such light elements on facades as window frames. The aesthetics of the shell of the sustainable luxury suitcase that came out of a collaboration between Bcomp and HORIZON STUDIO (Figure 90) served as the main inspiration for color and texturing detailing for the core enclosure (Pillay, 2023). Notably, the reinforcement fabric's texture practically disappears at a distance, which is considered to be desired to not overwhelm the viewer with details given the already relatively complex form factor and detailing of the EMDC. One variation of Bcomp's ampliTex™ and powerRibs™ was used in the suitcase design, while the company offers a wide variety of fabrics (Figure 90), providing a wide range of texturing possibilities.

As the lightly shaded core is expected to stand out from the relatively darker brick wall, following the design vision, the hue of the customizable sleeve is envisioned to blend the EMDC more into its environment, mimicking closely the wall's general tone. Figure 91 presents various monochromatic combinations. While Figure 91 proposes different hue possibilities for the core enclosure, it is envisioned that for the city center context, one hue would be offered. Therefore, it is important to select a neutral enough hue for

Figure 91 - Variety of brick walls found in Delft historic city center (top) and possible monochromatic combinations (bottom).

Figure 92 - Brick building with colorful accents found in Amsterdam city center.

the core enclosure that would be easy to combine with a wide range of colors of the sleeve as brick walls come in a variety of general tones (Figure 91).

Regarding surface finishing, a smooth, non-textured surface finish was chosen to minimize dirt and dust accumulation and maximize its wash-off from the enclosure during rain (ER 8). STUDIO HIROZON's suitcases are also believed to provide a good example of a glossy composite surface finish that does not overwhelm the viewer with its overly shiny highlights.

In the proposed scenario, Hiro might have to work with such stakeholders as the leasing client, city municipality, and perhaps even the residents of the building EMDC would be mounted on to align the color palette for the EMDC. It is believed that the residents of the building are important stakeholders to get involved as they would arguably encounter EMDC the most in their daily lives. In buildings where other colorful features might be prominent, as in the example in Figure 92, residents might want to see these hues mimicked in the EMDC customizable features to further promote their building's character.

Detailing the appearance, specifically the hues of the core enclosure, for the other two contexts of interest (manufacturing and healthcare) was outside the scope of this project. Online research on the topic coupled with a survey among potential clients to get a better understanding of color and general aesthetics preferences in their industries would be advised for color offerings of the EMDC core enclosure for those settings.

Design step back

The design iteration described above allowed obtaining a greater resolution on incorporating various micro detailing elements, specifically focusing on their sizing, placement, and interaction considerations.

However, it was determined that the proposed macro form factor and micro detailing, front opening design specifically, deviated from selected classic designs and AI-generated inspiration in a way significant enough to take a step back.

As a first step in this activity, a fresh look has been cast on AI-generated inspiration, this time focusing specifically on looking for the missing elements in the first shape interpretation. It was determined that the 'Hourglass accent' (Figure 93 on the next page) that emerges due to highly contrasting areas is something that was not expressed sufficiently in the first CAD embodiment, perhaps leading to its geometrical, rectangular perception. Another important observation concerned the concave down and up curving of the top and the bottom of the side of the AI-generated shape. Reverse curve behavior was embodied in the first CAD, driven by bird perching consideration as well as the thought that such shaping will be beneficial in helping the perception of the shape as merging with the wall. However, this time it was determined to mimic AI inspiration more closely in this detail.

Vizcom CAD approximation was also further

analyzed, this time paying more attention to the relative positioning of different parts with respect to one another (Figure 93). This analysis confirmed the observation that the concave-up wings on the top and the bottom are shorter compared to the protruding flat front area. The wings also seem to be of the same length, however, due to EMDC MCO, it was decided to keep the bottom wings protruding more compared to the top ones as hand grips (FR 6). An even more importartant observation concerning the Vizcom model was the direction of the flaps that point upwards on the top and downwards - on the bottom. It led to the realization that perhaps this detail helps the perception of the desired hourglass accent (the first CAD embodiment featured flaps that were pointing horizontally outwards from the EMDC body) and needs to be brought back into the design.

In addition to the form factor, the sleeve design required adjustments as well. Specifically, similar to the AI inspiration, it was decided to make the sleeve one part with the core EMDC body. This decision was primarily driven by the design simplification objective. It was determined that the sleeve's main functions, including enabling customization and concealing functional features, could also be successfully achieved with the sleeve being one part with the core enclosure. Merging the sleeve implies that it loses its DC unit guidance functionality. However, the back plate slit can be implemented in other parts, such as the Cooling unit's back lid, and the side guiding of the sleeve was determined insignificant for the positive user experience during the ergonomics testing. In addition, more practical considerations, such as concerns over dust and dirt accumulation in the space between the sleeve and the core enclosure, played a role in combining two parts into one. Customization would be enabled by applying a vinyl wrap over the sleeve area of the core enclosure. Selection criteria that led to such a decision included the non-destructiveness/removable nature of the solution as well as sustainability, environmental resistance, and aesthetics flexibility (color, finish, etc.). Vinyl wrapping was selected primarily for its non-destructiveness to the core enclosure and excellent environmental resistance properties which are particularly seen in this solution's popularity in the automotive industry for custom car surface finishing (Figure 94). However, it must be acknowledged that vinyl wraps present sustainability challenges, including during its manufacturing (an energy-intensive process (ProVinyl Solutions, 2023)), lifecycle (release of toxic substances called dioxins to name one

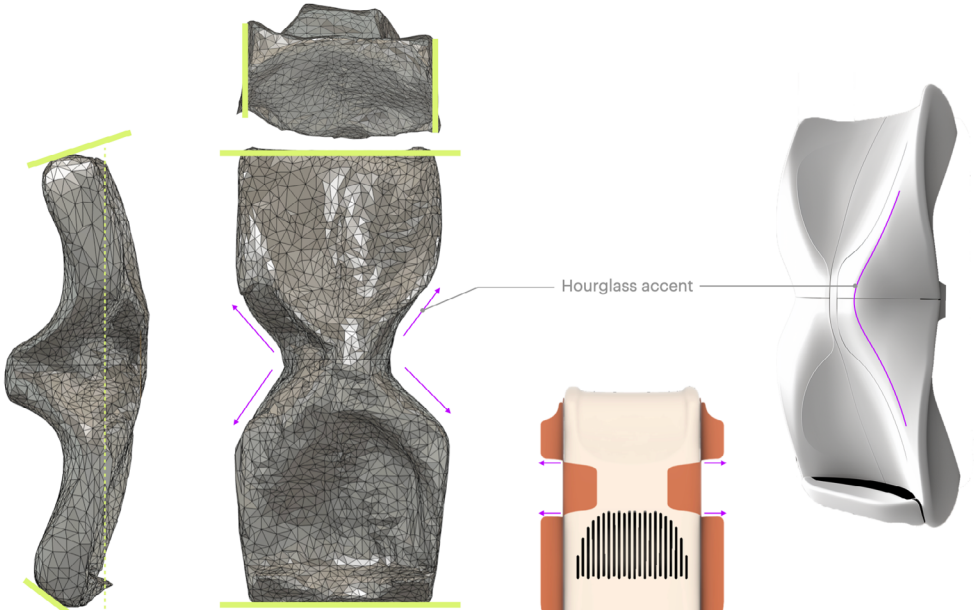


Figure 93 - Re-evaluation of AI inpsirtaion shape.

Figure 94 - Vinyl wrapping for custom car surface finishing (De Blindeer Koning, n.d.).

example (Nussbaum (2022)), and disposal (vinyl wraps recycling is not a straightforward process (FasterCapital, 2024) while landfilling this material must be avoided for plastic pollution reasons). However, in recent years there has been a push for more sustainable vinyl wrapping solutions, including PVC-free wraps and eco-solvent/latex inks (ProVinyl Solutions, 2023), that maintain this route as a viable option to pursue.

While the sleeve subpart changed, it was decided to keep the sides of the Cooling and DC units flat. As described earlier, the vast majority of functional elements, including cable connectors and handle holes, are located on EMDC sides, making the simplicity and usability that a flat surface provides for these features an indispensable attribute. However, it was decided that the interface area between the units can feature a slight curvature, whose extent would need to be determined by testing with a range of ratchet levers. To synthesize findings and considerations from AI inspiration form factor analysis described above and adapt them to the EMDC MCO, further sketching activity has been performed (Figure 96 on the next page). Next, the selected sketch from Figure 96 was used as a reference to mock up a small, quick plasteline model. Figure 96 showcases the sequence of steps in creating the intended form factor. To materialize the concept further, a concept board was created (Figure 97 in two pages, Figure 95 on this page explains the concept with callouts). The CAD model was developed simultaneously, with a plastieline mock-up serving as guidance. While the CAD model, created parametrically, was limited in its precise representation of the concept board design, it was primarily created for the purposes of being able to see the concept from multiple angles and aid in further front opening design exploration.

In addition to macro form factor sketching, further front opening ideation was carried out, with a focus on alternative ways of compatibility with the macro form factor that has not been explored before (Figure 98 in three pages). As can be seen, the two main ideation directions revolved around the front opening being comprised of small holes or slits. Horizontal slits were selected as the path to proceed along considering factors such as macro form factor compatibility, airflow facilitation, and remaining enclosure strength (see Appendix S for more details). As highlighted in Figure 98, a slit design gradually going from sharp curvature on the bottom, mimicking the characteristic U shape of the unit, to a flatter, wider curvature toward the top resembling a horizontal interface between the units got the attention for it complementing the macro form factor. Ribs on the DC unit mirror the same curves, striving to bring the two halves of the enclosure together. This design was combined with airflow facilitation considerations that pointed at vertical slits to arrive at the new front opening design. Illustrator was then utilized to create an underlay for the front opening and the corresponding DC unit ribs that were further developed and embodied in CAD (Figure 98). 11 slits were implemented to mimic the same number of server nodes in one-row EMDC. Illustrator underlay was utilized to transfer the proposed front opening design onto the concept board which was used to further explore the customization potential of the new design proposal (Figure 99).

A foam model was milled to help the assessment of this new macro form factor and front opening design iteration (Figure 100). However,

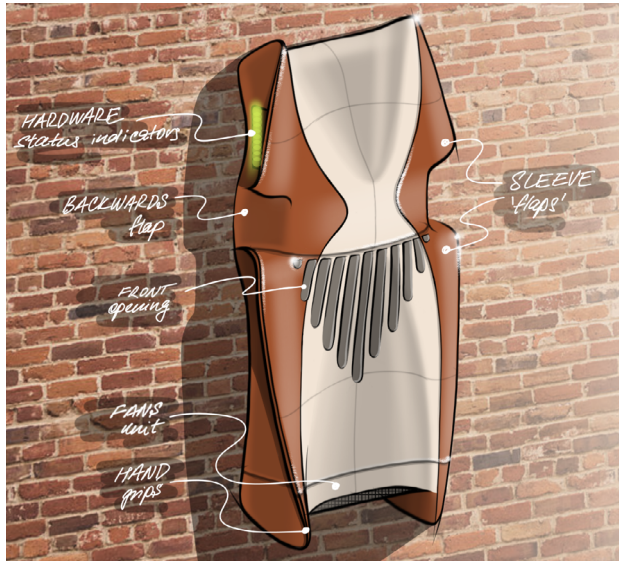


Figure 95 - The new concept with callouts.


Figure 100 - Foam model with initial front opening design and corresponding DC unit elements. The mill bit was too big to be able to accurately recreate concave ends of the slits.

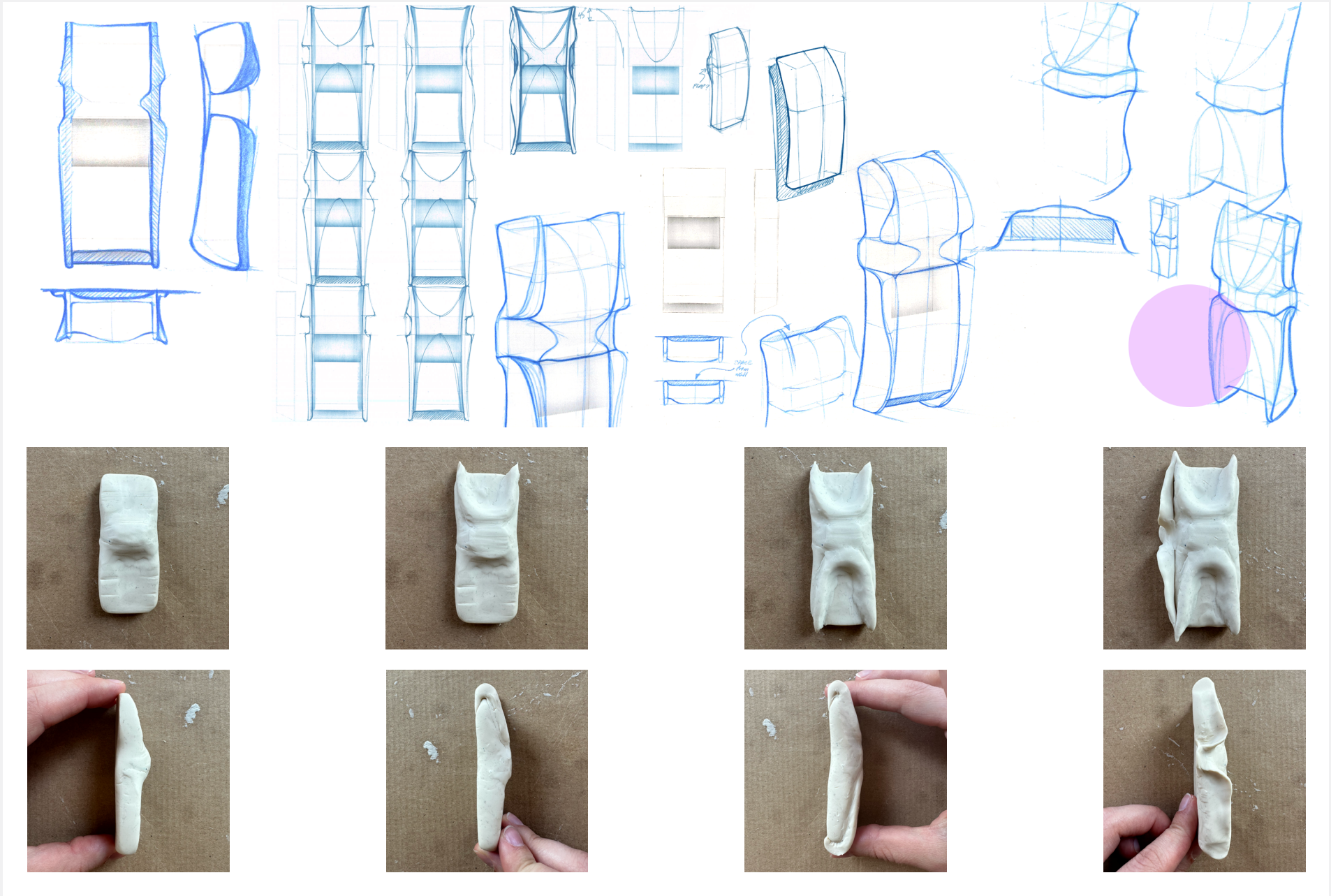


Figure 96 - Further sketching (top) and plasteline mock-up creation sequence (bottom).

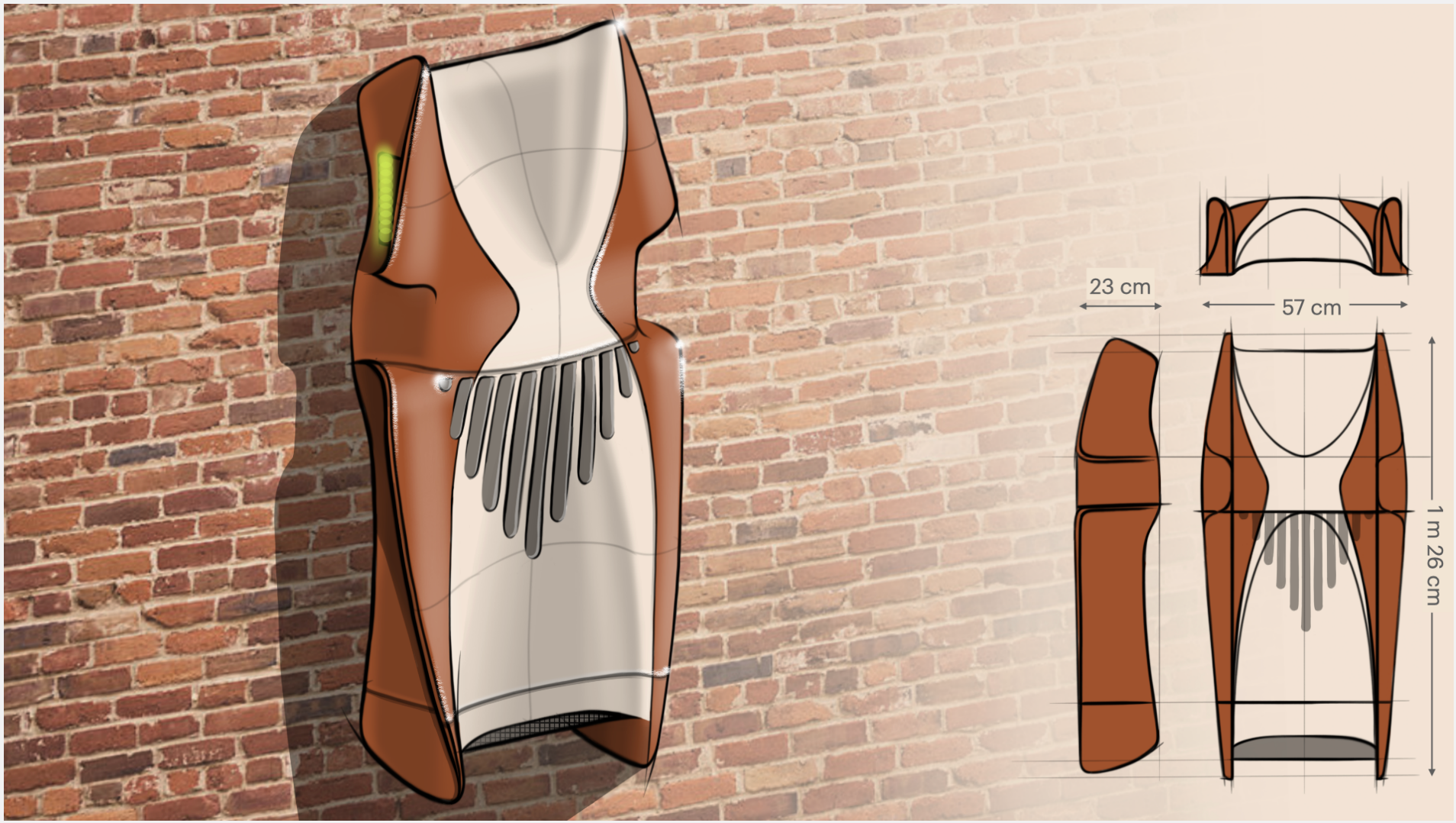


Figure 97 - The concept board.

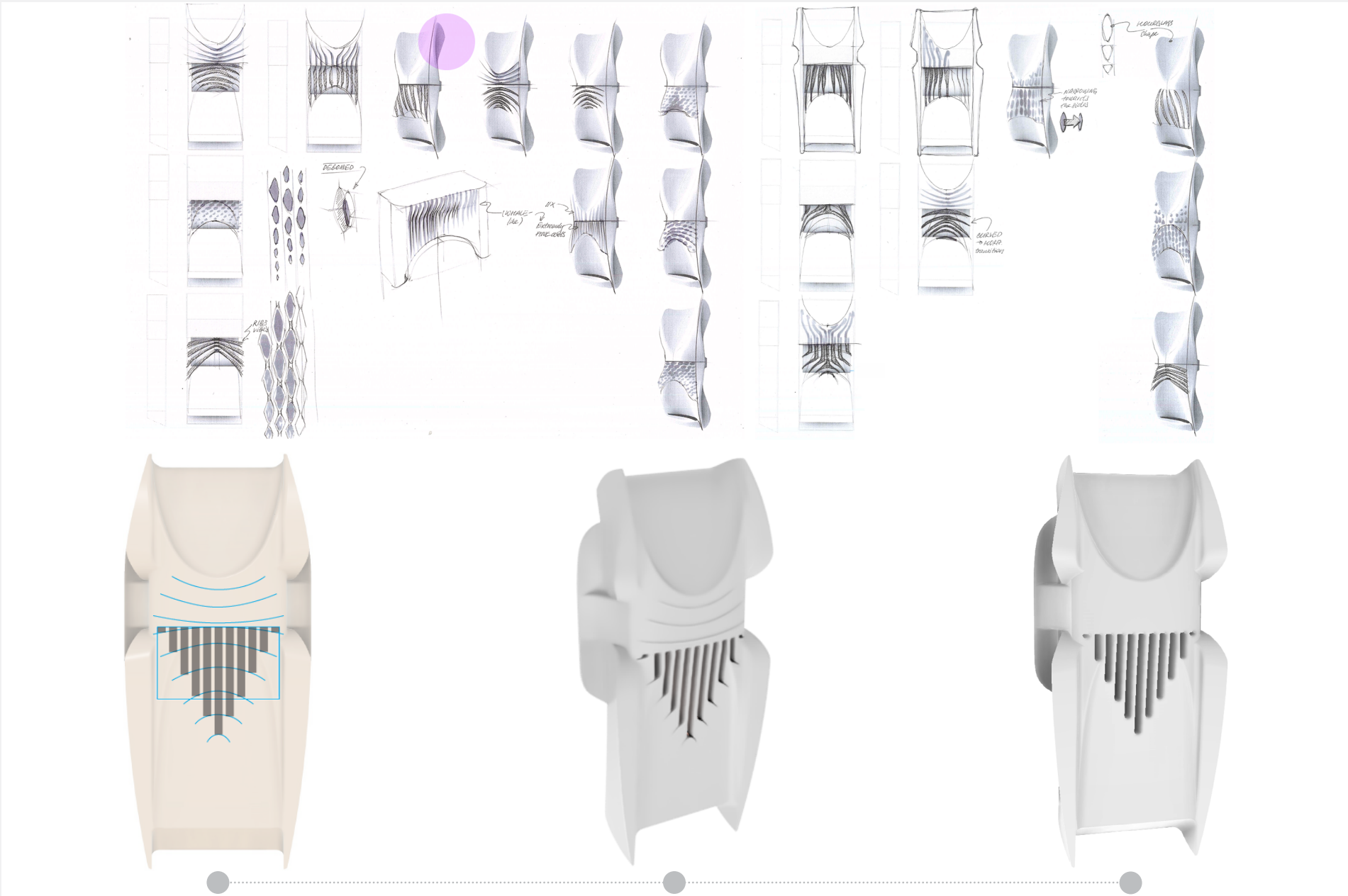
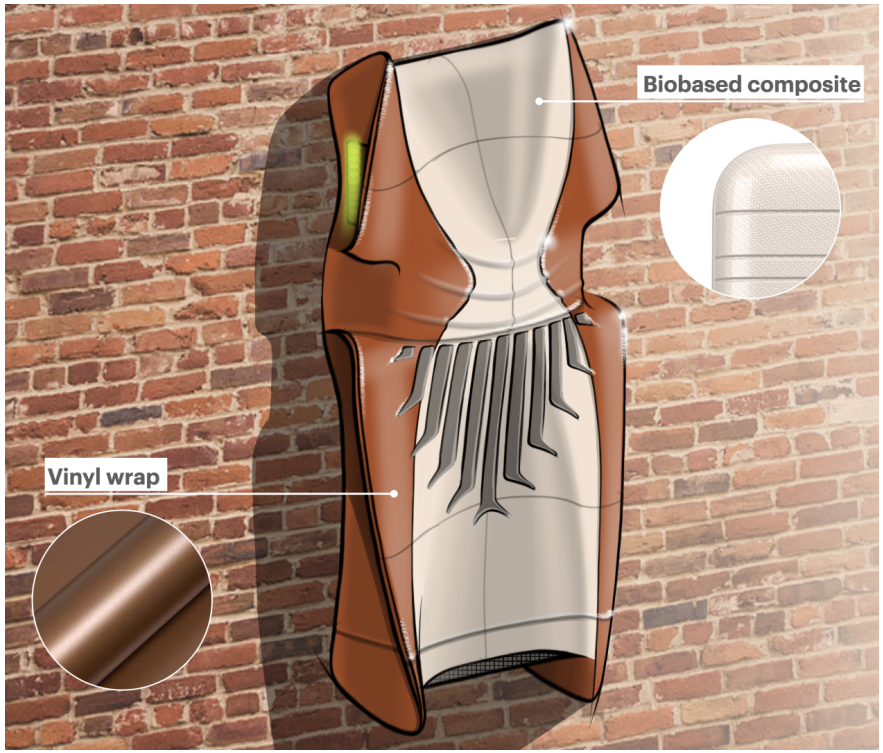
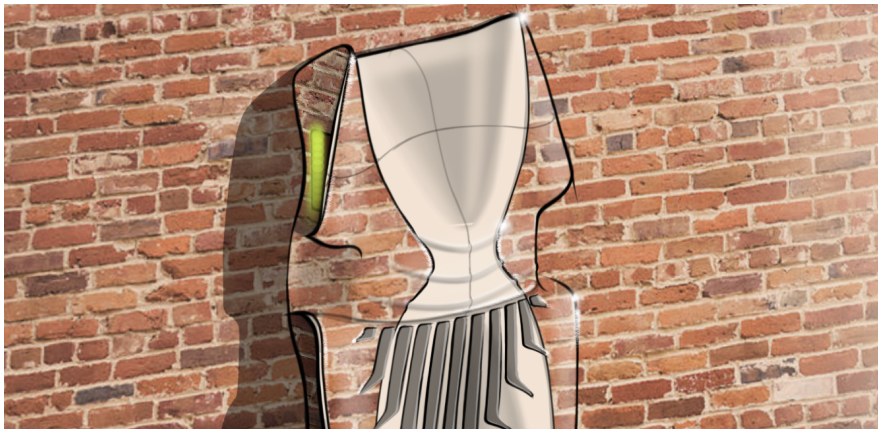


Figure 98 - Revised front opening design development: ideation (top), Illustrator underlay (bottom left), its first CAD embodiment (bottom middle), and simplified design (bottom right).





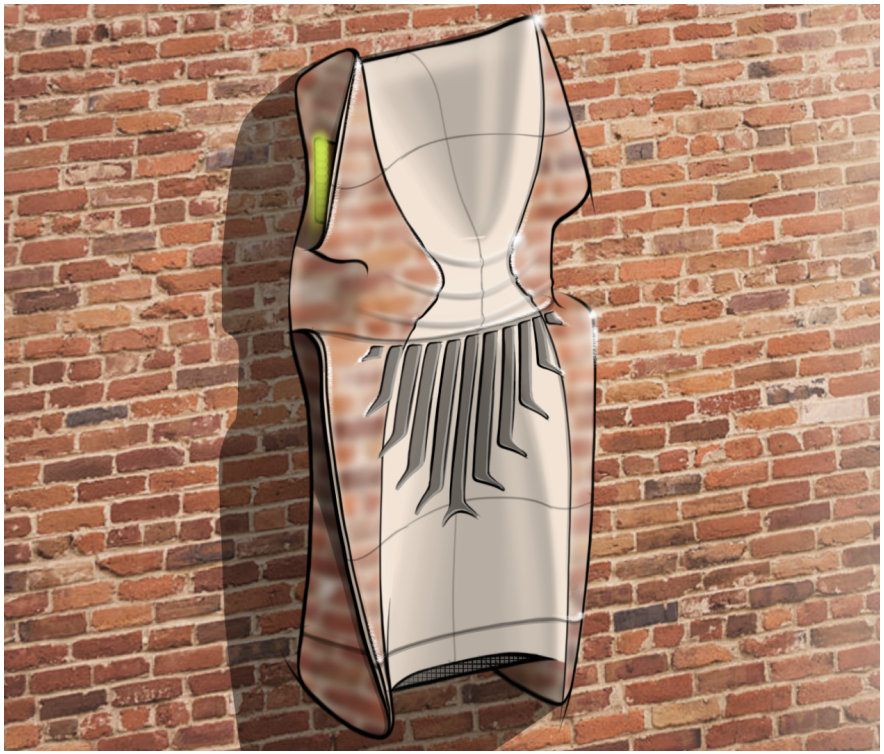


Figure 99 - Explorations the customization potential of the new design proposal.

after holistically assessing the new proposal specifically focusing on the front opening design, it was determined to be overly complex and deviating from the monolithic character of AI inspiration (OR, OW 4). The design was simplified by removing the concave down elements from the front opening and the DC unit (as presented in Figures 96 and 98). Notably, it can be argued that the new front opening is a horizontal flip of the first design. However, it is believed that placing its horizontal side along the also horizontal interface between the two units presents a better intergration into the macto form factor.

Assessing this final iteration of the form factor critically, it would be recommended to take the following form factor and interaction/feasibility considerations into account for the next iteration:

Form factor |

Width/height/length ratios were compared across the 3 designs/models (Figure 101). Inspecting the ratios, it can be seen that the Revised EMDC comes very close to the Vizcom 3D model ratios, arguably approaching the AI inspiration with its shorter W dimension to an even greater extent. More iterations can be done on the L dimension, though, shrinking its size and ratio to H.

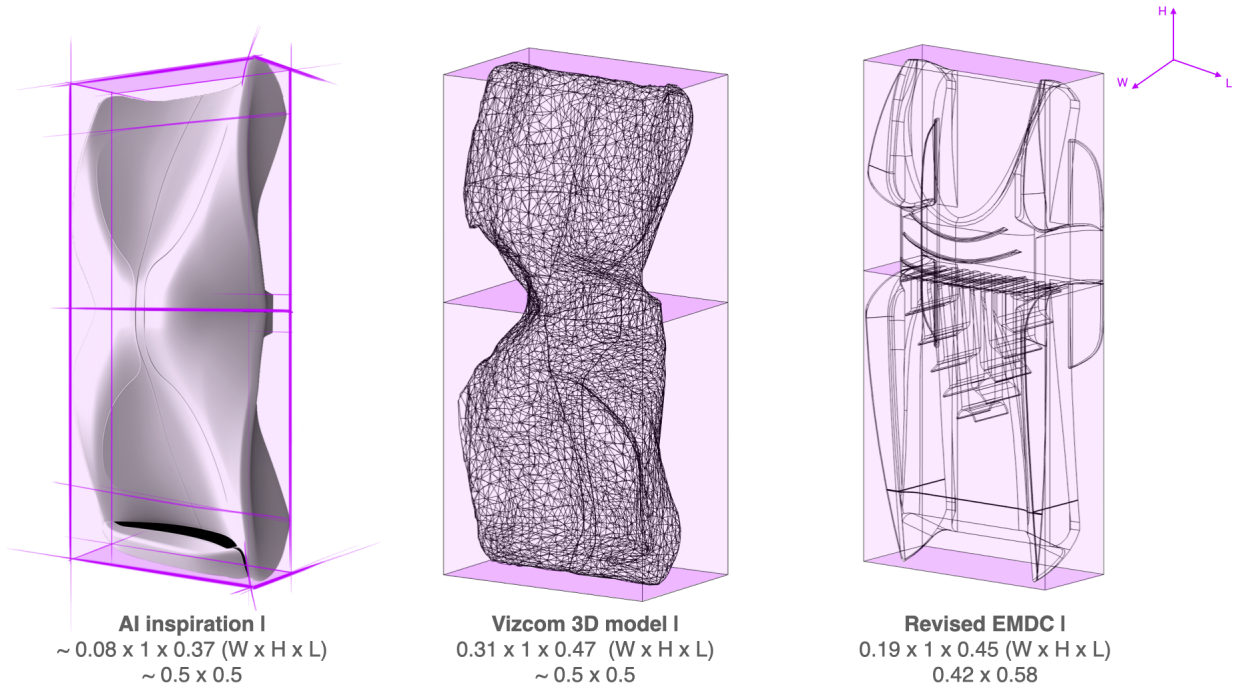


Figure 101 - Width/height/length ratios comparison across the 3 designs/models.

However, it must be noted that AI inspiration ratio estimates are likely to be inaccurate due to the hand-drawn bounding box and dimension skew due to the perspective. Yet, it can be argued that the visual 'slimness' along W of the AI inspiration is its characteristic trait and the effect to strive for in the EMDC enclosure design.

Another strong characteristic of the AI inspiration is its visual symmetry which was also confirmed by estimating the ratios (second row in Figure 101). As can be seen, the Revised EMDC design is currently not symmetrical at the 0.4/0.6 breakdown primarily due to the preference to optimize space and material utilization (EW 4) concerning the DC unit design specifically. However, it was realized that the detailed model described earlier missed 7 Ethernet connectors (an enclosure needs to provide a total of 8 Ethernet connectors, one for each compute node). This discrepancy might justify increasing the DC unit's H dimension to make it equal to the Cooling unit's H as Ethernet connectors might need to be put in a line with ample space between them for accessibility and usability purposes (Figure 102, see next page). A quick visualization of bounding boxes (following AI inpiration and Vizcom ratios) for symmetric EMDC units was thus created (Figure 102 on the next page). As can be seen, the proportions of AI inspiration yield a visually disproportionate volume that is perceived to be too thin along its W dimensions, while Vizcom ratios result in a shape that feels too bulky. The 'truth,' therefore, is arguably somewhere in between these two volumes.

Another important detail in the perception of the symmetricality of the AI inspiration is the positioning of the split line that visually divides the central, flat area of the shape in half. Currently, the split line between the DC and Cooling units is on the bottom of the flat area. An iteration where the split line is pushed halfway up is therefore advised. However, while it's expected that the Cooling unit enclosure can be adjusted relatively easily for such change, the protective function of the DC unit (DR 2) would be compromised if it were to be made shorter, exposing internal hardware. This can potentially be mitigated with a DC unit enclosure having 2 walls if the weight and manufacturing complexity that such mitigation would imply are deemed appropriate.

Feasibility |

- **Front opening |** Further front opening design and optimization activities are necessary. The front opening CAD sketch was used to estimate that 49% of the front opening area is open to the air, so further optimization is required to reach the desired 70% (OR 1). However, the remaining enclosure strength needs to be balanced with removing the material for the front opening to ensure that the Cooling unit enclosure still meets the desired impact resistance specifications. Lastly, it would also be advised to iterate on the hole front opening design for its strength in compatibility with the macro form factor (small holes practically disappear at a distance, creating a more uniform core enclosure look). However, its airflow infringement concerning turbulence creation needs to be checked using computer simulation or physical prototyping.

- **Manufacturing |** Unifying sleeve and core enclosure presents challenges with the proposed materials/manufacturing combination. It is expected that RTM composite method would still be appropriate for creating the revised form factor. However, laying out reinforcement fabric in the tight space of the sleeve thickness might be problematic. RTM experts need to be consulted for the best approach to mold design and reinforcement layout for the unified EMDC enclosure.

Interaction |

Unifying the sleeve with the core enclosure has implications for the proposed enclosure interaction. Considering the insertion of the DC unit specifically, the guiding plate with the slit can become part of the Cooling unit's back lid. The sleeve side guides' usefulness was determined to be insignificant during ergonomics testing and the participants also stated that paper flaps did not obstruct their actions in any way. However, testing paper flaps were significantly smaller compared to the ones proposed in the detailed designs for concealment purposes, thus sleeve flaps might present considerable obstacles to the units' handling, especially thinking about the Cooling unit and its heavy weight. Further user testing would need to be carried out to optimize sleeve shaping and dimensioning to balance the sleeve flaps concealment function with the user experience they yield.

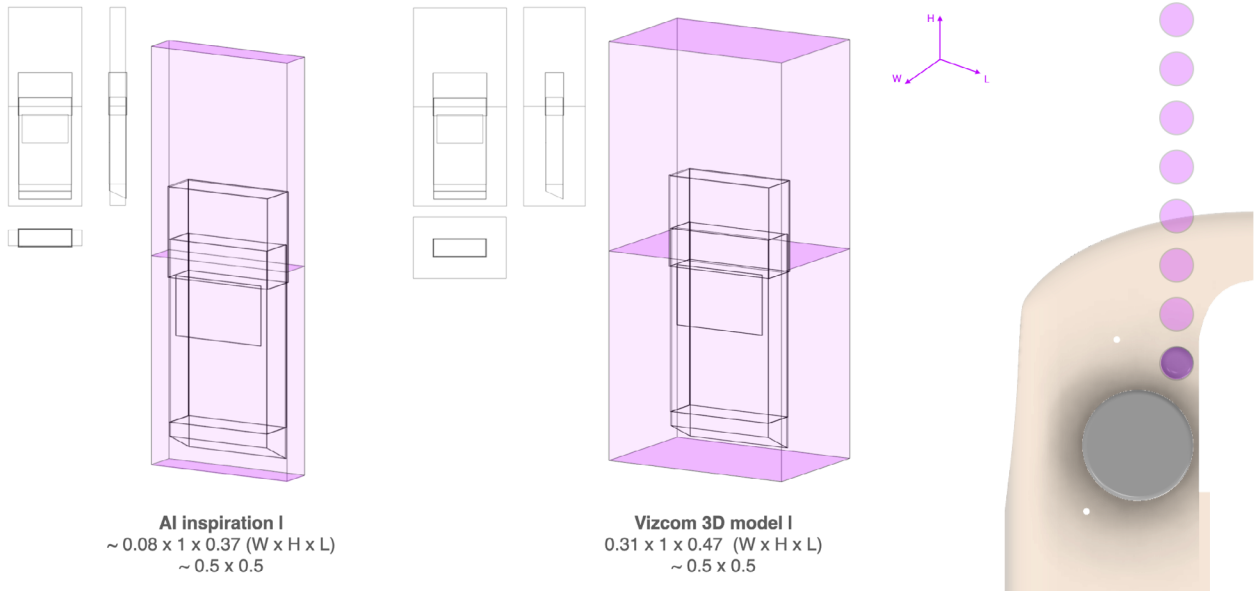


Figure 102 - Bounding boxes (left) and 8 Ethernet ports (right).

Proposed design as a reflection of desired brand identity

A Google Forms public survey was conducted to determine the extent to which the presented EMDC design iteration reflects the desired Hiro identity (that of a pioneering, elegant, refined, empowering, and assertive brand). The same set of questions (with additional, unique questions being added when necessary) was asked across 3 design development stages: AI Inspiration image, Monochrome CAD model, and Color Rendering concept board (Figure 103). Additional questions included general feelings (pleasant/neutral/unpleasant) participants experienced towards the 3 designs as well as any associations that come to their minds when looking at visual stimuli presented. It is important to note that participants were not told what the object was (it was decided that their answers would be less biased in that way) and were only revealed that it was an EMDC at the end of the survey. See Appendix T to access the questions asked.

The survey got 19 responses in total (n = 19). The survey results are summarized and discussed below with more information presented in Appendix T.

Reflection of the desired brand identity | Refer to Figure 104 for the comparison of mean scores and corresponding standard deviations for the 5 keywords across the 3 options presented in the survey.

- **Assertive** | All 3 options scored above the global average of 3, indicating that all of them are perceived as overall assertive by the participants. The 3 designs exhibited similar levels of assertiveness, with the CAD model scoring slightly lower. Relatively low standard deviation values for the 1-5 response scale indicate that participants' opinions on assertiveness were consistent across the 3 options. Respondents who gave average or below average scores commented that to be perceived as more assertive, the design should be less 'subtle and blended in' by

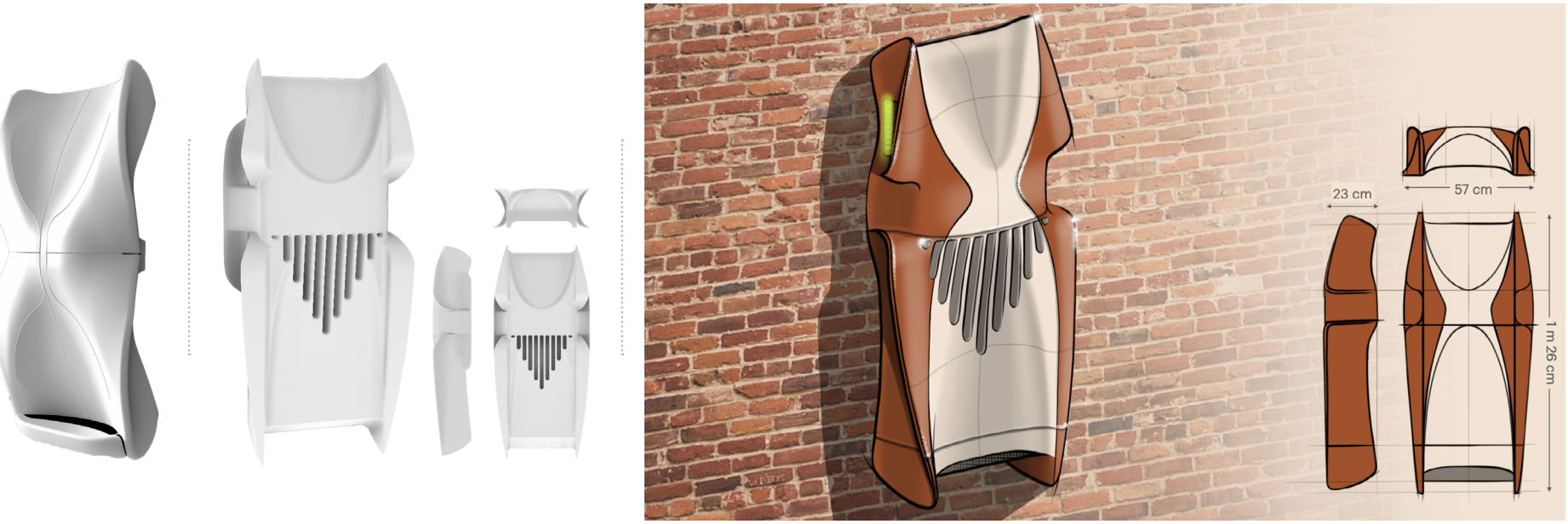


Figure 103 - Survey visual stimuli: AI Inpiration image (left), Monochrome CAD (middle), Color Rendering (right).

having ‘bold colors’ and ‘pointy shapes,’ for example. Interestingly, one comment read ‘make it less elegant,’ implying that the 2 qualities are at odds. Another interesting comment pointed out that the inwards pointing nature of the shapes presented makes the designs feel less assertive.

- **Elegant** | This trait got the overall highest average score for the AI Inspiration option across all keywords and designs. The variability of responses in this case was also the lowest, indicating the respondents’ high degree of unison in this opinion. The other 2 options fell short of the AI Inspirations high scoring, with Monochrome CAD scoring below the global average, indicating that this design is not perceived as elegant. Again, variabilities for the Monochrome CAD and Color Rendering options were relatively low, indicating consistency in opinion across survey respondents. Pertaining to the Monochrome CAD and Color Rendering designs, decreasing the complexity of macro form factor and detailing emerged as the main theme of making these designs more elegant. In addition to making the lines ‘cleaner,’ respondents named decreasing color contrast or even making it monochromatic as another mitigation strategy. Another specific comment called for decreasing the size of front opening slits. Interestingly, one participant mentioned ‘textured fiberglass,’ questioning the perception of the materials/manufacturing combination proposed earlier as elegant.

- **Refined** | AI Inspiration and Color Rendering received similar mean rankings that indicated their perceived refined nature, with monochrome CAD falling short again (and below the global average). Standard deviation values continued to be relatively low across all 3 options, indicating that participants expressed consistent opinions of this keyword across all 3 designs. Bulkiness was the most popular comment when it came to the perception of the designs as less refined.

- **Empowering** | For this keyword, all 3 options scored above the global average indicating that all designs were perceived as more empowering than not, with AI Inspiration getting slightly higher rankings. Standard deviation values continued to be relatively low, indicating a low degree of variability across respondents’ opinions. Notably, standard deviations are higher in the latter two design options (and some of the highest values in this analysis overall) which points to a slightly greater range of opinions regarding the expression of empowering quality for these 2 designs. As can be seen, ‘empowering’ and ‘pioneering’ keywords generated the highest variability of opinions, an observation that is consistent with the initial survey discussed in the ‘Macro form factor selection’ chapter, where these qualities were harder for participants to interpret as well. Respondents seemed to predominantly interpret empowerment in the context of the product’s functionalities and what it would enable them to do. Lacking information about what the product was thus prevented participants from adequately judging the empowerment degree of the shape. Speaking of specific comments, the direction in which the shapes seem to be pointing was coined as shugging by one

Figure 104 - Comparison of mean scores and corresponding standard deviations for the 5 keywords across the 3 options (top and middle) and general feelings towards each option (bottom).

respondent, which goes against the sense of empowerment that the shapes are intended to convey.

- **Pioneering** | This keyword presented the only instance where the embodied design, Color Rendering specifically, scored on average higher than its AI inspiration. The CAD model lagged behind again, however its mean was still above the global average for this keyword. Interestingly, Monochrome CAD also had the overall highest standard deviation value for this keyword (yet still relatively low on a global scale), indicating that participants were not in unison when it came to the perception of this design as pioneering. The other 2 options exhibited low standard deviation values and a greater degree of opinion holism. No coherent comments were received regarding the ways to facilitate perceptions of the designs as pioneering. Similar to the empowerment quality, it seemed like the lack of information about what the product interfered with participants' ability to judge whether it was pioneering as they did not have a benchmark to compare it to.

Taking a holistic view of the results described above, averaging means for 5 keywords for the 3 design stages, all 3 of them score above the global average (meaning that all of them do express the desired holistic brand identity), overall AI Inpiration leads (3.82 mean across all 5 keywords, Appendix T) leads the way in articulating the desired brand identity with Color Rendering following closely after (3.62). As discussed earlier, the current CAD model is the best representation of the desired form factor given skill and time constraints and, as expected, currently it is indeed missing the essence of the desired design which is reflected in its lower mean score compared to the other 2 alternatives (3.11). AI Inspiration also experiences the least degree of opinion variability (1.02 against 1.12 for CAD and 1.13 for the Color Rendering, Appendix T), yet the differences in standard deviation values are not significant enough. However, when it comes to the high-level visual appeal and perception of the 3 options presented, AI Inspiration exhibits even a greater lead with over half of respondents (57.9%) indicating that they experience 'pleasant' emotions when looking at the design. While the Color Rendering presents an improvement compared to the CAD model (over a third of respondents experience a 'pleasant' feeling towards this design), it also has a greater share of responses that indicate it as something 'unpleasant' to look at compared to CAD. Among specific comments regarding the unpleasantness of the Color Rendering, two participants mentioned how such a modern device would not fit with the historic city center aesthetic. This statement is also consistent with respondents indicating that on average Color Rendering design stands out (3.47 mean) more to them than it blends in (3.11 mean). Standard deviation values are also relatively low (1.07 and 0.99, respectively), showcasing the unison in respondents' opinions. Contrasting colors, modern, organic form, front opening design, and, interestingly, the unfamiliarity with the product were called out as the main factors that make the presented design stand out. As expected, the brick color of the sleeve helps the design to be perceived as blending in with the wall. One respondent commented that the design resembles 'small clay features, such as statues' that are sometimes incorporated into the walls in the Mediterranean. Still, as the two mean values are within 1 unit of the global mean (3), it can be argued that the Color Rendering concept successfully embodies the design vision of creating an object that blends in and stands out equally.

Figure 105 on the next page presents word clouds for the most popular associations among respondents. Notably, the personification theme was quite prominent among the responses with references to evil villains and Darth Weider being not numerous, yet still concerning instances. Interestingly, perhaps due to its more geometrical nature, Monochrome CAD

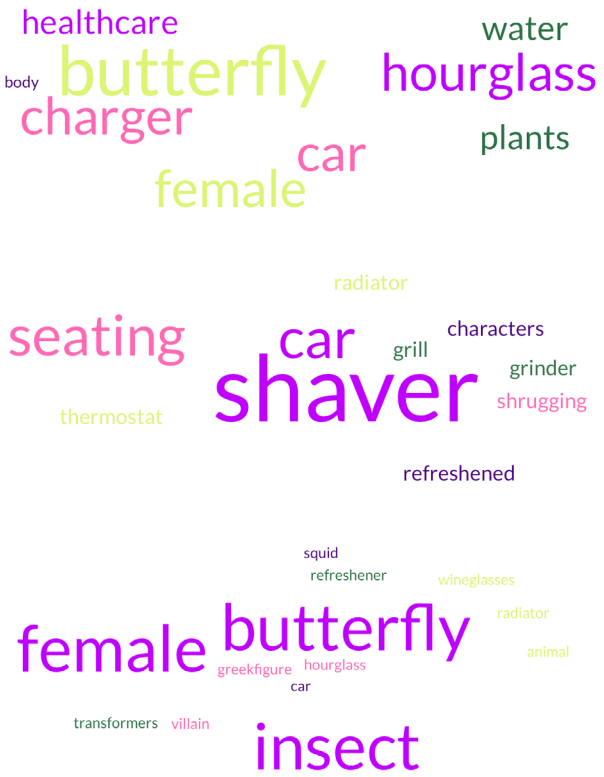


Figure 104 - Word clouds for the most popular associations for AI Inspiration (top), Monochrome CAD (middle), and Color Rendering (bottom).

was predominantly associated with domestic appliances, such as shavers, radiators, and vegetable grinders. As expected, Color Rendering went back to more organic associations such as the female body, butterflies, and wine glasses, reflecting its greater proximity in perception that was also proven numerically earlier. However, the variability of associations was the least for AI inspiration, indicating that the majority of people interpret this shape in a similar way (which is arguably desired). While Color Rendering has similar associations to AI Inspiration, it still received references to an air refreshener and a radiator, arguably indicating its perceived connection to the CAD model.

The vast majority of respondents (84.2%) indicated a desire to know what these objects are when seeing them in a historic city center. When asked to guess what the device might be, two predominant themes emerged: tourist- and technology-centric. Reflecting on the speaker-looking openings and perhaps its historic city center location, many respondents guessed that it might be an information station for tourists or a rest area where people can lean or hide inside. Continuing with the openings, some people hypothesized that the product might be an air purifier. Along with the technology theme, an electric car charger was the most popular response (3x) with single mentionings of an AC unit and network connectors. It can be thus implied that the public is not familiar with the concept of an edge micro data center and their coming introduction into city centers.

Survey limitations |

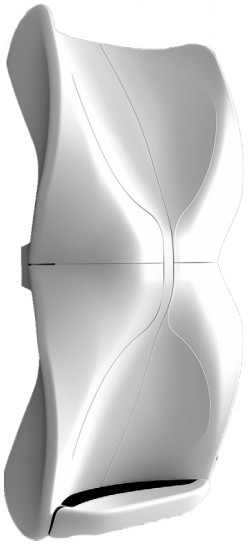
This survey presents limitations when it comes to the age, occupation, and place of origin of the participants. The vast majority of participants were between 18 and 30 years old (84.2%), coming from Europe (89.5%), and involved in an art/design occupation (63.2%). If a similar survey is to be conducted for the next design iterations, it would be advised to involve a more diverse group of participants, specifically focusing on increasing variety in the age and place of origin, to reflect the diverse nature of the city center public.

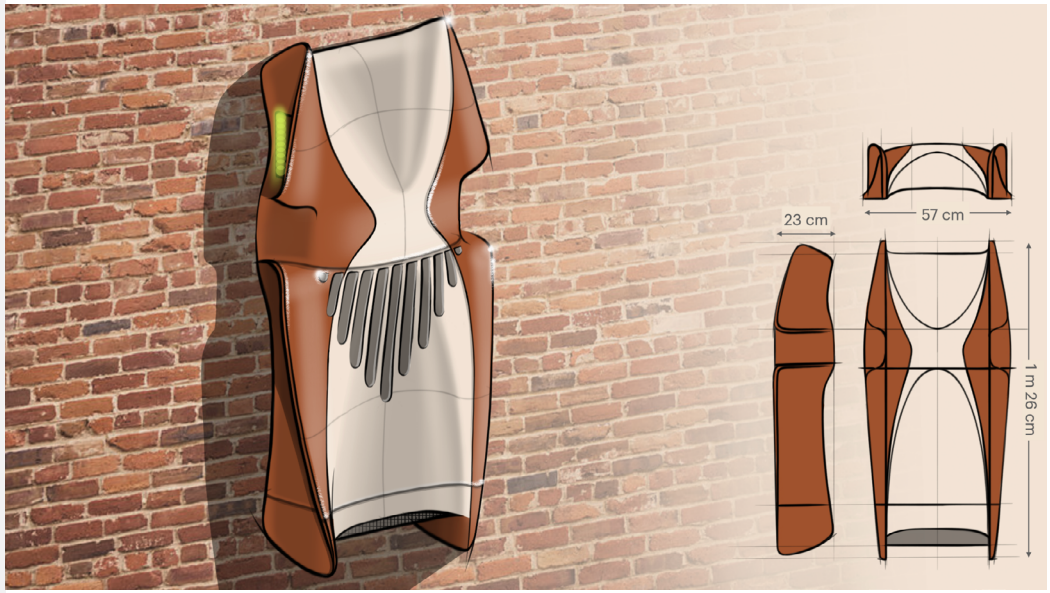
Overall, it can be argued that survey results indicate that on average AI Inspiration succeeds at expressed desired brand identity to the greatest extent, being associated with such elegant items as a human body and butterflies and arguably such pioneering objects as concept cars. Color Rendering comes reasonably close to a similar perception as the AI Inpiration, yet its functional requirements that resulted in the added complexity to this design seem to hurt its interpretation. With its implementation limitations that resulted in greater geometricity and sharpness, the current CAD model does not reflect the desired aesthetic in a satusfactory way. Based on the survey results, recommendations for the next design iteration will be discussed in the 'Recommendations section.'

Comparison to the initial public survey and its classic designs

Comparing the survey results presented above to the initial public survey and classic designs presented in it, it can be argued that certain themes emerge that can be drawn upon for the next design iteration. AI Inspiration and Color Rendering will be discussed further as these two options emerged as the most successful in conveying the desired brand identity. 'Assertive,' 'elegant,' and 'empowering' keywords will be focused on as 'empowering' and 'pioneering' qualities were challenging to interpret across both surveys. Figure 106 on the next page refreshes the reader's memory on the concepts and keywords that will be further discussed.

AI Inspiration | Looking at the classic designs and keywords used to describe them alongside their explanations, it becomes clear why this design received high scores. Interestingly, the shape was predominantly associated with a butterfly which coincides with the Butterfly Stool also being interpreted as an elegant and refined design. AI shape's smoothness and soft, flowing curves resemble the Jaguar and the Butterfly Stool, contributing to this shape being interpreted as elegant. Minimal details (such as split lines) and the two halves of the shape blending into one another subtly leads to it being





Assertive


form factor
bold
aggressive
geometric
(significant) **size**
'strong, solid, tough'
symmetry & asymmetry
noticeable
resembling power
inclination




Elegant

(soft) **curves**
smoothness
organic
flowing
compact & minimal/clean
thin elements
elongated



Refined

smooth shape
curvature
clean design
basic, minimum (no waste) features
symmetry & asymmetry
understandable
(balanced) **proportions**
seamless
Shapes flowing/blending into one another subtly
material
polished
well-constructed
thin




Figure 106 - The two concepts (left) and keywords (right) discussed.

perceived as a ‘clean’ design and being coined as a refined object. It can be argued that like the Eames Lounge Chair, the AI-generated shape is a bold, noticeable statement in its context, contributing to its interpretation as an assertive object.

Color Rendering | While this design still maintains a degree of smoothness and fluidity of the Butterfly Stool and the Jaguar, a significant amount of complexity introduced in this shape leads to it being perceived as less minimalist and clean, hurting its elegance and refinement scores compared to the AI Inpiration. While the Jaguar also features lots of details, it can be argued that they mimic and go along the fluid macro form factor in a more pleasant, appropriate manner. Perhaps familiarity plays a role in the perception and interpretation of detailing as well. Even if the complexity of detailing stays around the same level, making it go along with familiar electronics features might help in making this interpretation be perceived as more elegant and refined. While lagging behind AI Inspiration in the two keywords discussed above, Color Rendering scores close to it in the assertiveness aspect. Its asymmetry and more distinct split up between different product parts resemble similar traits in the Eames Chair.

Final concept assessment against set requirements

The final concept assessment against set requirements can be seen in Appendix U. The rankings were given in color, with green indicating that the requirement has already been met, yellow - that the design is expected to meet the requirement yet further investigation is necessary to confirm, and red - further work and detailing are necessary to meet the requirement. Brief explanations are also given to support the color rankings when appropriate. As can be seen, the vast majority of requirements have been addressed in this project at least to an extent where they should be met theoretically.

While the client came in with the claims of desirability and viability of the alternative approach to edge infrastructure enclosures design (one that focuses on beautifying its environment as opposed to serving as a purely functional entity), these claims have been further verified and proven through various research activities during the Discover phase of the project. The Design phase tapped into the feasibility of the envisioned enclosure embodiment, addressing this aspect across various parameters from manufacturing to airflow facilitation. While the final result of this project needs further iterations, information and understanding gathered along the way provide enough evidence to support the statement that the final Hiro EMDC enclosure would be a feasible, desirable, and viable design.

Recommendations for further concept development

Thinking ahead to the next design iteration, the following activities are recommended and organized in chronological order:

Internal hardware optimization and design freeze |

As shown many times throughout this report, internal hardware presents considerable limitations for the enclosure design. Therefore, it is believed that the first focus point for the next design iteration should be obtaining a nearly final resolution on internal hardware design. In addition to EMDC sizing, special attention must be paid to detailing and optimizing passive cooling solution hardware for weight as the Cooling unit currently borders allowable weight lifting limits. This design stage should also include picking various off-the-shelf items that meet the requirements posed by internal hardware. As discussed earlier, the size of the power connector, for example, appears to be quite big and is expected to significantly impact the aesthetic and perception of the enclosure design.

Macro form factor embodiment |

The Final feedback survey described above pointed to the fact that AI inspiration succeeds in embodying the desired brand identity. Therefore, as the next design iteration step it would be advised to look for a CAD modeling professional with experience in the automotive industry, for example, where similar form factors are dominant. As a baseline, it would be recommended to create as close of a copy of the AI inspiration shape around EMDC MCO as possible and work backward from it by gradually incorporating various features driven by internal hardware requirements and critically assessing what they do to the desired shape. In addition, as another survey conclusion, de-personification (specifically possible associations with 'villains') must be always kept in mind when assessing new iterations. It would be particularly advised to explore a symmetrical design. However, in this case, a client would need to critically assess whether the resulting symmetrical aesthetics are worth a greater 2D footprint of the EMDC on the wall and material utilization (which also leads to greater weight). While not addressed in this project due to time constraints, further form factor explorations should start considering second and perhaps even third server rows enclosure aesthetics.

Thinking about the macro form factor on a high level, it would also be recommended to keep the mind open about further functionalities that such a wall-mounted object can offer that were briefly explored at the beginning of ideation activities (refer back to Figure 33). Finally, if a client is to launch a commercial EMDC enclosure and claim it was co-created with generative AI, special care needs to be taken concerning copyright issues. In conversation with the Nike designer, it was learned that they were able to claim it as the project was conceptual and the designs would never be released on the market and monetized.

Further microelements and subparts detailing |

As mentioned in the 'Design step back' section, it would be advised to give a second consideration to the small holes front opening design for its expected strength in preserving the monolithic nature of the macro form factor. A first step in this activity would be conducting a physical or digital airflow simulation to determine whether turbulence that small holes are expected to create still yields desired airflow levels. If it does, looking for expertise in computational design to create intricate hole patterns would be recommended for detailing the front opening design. Due to time constraints, the Trombe wall subpart was not addressed in this project. Figure 107 on the next page presents Pinterest inspirational designs that have been collected for it and that can be used to kick-start this part's ideation and development.

Manufacturing |

The most important next step in detailing the manufacturing of EMDC enclosure is getting more resolution on meeting real-life rugged enclosure requirements in terms of industry-standard IP and IK10 ratings that are expected to pose considerable limitations and challenges. While the proposed manufacturing methods and materials are believed to provide feasible opportunities for achieving the desired form factor and meet the above-mentioned requirements,

manufacturing specialists need to be further consulted on the matter. For example, compression molding is a technique that was not explored in detail in this project but might provide certain desirable strengths. If the proposed biobased composite/RTM combination is desired to proceed with, Bcomp can be contacted as the next step.

If further analysis points to the fact that necessary performance cannot be met with the proposed form factor, an approach of decoupling aesthetics from functionality can be leveraged as has been done on multiple occasions in this project. This implies perhaps going down the route of having a more functional, less aesthetically pleasing 'box' around EMDC MCO and creating an aesthetical layer (in the shape of AI inspiration) around it.

Interaction optimization | A few final recommendations pertaining to EMDC interaction are as follows:

- Adding damping for DC unit lowering
- Incorporating light sensors or other means of controlling status LEDs brightness to avoid light pollution

As can be seen, the activities described above require HIro to build and work with a highly multidisciplinary team of experts. While this project tapped into a wide array of considerations and provided the best knowledge and recommendations for them, future design iterations should continue relying on various types of user tests (from online surveys focusing on the aesthetics of the enclosure to in-personal ergonomics and usability tests) and start incorporating engineering simulations and prototypes to ensure that the design exhibits the desired performance.

Lastly, a point that came up during the last round of feedback with Delft municipality, as a leader in the initiative to rethink the role of edge infrastructure in the public environment, Hiro might want to think ahead to what happens if and/or when other companies follow the same route. Hiro might want to initiate conversations about regulations and perhaps even legislation that might be necessary to ensure that various edge infrastructure designs do not create a visual cacophony in public spaces and that designs from different brands co-exist organically together.

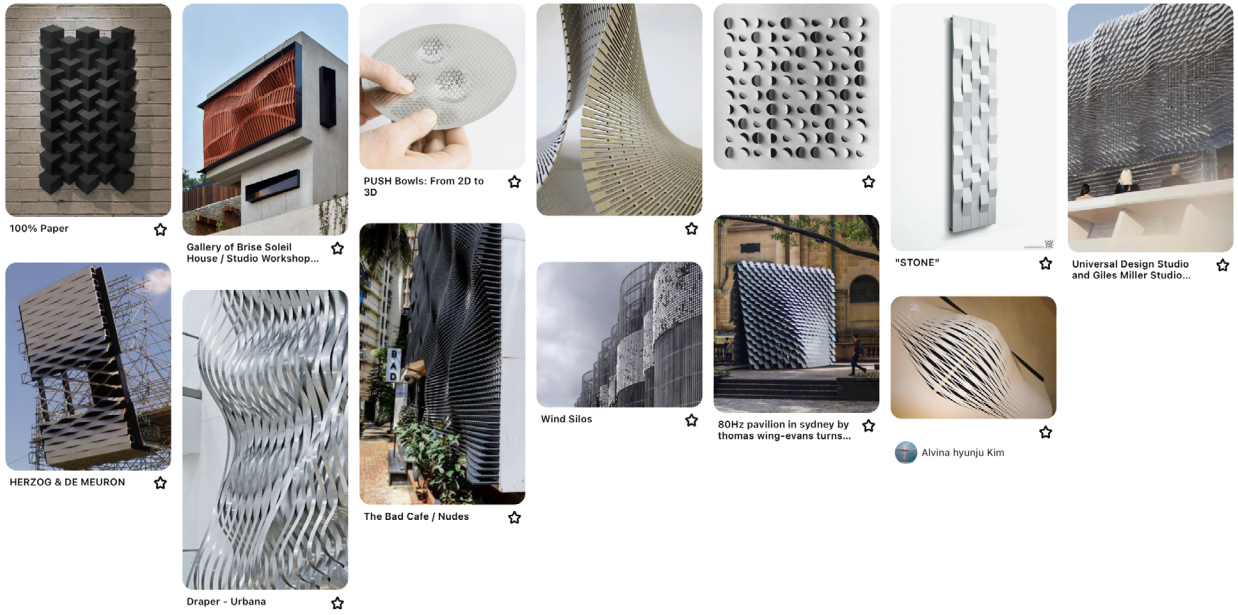


Figure 107 - Pinterest inspirational designs collected for the Trombe wall development.

Personal reflection

As reflected in the original project brief (Appendix A), one of the greatest aspirations for my graduation project was exploring opportunities and limitations of generative AI within my design process. Further problem definition led to a different AI application goal, where I used it more as an ideation aid rather than utilizing it for environment customization purposes. While I did not utilize AI (time constraints prevented me from exploring this avenue more) for concept presentation, its utility in generating unexpected concept directions was paramount during macro

form factor ideation. I would say that to me that was the greatest strength of generative tools, MidJourney specifically, that I discovered during this project and learned how to leverage. I see it especially beneficial in cases of creating innovative, novel products where previous product aesthetics history is limited or does not exist at all (arguably I only had standard metal box enclosures as a reference). However, if the team comes up with other designs that they want a new product to feel like, I found AI's ability to help designers visualize how an X product might look based on inspiration designs or their combinations truly powerful. I especially experienced it when working with generations for the Moon Lamp, for example, where imagining this product in the context of a data center design was quite challenging (Figure 108). However, I also discovered that there is a skill to using AI tools masterfully and it takes some time before you get results that feel truly useful and inspirational.

Figure 108 - Some of the inspiring Moon Lamp classic design generations.

Reflecting on the selected AI inspiration image, it is highly unlikely that on my own I would have gone down the route of a form that fluid and organic. While I knew that pursuing such a complex design would challenge my skills and experience, I decided to go beyond my comfort zone and change concept selection from geometric design 1 which I felt more capable of pursuing to organic design 2 (Figure 109). However, this moment is also perhaps where the 'AI trap' begings as generated concepts look like finished, feasible products (as opposed to a sketch, for example, that covers main ideas about desired concept embodiment but is still open to further interpretation and modification based on design's requirements). Throughout AI-powered ideation, I have been sketching largely to make sense of what I was seeing and apply it to the EMDC-specific context. From my experience, if an AI-generated concept is to be used as the main design driver, the next most critical activity after its selection should be interpreting it. Through rapid digital and physical prototyping, a 2D image needs to be interpreted in 3D as various requirements are applied to assess the extent to which the AI form factor actually works for the given context and application. It needs to be determined what about AI-generated inspiration is so powerful as well as what it means and how it can be applied in the specific project context. This process also requires close communication with project stakeholders and alignment on expectations.

When working with AI-generated inspiration material, the team needs to decide whether the goal is to mimic the generated aesthetics as closely as possible, potentially sacrificing product performance, or if deviations are acceptable and if so to which extent. On a positive note, however, the process I have gone through in this project convinces me that at least in its current state of development, generative AI is not yet capable of replacing us in our jobs as designers

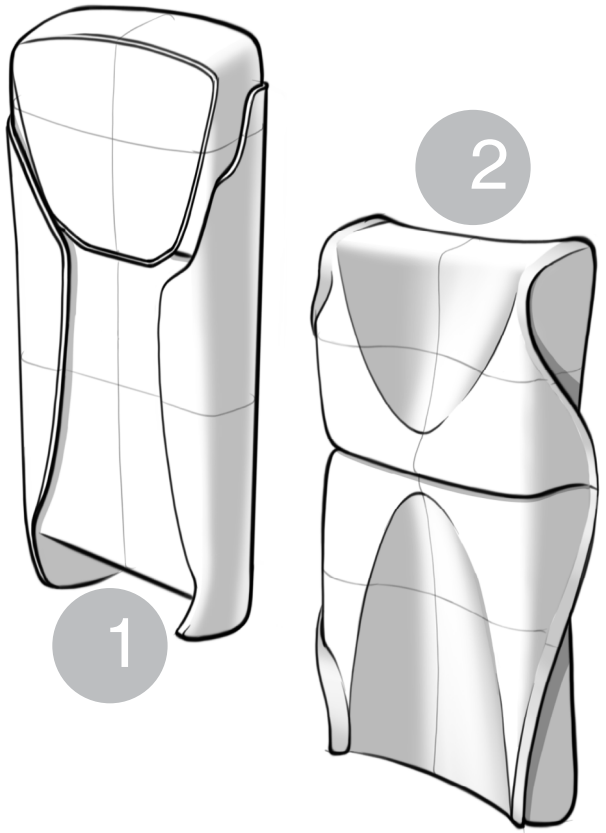


Figure 109 - Designs 1 and 2 from macro form factor selection.

as much interpretation and adaptation work needs to be done when developing AI-generated concepts.

Reflecting on the planning, this project was another instance where my technical background clashed with more of the conceptual nature of the assignment. As a designer, I am intrigued to work at the intersection of engineering and aesthetics, and this time it felt like I fell short on time for the aesthetics part of the design. If I were to do something differently, I would perhaps spend more time on the interpretation described above, thinking about what made the shape in the AI inspiration special and relating it to the EMDC MCO by doing more sketching and rapid prototyping, such as plasteline modeling, right after concept selection. However, at the same time, I also believe that my research on manufacturing methods and various subsystems and components was an invaluable asset as it pointed to where AI-generated shape might not be fully appropriate for the product I was tasked to embody. In high-sight, that research, however, could have been scoped down.

The greatest strength of AI for us as designers is helping us imagine the unimaginable and taking us places we would not have dared to go on our own. However, during this thesis and reflecting on my conversation with a Nike designer involved in the AIR project, I also realized that AI-driven projects thrive in multi-disciplinary teams, where different team members bring in different skills and strengths to embody the 'unimaginable.' During concept embodiment, I was really missing a team setting, given the complexity of the product and various aspects that needed to be researched as well as greater skill diversity (such as organic modeling, for example).

Finishing off the rest of my learning ambitions from the original project brief, I learned about other manufacturing methods that are appropriate for small-batch production in addition to large-scale 3D printing. One learning objective that I would have really liked to get to was leveraging AR for concept presentation. Trying out Apple Vision Pro this past summer, I could not stop thinking about how utilizing augmented reality would provide a more immersive and premium-feeling experience for introducing Hiro EMDCs to clients and helping them imagine customized versions of these devices on their premises. In addition, AR can also be handy in more practical matters, such as instructing electrical engineers at client companies about EMDC installation procedure. The last of my learning objectives was improving my rendering skills (utilizing software such as Keyshot, for example) to deliver realistic marketing material. The time limitations of this project did not allow me to achieve this learning objective. However, it allowed me to spend time going through various online tutorials and learning new skills and I am looking forward to applying these skills in the future.

I believe that the widespread introduction and utilization of AI generative tools in the design field is imminent and is already happening as individual designers and studios are figuring out what are the best ways of using these powerful tools in their design processes. To wrap up, thinking ahead to my future career, the three takeaways from this project that I would like to remember concerning using generative AI tools are as follows:

1. Spending a significant amount of time interpreting AI-generated concept(s) through rapid digital and physical prototyping while not fixating on the 'looks' of a particular AI image.

2. Communication, communication, communication. As AI-generated content becomes more and more hyperrealistic, communication between project stakeholders on expectations regarding the extent to which the to-be-embodied product should and can follow AI-generated aesthetics is crucial.

3. Leveraging my personal strengths in interpreting and embodying the desired concept, while seeking multi-disciplinary collaborations to achieve the rest.

Supplements
Appendices & References

Why hide it? Reimagining the role of urban edge computing
in an AI-inspired, human-embodied manner.

Appendix list

Appendix A | Original project brief

TU Delft

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

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

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME
Complete all fields and indicate which master(s) you are in

Family name	Pozniak
Initials	AP
Given name	Anna
Student number	5598095

IDE master(s) IPD ✔ Dfl ☐ SPD ☐
2nd non-IDE master
Individual programme (date of approval)
Medisign ☐
HPM ☐

SUPERVISORY TEAM
Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Jan Willem Hoftijzer	dept./section	HCD
mentor	Mark Sypesteyn	dept./section	HCD/HICD
2nd mentor	Fred Buining		
client:	HIRO-MicroDataCenters BV		
city:	Voorburg	country:	Netherlands
optional comments			

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

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

tudelft.protect Jamf Protect CSR Identity — Digitally signed by tudelft.protect Jamf Protect CSR Identity Date: 2024.04.22 10:06:54 +02'00'

Name Hoftijzer, J.W. Date 22-4-2024 Signature

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

Master electives no. of EC accumulated in total ____ EC

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

	YES	all 1st year master courses passed
★	NO	missing 1st year courses

Comments:
ID4070 IDE Academy (4,0)
(mve)

Sign for approval (SSC E&SA)

Robin den Braber — Digitaal ondertekend door Robin den Braber Datum: 2024.04.29 10:49:13 +02'00'

Name Robin den Braber Date 29-04-2024 Signature

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	★	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

★	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:
- the above mentioned missing course should be finished before the green light meeting

Sign for approval (BoEx)

Name Monique von Morgen Date 1/5/2024 Signature MvM

DESIGN FOR our future

TUDelft

Personal Project Brief – IDE Master Graduation Project

Name student Anna Pozniak **Student number** 5598095

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Innovative enclosure design for HIRO edge micro data centers

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

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Every year sees an exponential increase in the computing power required by such developments as smart cities, increasingly complex IoT systems, and, most recently, AI-powered applications. Data centers play a key role in modern computing infrastructure, providing the necessary resources for cloud computing, internet services, enterprise applications, and much more. Main stakeholders and their interests in this field are as follows:

- Clients | A client implies a company that seeks computing power for their enterprise and operations (content delivery networks, mobile edge computing, real time data stream processing, etc.). Clients desire fast, reliable, and cost-effective solutions that meet their data security requirements and adapt to constantly increasing computing needs.
- End users | Users refer to the consumers of the clients' enterprise products that utilize computing power delivered by data centers. End users desire low latency communications and information security.
- Data center manufacturers | Main players in the data center market want to maximize their profits, while minimizing supply chain disruptions and installation/maintenance and design/manufacturing costs.
- Data center installation & maintenance teams | Data centers require minimal installation and maintenance.

In the context of this project, there're multiple opportunities to better serve the stakeholders. Firstly, computing resources can be placed closer to data generation/consumption locations (aka edge computing). Within this opportunity, design enablers include customizing data center offerings for different types of clients; enhancing data center aesthetics; and decreasing floor space needed for a data center. Secondly, installation and maintenance needs can be decreased. Thirdly, enclosure of a data center can be utilized as another source of heat dissipation. And finally, hardware components can be manufactured locally to increase supply chain resilience.

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introduction (continued): space for images

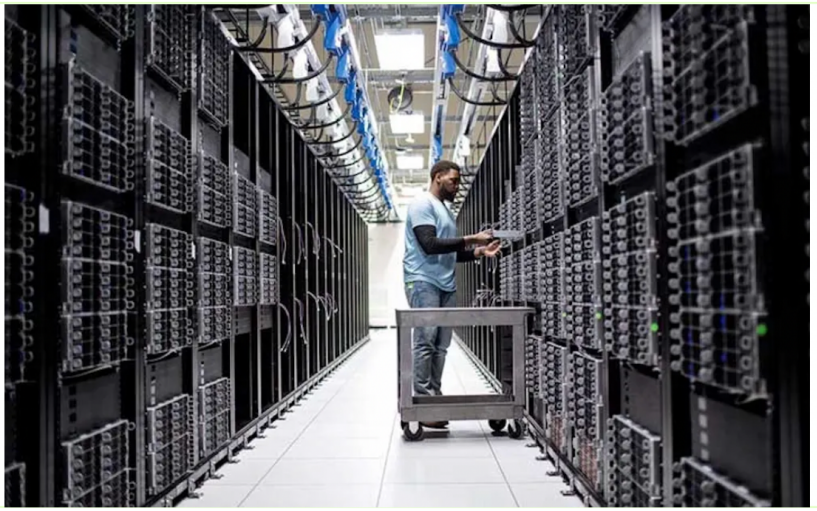

image / figure 1 Current data center (Microsoft Azure) looks and expereince.

image / figure 2 Visualizations/renders (non-functional) of HIRO's EMDCs

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

To harvest opportunities and better meet stakeholder interests described above, HIRO is developing Edge Micro Data Centers (EMDCs). The one-of-a-kind software/hardware offering is an on-/near-premise data center that offers a modular and scalable solution. To date, main hardware components, such as cooling system, server stacks, etc., have been detailed to an extent where it's possible and necessary to start designing high-level housing and physical interface concepts that would enclose these functional blocks. As the proposed solution is an on-premise data center, enhancing and customizing aesthetics and performance requirements of a data center enclosure to varying clients' environments (from hospitals to manufacturing facilities) becomes a crucial factor for the desirability of HIRO offering.

Utilizing and developing innovative technologies is at the heart of HIRO, and the company wishes to do so for the development of the housing of their EMDC offering as well. Therefore, how current cutting-edge technologies (such as generative AI, 3D printing for manufacturing, and VR) can facilitate the development and presentation of customizable enclosure designs for HIRO on-premise data centers?

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Develop a framework for designing customizable enclosures for HIRO micro data centers and apply it on a specific context example, resulting in a prototype (digital (CAD model and a VR showcase)) and physical (if time allows) and creating physical brand identity for HIRO that reflects the company's innovator positioning in the data

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

I see the project development in 3 main stages. 'Initial research' stage: understanding developed mechanical functional blocks; overview of Hiro's competitors and other existing relevant designs, the context the enclosures will be placed, and the environment in which the to-be-designed enclosure needs to exist; critical evaluation of the application (what and how) of AI tools in my design process. Stage outcome: a comprehensive list of requirements/wishes for the enclosure design. 'Ideation/conceptualization' stage: conducting ideation to synthesize research into enclosure concepts; executing enclosure customization to context using appropriate (generative) AI tools; researching enclosure manufacturing methods (3D printing and others). Stage outcome: proposal of a framework for designing customizable data center enclosures given context parameters. The 'Embodiment' stage: applying developed framework on one specific client context example. The output of the framework will be transferred into CAD (a physical prototype will be created as time allows). CAD model will also be utilized for concept presentation through renders and VR showcase (focusing on context immersion and interaction aspects).

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	08/04/24
Mid-term evaluation	19/06/24
Green light meeting	21/08/24
Graduation ceremony	18/09/24

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	✔
For how many project weeks	8
Number of project days per week	4.5

Comments:
Taking an elective; 1st working week:1.5 days

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

Personal learning ambitions:

1. How can I use (generative) AI tools to facilitate the customization of enclosure aesthetics to unique context attributes in each case?
2. How can (generative) AI tools help me streamline my design process specifically thinking of generating unexpected concept directions and concept presentation?
3. How can 3D printing be used for the manufacturing of customizable, low-volume data center enclosures?
4. How can VR facilitate the presentation of enclosure designs in a context-immersive manner and explanation of relevant interaction points (module replacement)?
5. How can I provide HIRO with compelling content for their marketing campaigns through enhanced renderings, specifically improving my lighting, context placement, and materials/texturing skills?

Appendix B | Client brand identity interview digest

1. Why must this brand exist? *What would consumers be missing if the brand did not exist?*

Without Hiro, consumers would be missing the means to transition to digital sovereignty aimed for by the EU, both in hardware and software. As cities worldwide see more and more edge infrastructure introduced in the coming years, consumers will also be missing someone willing to put an effort into making these additions an organic and aesthetically pleasing extensions of their cities.

2. Standpoint. *From where does the brand speak?*

Hiro's standpoint can be summarized as that of an 'innovative and intrepid trailblazer.' Being an SME in a market dominated by big tech (players like Amazon, Dell, and Google), Hiro's unique narrative is centered on providing digital sovereignty and an escape from being locked into the terms set by big players.

- **Perspective** | Innovative and customer-centric business
- **Messaging framework** | In their regular communication with the public (currently mostly done through Linledin) Hiro highlights and brings to attention innovative technology developments and transitions relevant for the market. Hiro's current messaging is focused on highlighting their commitment to digital sovereignty and building an innovative, one-of-a-kind software and hardware offerings.
- **Engagement approach** | Aiming to be an industry leader in edge computing, Hiro draws attention to itself through various platforms such as Linkedin, media, and conferences. Through these platforms, Hiro not only discusses what they're working on but also points out industry trends that they find exciting and noteworthy. Hiro's leadership also engages with their potential future clients, such as the healthcare and telecommunications industries, by seeking collaborations on pilot projects with them to showcase proof of their concept and attending events and conferences where these industries are present.

3. Vision. *What is the brand's vision in the product category?*

Edge computing infrastructure is a relatively new field with very few players. Arguably, Hiro currently has only one competitor, IP65 Server Platform from Supermicro. As a result, Hiro is at the privileged, yet pressing at the same time, the position of establishing a benchmark for the edge product category.

Hiro deeply believes in providing digital sovereignty, which involves both the software and hardware parts of their offering. Hiro believes in innovating across all aspects of their offering, which extends both on hardware and software. They believe that each of their customers should have a unique solution that matches their computing needs perfectly, thus Hiro's promise is a heterogenous EMDC. The company aims to provide 'edge as a service,' which involves assessing client's computing needs as mentioned before, but also monitoring the system and identifying when an upgrade is beneficial based on the client's operations. With the hardware design being modular, Hiro would be able to provide a more powerful and/or a different heterogeneous solution without the client having to replace an entire EMDC. Finally, Hiro believes that they're responsible for making their edge products to be aesthetically pleasing additions to any environment they might be placed in.

4. What are our values?

- Digital sovereignty
- Emphasis on aesthetics
- Innovation as a core concept driver
- Ease of use (modularity)
- Resiliency
- Tailoring to each customer (heterogeneity)
- Proving best in class, premium 'edge as service'
- Promoting (international) collaboration

5. Mission. *What specific mission does the brand want to carry out in this market?*

Following EU goals, Hiro wants to provide its customers with digital sovereignty and freedom

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5. Mission. *What specific mission does the brand want to carry out in this market?*

Following EU goals, Hiro wants to provide its customers with digital sovereignty and freedom of choice when it comes to their computing, data storage, and processing needs. Hiro's mission is also to provide best-in-class customer service and experience. To achieve that the company is going to offer 'edge as a service,' taking up much-dreaded monitoring and maintenance of hardware equipment. Hiro is committed to providing beautiful and user friendly solutions across both they software and hardware offerings.

6. Know-how. *What is the brand's specific*

Appendix C | Explanation of design aesthetics categories rankings

		Indoors	Outdoors
Manufacturing	*1. Specific customer identity*	**(5/5)** Customers are expected to prefer a full expression of their company identity (includig company colors, logo, etc.) inside for purposes such as brand pride among employees and brand communication to the visitors, for example. Such preference is expected due to inherently more secure environment of edge equiment inside the premises, being safe from vandal actions by adversaries, for example.	**(2/5)** Customers are expected to prefer little of their identity expressed in their edge equipement outside (e.g. company colors only), fearing vandal actions from their adversaries, for example.
	2. Immediate environment customization	**(3/5)** Customers are expected to be interested in edge equipment serving as an aesthetical statement for their inside environment that is balanced with 'blending in' it.	**(4/5)** The importance of integration of this customization category is expected to be relatively high. While the territoty of the majority if not all manufacturing sites are only accesible to staff members, it's expected that customers in this segment would prefer to 'hide' any edge equipment on their facades from the public eye as much as possible for the equipments safety and security reasons.
	3. Segment identity	**(4/5)** Manufacturing segment identity is typically characterized by 'rugged, tough' aesthetic that the industry is proud of. Inside/outside factor is not expected to have an influence for this category, so the same score was given. High degree of cutomization in this category is also expected to aid the expression of the first category for this market segment.	
Healthcare	*1. Specific customer identity*	**(5/5)** Considering medical facilities from the inside, it can be observed that their interior design features lots of customer identity details, such as brand colors, logos, names, etc. Therefore it's logical to expect that such trait will be extended to an EMDC which will become part of the interior.	**(3/5)** While less prominent compared to the inside elements, especially thinking about hospitals, medical facilities still feature their specific brand identity on the outside (most often through color usage, for example). Therefore, some degree of interest towards customer identity expression is still expected in the outside scenario, yet to a lesser degree compared to the inside environment.

	2. Immediate environment customization	**(5/5)** It's expected that a high degree of environment customization will be apropriate for the healthcare segment. In the inside case, such expectation is based on the fact that healthcare facility design tends to emphasize peace of senses, with the objects not calling too much attention from the visitors. On the outside, hardware safety might be more of a concern where an EMDC that 'blends in' with the wall it's on might call less attention, thus detering potential malicious attacks.	
	3. Segment identity	**(5/5)** Healthcare industry has pronounced aesthetics, featurng such elements as nude color palette and organic form factors, for example, that spans across many, if not all, of the objects that find themselves in that environemnt, from medical devices to furniture. Therefore, it can beinferred that assuming the same segment aesthetics will be expected from an EMDC placed in a healthcare setting.	**(3/5)** As segment identity tends to be less pronounced on the outside of healthcare facilities, there should also be less of an expectation for an EMDC to comply with it in this context.
City centers	*1. Specific customer identity*	**(3/5)** Assuming that certain customer's EMDC can be placed in an indoor setting that is not their premise and is publically available, a moderate degree of importantce of expressing that customer identity is expected. This is due to the safety concerns over vandal actions from their adversaries possible in a public setting.	**(1/5)** With an EMDC being even more publically exposed in the outside environment and due to the same safety concerns described for the indoor setting, even lesser degree of importance is expected for this category when considering the outsoors.
	2. Immediate environment customization	**(5/5)** In both settings, a high degree of environment customization is expected to be important due to safety reasons. Slightly lower importance of this category for the indoor setting **(4/5)** is explained by the assumption of it being marginally less exposed and vulnerable compared to the outdoor environment.	
	3. Segment identity	**(1/5)** Smart city aesthetics is generally portrayed and described in futuristic, 'tech-y' terms and visuals. In both cases it's expected that public opinion woud go against more 'gadget-y,' 'electronic-y' objects in a public setting and rather prefer an alternative design that would focus on beautifying the environment, while also blending in with it to an extent.	

Appendix D | Preliminary requirements and wishes

Requirements/Must-haves	Wishes/Nice-to-haves
Enclosure interaction (I)	
IR 1 | All procedures with EMDC must require common tools only.	
IR 2 | All procedures must be possible to do safely at en elevation.	
IR 3 | 1 person must be able to insert the Data center unit into the Cooling unit.	
IR 4 | 2 people must handle lifting and mounting of the Cooling unit.	
IR 5 | Client company must have a choice between conducting procedures themselves or opting out for assistance by a 3rd party service providers.	
IR 6 | Installer(s) must have clear guidance for each procedure with EMDC.	
IR 7 | Enclosure elements cannot hurt installer(s) at any point during handling it (sharp edges, contact with electricity, etc.)	
IR 8 | Mounting/demounting every unit must take *X minutes* or less	**IW 9 |** Mounting/demounting should be as fast as possible
IR 10 | Mounting/demounting every unit must have *X steps* or less	**IW 11 |** Mounting/demounting should be as easy/user-friendly as possible
IR 12 | Only authorized staff must be able to interact with the EMDC.	
	IW 13 |Various procedures must provide feedback to reassure the user in their successful completion.
Overall enclosure (E)	
ER 1 | Enclosure must provide adequate protection from outside environmental hazards • Enclosure design must aim for IPX4 watertightness level at all interfaces • Enclosure design must aim for IP5X solids protection level • UV resistance accounted for • Scratch resistance accounted for	**EW 1 |** Enclosure should aim for IP67 standard.
ER 2 | Enclosure must prevent forced openings of the EMDC.	
ER 3 | Enclosure must **minimize** it **heating up** from the environment.	**EW 3 |** Enclosure should heat up from the environment as little as possible.
	EW 4 | Enclosures design should optimize material usage/ MCO wrap up.
ER 5 | Enclosure design must account for EMDC assembly.	
	EW 6 | Enclosure should minimize the amount of water that gets inside the Cooling unit through the front opening.
	EW 7 | Core (non-customizable) parts should feature Hiro branding element(s).
ER 8 | Enclosure surface finish must facilitate dirt and dust wash off with rain.	

Data center (DC) unit enclosure (D)	
DR 1 | DC unit enclosure must house 1 row of 11 servers.	**DW 1 |** DC unit enclosure design should be adaptable to accommodate 2 rows.
DR 2 | DC unit enclosure must **protect internal hardware** from damage during shipment and installation.	
	DW 3 | 1 row DC unit enclosure aesthetics should be extendable to 2 rows of nodes.
DR 4 | DC unit enclosure must take measures against bird perching.	
Hardware status indicators (I)	
IR 1 | Each node must have its own hardware status indicator.	
IR 2 | Hardware status indicators' incorporation into the DC unit's enclosure must be appropriate for the outdoors application.	
	IW 3 | Hardware status indicators design should account for the implementation of the second row of nodes.
IR 4 | Hardware status indicators must be positioned in the area surrounding the back PCB.	
IR 5 | Hardware status indicators must be visible... • in high UV context • from the ground level	
	IW 6 | Hardware status indicator's correspondence to its node node should be straightforward.
	IW 7 | Hardware status indicators should obstruct water run off from the DC enclosure as little as possible.
IR 8 | Hardware status indicators must avoid 'personification' of the EMDC.	
	IW 9 | Hardware status indicators design must avoid information overload as much as possible. • possibility to turn the lights off when not needed • adjustable brightness
IR |10 Front opening design must be stylistically appropriate for the selected macro form factor.	**IW 10 |** Front opening design should preserve the 'monolithic' nature of the selected macro form factor.
EMDC powering (P)	
PR 1 | Power button incorporation into the DC unit's enclosure must be appropriate for the outdoors application.	
PR 2 | Power button must be positioned in the area surrounding the back PCB.	
PR 3 | Power button must be an off-the-shelf design.	**PW 3 |** Off-the-shelf solution should provide high degree of customization.

Cable connectors (Ca)	
CaR 1 | The enclosure must accommodate 8 Ethernet cable and 1 power cable inlets.	
	CaW 2 | Cable connectors considered for sizing should be appropriate for outdoors applications. • IP67 compliant
CaR 3 | Off-the-shelf solutions must be considered for the connectors.	
CaR 4 | Enclosure must account for the average sizing of existing capped cable connectors.	
CaR 5 | Considered power connector must meet desired performance metrics of current rating for 1.8-6 kW power delivery at 120V.	**CaW 5 |** Power connectro should have current rating for 1.8-6kW power delivery at 240 kW.
	CaW 6 | Cables insertion and removal should be as ergonomic as possible
CaR 7 | Appropriate cable length must be achieved before insertion of the cables into EMDC cable connectors • Cable slack must be managed before hand	
Cooling unit enclosure (C)	
CR | Total Cooling unit weight must be under 46 kg • 23*2 kg to be allowed to handle with 2 people	
CR | Cooling unit enclosure must incorporate features that facilitate passive cooling through chimney effect.	**CW |** Cooling unit enclosure should remove 70% of heat through passive cooling
	CW | Enclosure should incorporate internal features that guide airflow along the desired path.
	CW | Enclosure internal cross section shape should facilitate smooth airflow throughout the chimney.
	CW | Enclosure internal shaft should be airtight • Facilitating chimney effect by preventing air leaks
	CW | Enclosure walls should possess insulating properties • Cavities with air in the enclosure wall
CR | Cooling unit enclosure must **protect internal hardware** from damage during shipment and installation.	
Front opening (O)	
OR 1 | Front opening design must have at least 70% of the designated opening area open.	
OR 2 | Front opening design must prioritize optimal airflow above aesthetics.	
	OW 3 | Front opening should let at little water in as possible.
OR 4 | Front opening design must be stylistically appropriate for the selected macro form factor.	**OW 4 |** Front opening design should preserve the 'monolithic' nature of the selected macro form factor.
OW 5| Front opening design must yield satisfactory mechanical and impact resistance performance of the remaining enclosure material.	

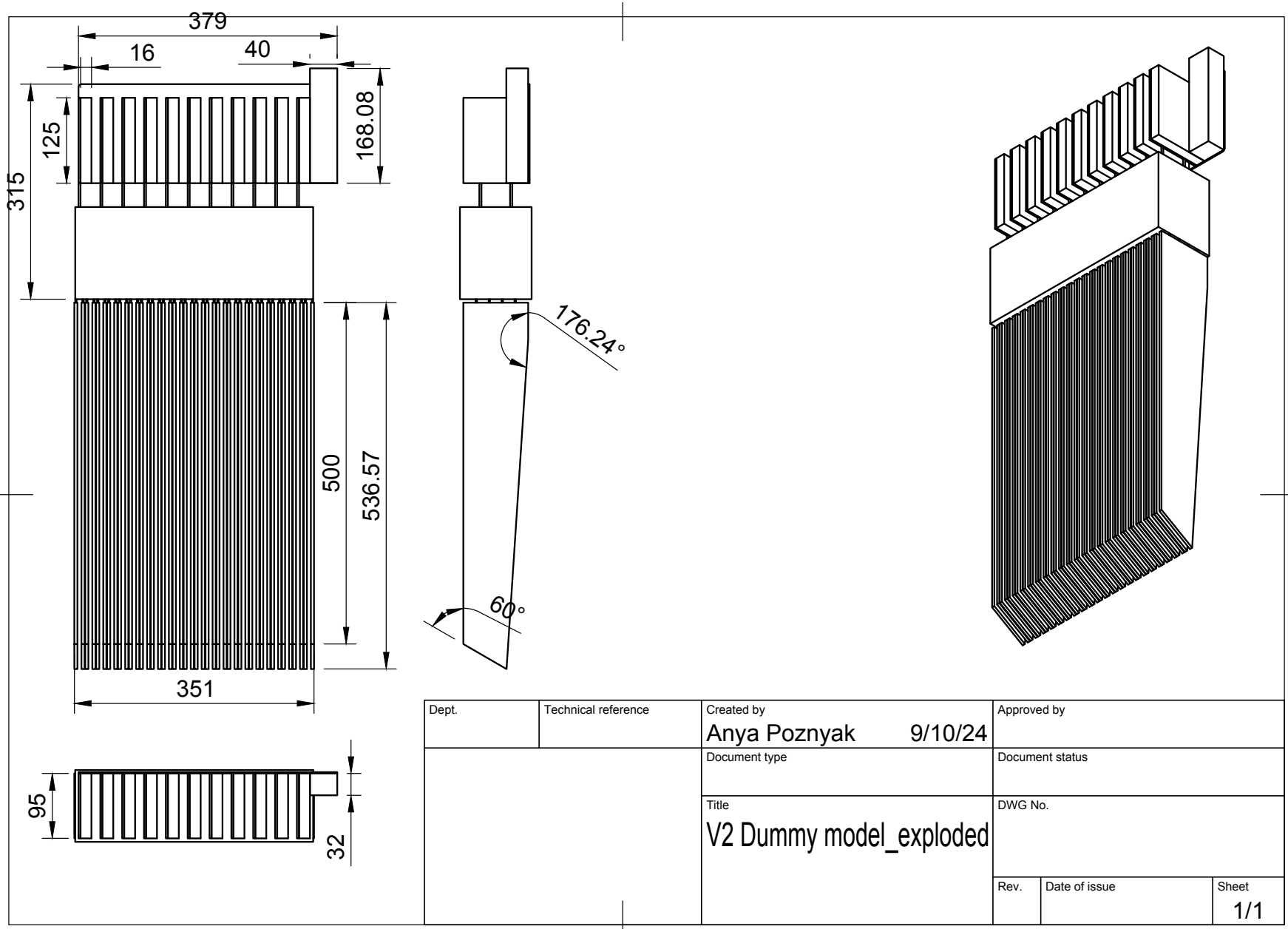
Fans unit (F)	
FR 1 | Fans unit attachment must take up 10 seconds less.	
FR 2 | Fans unit attachment must only require 1 installer.	
FR |3 Fans unit attachment method must support the estimated weight of the fans unit.	
FR 4 | Fans unit attachment solution must be suitable for outdoors use.	
FR 5 | Fans unit attachment must require little to no maintenance.	
FR 6 | Fans unit enclosure must provide means of securely grabbing it for attachment to the Cooling unit.	
FR 7 | Fans unit attachment method must prioritize visibility of actions and space accessibility.	
FR 8 | Fans unit attachment method must utilize existing/off-the-shelf solutions.	**FW 8 |** Off-the-shelf solution should be easily adaptable/customizable.
	FW 9 | Fans unit attachment method should be as light as possible.
	FW 10 | Fans unit attachment should be as compact as possible.
The sleeve (S)	
SR 1 | The DC unit must be properly aligned before entering the clamping mechanism area.	
SR 2 | The sleeve must ensure precise and sturdy guidance of the DC unit in with the accuracy of 2.5 mm (clearance between meshed plates).	
SR 3 | The sleeve must hide functional elements on the sides of the enclosures from viewed from the front.	
	SW 4 | The sleeve should facilitate the 'blending in' part of the design vision.
SR 5 | The sleeve must the rigidly secured to the core enclosure.	
	SW 6 | Sleeve's weight should be supported independently.

Clamping actuator, driver & interface (CI) | User-facing hardware necessary to set clamping mechanism in motion	
	CIW 1 | Clamping actuator should amplify user's force input as much as possible.
	CIW 2 | Clamping actuator should require as small of force input as possible.
CIR 3 | Clamping actuator must facilitate precise transfer of force.	
CIR 4 | Clamping actuator must be positioned to maximize **force transfer** to the clamping mechanism.	**CIW 4 |** Clamping actuator must be transferring as much force as possible.
CIR 5 | Clamping actuator must be appropriate for both right handed and left handed people.	
CIR 6 | Clamping actuator must be hidden from the public eye • A person must be unable to tell what that feature is for	**CIW 6 |** Clamping actuator must only be accessible to 'authorized users.'
	CIW 7 | Clamping actuator and driver should be off-the-shelf hardware.
CIR 8 | Clamping actuator must be easily aligned with the driver in a tight space • must take 10 seconds or less • 135 mm vertical space corresponding to the overlap of the Cooling and DC units.	
Mounting solution (Mo)	
MoR 1 | EMDC must be mountable on all common (inside and outside) surface types.	
MoR 2 | Enclosure mounting must be non-destructive to the surface it's put on.	**MoW 2 |** Enclosure mounting should affect the surface as minimally as possible.
	MoW 3 | An off-the-shelf mounting solution should be utilized.
MoR 4 | Mounting solution must support up to 100 kg. • The weight of an EMDC up to 3 nodes rows	
MoR 5 | Off-the-shelf solution must meet IP66 standard.	
MoR 6 | Mounting solution must be appropriate for uneven surface (must avoid causing damage to uneven bricks surface).	
Mounting/insertion handles (H)	
HR 1 | The handles must feature safeguards preventing accidental dropping of the units.	
HR 2 | The handles must prioritize ergonomics over aesthetics.	
HR 3 | The handles must only detach at installer's intention (no accidental detachments).	
HR 4 | The handles must feature details that ensure optimal ergonomics in terms of force loadings in arms and wrists.	
HR 5 | Handles design must be appropriate for the weight they're supposed to handle.	

Design aesthetics (A)	
	AW | Enclosure design should be mindful of its coexistences with antennas
AR | Enclosure macro form factor must communicate Hiro brand identity • An independent viewer must use 3/5 Hiro brand identity keywords (or their synonyms) to describe the macro FF	
	AW | Enclosure design should account for EMDCs' scalability • Possibility of multiple EMDCs 'co-existing' on the same facade
AR | Enclosure design aesthetics must incorporate features that help it blend in with its environment in public perception	
AR | Enclosure aesthetics must offer a solution that is the most advanced design possible, yet still acceptable by the public (MAYA principle)	
AR | Enclosure aesthetics must broaden public's view on the role that edge infrastructure can play in its environment • Edge infrastructure that can enhance the visual appeal of its environment • At least 50% of viewers should identity that EMDC enclosure would beatify their public spaces	
AR | Enclosure aesthetics must offer a 'signature' design, meaning that it looks appropriate across 3 placement contexts of interest • Urban, manufacturing, healthcare	
AR | Enclosure design must avoid personification trait • Being perceived as a person/creature	
AR | Enclosure aesthetics must maintain its desired visual impact when viewed from a distance. • Distance from the ground to the 1st floor level or higher	
	AW | Enclosure aesthetics should be independent of such variable environmental factors as light angle and intensity • Maintain its sticking qualities regardless of possible environment limitations
Sustainability (S)	
	SW | The enclosure material should have *at least 25%* recycled content in it.
	SW | The enclosure material should be 100% recyclable.
	SW | Enclosure materials should be bio-based.
SR | Customizable enclosure part(s) must be 100% recyclable.	
Manufacturing & materials (M)	
MR 1 | Selected materials/manufacturing combination(s) must balance costs with not compromising on aesthetics.	
MR 2 | Selected manufacturing processes and materials must maintain essential form factor elements.	
MR 3 | Selected materials must allow for minimal dirt and dust accumulation.	**MW 3 |** Selected materials should be dust/dirt repellant.
MR 4 | Selected material/manufacturing combination must be appropriate for outdoors placement in terms of common temperature differences.	
MR 5 | Selected materials/manufacturing combination must theoretically account for IK10 impact test.	
MR 6 | Materials/manufacturing recommendations must be appropriate for the expected production volumes • 250-500 units/year	

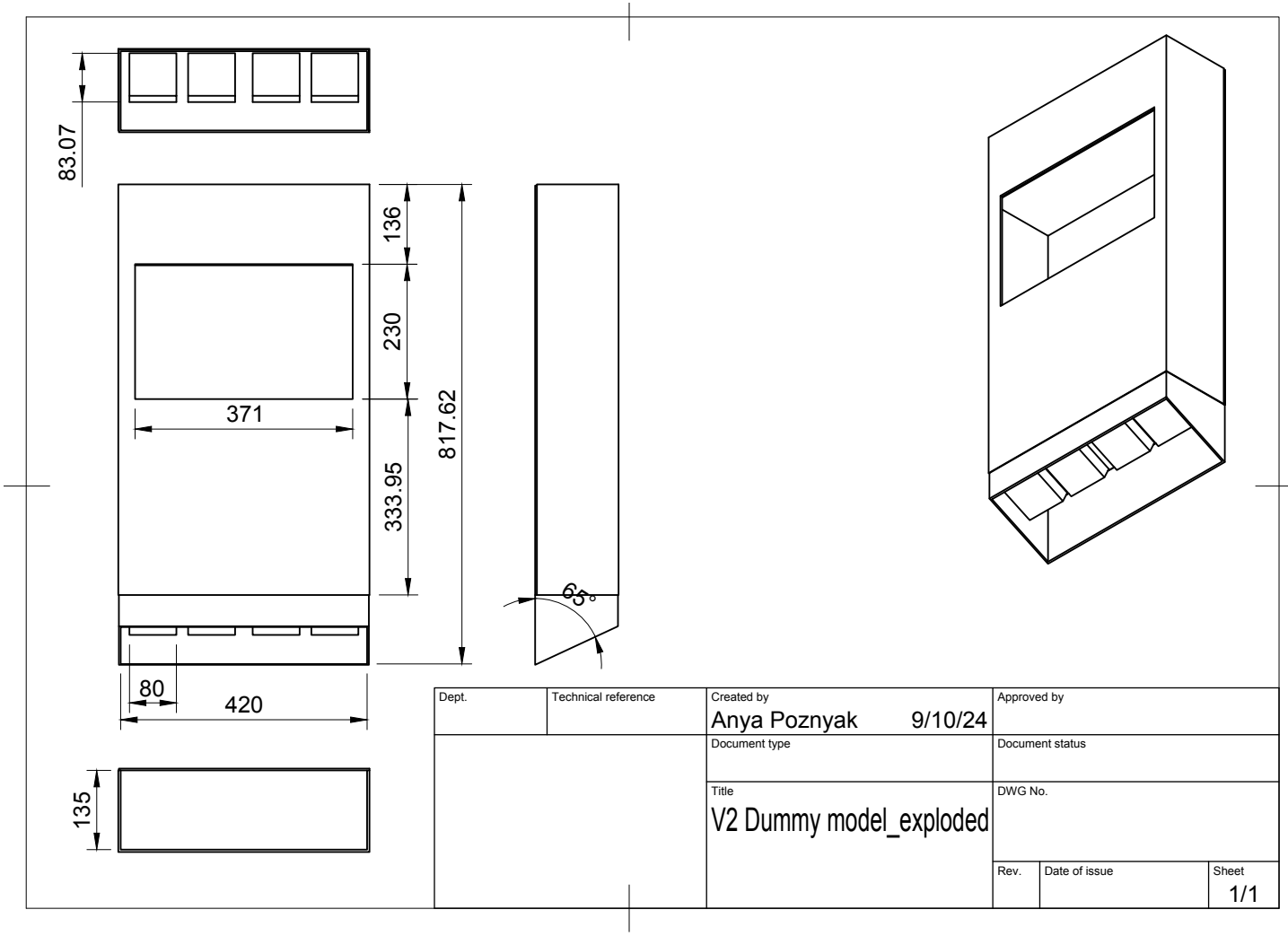
Appendix E | Relevant preliminary CAD dimensions

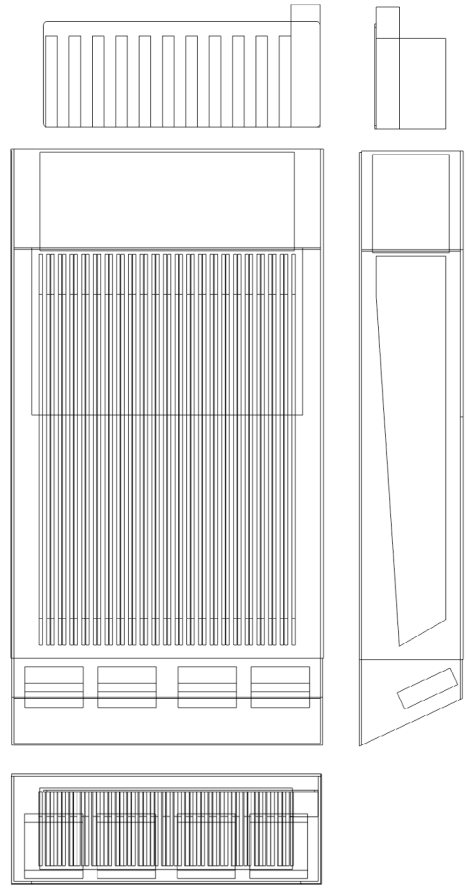
Internal hardware



Dept.	Technical reference	Created by	Approved by
		Anya Poznyak 9/10/24	
		Document type	Document status
		Title: V2 Dummy model_exploded	DWG No.
			Rev. / Date of issue / Sheet: 1/1

Cooling unit





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		Anya Poznyak 9/10/24	
		Document type	Document status
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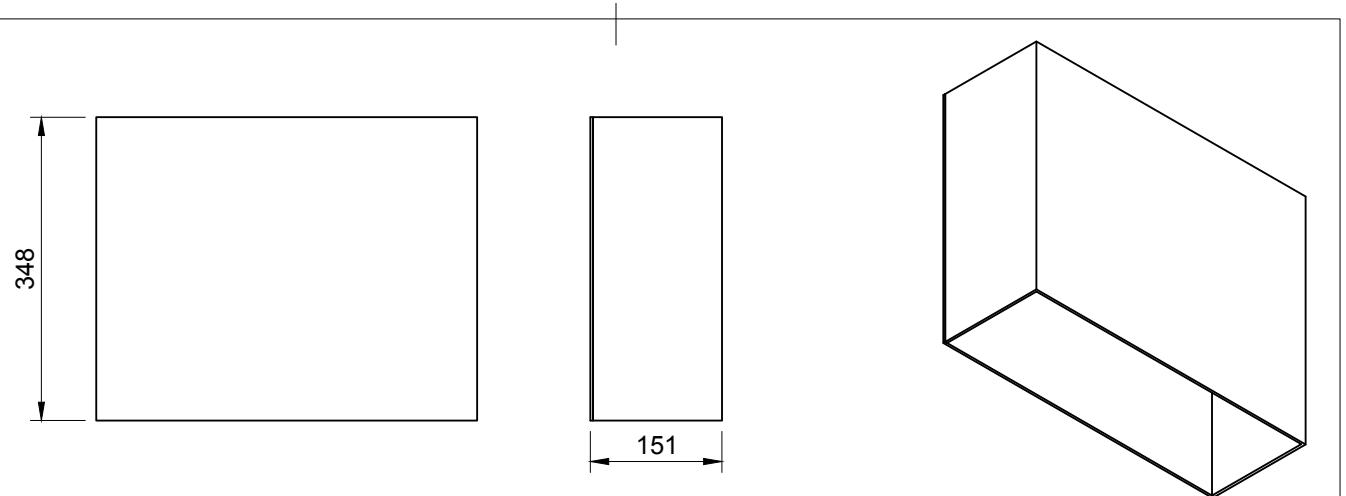
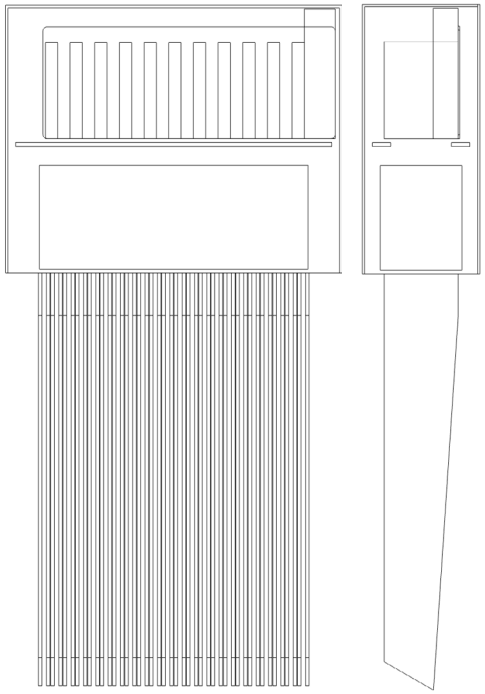
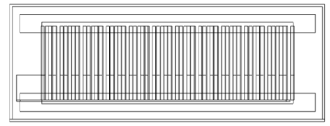
			Rev. / Date of issue / Sheet: 1/1

DC unit







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			Rev. / Date of issue / Sheet: 1/1

Appendix F | Considerations & uncertainties of EMDC interaction

Hiro's digital interfaces/ interactions/ services

Pre-purchase

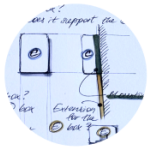
- Computing needs assessment

First time installation

1 Unboxing the EMDC
- Both units in one box?

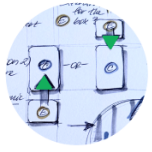
- How to make opening the box as easy and enjoyable as possible?
- Where to open the box - on the ground/on the platform?
- How to remove the units from packaging...
  - Safely (nothing in EMDC breaks)? Especially thinking about the condenser plates, sticking out?
  - Ergonomically? How to provide guidance for ergonomic lifting?

2 Mounting unit(s)
- Just the Cooling unit at first?
- Does it support the DC unit? How?



- How to explain mounting procedure to the installer?
  - Paper manual, digital interface (VR experience)?
- How to make the process as easy and enjoyable as possible?
  - Built in levels, alignment guides, etc.
- How to mount safely at an elevation?
  - Safety for the installer
  - Safety for the people passing underneath
- What are ergonomic consideration for Cooling unit mounting?
  - Cooling unit weight?
  - Elevation
- How many steps does mounting involve?
- How many people required?
- Tools required?
- When to mount?
  - Avoid crowds to prevent unauthorized access or damage
- Only wall mounting? What kind of surfaces?
- The exact mounting way/mechanism?
  - Does standing on the platform as opposed to on the ground have any effect on experience and what can be done?
- How do you make Cooling unit grippable?

3 DC unit insertion



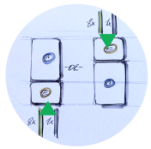
- What are ergonomic considerations for inserting DC unit from the top (Option 2)?
  - DC unit weight?
  - Going with gravity
  - Grips required
- How to insert safely at an elevation?
  - Safety for the installer
  - Safety for the people passing underneath
- How to ensure necessary alignment?
  - Maintaining clearances to not hurt the internals

4 Clamping activation
- Condenser plates clamped very tight with Al plates

- How to estimate (realistically) the clamping mechanism?
- Ergonomics
  - Height @ which it needs to be clamped
  - What's the most ergonomic 'clamper' (lever, knob, bar down, etc.)?
  - How much force will it take to activate the clamping mechanism? Any guidelines?
- Any tools required?
- How to best explain how to do it?
  - Digitally? Animation?
- Does having to clamp @ elevation change anything? (stability needed)

OR

4 Connect cables into DC unit
- Up to 8 ethernet and 1 power cable



- What's the ergonomic way of doing it?
  - How much force is required?
  - Motion (twisting, etc.)
  - Implication of Option 2 for cable connections
  - Spacing between connectors for a hand to fit
- Cable management for cable slack?
- Does having to clamp @ elevation change anything? (stability needed)

5 Enclosure 'closure' & EMDC powering
- Closing/locking anything necessary and preparing for 'daily operation'

- How many 'closures' are required?
- How to provide the installer with the feedback that they did everything right and EMDC is good to go?
  - Evoking trust in the installer (emotional design)
- How does EMDC 'turn on'?
  - How does the switch (button, etc.) look like and how is it activated (pressing, etc.)?
  - Where is it located (ergonomics)

- Installation manual/videos
  - *VR experience where a user can practice installing virtually before they do it in real life? Or a user wearing a VR headset while installing for instructions and confirmation (they're doing everything right/well)?*
  - *Or mb just a video call with Hiro support for reassurance?*
- Installation customer service

While in use

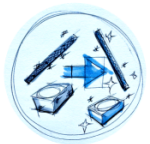
Monitoring EMDC status

- How to communicate necessary hardware status?
  - How to notify when it's time to swap replaceable parts?
- How to make status visible at an elevation?
- Differences indoor Vs outdoor
  - Light visibility
  - Amount of info that needs to be communicated
- Who needs to see it
  - Hidden (only owners/clients/maintenance specialists can see)
  - Exposed (general public cab see)
- How to not freak out general public with alarm statuses?

Public interaction

- How to make vandalism undesirable
  - Look at it, but don't mess with it

Necessary hardware replacements
- Filters & fans

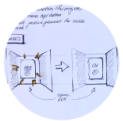


- How to deliver replaceable parts to the customers?
  - What do customers do with the old parts?
- How to explain how to do the replacement?
- How to notify when it's time to swap?
- How to make these parts easily accessible?

- Majority of system and status monitoring will be done digitally/remotely by Hiro → minimal physical status interface required
  - They'll inform the clients of any issues/ upgrades needed; *may be even intervene on their behalf in case of emergencies? can it be somehow beneficial in vandalism cases?*

Upgrades

(1) Remove the DC unit from packaging
- Use the same packaging to ship old DC unit back?



- How to remove the units from packaging...
  - Safely (nothing in E unit breaks)? Especially thinking about the condenser plates, sticking out?
  - Ergonomically?
- Where to open the box - on the ground/on the platform?
- How to fit an old unit in?
  - Could be of different size

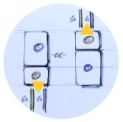
*Does it make more sense to unpack the new DC box or 'unplug' the old one first?

OR

(1) Open up the enclosure
- Getting to cables and clamping mechanism

- How to explain how to do it?
- How/when to turn off the power?
- How to ensure a person (an installer) in the safety of opening up the enclosure?
  - Evoking trust in the installer (emotional design)

(2) Disconnect cables from DC unit
- Up to 8 ethernet and 1 power cable



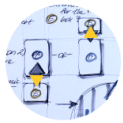
- How to explain how to do it?
- What's the ergonomic way of doing it?
  - How much force is required?
  - Motion (twisting, etc.)
  - Implication of Option 2 for cable connections
  - Spacing between connectors for a hand to fit
- Cable slack getting in the way?
- Does having to clamp @ elevation change anything? (stability needed)
- What to do with cables once they're disconnected?
  - Just throw on the platform?..

OR

(2) Unclamp DC unit from Cooling unit

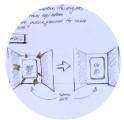
- How to best explain how to do it?
  - Digitally? Animation?
- Ergonomics
  - Height @ which it needs to be clamped
  - What's the most ergonomic 'clamper' (lever, knob, bar down, etc.)?
  - How much force will it take to activate the clamping mechanism? Any guidelines?
- Any tools required?
- Does having to clamp @ elevation change anything? (stability needed)

(3) Extract CD unit from the Cooling unit



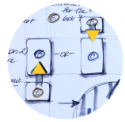
- How to ensure that un-clamping has been done fully/correctly/enough?
  - Potentially hurting LHPs
- What are ergonomic considerations for extracting DC unit from the top (Option 2)?
  - Going against gravity
  - DC unit weight?
  - Grips required
  - Placing it on the platform
- How to ensure necessary alignment?
  - Maintaining clearances to not hurt the internals
- How to safely place it on the ground?

(3) Package the old DC unit
- Use the same packaging to ship old DC unit back?



- How to package the old DC unit ergonomically?
  - Bending over, etc.
  - DC unit weight
- How to fit into an old box?
  - Could be of different size
- Evoking trust in the person that it's gonna ship back safely/they did everything correctly (emotional design)

4 Insert DC unit into the C unit



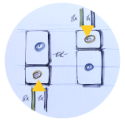
- What are ergonomic considerations for inserting E unit from the top (Option 2)?
  - E unit weight?
  - Going with gravity
  - Grips required
- How to insert safely at an elevation?
  - Safety for the installer
  - Safety for the people passing underneath
- How to ensure necessary alignment?
  - Maintaining clearances to not hurt the internals

(5) Clamping activation

- How to estimate (realistically) the clamping mechanism?
- Ergonomics
  - Height @ which it needs to be clamped
  - What's the most ergonomic 'clamper' (lever, knob, bar down, etc.)?
  - How much force will it take to activate the clamping mechanism? Any guidelines?
- Any tools required?
- How to best explain how to do it?
  - Digitally? Animation?
- Does having to clamp @ elevation change anything? (stability needed)

OR

(5) Connect cables into DC unit
- Up to 8 ethernet and 1 power cable



- What's the ergonomic way of doing it?
  - How much force is required?
  - Motion (twisting, etc.)
  - Implication of Option 2 for cable connections
  - Spacing between connectors for a hand to fit
- Cable management for cable slack?
- Does having to clamp @ elevation change anything? (stability needed)

6 Enclosure 'closure'
- Closing/locking anything necessary and preparing for 'daily operation'

- How many 'closures' are required?
- How to provide the installer with the feedback that they did everything right and EMDC is good to go?
  - Evoking trust in the installer (emotional design)
- How does EMDC 'turn on'?
  - How does the switch (button, etc.) look like and how is it activated (pressing, etc.)?
  - Where is it located (ergonomics)

- Upgrading manual/videos
  - Specifically focused on unclamping since it's an new interaction
  - *VR experience where a user can practice unclamping & reinstalling data center virtually before they do it in real life? Or a user wearing a VR headset while installing for instructions and confirmation (they're doing everything right/well)?*
  - *Or mb just a video call with Hiro support for reassurance?*
- Upgrading customer service

Decomissioning

0 Removing DC & Cooling units
- Similar/same steps as in 'Upgrades'

1 Remove mounts from the wall

- How to best explain how to do it?
- Procedure
  - Number of steps
  - Number of people required
  - Any special tools
- Mount weight?
- Sharp edges or other elements that could hurt a person?
- How to cover up any damage (holes, etc.) caused to the wall?
- Does having to do it @ elevation change anything?

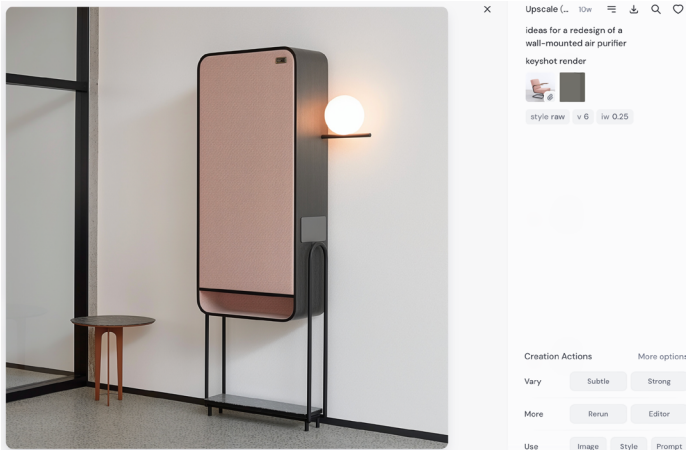
Is mounting part of the enclosure or a separate thing?

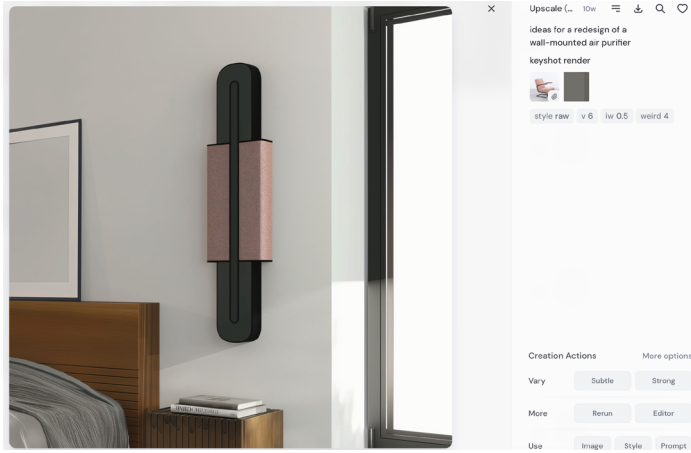
- Uninstalling manual/videos
  - Specifically focused on removing the boxes and removing the mounts from the wall since they're new tasks
  - *VR experience where a user can practice these tasks virtually before they do it in real life? Or a user wearing a VR headset while doing the tasks for confirmation (they're doing everything right/well)?*
  - *Or mb just a video call with Hiro support for reassurance?*
- Final removal customer service

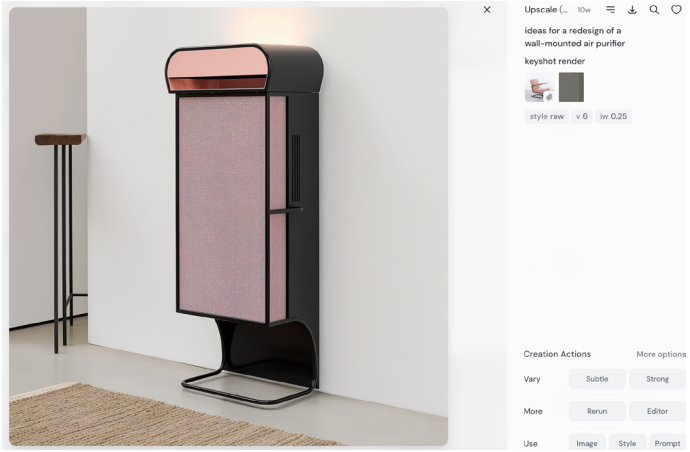
Appendix G | Further selected MidJourney inspirational material

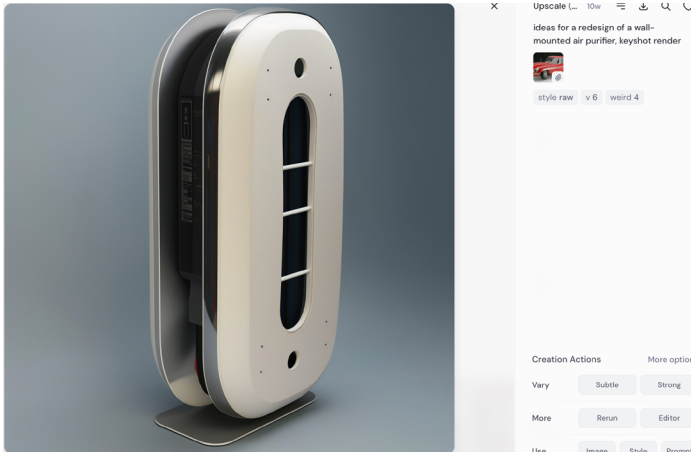
More downselected inspirational designs

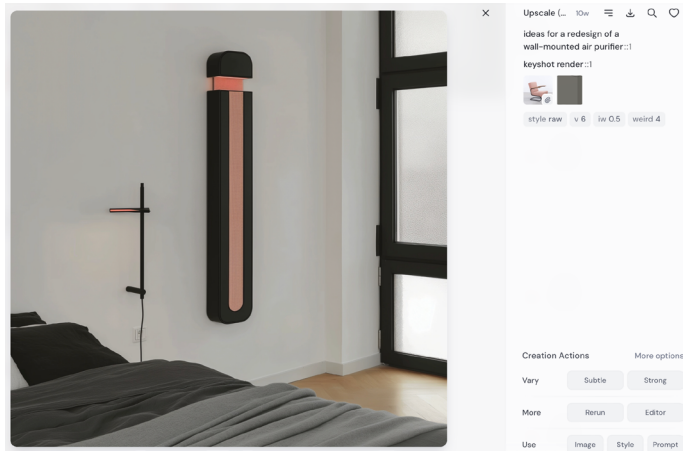
*Image with the paper pin icon is the --sref image for the generation. Small image without the icon is the CAD screenshot.

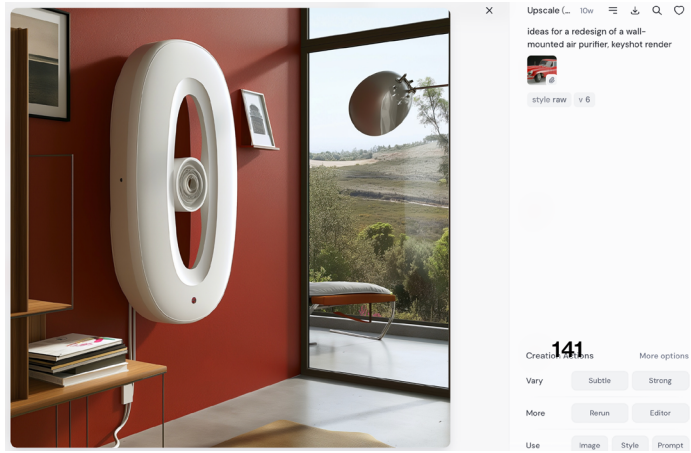












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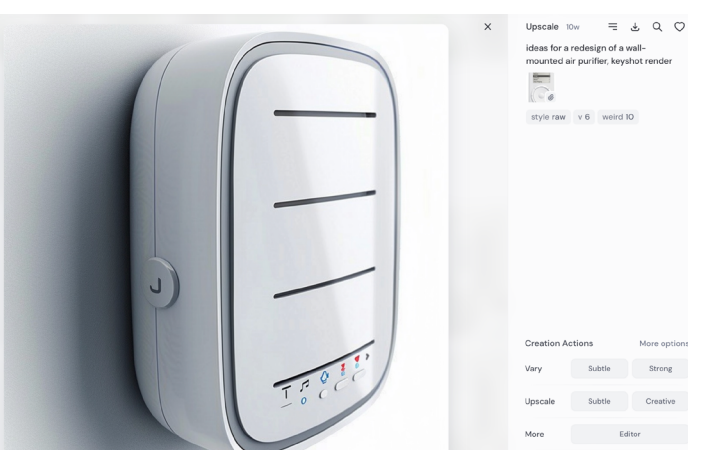

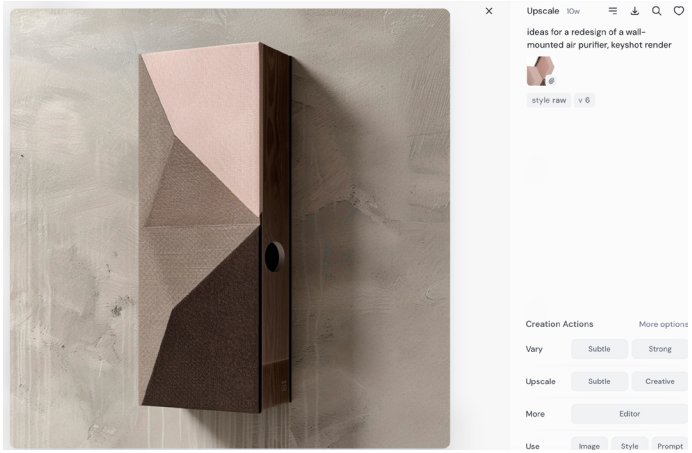

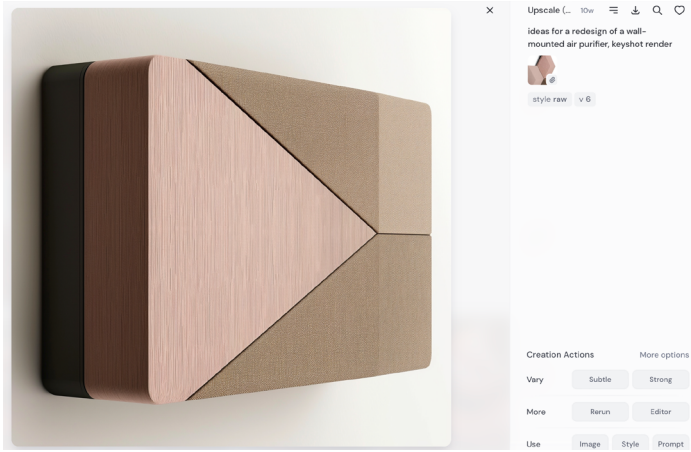

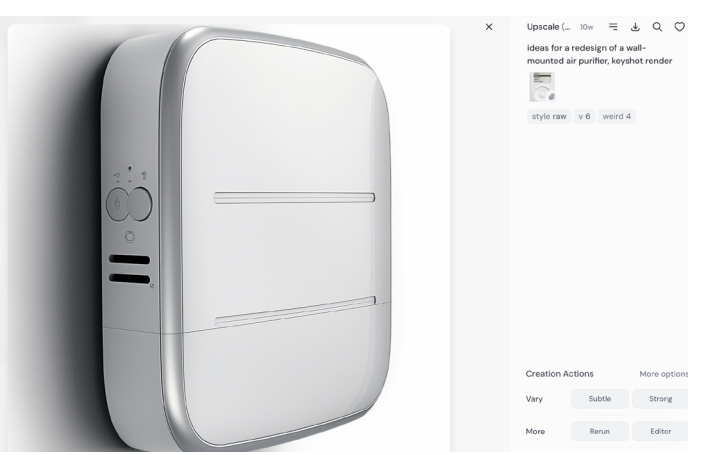

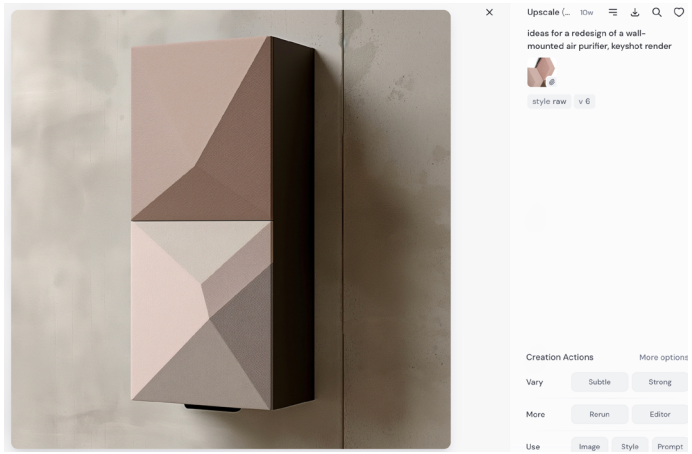

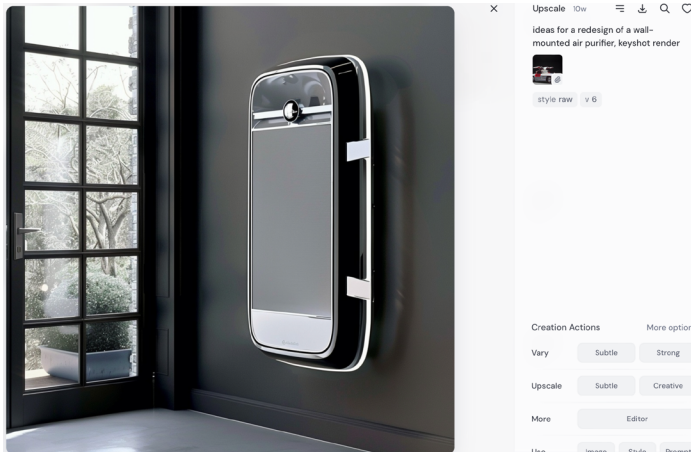

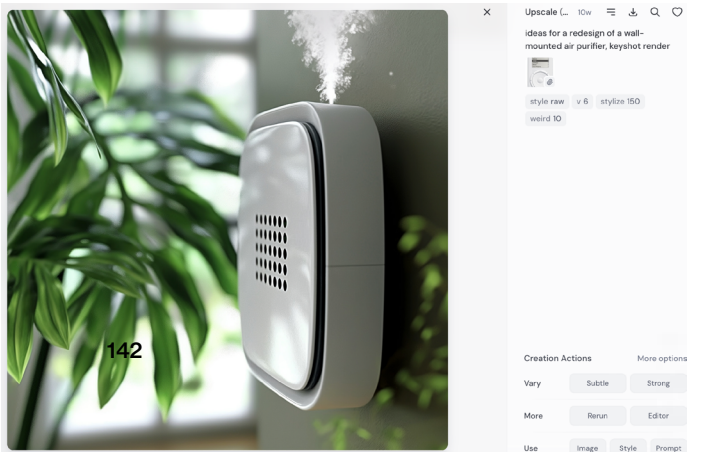

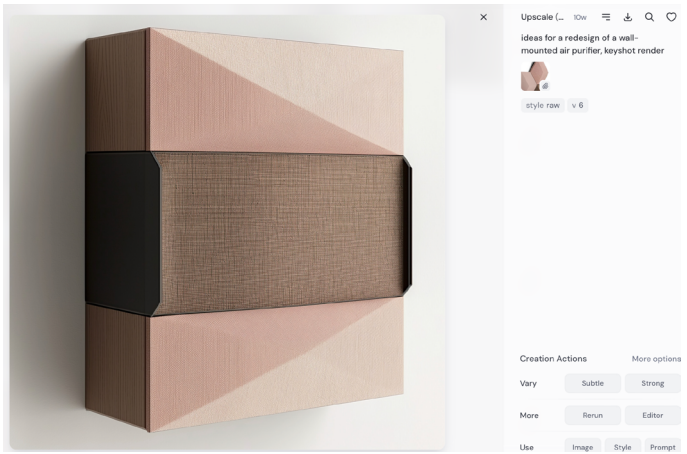

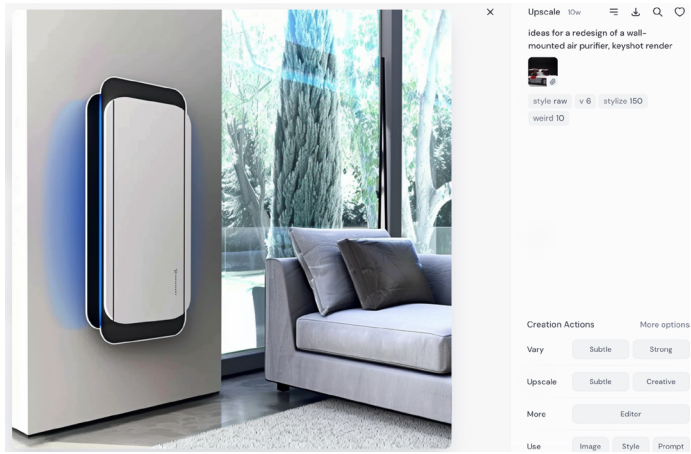

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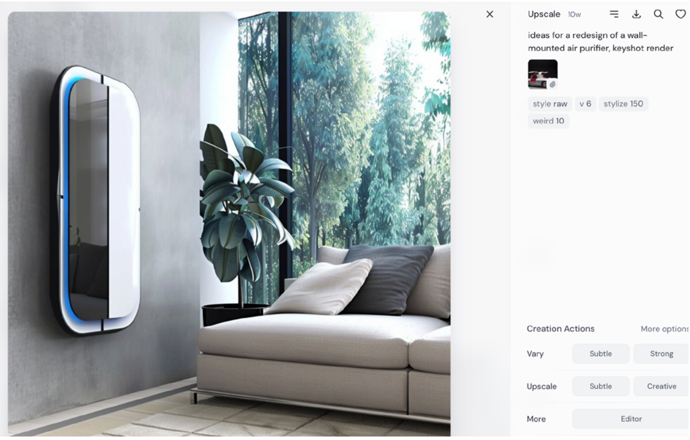

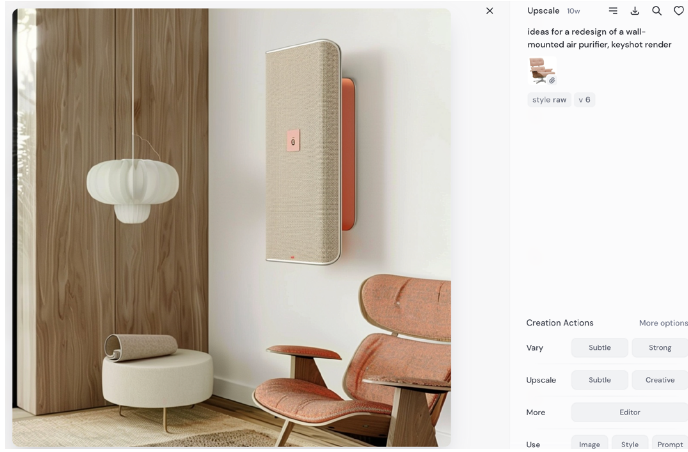

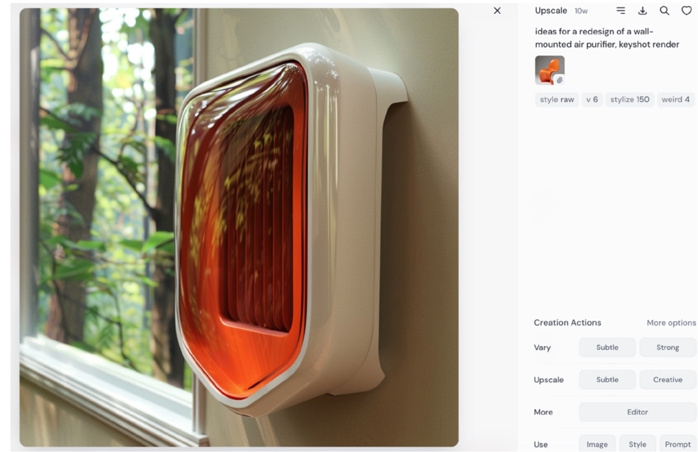

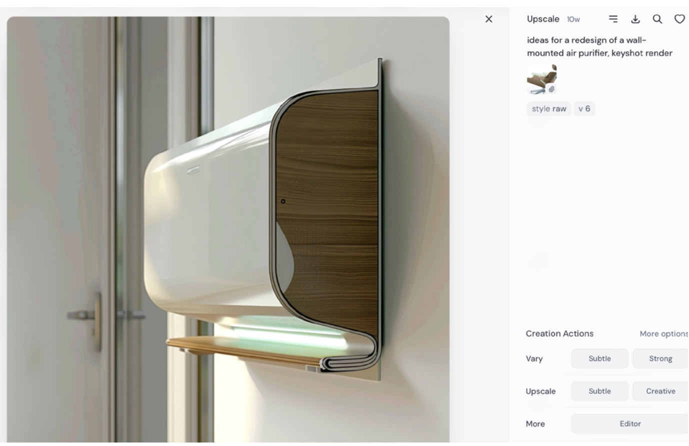

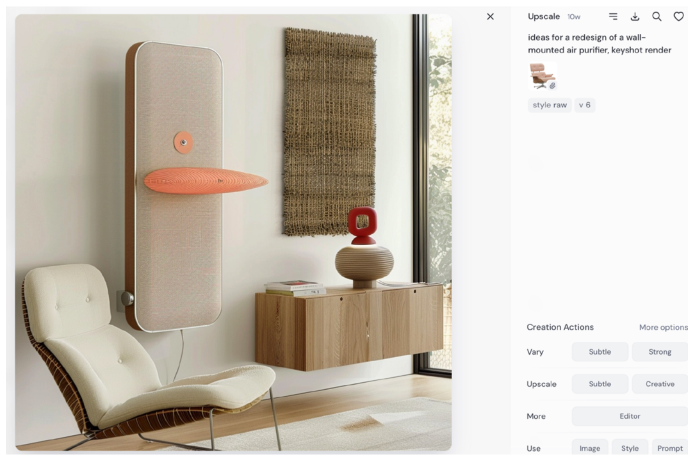

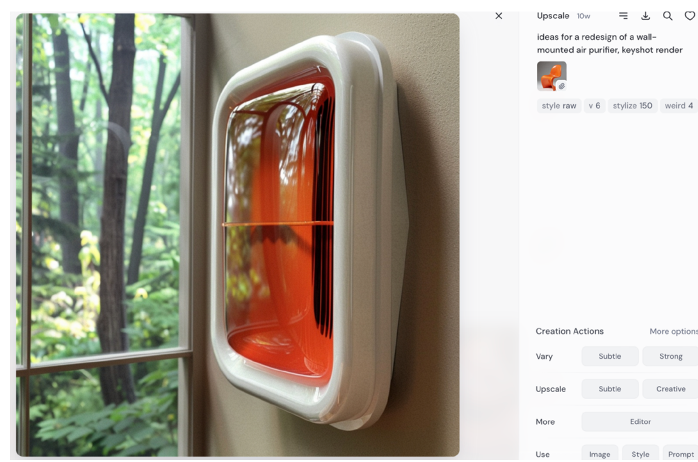

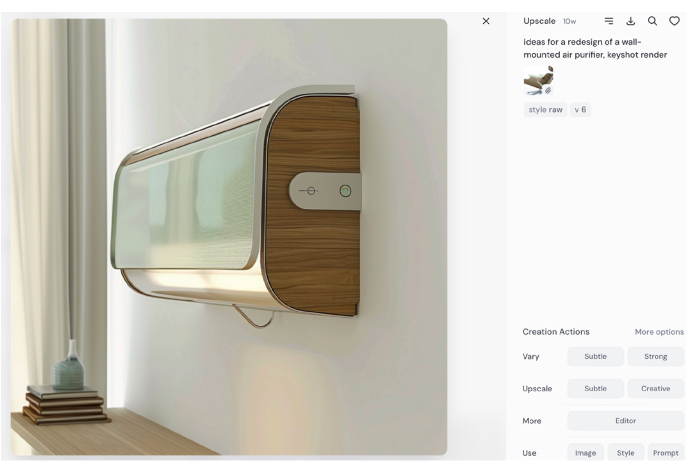

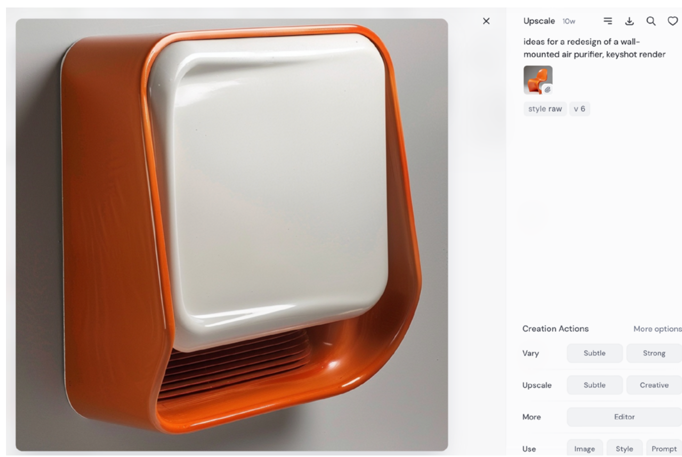

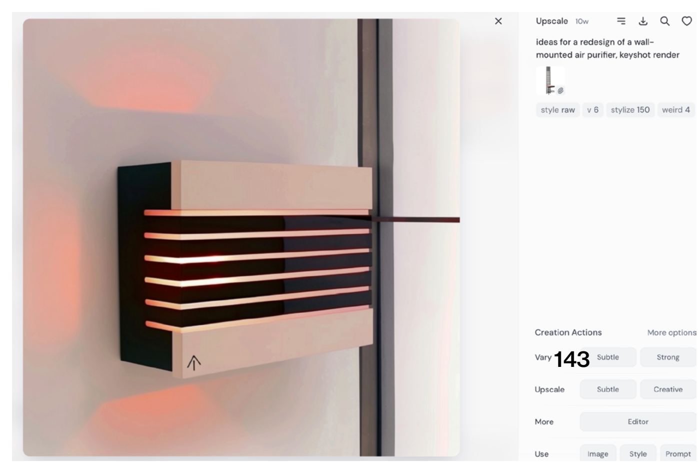

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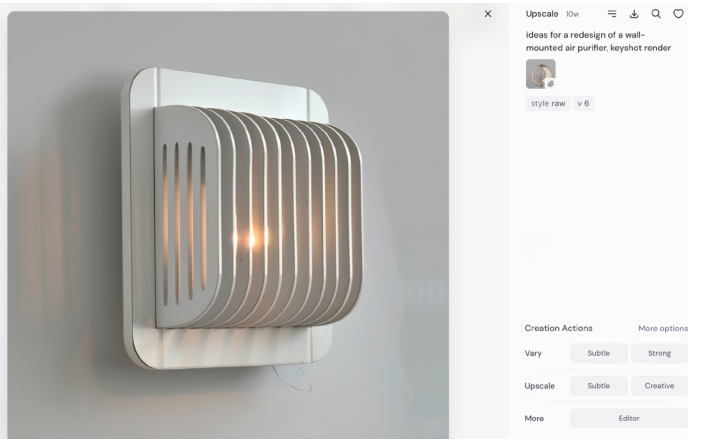

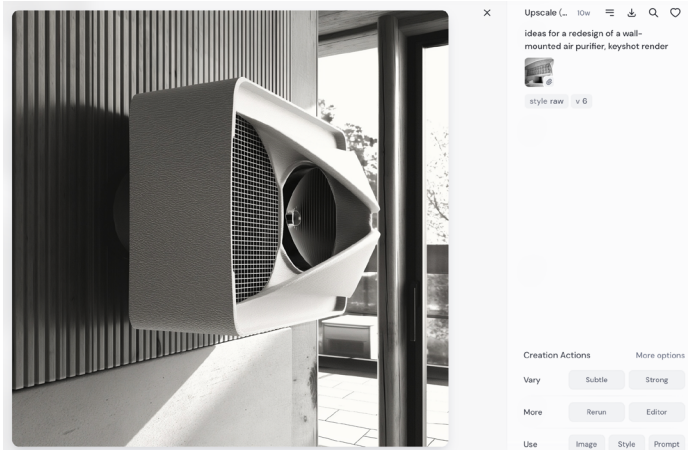

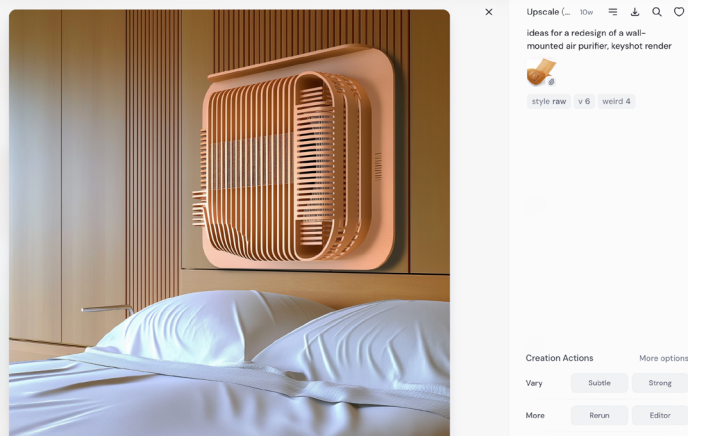

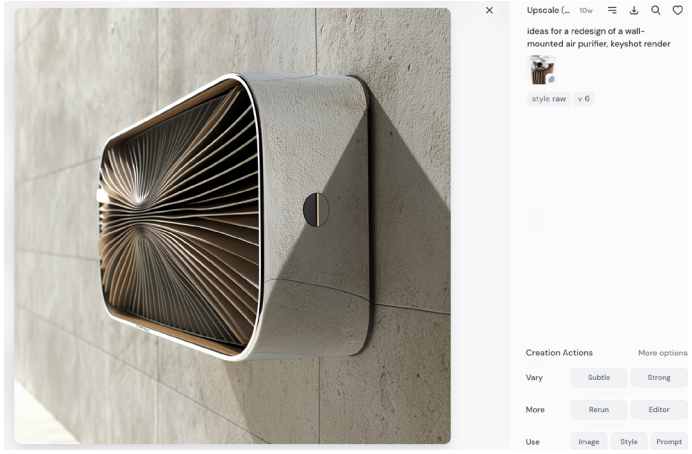

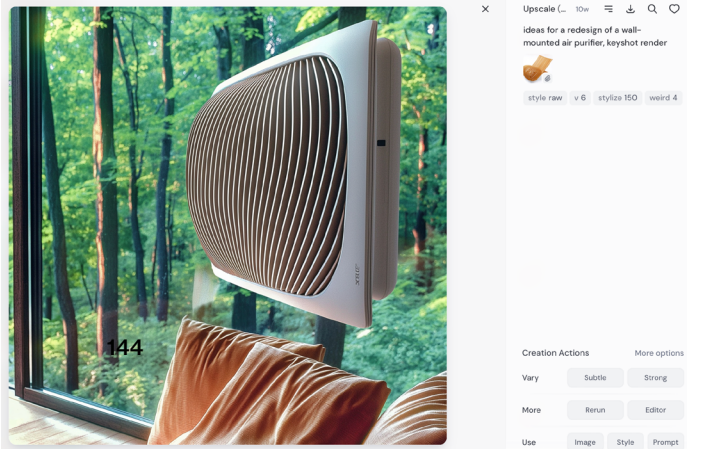

Some examples of less successful/bizarre generations

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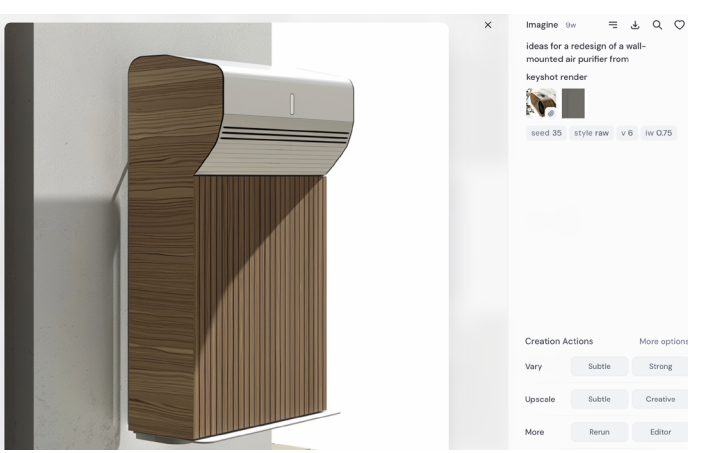
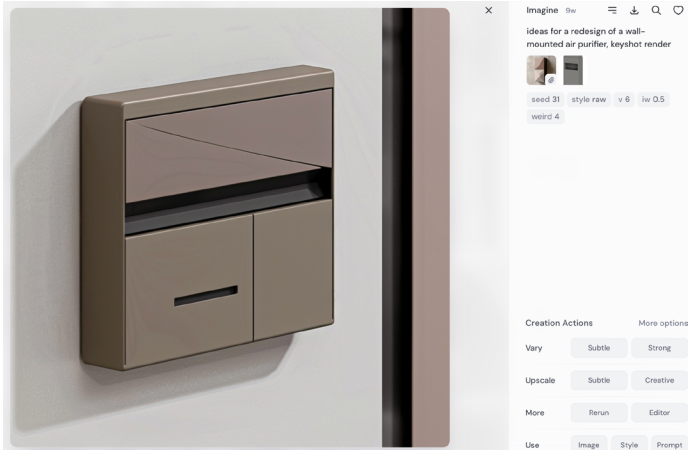
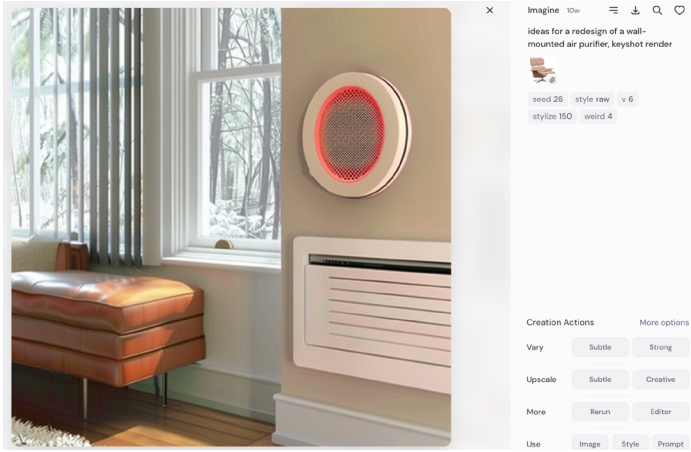
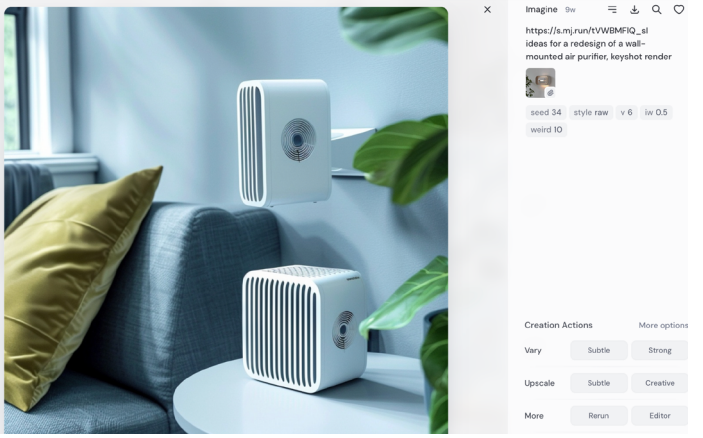
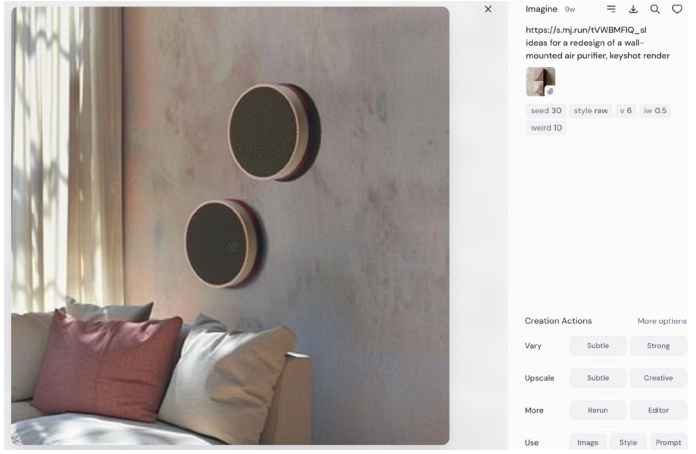
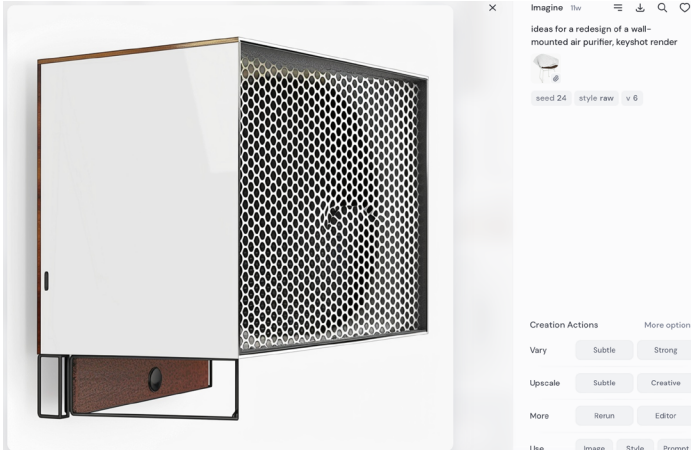


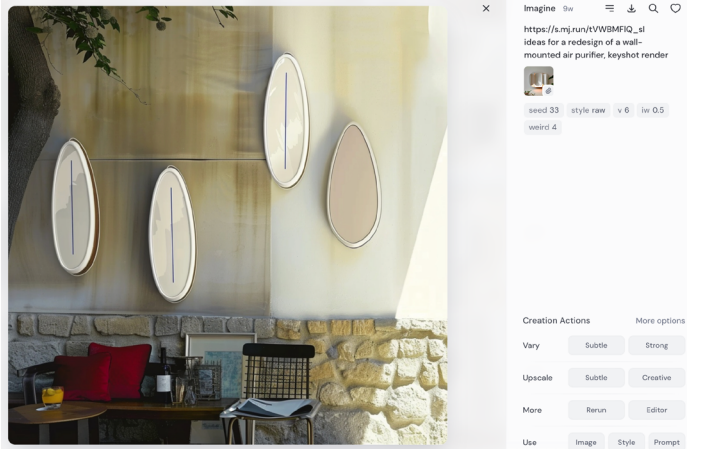


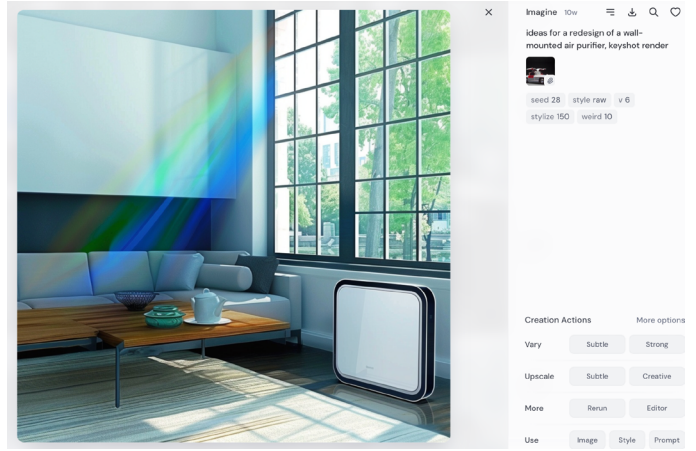


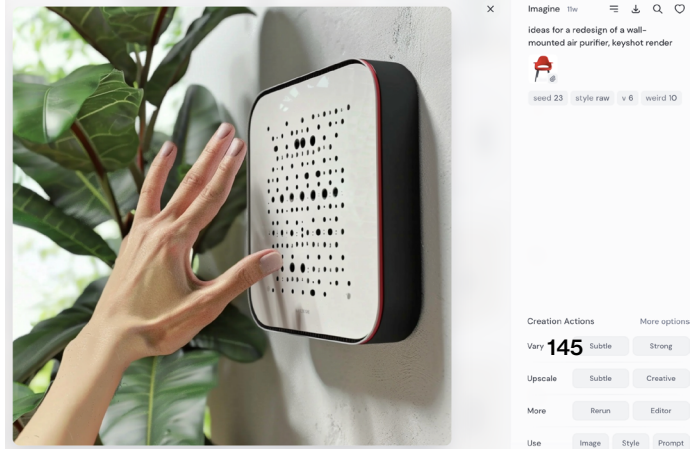












Appendix H | Convergence 1.0 user survey

Survey hyperlink | https://forms.gle/LExcJnxiKmbWkV6q8

Enclosure Aesthetics for an Edge Micro Data Center

Hey there! My name is Anya, I'm an IPD student at TU Delft working on my **graduation thesis**. In my project, I'm designing an **enclosure** for an **edge micro data center** (don't worry, I'll explain what that means later :)), a computing device that will be placed in public spaces, such as city centers, and seek an elegant integration with its environment. The **purpose** of this survey is to help me narrow down my ideation scope for **defining the overall form factor** of the enclosure. The survey is **anonymous** and it will take **10-15 minutes** to complete. Thanks in advance for your time!

Switch account

Not shared

Timestamp	For the design shown above, please select **3 top traits** that you believe describe this product.	Now, what is **one trait** that you would use to describe this design?	For your **top (#1) trait**, please describe **one detail/element** from the design related to **its form factor/shape** (you can consider both the macro/overall level and micro/detail level) that encompasses that trait to you.	For the design shown above, please select **3 top traits** that you believe describe this product.	Now, what is **one trait** that you would use to describe this design?	For your **top (#1) trait**, please describe **one detail/element** from the design related to **its form factor/shape** (you can consider both the macro/overall level and micro/detail level) that encompasses that trait to you.	For the design shown above, please select **3 top traits** that you believe describe this product.	Now, what is **one trait** that you would use to describe this design?	For your **top (#1) trait**, please describe **one detail/element** from the design related to **its form factor/shape** (you can consider both the macro/overall level and micro/detail level) that encompasses that trait to you.
7/3/2024 12:12:25	Elegant, Refined, Assertive	Refined	The curved and polished plywood	Pioneering, Empowering, Assertive	Assertive	Its geometricness	Refined, Empowering, Assertive	Empowering	The usage of the chair hints at power
7/3/2024 12:29:16	Pioneering, Elegant, Assertive	Assertive	The shape top of the stool sticks out to the sides. Its hard to look past it, making an clear impression. Making it assertive to me	Pioneering, Elegant, Refined	Refined	The cubes are meat and clean, making it refined to me	Pioneering, Empowering, Assertive	Empowering	The cushioning seems very bulky, making the overall shape seem if i sit on it i would be bigger
7/3/2024 12:31:35	Elegant, Empowering, Assertive	Elegant	Curvy lines	Pioneering, Elegant, Refined	Pioneering	Unusual shape for speakers	Elegant, Refined, Assertive	Elegant	Juxtaposition between the soft seating and the hard wood
7/3/2024 12:32:41	Elegant, Refined, Assertive	Refined	The two bent plywood sheets that kiss in one specific point	Elegant, Empowering, Assertive	Empowering	The 3D cube that the hexagon implies, it feels stable and powerful	Pioneering, Elegant, Empowering	Pioneering	The rounded corners of the plywood
7/3/2024 12:40:07	Pioneering, Elegant, Refined	Elegant	Organic flowing shape	Pioneering, Elegant, Refined	Pioneering	Looks futuristic due to its uniform nature inspired pattern	Elegant, Refined, Assertive	Assertive	Seems a bit commanding like someone in power would sit on such a chair
7/3/2024 13:57:14	Pioneering, Elegant, Refined	Pioneering	The combination of organic matter (wood) and unique shape	Pioneering, Elegant, Empowering	Elegant	The light pkay on the shape giving it texture	Elegant, Refined, Empowering	Empowering	The combination of materials with perceived comfyness and usefulness
7/3/2024 14:04:30	Elegant, Refined, Assertive	Elegant	Combination of black wood material and shape curves	Pioneering, Empowering, Assertive	Assertive	Seriousness and dull colours and shapes	Refined, Empowering, Assertive	Empowering	Looks like it is used by powerful people
7/3/2024 14:09:46	Elegant, Refined, Assertive	Refined	The curvature and how the material is well-constructed	Pioneering, Refined, Empowering	Pioneering	The first audio system combined with wall art	Refined, Empowering, Assertive	Assertive	The size of it
7/3/2024 15:13:22	Elegant, Refined, Assertive	Elegant	the soft curves, not too expressive	Pioneering, Refined, Empowering	Empowering	the modular/flexible aspect of the design	Pioneering, Elegant, Assertive	Assertive	its just a very open and out-there shape
7/3/2024 23:02:41	Pioneering, Elegant, Refined	Elegant	The overall smoothness	Pioneering, Empowering, Assertive	Assertive	The redefinition of such a product as a functional and decorative item	Pioneering, Elegant, Assertive	Elegant	CMF and curved wood
7/4/2024 19:58:14	Elegant, Refined, Empowering	Empowering	It has a wide stance that expresses strength and stability. Also it can be interpretated as a set of hands holding up the seated one which makes them feel important and empowered. The fact that it is made of 2 solid pieces adds to the feeling of power	Pioneering, Refined, Assertive	Pioneering	In the asymmetric configuration it looks like it is in the process of growing which is a trait i would assign to the term pioneering. Also on a macro level it is quite renewing for speaker design i think so that adds to the pioneer vibe	Elegant, Refined, Empowering	Empowering	Though elegance is definitely reflected in the bent plywood, as well as pioneering in the sense that the eames lounge set was the avant garde when it comes to bent plywood in furniture, the product has a status that matches powerful working men. It was also advertised in the 60s with a man and a pipe reading the newspaper after a long day of work. Plus its expensive and exclusive and usually you only have one in the room, the one who sits in it differentiates themselves and looks powerful. On a more micro level the embracing shape of the plywood has similar qualities as the first stool that express empowerment
7/5/2024 10:19:16	Elegant, Refined	Elegant	It feels compact and minimal (the use of 2 simple pieces of material) and yet has its own unique style (the curves).	Pioneering, Refined, Assertive	Pioneering	The fact that it has minimal depth (as seen in the detail) but is also bold and eye catching with the colours and shapes.	Empowering, Assertive	Assertive	The laid-back nature of the chair, the way its designed at an inclination resembles power
7/5/2024 10:53:55	Pioneering, Elegant, Assertive	Assertive	It's bold to bring two shapes like this together and tell the user: "this is a stable chair".	Pioneering, Refined, Empowering	Empowering	It's modular and suggests the user can customize the arrangement.	Refined, Empowering, Assertive	Refined	A corner office chair stripped to the very most high-quality essentials
7/5/2024 15:43:27	Pioneering, Elegant, Refined	Pioneering	The overall shape is nothing I have seen before. The bent wooden pieces look like a new idea of design	Pioneering, Refined, Assertive	Assertive	Very bold/aggressive shape of the product	Refined, Empowering, Assertive	Empowering	Comfortable looking seat makes me want to try it
7/5/2024 15:54:54	Pioneering, Elegant, Refined	Refined	How thin the pieces are	Pioneering, Elegant, Assertive	Elegant	The shape of pieces together	Refined, Empowering, Assertive	Assertive	The way pieces work together
7/5/2024 16:22:41	Pioneering, Refined, Assertive	Refined	The material embodies refinement to me	Elegant, Empowering, Assertive	Assertive	The shape of the speakers is something that really stuck out to me, I found the speakers to be very assertive/noticeable.	Pioneering, Empowering, Assertive	Pioneering	I've never seen wooden material mixed with chair cushion material in that way, so it felt innovative to me
7/5/2024 16:38:35	Refined, Empowering, Assertive	Empowering	The design looks like two hands and forearms holding you up, and hands tend to be associated with power	Pioneering, Elegant, Refined	Refined	It's a crisp, clean design	Pioneering, Elegant, Refined	Refined	It feels like a classy kinda of chair
7/5/2024 16:48:20	Pioneering, Elegant, Refined	Refined	Minimalism and symmetry	Pioneering, Elegant, Refined	Pioneering	Encompassing function in art	Pioneering, Elegant, Refined	Elegant	Ergonomic and modern

Now, what is **one trait** that you would use to describe this design?	For your **top (#1) trait**, please describe **one detail/element** from the design related to **its form factor/shape** (you can consider both the macro/overall level and micro/detail level) that encompasses that trait to you.	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [Design 1]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [Design 2]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [Design 3]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [Design 4]	Which design appeals to you the most?	For your **favorite design**, in **1 sentence** please describe **one detail/element** from that product related to **its form factor/shape** (you can consider both the macro/overall level and micro/detail level) that encompasses the **trait/adjective** that you picked for it.	For your **favorite design**, **why** does it appeal to you? Which **detail(s)/feature(s)** stand out to you? Please describe in 1 sentence	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [1]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [2]
Pioneering	Its aerodynamism	Elegant	Pioneering	Assertive	Refined	2	The fan gives it a feeling of movement and speed	I like the roundness of it and the fact that the fan helps me guess at its function	Elegant	Refined
Elegant	Overal shape seems to flow.	Refined	Assertive	Elegant	Assertive	3	Overal shape seems simple and not bulky	With the lines going vertical its nice to look at and fits the wall "lines"	Elegant	Assertive
Empowering	The big hood looks cool and controlling	Assertive	Refined	Assertive	Elegant	4	The retro shape on the front looks elegant bc of the material use	The overall shape and retro vibes on the front panel	Pioneering	Elegant
Elegant	The elongated front of the car	Pioneering	Elegant	Assertive	Refined	1	I like that it looks like a carved monolith, ancient but cutting edge	How the top adds direction and movememt upwards	Elegant	Pioneering
Refined	Slowly smooth shapes	Assertive	Refined	Assertive	Elegant	2	I like that it has a smooth dhape		Elegant	Assertive
Assertive	The lines are sublime	Pioneering	Elegant	Pioneering	Refined	2	Seemless integration of utility (fan exhaust I'm guessing) in the shape	Organic round shape with intended use for data (usually associated with angles and blocks) makes it intriguing and elegant	Pioneering	Pioneering
Pioneering	It looks like it used to be a unique and innovative car	Elegant	Empowering	Refined	Pioneering	1	It looks like an object that would actually be found around a city. It looks robust and grounded.	It looks sturdy and minimalistic.	Assertive	Assertive
Pioneering	Its nose	Assertive	Refined	Elegant	Empowering	3	The sleekness	how it blends in its environment	Refined	Empowering
Refined	character lines	Elegant	Empowering	Refined	Assertive	3	the lines and shapes are subdued, there is no wasted elements it seems	the design seems honest- compared to the others. in a public space that seems important.	Assertive	Empowering
Refined	The sleekness inspired by the streamlined aesthetic	Assertive	Refined	Empowering	Refined	1	The contemporary shape		Assertive	Assertive
Elegant	The curvy styling is in the male mind linked to female shapes, which is something we associate with the term elegant.	Elegant	Pioneering	Refined	Assertive	3	By embracing the core with the wood it looks humble and like it got its stuff together, it looks more unified than other concepts	It can blend more easily in an urban environment but would also look good surrounded by nature, good balance between industrial metal and wood vibes, not in the way because its on the wall. Cant be confused with a trashcan	Empowering	Assertive
Elegant	Once again, a characteristic form such as the bonnet and the placement and shape of the headlights make it seem like it has its own personal style	Pioneering	Refined	Pioneering	Elegant	2	It seems like a clean design with basic and minimum contrasting factors, making it refined	It feels like a product i've already seen before (the ribs and the fan)	Refined	Pioneering
Assertive	Huge front / hood. Uncommon design nowadays. It conveys: speed, stability, status, confidence.	Refined	Empowering	Refined	Pioneering	4	It looks like a VR headset, which is an interesting crossover as VR imagemaking is already closely related to AI (GANs etc.) and will require a much greater compute power. It's futuristic not aesthetically, but conceptually.	It's the only one that really truly stands out. 1 and 3 look pretty normal, 2 looks a bit like an A/C device.	Elegant	Refined
Assertive	The shape of this car will definitely attract attention and stand out a mile	Elegant	Refined	Empowering	Empowering	1	One of the kind piece, modern, not looking like AC	Nice proportions	Pioneering	Refined
Elegant	The shape looks really elegant	Refined	Elegant	Elegant	Assertive	4	It's symmetrical	The symmetry	Refined	Empowering
Pioneering	The design of the car is very reminiscent of some of the first cars designed, so that's why I'd say it was pioneering (for the time)	Assertive	Pioneering	Refined	Assertive	3	I picked 3 because the shape/size feels the most finished/refined to me.	I think it is the only one that has interest and proper placement, while giving the messaging that it is something that isn't for recreational use	Assertive	Refined
Refined	It has a clean, classy design	Empowering	Refined	Assertive	Pioneering	2	The proportions between shapes work well and the lines are clean, which gives it a refined look	I like the shapes and the way that lines and smooth parts work together	Assertive	Elegant
Assertive	Attention grabbing	Elegant	Elegant	Elegant	Elegant	4	Round/curved shape	Enclosed and inconspicuous	Refined	Empowering

For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [3]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [4]	Which design appeals to you the most?	For your **favorite design**, in **1 sentence** please describe **one detail/element** from that product related to **its form factor/shape** (you can consider both the macro/overall level and micro/detail level) that encompasses the **trait/adjective** that you picked for it.	For your **favorite design**, **why** does it appeal to you? Which **detail(s)/feature(s)** stand out to you? Please describe in 1 sentence	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [1]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [2]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [3]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [4]	Which design appeals to you the most?	For your **favorite design**, in **1 sentence** please describe **one detail/element** from that product related to **its form factor/shape** (you can consider both the macro/overall level and micro/detail level) that encompasses the **trait/adjective** that you picked for it.	For your **favorite design**, **why** does it appeal to you? Which **detail(s)/feature(s)** stand out to you? Please describe in 1 sentence	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [1]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [2]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [3]
Assertive	Elegant	4	The shine and symetrical structure make me think of a fancy mirror	It looks familiar and elegant in a simple way because of its shape	Assertive	Assertive	Assertive	Refined	1	The shape is quite blunt and present	It reminds me of folded paper and that makes it feel more organic	Pioneering	Pioneering	Pioneering
Pioneering	Refined	1	Overal shape seems more compact	Its gives a sense of a intricate decorative lamp	Elegant	Refined	Assertive	Assertive	2	Because of its long shape it sticks out less	That is long	Pioneering	Elegant	Pioneering
Elegant	Pioneering	2	It looks slim and reflective in a nice way	Looks like a cool lamp	Pioneering	Refined	Assertive	Assertive	2	It looks simple and understandable compared to the others. Why the weird geometric shapes and why does no 3 have a top hat?	The geometric lines on the product	Assertive	Assertive	Elegant
Assertive	Refined	1	The offset curved lines	It's a bkt hypnotising	Pioneering	Elegant	Assertive	Empowering	4	The symetry horizontally, but asymettry vertically	It feels balanced but not boring	Assertive	Pioneering	Refined
Pioneering	Refined	3	Feels like a futuristic portal		Pioneering	Refined	Assertive	Assertive	1	looks a bit organic like a stone		Empowering	Refined	Assertive
Pioneering	Pioneering	1	Compact shape yet stylish and not over-the-top	Elegant pionneering design with nice light integration while staying sober enough	Elegant	Pioneering	Assertive	Assertive	2	The elongated design	The different form factor than the rest, with 2 contrasting tones, makes a bold statement I like	Pioneering	Pioneering	Assertive
Pioneering	Empowering	3	I like the rounded thick matte details.	I like its overall shape and dimensions.	Empowering	Elegant	Assertive	Empowering	2	I like its minimalistic design	I like its rounded features.	Assertive	Assertive	Refined
Pioneering	Assertive	3	The light reflections	The way the light plays on the wall	Assertive	Refined	Elegant	Empowering	4	the lip	Unobtrusive	Assertive	Elegant	Empowering
Empowering	Elegant	3	the light emitting elements in the inside of the product just seems to exude some energy, thus empowering.	its mostly by process of elimination. the others all have shapes that dont flow into each other/dont make much sense to me	Assertive	Refined	Pioneering	Assertive	4	geometric shapes makes it look tough	the right amount of variety in textures but it still looks cohesive	Assertive	Pioneering	Elegant
Elegant	Assertive	3	The smoothness		Empowering	Assertive	Assertive	Empowering	1	"The low poly aesthetic (if combined with the right material, in my opinion)"		Assertive	Assertive	Empowering
Refined	Empowering	1	It is a bit more subtle by its horizontal orientation, suits better in a living room context as most furniture is longer in the x direction than the y. also it looks like a squinting eye which is quite expressive of strength	Not too much light, looks quite calm and collected yet powerful	Pioneering	Refined	Assertive	Empowering	4	Looks strong and solid and has a feature that suggests you can open it which feels empowering to the user	It is more suitable for different interior stylings	Assertive	Assertive	Elegant
Empowering	Elegant	2	the way the edge is at an incline is really nice, it makes the product feel like a statement piece	its big but also not overwhelming (see above detail for this bit), making it seem like it's a classic	Elegant	Assertive	Pioneering	Assertive	1	The topical surfaces are different for both shapes bring out a nice style	the aforementioned detail makes it unexpected and unique	Assertive	Pioneering	Empowering
Refined	Empowering	1	It combines the function (cools down the device well) and the form (elegant lamp) very well.	Something about it feels ethereal and *connected*.	Assertive	Empowering	Empowering	Assertive	2	It's there, but is narrow enough that it won't obstruct human traffic. It's there to empower but not take up space.	nice mix of present and blended in.	Pioneering	Pioneering	Pioneering
Refined	Elegant	4	Nice reflection from the surface that gives it an additional depth	Reflecting material on the front	Elegant	Refined	Refined	Empowering	1	Edges on the front	The shape is unusual and it makes it look like an art object	Empowering	Assertive	Refined
Elegant	Assertive	3	It looks dynamic	I like the lighting	Pioneering	Elegant	Assertive	Refined	4	It looks geometrically appealing	I like how the shapes and angles work together	Elegant	Pioneering	Empowering
Assertive	Elegant	4	The curvature and sleekness of this design are satisfying to me	The curvature	Pioneering	Refined	Assertive	Assertive	1	I like that it is more compact	It is more simplistic	Assertive	Assertive	Refined
Elegant	Assertive	3	The lines inside the design look organized and refined	I like the contrast between sharp lines and smooth, round shapes	Assertive	Assertive	Elegant	Assertive	3	The clean lines and thin shape make it look elegant	It looks kinda art deco-y	Empowering	Empowering	Empowering
Empowering	Refined	4	Simplest	easiest to clean	Empowering	Refined	Refined	Elegant	2	Looks like art	Vertical shape could look good anywhere	Empowering	Elegant	Elegant

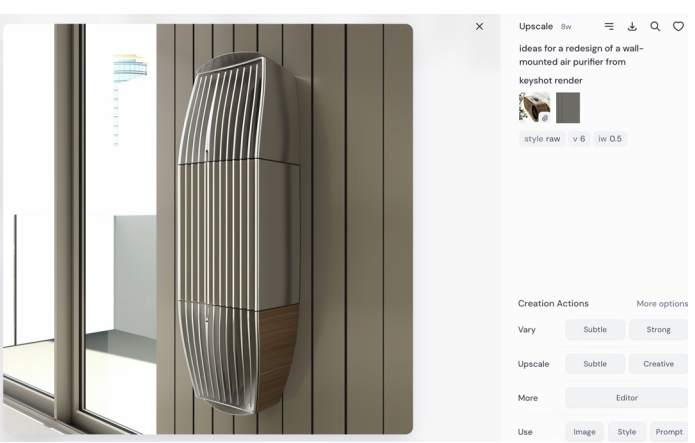
Which design appeals to you the most?	For your **favorite design**, in **1 sentence** please describe **one detail/element** from that product related to **its form factor/shape** (you can consider both the macro/overall level and micro/detail level) that encompasses the **trait/adjective** that you picked for it.	For your **favorite design**, **why** does it appeal to you? Which **detail(s)/feature(s)** stand out to you? Please describe in 1 sentence	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [1]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [2]	For **each design** shown above, please pick **one trait/adjective** that encompasses that design to the greatest extent to you (feel free to use the same trait/adjective multiple times if needed). [3]	Which design appeals to you the most?	For your **favorite design**, in **1 sentence** please describe **one detail/element** from that product related to **its form factor/shape** (you can consider both the macro/overall level and micro/detail level) that encompasses the **trait/adjective** that you picked for it.	For your **favorite design**, **why** does it appeal to you? Which **detail(s)/feature(s)** stand out to you? Please describe in 1 sentence	Are any of the enclosure designs/form factors from this group appeal to you? Please select all that apply.
3	They are all very aerodynamic	The shapes are a bit cleaner	Elegant	Assertive	Refined	3	The shapes blend very well into each other	It is minimal and clean	1, 7
2	No harsh angles in the shape, making it flow nicer	It sticks less ou	Elegant	Empowering	Refined	3	Has less smaller parts	Its not that noticable	2
3	They all look enormous but the 3rd has the thinner edge that makes it more elegant compared to the others	The thinner edge	Empowering	Elegant	Refined	3	The geometric shape makes it more business-y	It looks like what you'd expect for a data center	1, 5
2	Organic curves	The sensuous organic curves	Empowering	Pioneering	Refined	1	The happy soft edges	The rounded edges and curved shape make it futuristic but still soft and friendly	3, 4, 5
2	Feels like a cohesive shape		Refined	Elegant	Pioneering	2	Smooth shape		1, 2, 4
3	The sharp fin-like protusion	Breaking the round shape	Pioneering	Pioneering	Pioneering	3	Cose to the wall (compact)	Colour contrast makes it elegant	1, 6
3	It looks more like a finished product.	I like how the vents are integrated inside the enclosure.	Assertive	Assertive	Pioneering	3	It looks the least generic and least like a WiFi router.	I like the white unibody and pill shape.	2
3	Its personality	the points are intriguing	Refined	Pioneering	Assertive	1	The interface and intention is clear		1, 4, 5, 7
3	flowy outer 'shell', still subdued	its more cohesive than the others.	Assertive	Empowering	Refined	3	not over done, no wasted design elements.	balanced textures/colors, not too busy	1, 2
3	"Even if the overall appearance is not elegant, I do like the smoothness of the front part."		Elegant	Pioneering	Empowering	2	"The kind of optic loop effect"		1
3	Curves like the car	I like subtlety and organic shapes and they are quite balanced with, on a macro level, more big and powerful shapes	Elegant	Empowering	Refined	3	Asymmetry and shapes flowing into each other subtly	It looks humble, thin, not very present, but still cool styling and confident stance	2, 3
3	the material jutting out of the front surface makes it feel very bold and still clean	aforementioned detail is my fav because it takes up space but not in an overwhelming way	Pioneering	Elegant	Refined	3	The flatness of the surface makes it seem minimal and simplistic	the detail that stands out is the white and black contrast and the way its placed, its quite beautiful	2, 3, 4, 5
3	They're all quite similar but the round shapes on them make for a really bold design. The #3 looks like a vessel, which fits the bill for a data processing device.	it's a mix of "organic" and "industrial"	Assertive	Assertive	Elegant	3	Fits into many design contexts elegantly.	It's background architecture.	4
3	Extended wings covering the grid	Wings add some design to this piece of equipment	Empowering	Refined	Elegant	3	Nice proportions and contrasting colors	Simple but elegant	1, 2, 5
1	It looks futuristic	The shapes work together well	Pioneering	Elegant	Refined	2	I like the shape	The two dominant shapes work well	1, 4, 6
3	This one is more simplistic in shape and more visually appealing	The way the light hits it is more visually appealing than the rest	Assertive	Assertive	Elegant	3	The flat shape is more appealing and reminiscent of modern devices	The other two designs sort of resemble airport technology, which I personally have a more negative association with, and the third one just looks more modern	2, 5
3	It's blocky and imposing, which fits the empowering trait	It has a good combination of large direct shapes and lighter, flowing shapes	Assertive	Assertive	Refined	3	It has a few simple, clean shapes that work well together	It's minimalist but it's few layers fit together in an interesting way	4, 5, 6
2	The top/bottom oval shapes make it less heavy looking	Sleek modern look	Elegant	Pioneering	Elegant	1	Thinness and rounded corners	Appears to be smaller than the others in the space	4, 5

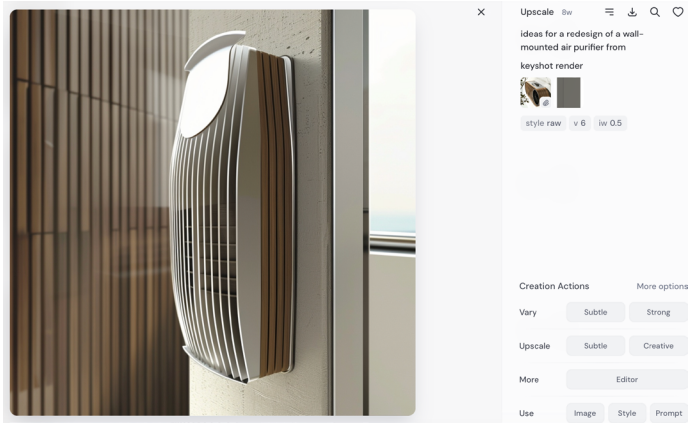
In 1-3 sentences, please share what you like about the designs you selected above.	Are any of the enclosure designs/form factors from this group appeal to you? Please select all that apply.	In 1-3 sentences, please share what you like about the designs you selected above.	**Thinking of all 3 groups presented above |** Considering the fact these devices will be placed on building facades in city centers, which group(s) of designs appeal to you the most? Which group of designs would you like to see on building facades as you're walking around a city center? Please select all that apply.	Please share any thoughts you have regarding your answer above here.	Part of my vision for the design of an enclosure for these devices is expanding their role beyond just being data centers. If you have any **ideas/wishes for what other roles** these facade-mountable devices can serve in city centers, please share them below.
	1, 2, 8		Wrapping Planes, Visual Illusion		
Can understand the sliding quick. And like the idea of having visibility at the front opening	None		Wrapping Planes		
I like the organic shapes. 1 looks like it could sort of merge with the wall	2, 4	2 looks like it could be inside the wall which seems handy for not standing out too much. 4 looks futuristic, bit like evee from wall-e	Wrapping Planes, Something that doesn't stand out on building façades bc there's rules about visual clutter on buildings	Who said the boxes need to stand out? Personally i prefer not seeing any data/monitoring related electronics in daily life	If they generate heat it could be nice for nesting birds or giving the heat back to the house
The curved shapes that wrap the box like leaves	3, 8	They have an interesting brutalist look	Wrapping Planes		Water storage, very useful in cities prone to drought! But then they would get more bulky...
	3, 4, 8		Wrapping Planes		
I like the overall idea, gives a nice organic feel, wrapping material around the data center, while keeping it stylish	7, 8	More traditionnal perceived conception of what a data center casing should look like	Wrapping Planes, Visual Illusion	A combo of visual illusion and wrapping planes would be very nice I believe	Generalized public wifi repeaters (to access basic features like city plans, weather, public annoucement etc) air quality sampling and monitoring (particles, CO2, etc) for starters
Symmetry and rounded features. The others look too cluttered and boring.	7	I like its subtle angled side walls.	Wrapping Planes, Incidentals	All of them look like generic devices that would be placed around the city and make it uglier. They look kind of cheap. Especially the more angled aggressive ones. They look like fancy lamps they placed sometimes on pavements but look out of places instead of improving the aesthetics of the city. Maybe consider more natural or classical shapes too.	Consider where they will be places. It's different to be on the ground and different hanging on the wall. Consider how to explain what the object is and how people will not damage it. It looks very inviting to just damage it and I still do not understand what their function is. Cities do not need more modernist clutter.
Sophisticated design	8	Flat, unobtrusive	Visual Illusion		Bird house or insect home
its hard to describe honestly-just intuitively it seems balanced	1, 2	1: I liked the combined sharp & flowy edges. 2: again the contrast of the materials is nice.	Visual Illusion	you could play around with visual illusions based on where the unit is placed to make it blend well.	
The compactness	4, None	Roundness	Visual Illusion		
Looks embracing, collected, cute, confident but also humble	8, None	Couldl ook pretty sleek	Visual Illusion	Pretty cool to have this interesting object, almost artistic by its asymmetry and illusional characteristics, however you should ask yourself if you want to get that attention for this application, perhaps you do to spark interest in the technology but i can also imagine people would rather have it more subtle and maybe even hidden	In public spaces you could fit them with an interface for navigation and information
Even though they look familiar, theres a unique characteristic to each one of them, varying from how it is to be placed to how it is expected to look	None		Wrapping Planes, Visual Illusion		
Looks elegant but still well-ventilated	3, 8	Cool but not overdone	Wrapping Planes, Visual Illusion	Whatever makes a practically recognizable visual language that doesn't interfere with other elements of the urban tissue (leaning towards wrapping planes)	
Simple but elegant for 1&2, and nice bent front panel for 5	1, 7, 8	Nice proportions , slender shape	Wrapping Planes, Incidentals, Visual Illusion	All 3 groups have plenty objects to enjoy.	To be some kind of art objects in the same time. To use materials/designs that prevents dust/dirt accumulation with time
The shapes work together	3, 6	Shapes work together	Wrapping Planes, Visual Illusion		
I think less is more, and I prefer the more simplistic designs over the more complex. I think when you introduce complexity to the design, it could confuse people more as to what the device is.	7, 8	The more simplistic designs with the rounded edges are more appealing to me.	Incidentals	I personally like the simplicity and curvature of the incidentals group	For some reason, a lot of them resemble modern thermostats to me, but I don't know how commonly those are found in city centers
I like that there's a bit more going on in these designs. I think the others have interesting shapes, but are subtle enough that they seem to be intended to fit in inconspicuously to their environment while the ones I selected are a bit more pronounced.	2, 4, 6	Again, these seem to have more interesting design while some are the other are still good but might blend in with the environment a bit more	Visual Illusion	There are designs in all three groups that I like, but I think the visual illusions group is the most interesting and would make the enclosure design more noticeable	
Organic curves	2, 8	Their slimness	Wrapping Planes	Organic wave shapes break up geometry of building	Surveillance

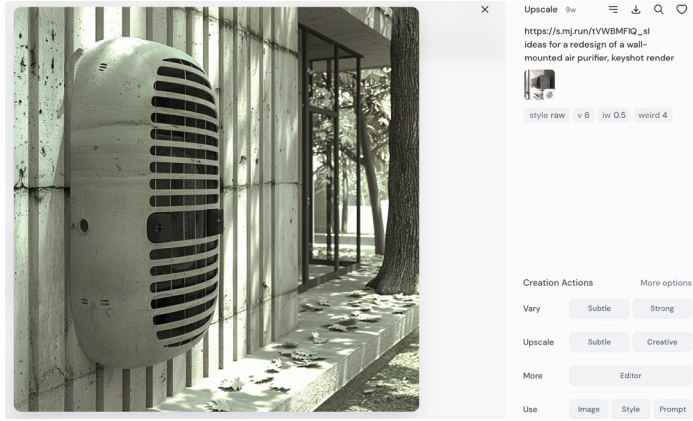
What is your occupation/study?	Which part of the world are you from?	If you enjoyed this topic/project and you'd like to continue being involved in it through another concept selection survey (~2 weeks) and a potential final design feedback focus group/survey (late August/early September), please leave your **email** and **first name** below. Thanks:)	
Arts/design	Europe		
Industrial design	Europe		
Arts/design	Europe		
Arts/design	Europe		
Arts/design	Asia		
Engineering/science/research	Europe		
Arts/design	Europe		
Arts/design	Europe		
Arts/design	Europe		
Arts/design	Europe		
Arts/design	Europe		
Arts/design	Asia		
Arts/design	Europe		
Healthcare	North America		
Healthcare	North America		
Arts/design	North America		
Engineering/technology	North America		
Arts/design	North America		

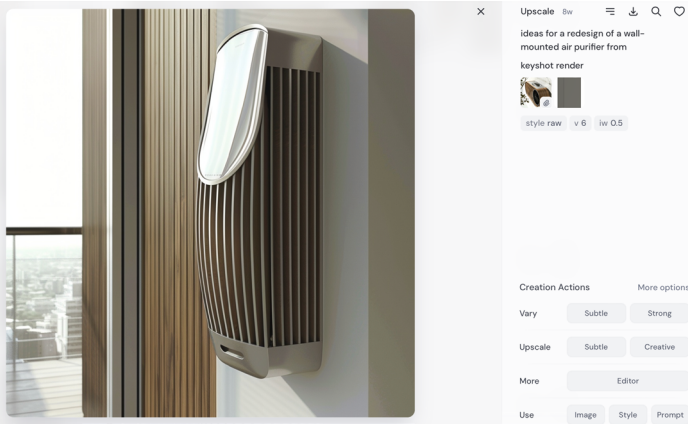
Appendix I | Divergence 2.0 selected MidJourney inspirational material

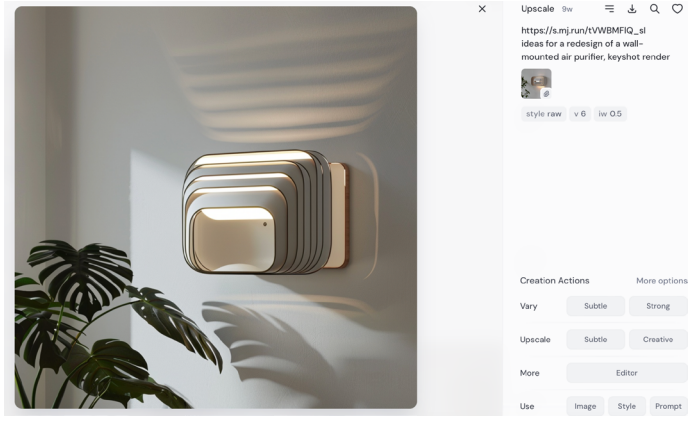
*Image with the paper pin icon is the --sref image for the generation. Small image without the icon is the CAD screenshot.

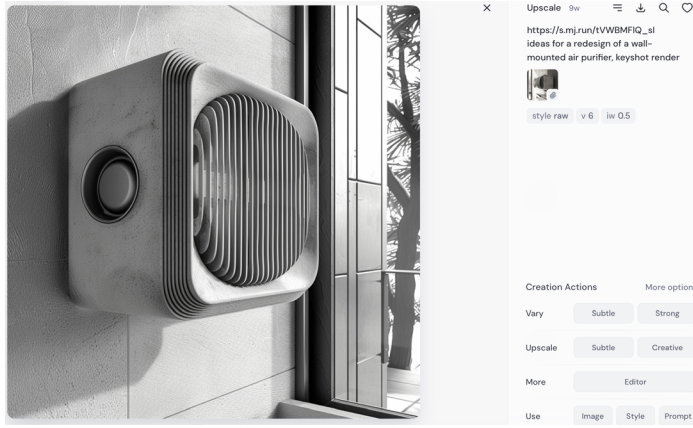


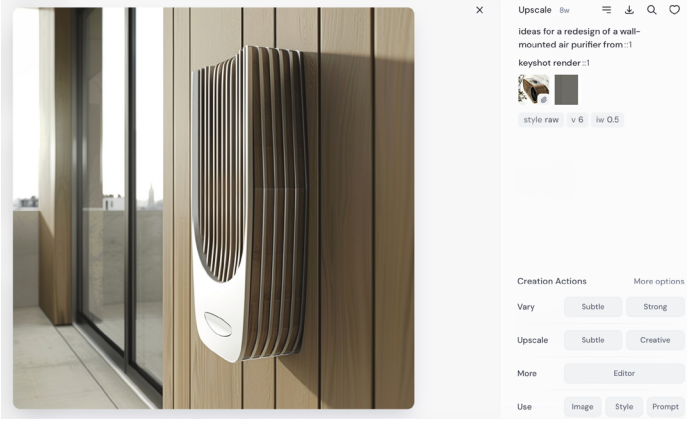


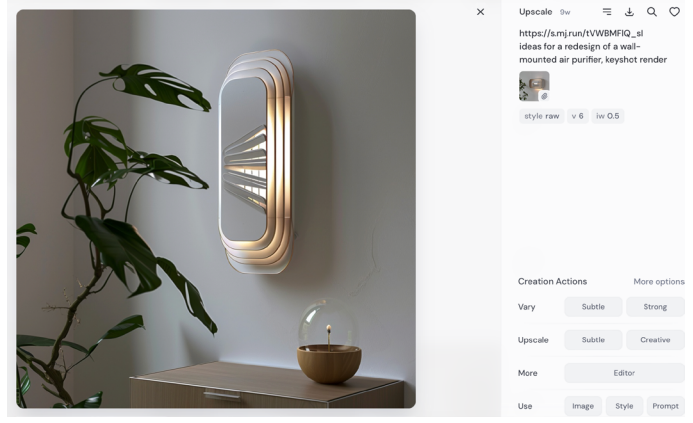


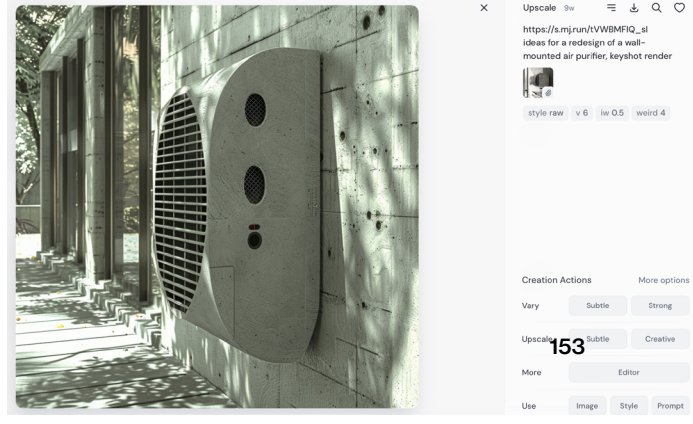












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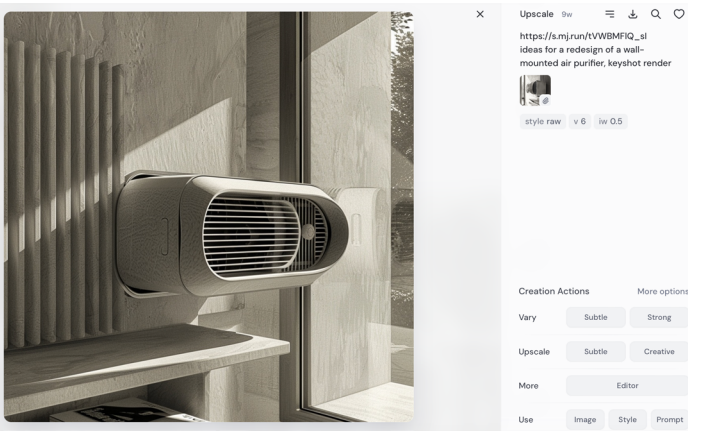
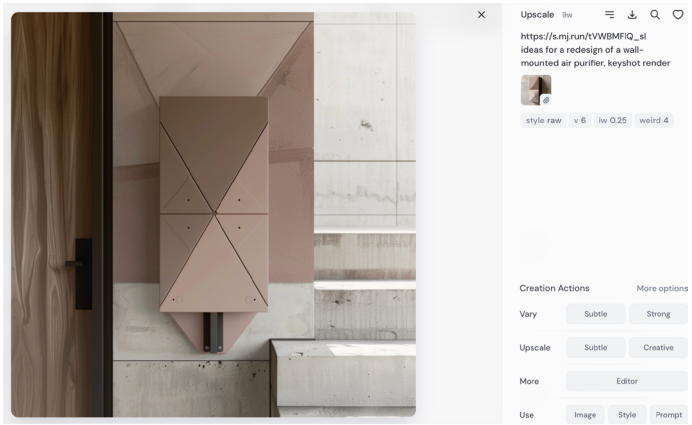
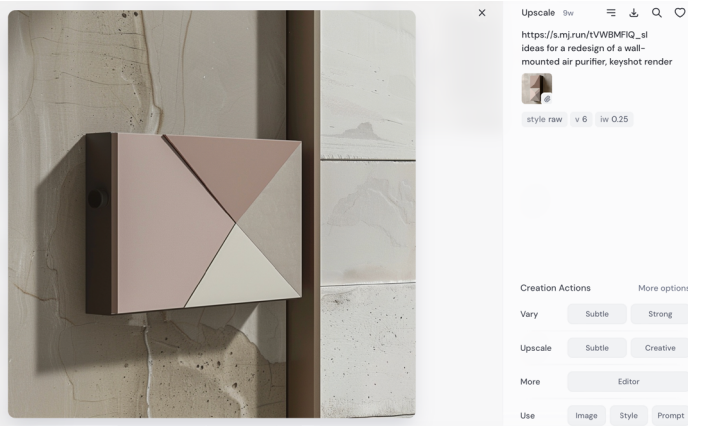
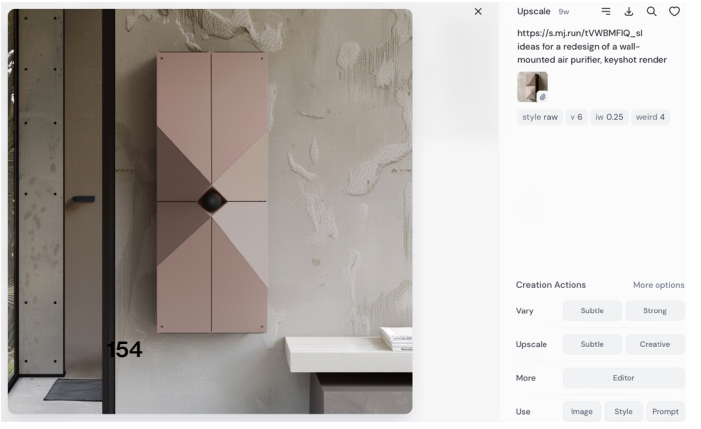








Appendix J | Macro form factor selection

Criteria definitions and conditions to be met to receive a certain ranking

Criterion	Implied meaning & ranking conditions
Blending in while standing out	While EMDC will stand out by its nature of being an external body on a building facade or a wall, this criterion looks at the extent to which a given macro form factor allows EMDC to blend in. Blending in implies that an observer perceives it as something that could 'emerge' or 'grow out' of a wall. - - | The concept stands out by its nature so much that no design iteration/adjustment can significantly 'blend it in' with the wall - | The concept has pronounced features that make it stand out in a significant way, while 'blending in' opportunities are not apparent/easily identifiable + | Concept has a 'blending in' potential, yet more design iterations are required to bring it out + + | Concept has 'blending in' features/nature by default; its main or one of its main characteristics is defined around this property
Expanding EMDC role	This criterion considers the extent to which a given macro form factor helps an EMDC be perceived as something beyond a mountable electronic piece of equipment, specifically focusing on its contribution to the visual appeal of its immediate environment. - - | The concept does not differ significantly in its visual appeal from standard metal box enclosures - | The concept features significant improvements over the standard enclosures, yet it is still expected to be associated with the negative aspects of current public electronic installations + | While still alluding to electronics enclosures to an extent, this concept is expected to bring up positive associations and emotions in its observers + + | Being on the 'functional piece of art' end of the MAYA spectrum, this concept masterfully balanced breaking away from tradiational electronics form factors with being expected to be positively perceived and accepted by the public

Hiro brand identity reflection	A combination of personal take on the extent to which a concept reflects the desired Hiro brand identity with its aesthetics with the client's opinion. - - | A concept completely misses the essence of the desired brand identity (an independent viewer would not be able to to corectly name any keywords or their synonyms in describing macro form factor) - | A concept is expected to communicate 1-2 desired brand identity keywords (an independent viewer would use 1-2 out of 5 keywords or their synonyms in describing macro form factor) + | A concept is expected to communicate 3-4 desired brand identity keywords (an independent viewer would use 3-4 out of 5 keywords or their synonyms in describing macro form factor) + + | A concept nails the desired brand identity (an independent viewer would be able to name all 5 keywords/their synonyms correctly in describing macro form factor)
Appropriateness across all 3 environements	Assessing the appropriateness of a given macro form factor for manufacturing and healthcare (in addition to urban) placement contexts. Appropriateness implies that an EMDC doesn't look out of place (too far on the right side of the MAYA spectrum) in environments other than an urban one. This criterion was assessed based on personal and client knowledge as well as feedback from the focus group participants. - - | A concept is not appppropriate in any of the interest settings - | A concept would be appropriate in the urban setting, but not the other 2 settings of interest + | A concept is appropriate in the urban context and at least 1 out of the 2 other settings of interest + + | A concept is appropriate across all 3 settings of interest
Concept aesthetics visual impact at distance	Especially relevant for an urban environment where EMDCs will be observed at a significant distance, this criterion assesses the degree to which each concept maintains its visual impact when viewed from a distance. - - | The concept loses nearly all of its visual impact/appeal if viewed from a distance - | Concept's most defining characteristic loses its visual impact/appeal at a distance + | Concept retains at least 1 of its defining characteristics if viewed at a distance + + | Concept visual impact/appeal is not affected by viewing distance and can even be enhanced by it

Dependence of visual appeal on environmental factors	This criterion assesses the degree to which the design and visual appeal of a concept depend on environmental factors, especially taking light direction and intensity into account. - - | A concept loses nearly all of its visual appeal if necessary environmental factors are not present or are significantly different - | Concept's visual appeal will be significantly affected if certain environmental factors aren't present; the concept loses at least one of its defining characteristics + | While one of the concept's defining characteristics might be affected by environmental factors, the concept has other characteristics that help it retain its visual appeal + + | Concept design and visual appeal are independent of environmental factors
Mesh-ability	This criterion considers the visual appeal of a given macro form factor when multiple EMDCs are placed in close proximity (a.k.a. meshed). This criterion was assessed by comparing a mesh of 2D footprints for each concept. - - | No way can be imagined that would enable a concept to co-exist with at least one copy of it on a facade - | While currently, a concept co-exists with its copy awkwardly, design interventions/ adjustments can be imagined that would improve this property + | A concept exhibits strong mesh-ability properties with at least 2 EMDCs, some design iterations/adjustments are necessary to take this property further + + | A concept easily meshes with 2+ EMDCs on a facade as it is, minimal to no design interventions/adjustments are required
Compactness with respect to internal hardware	Accounting for the ratio of the enclosure volume to the internal hardware volume. Ratios close to 1 (enclosure tightly encompasses internal hardware, taking up minimal space) are preferred. - - | Cocenpt's form factor does not allow for a reasonably tight enclosure wrap up and would need to be changed completely to do so - | Concept's form factor provides a reasonably tight internal hardware wrap-up, but the extent is determined to be insufficient; the form factor would need to be changed significantly to achieve the desired ratio + | Concept's form factor wraps up internal hardware in a satisfactory manner with minimal adjustments necessary to reach the desired ratio + + | A cocnept would facilitate close internal hardware wrap-up with no to minimal space wasted

Potential for future application scenarios	Opportunities that a given macro form factor presents concerning other possible installation scenarios (mast mounting, integration with small or large telco cell, etc.) with little to no modification to the EMDC enclosure. Criterion assessment and rankings provided by the client.
Customizable parts (Trombe wall) integration ease (expected)	This criterion accesses expected opportunities a given macro form factor presents for integrating customizable parts, specifically the Trombe wall. - - | There's no expected way of adding the Trombe wall in a manner that doesn't negatively alter the concept's aesthetics and perception - | Adding the Trombe wall will lead to significantly different and unfavorable concept's aesthetics and perception + | A way of integrating the Trombe wall can be envisioned that does not deter from the visual appeal of the concept's macto form factor ++ | A concept 'naturally' facilitates the integration of the Trombe wall with its visual appeal benefiting from this additional feature

Weighted criteria matrix

	Weight	1 - **Wrapping planes**	2- **Light & shadow**	3 - **The stack up**
Blending in/standing out	16	9	7	5
Expanding EMDC role	15	6	10	4
Hiro brand ID	15	8	9	5
3 environments	13	8	5	6
Impact @ distance	11	4	9	3
Environment dependence	10	7	5	9
Mesh-ability	8	5	8	5
Compactness	5	8	5	7
Future scenarios	4	9	8	4
Trombe wall	3	5	6	7
Total weight	100	667	718	512

Appendix K | Delft municipality feedback

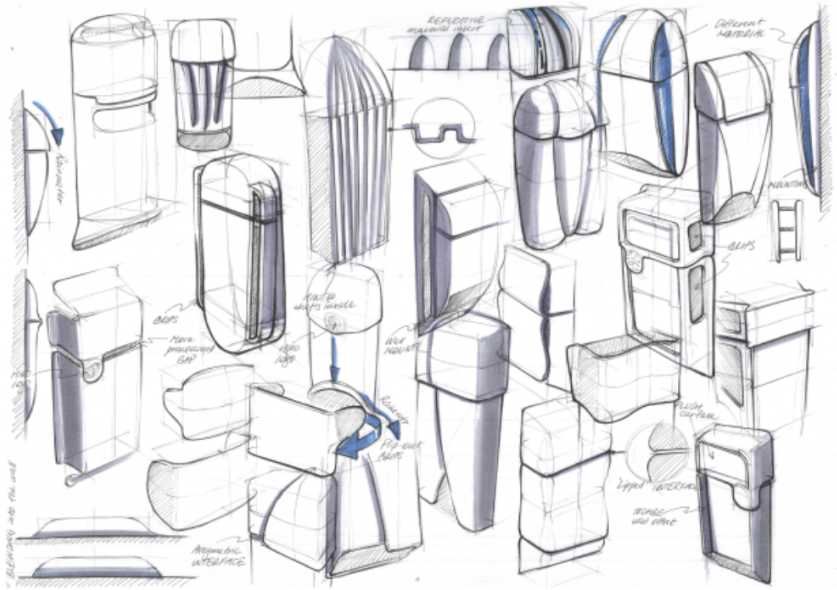
Survey hyperlink | https://forms.gle/ZqHa4xwC396jrxXB8

Macro Form Factor Feedback Form

Hello and thanks for taking the time to fill out this form! My name is Anya, I'm an Integrated Product Design Masters student at TU Delft. I'm currently working on my thesis project for which I'm designing an innovative enclosure for an edge micro data center by Hiro. Your feedback is really valuable in my selection process of the macro form factor direction for my design.

[redacted] Switch account

Not shared



Next

Clear form

Design directions and their concepts

After reviewing the concept from **Direction 1 - Wrapping planes**, what is **your perception** of this concept in the context of **Delft city center**? Do you see this form factor as a **non-disruptive** part of historic urban infrastructure?

1 response

It bothers me that the shape has been placed directly on the historic facade, almost glued. I would prefer the device to have some distance from the masonry.

After reviewing the concept from **Direction 1 - Wrapping planes**, what is **your perception** of this concept in the context of **Delft city center**? Do you see this form factor as a **non-disruptive** part of historic urban infrastructure?

1 response

Fluid shape versus geometric shape (rectangle, cylinder, ...). Personally I prefer a geometric shape. But that's an opinion....

After reviewing the concept from **Direction 1 - Wrapping planes**, what is **your perception** of this concept in the context of **Delft city center**? Do you see this form factor as a **non-disruptive** part of historic urban infrastructure?

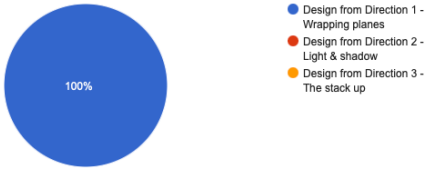
1 response

subordinate, that seems good but is not pronounced

Design from which concept direction do you see appearing in Delft city center within the next 5 to 10 years?

Copy

1 response



Please explain your selection above.

1 response

Direction 1 provided at some distance from the masonry. I think you can do that with the wings. Direction 2 has too much 'will to form', direction 3 might be too 'low profile'

Appendix L | Updated list of requirements and wishes

Requirements/Must-haves	Wishes/Nice-to-haves
Enclosure interaction (I)	
IR 1 | All procedures with EMDC must require common tools only.	
IR 2 | All procedures must be possible to do safely at en elevation.	
IR 3 | 1 person must be able to insert the Data center unit into the Cooling unit.	
IR 4 | 2 people must handle lifting and mounting of the Cooling unit.	
IR 5 | Client company must have a choice between conducting procedures themselves or opting out for assistance by a 3rd party service providers.	
IR 6 | Installer(s) must have clear guidance for each procedure with EMDC.	
IR 7 | Enclosure elements cannot hurt installer(s) at any point during handling it (sharp edges, contact with electricity, etc.)	
IR 8 | Mounting/demounting every unit must take *X minutes* or less	**IW 9 |** Mounting/demounting should be as fast as possible
IR 10 | Mounting/demounting every unit must have *X steps* or less	**IW 11 |** Mounting/demounting should be as easy/user-friendly as possible
IR 12 | Only authorized staff must be able to interact with the EMDC.	
	IW 13 |Various procedures must provide feedback to reassure the user in their successful completion.
Overall enclosure (E)	
ER 1 | Enclosure must provide adequate protection from outside environmental hazards • Enclosure design must aim for IPX4 watertightness level at all interfaces • Enclosure design must aim for IP5X solids protection level • UV resistance accounted for • Scratch resistance accounted for	**EW 1 |** Enclosure should aim for IP67 standard.
ER 2 | Enclosure must prevent forced openings of the EMDC.	
ER 3 | Enclosure must **minimize** it **heating up** from the environment.	**EW 3 |** Enclosure should heat up from the environment as little as possible.
	EW 4 | Enclosures design should optimize material usage/ MCO wrap up.
ER 5 | Enclosure design must account for EMDC assembly.	
	EW 6 | Enclosure should minimize the amount of water that gets inside the Cooling unit through the front opening.
	EW 7 | Core (non-customizable) parts should feature Hiro branding element(s).
ER 8 | Enclosure surface finish must facilitate dirt and dust wash off with rain.	

Data center (DC) unit enclosure (D)	
DR 1 | DC unit enclosure must house 1 row of 11 servers.	**DW 1 |** DC unit enclosure design should be adaptable to accommodate 2 rows.
DR 2 | DC unit enclosure must **protect internal hardware** from damage during shipment and installation.	
	DW 3 | 1 row DC unit enclosure aesthetics should be extendable to 2 rows of nodes.
DR 4 | DC unit enclosure must take measures against bird perching.	
Hardware status indicators (I)	
IR 1 | Each node must have its own hardware status indicator.	
IR 2 | Hardware status indicators' incorporation into the DC unit's enclosure must be appropriate for the outdoors application.	
	IW 3 | Hardware status indicators design should account for the implementation of the second row of nodes.
IR 4 | Hardware status indicators must be positioned in the area surrounding the back PCB.	
IR 5 | Hardware status indicators must be visible... • in high UV context • from the ground level	
	IW 6 | Hardware status indicator's correspondence to its node node should be straightforward.
	IW 7 | Hardware status indicators should obstruct water run off from the DC enclosure as little as possible.
IR 8 | Hardware status indicators must avoid 'personification' of the EMDC.	
	IW 9 | Hardware status indicators design must avoid information overload as much as possible. • possibility to turn the lights off when not needed • adjustable brightness
IR |10 Front opening design must be stylistically appropriate for the selected macro form factor.	**IW 10 |** Front opening design should preserve the 'monolithic' nature of the selected macro form factor.
EMDC powering (P)	
PR 1 | Power button incorporation into the DC unit's enclosure must be appropriate for the outdoors application.	
PR 2 | Power button must be positioned in the area surrounding the back PCB.	
PR 3 | Power button must be an off-the-shelf design.	**PW 3 |** Off-the-shelf solution should provide high degree of customization.

Cables connection (Ca)	
CaR 1 | The enclosure must accommodate 8 Ethernet cables and 1 power cable inlets.	
CaR 2 | Enclosure must accommodate existing/off-the-shelf cable connectors.	
CaR 3 | Enclosure must account for the sizing of existing cable connectors	
	CaW 4 | Cables insertion and removal should be as ergonomic as possible
CaR 5 | Cables compartment must provide a solution for cable slack.	
Mounting/insertion handles (H)	
HR 1 | The handles must prioritize ergonomics over aesthetics.	
Design aesthetics (A)	
	AW 1 | Enclosure design should be mindful of its coexistence with antennas.
AR 2 | Enclosure macro form factor must communicate Hiro brand identity • An independent viewer must use 3/5 Hiro brand identity keywords (or their synonyms) to describe the macro FF	
	AW 3 | Enclosure design should account for EMDCs' scalability • Possibility of multiple EMDCs 'co-existing' on the same facade
AR 4 | Enclosure design aesthetics must incorporate features that help it blend in with its environment in public perception.	
AR 5 | Enclosure aesthetics must offer a solution that is the most advanced design possible, yet still acceptable by the public (MAYA principle).	
AR 6 | Enclosure aesthetics must broaden public's view on the role that edge infrastructure can play in its environment • Edge infrastructure that can enhance the visual appeal of its environment • At least 50% of viewers should identity that EMDC enclosure would beatify their public spaces	
AR 7 | Enclosure aesthetics must offer a 'signature,' 'timeless' design that it looks appropriate across 3 placement contexts of interest • Urban, manufacturing, healthcare	
AR 8 | Enclosure design must avoid personification trait • Being perceived as a person/creature	
AR | Enclosure aesthetics must maintain its desired visual impact when viewed from a distance. • Distance from the ground to the 1st floor level or higher	
	AW 10 | Enclosure aesthetics should be independent of such variable environmental factors as light angle and intensity • Maintain its sticking qualities regardless of possible environment limitations
Sustainability (S)	
	SW 1 | The enclosure material should have *at least 25%* recycled content in it.
	SW 2 | The enclosure material should be 100% recyclable.

Manufacturing & materials (M)	
MR 1 | Selected manufacturing processes and materials must maintain essential form factor elements.	
MR 2 | Selected materials must allow for minimal dirt and dust accumulation.	**MW 2 |** Selected materials should be dust/dirt repellant.
	MW 3 | Enclosure manufacturing should be as cheap as possible • As little post-processing (machining, etc) as possible

Appendix M | Selected cable connectors sizing information

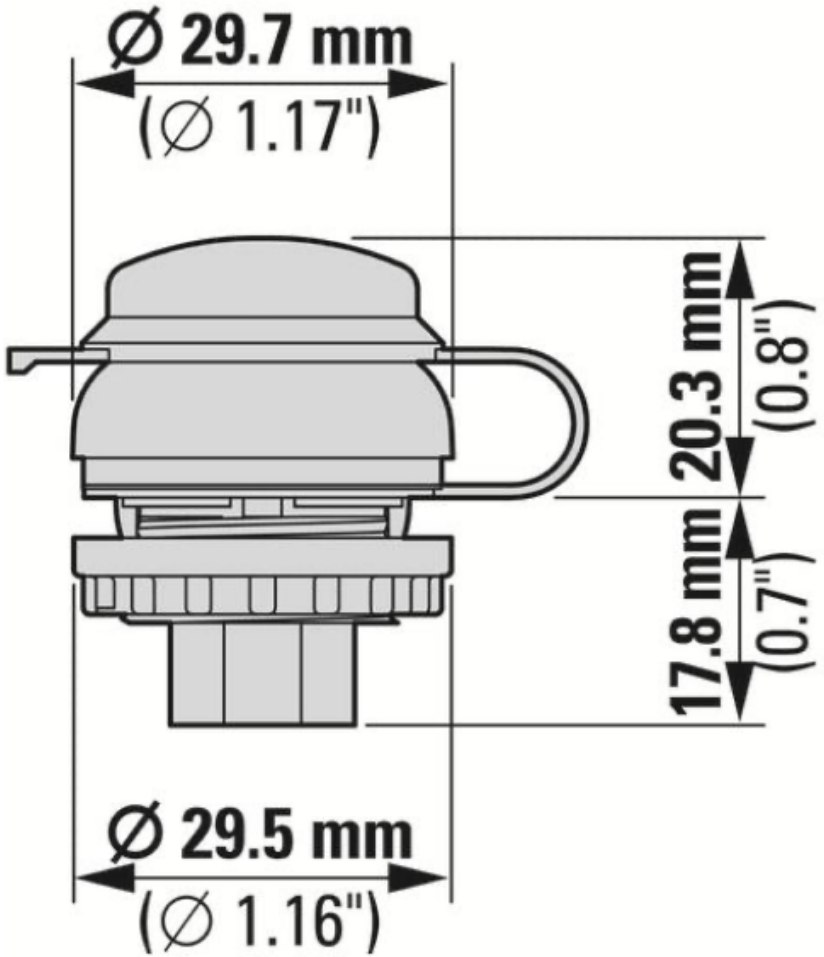


Figure 1 - Eaton RWQ M22 capped cable connector dimensions (*Datasheet - M22-USB*, n.d.).

AMPHE - 309 WATERTIGHT IP67

A309 - ▲ ⬢ C 🕓 W

Amphenol®

CONNECTOR WITH SOCKETS IP67

A 3 0 9 ▲ ⬢ C 🕓 W

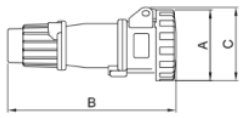
Number of Contacts: 2P+E 3; 3P+E 4; 3P+N+E 5

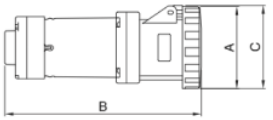
Amperage: 16A 16; 20A 20; 30A 30; 32A 32; 60A 60; 63A 63; 100A 100; 125A 125

Type: Plug, P; Connector Receptacle, C; Receptacle for Panel Mounting, R; Inlet for Panel Mounting, B

Clock Keyway position of female Grounding: 1 to 12

Protection: IP44 S; IP67 W





CONNECTOR IP67 16/20A AND 30/32A

	A		B		C		Corp grip range	
	inches	mm	inches	mm	inches	mm	inches	mm
16/20A 2P3W	2.87	73	6.75	171	2.97	75	.570-.710	14-18
16/20A 3P4W	3.17	81	7.04	179	3.28	83	.570-.710	14-18
16/20A 4P5W	3.48	88	7.62	194	3.75	95	.570-.710	14-18
30/32A 2P3W	3.66	93	8.04	204	4.04	103	.675-.910	17-23
30/32A 3P4W	3.66	93	8.04	204	4.04	103	.675-.910	17-23
30/32A 4P5W	3.96	101	8.83	224	4.03	102	.675-.910	17-23

CONNECTOR IP67 60/63A AND 100/125A

	A		B		C		Corp grip range	
	inches	mm	inches	mm	inches	mm	inches	mm
60/63A 2P3W	4.41	112	10.52	267	4.47	114	.937-1.375	24-35
60/63A 3P4W	4.41	112	10.52	267	4.47	114	.937-1.375	24-35
60/63A 4P5W	4.41	112	10.52	267	4.47	114	.937-1.375	24-35
100/125A 3P4W	5.06	129	12.80	325	5.06	129	1.265-1.790	32-45
100/125A 4P5W	5.06	129	12.80	325	5.06	129	1.265-1.790	32-45

Figure 2 - AMPHE - 309 WATERTIGHT IP67 cable connector dimensions highlighted in pink (*Amphenol*, n.d.).

Appendix N | Internal hardware weight estimation

Due to confidentiality reasons, calculations for ‘Passive cooling solution, component 1’ and ‘Passive cooling solution, component 2’ cannot be shown. These weights were estimated using volume calculations from the CAD software and corresponding material densities.

	Weight (g)	1 row DC unit (kg)
Ethernet switch	350	6.1
PCIE switch	200	
Power board	250	
Compute node	250	
Passive cooling solution (1 row)	300	
Passive cooling solution (additional row)	310	
		Cooling unit (kg)
Passive cooling solution, component 1	38260.992	42.862492
Passive cooling solution, component 2	2821.5	
Clamping mechanism	1500	
Fan	70	

Appendix O | Mounting/ insertion handles design

Initial handle dimensioning breakdown

Handle length = 13 cm | First, DINED (DINED, n.d.) was referenced to check hand width (without thumb) dimension: P50 = 85 mm, P99 = 101 mm (Dutch adults, m+f 20-60, 2004). However, to account for expected hand deformations when handling heavy weights, dumbbell handle length dimensioning (Dumbbell Handle Compare Chart | Fitness Depot, n.d.) was referenced and the average was calculated to equal 130 mm (13 cm). It was decided to proceed with the greater length corresponding to the dumbbell average for an extra margin of safety.

Handle diameter = 3 cm | As no dimension was available on DINED, dumbbell grip diameter dimensions (Dumbbell Handle Compare Chart | Fitness Depot, n.d.) were referenced again and their average (about 30 mm or 3 cm) was assumed for this handle dimension.

Minimum distance from the enclosure = 5 cm | It can be argued that the desired amount for this dimension roughly equals to the 'Hand thickness' DINED dimension (DINED, n.d.). 'Hand thickness' P99 = 40 mm (Dutch adults, m+f 20-60, 2004). An extra 10 mm of clearance was added between the enclosure wall and the outer surface of the hand, resulting in a total of 50 mm (or 5 cm) for the 'Minimum distance from the enclosure' dimension.

Distance between 2 handles = 6 cm (at least) | It can be argued that when viewed from the top, the inner 'clearance' required between two fists can be approximated by doubling the 'Thumb breadth' DINED dimension (DINED, n.d.). 'Thumb breadth' P99 = 27 mm (Dutch adults, m+f 20-60, 2004), which was doubled for 2 hands and rounded off to 60 mm (or 6 cm) for the 'Distance between 2 handles' dimension.

Figure 1 presents a DINED screenshot with all relevant dimensions used for handle sizing determinations.

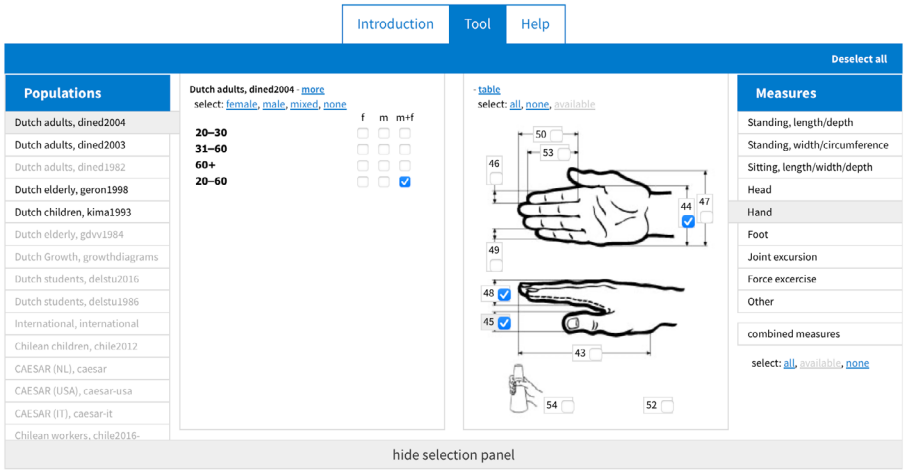


Figure 1 - DINED screenshot with all relevant dimensions

Quick-release pin sizes calculations

$\tau = \frac{F}{A}$, where τ = shear stress (MPa)

↳ τ stainless steel = 74.5 – 597 MPa (shear strength) — more conservative

F = applied force (N)

A = cross-sectional area subject to shear F (m^2)

↳ $A = \pi\left(\frac{d}{2}\right)^2$, d = pin diameter (mm^2)

$A_{M6} = \pi\left(\frac{6}{2}\right)^2 = 9\pi \cong 28.27\ mm^2$

$A_{M8} \cong 16\pi \cong 50.27\ mm^2$

$F_c = \frac{m_c \times g}{4} = \frac{46\,kg \times 10\,m/s^2}{4} = 115\,N$

$F_{DC} = \frac{m_{DC} \times g}{4} = \frac{10\,kg \times 10\,m/s^2}{4} = 25\,N$

$\tau_{M6,C} = \frac{F_C}{A_{M6}} = \frac{115\,N}{28.27\,mm^2} \cong 4.06\ MPa$

$\tau_{M8,C} = \frac{F_C}{A_{M6}} \cong 2.29\ MPa$

$\tau_{M6,DC} = \frac{F_{DC}}{A_{M6}} = \frac{25\,N}{28.27\,mm^2} \cong 0.88\ MPa$

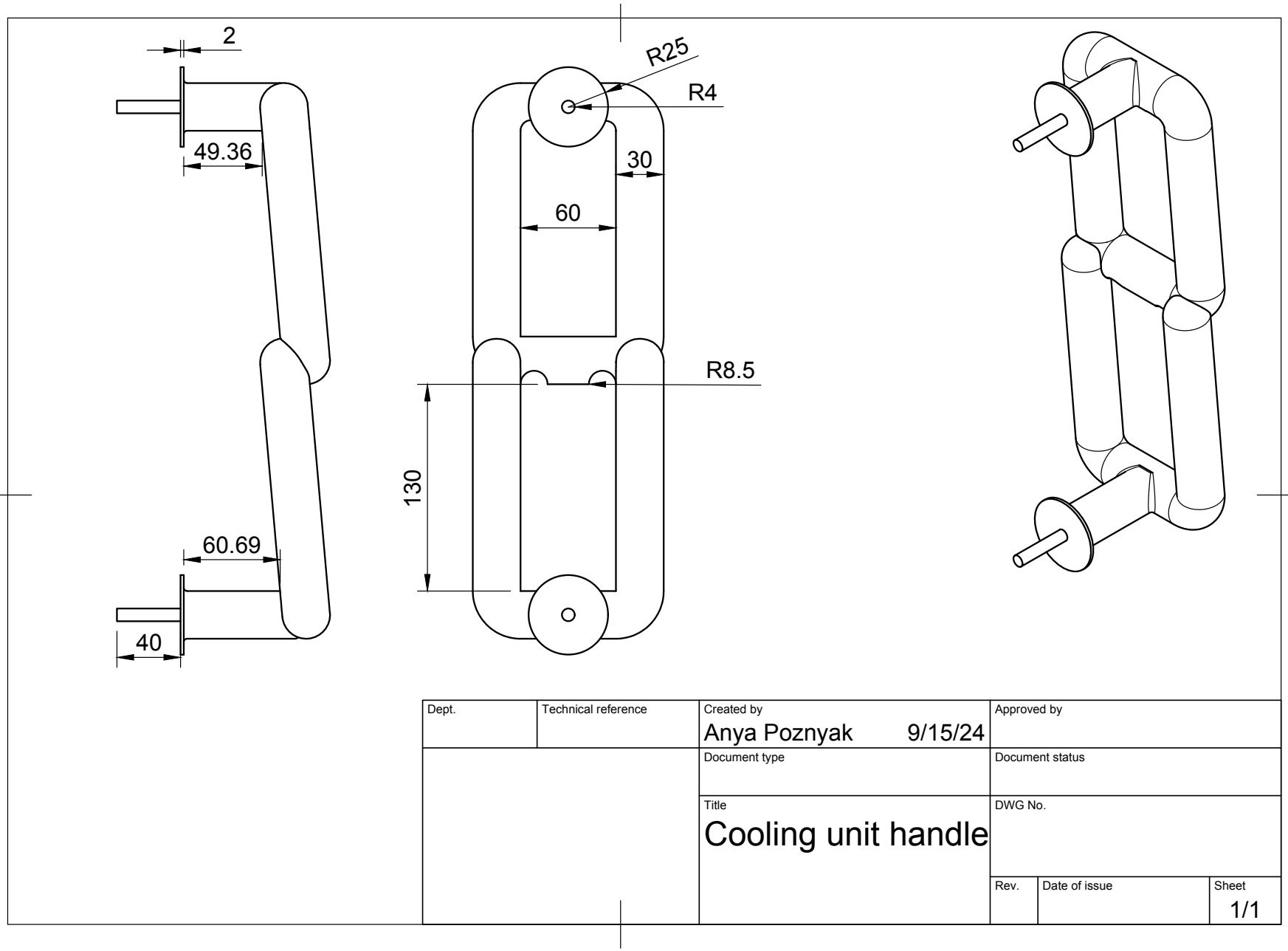
$\tau_{M8,DC} = \frac{F_{DC}}{A_{M8}} = \frac{25\,N}{50.27\,mm^2} \cong 0.50\ MPa$

All 4 shear stress values are significantly under the more conservative estimate of stainless steel shear strength (74.5 MPa). M6 pin is chosen as sufficient solution for the DC unit. For extra safety margin due to heavy weight, M8 pin is selected for the Cooling unit.

Sources:

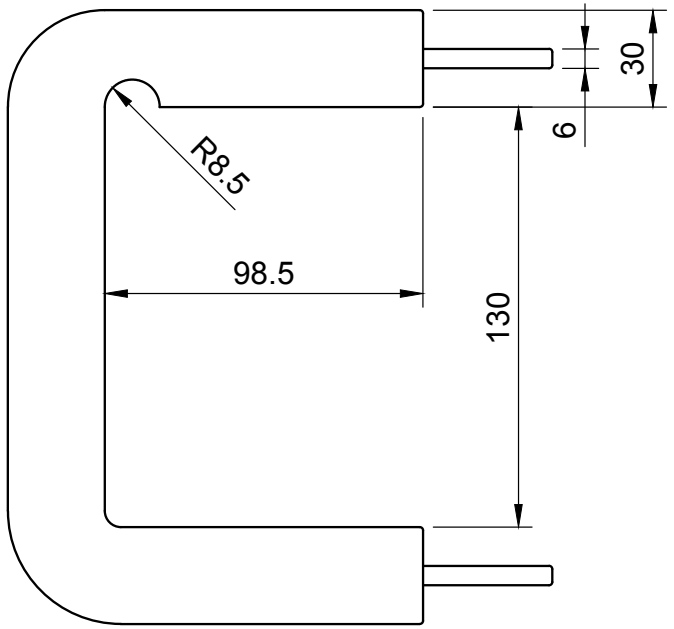
https://www.matweb.com/search/datasheet_print.aspx?matguid=71396e57ff5940b791ece120e4d563e0

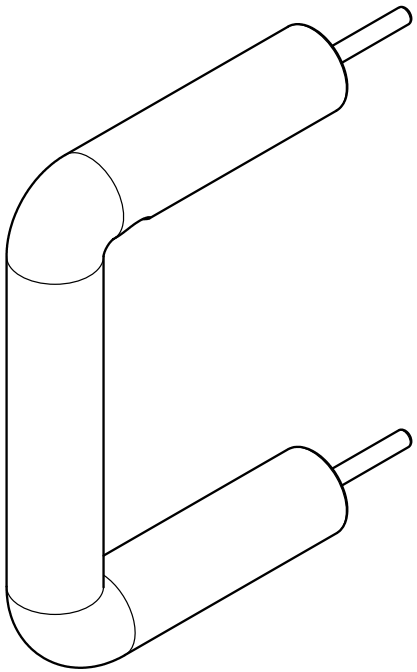
Cooling unit handle drawing



Dept.	Technical reference	Created by Anya Poznyak 9/15/24	Approved by
		Document type	Document status
		Title: Cooling unit handle	DWG No.
			Rev. / Date of issue / Sheet 1/1

DC unit handle drawing

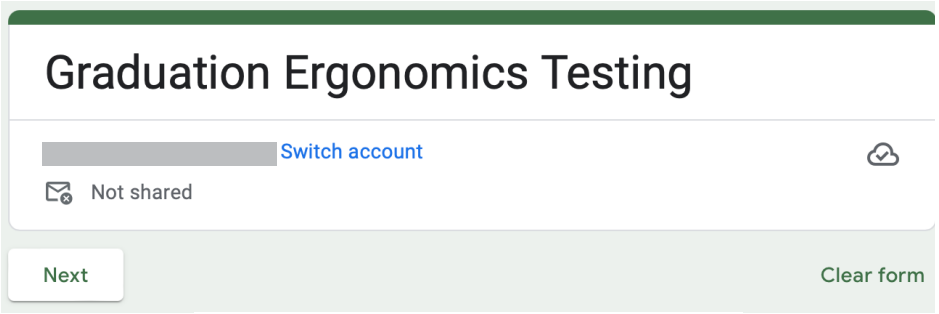




Dept.	Technical reference	Created by Anya Poznyak 9/15/24	Approved by
		Document type	Document status
		Title: handles	DWG No.
			Rev. / Date of issue / Sheet 1/1

Appendix P | Mounting/insertion handles design

Survey hyperlink | https://forms.gle/9o13vASGFVKZfMyd6



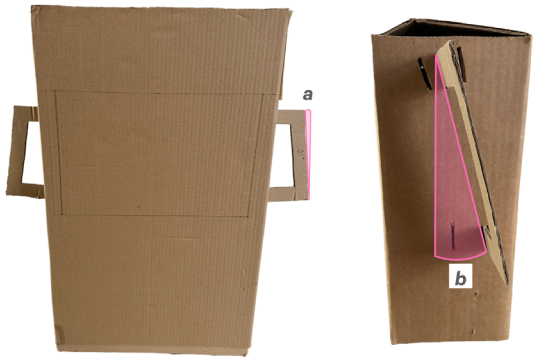


Figure 1 - Handle tilt angles under investigation.

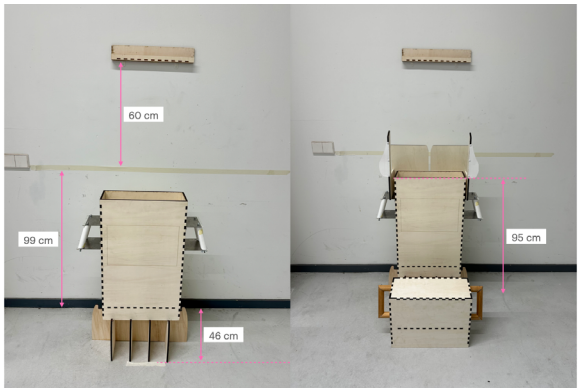


Figure 2 - Two set-ups used during different parts of the experiment and the dimensions involved.

Research summary

Research questions |

1. What tilt angle (a, Figure 1) of the Cooling unit handles will yield the least straining lifting and mounting experience?
2. How hard do participants find it to align the mounting bracket on the wall with the Cooling unit's mounting hooks, given the proposed hand positioning on the Cooling unit?
3. What tilt angle (b, Figure 1) of the Data Center unit handles will yield the least straining insertion experience?
4. Does the proposed sleeve design with slated sides and a back rib provide sufficient guidance and affirmation of the successful insertion of the Data Center unit into the Cooling unit?

Hypotheses |

1. Participants will prefer the 15-degree tilt angle as it corresponds to a more natural wrist position.
2. Participants will find it harder than not when it comes to aligning the mounting bracket on the wall with the Cooling unit's mounting hooks (mean ranking below the global average).
3. Participants will prefer the 15-degree tilt angle as it corresponds to a more natural wrist position.
4. Proposed sleeve guiding features are expected to provide sufficient guiding of the DC unit.

Methods |

Participants |

All participants were male between the ages of 18 and 30. Half of the participants had professional experience (getting paid to perform this kind of work) in lifting/mounting work.

Equipment | Main equipment in this research included:

- Cooling unit prototype (46 kilograms total weight)
- PLA 3D-printed replaceable handles (6x; 5, 10, 15 degrees) placed in between 2 steel brackets.
- Cooling unit stand
- Mounting bracket on the wall for Cooling unit alignment
- DC unit prototype (8.7 kilograms total weight)
- Two wooden handles
- Sleeve prototype
- Paper flaps attached with pins
- A camera on a tripod

All prototypes were created using 9-millimeter plywood boards that were laser cut and glued. It must be noted that both unit prototypes were created after the sizing of the preliminary CAD enclosure presented in Appendix E.

Observations and audio and video recordings were utilized throughout the experiment. Figure 2 on previous page presents two set-ups used during different parts of the experiment and the dimensions involved.

Procedure |

After entering the test location, participants were asked to put on the safety shoes. They were then first shown a few slides, familiarizing them with the product and its parts as well as the main activities of the first-time installation that they would be asked to perform. Participants were them given an opportunity to review a consent form and sign it. Participants were given gloves to use during the experiment for better grip and to avoid hurting themselves on any sharp edges of the prototypes. After that, the experiment proceeded in two main parts:

Part 1 | Cooling unit lifting and placement against the wall bracket

1. **Test part introduction** | Participants were first read the following paragraph out loud: “In this first part of the experiment, you’re asked to perform the first half of the EMDC installation, which involves lifting up and mounting the Cooling unit. As you might already know, the Cooling unit weighs 46 kg, so each of you is expected to handle 23 kg. The main point of interest during this part of the experiment is the angle tilt of the handles and which one you prefer for the tasks in this part. We’ll be testing 3 different handle angles, which I’ll change in between the runs. I’ll ask you to fill out a few questions about the tilt angle you just experienced as I’m changing the angles. The second point of interest in this part of the experiment is putting the cooling unit against the wall. After squat lifting and standing up straight with the unit, I’d like you to pay attention to your elbows and readjust for any height differences present so that each of you has elbows bent at about 90 degrees (demo it quickly). Then grab the unit on its bottom one by one. Please decide who’s going first now (let them decide). My suggestion would be to keep the hand towards the front of the unit on the handle. You should feel a knob that is meant to help you control the unit better on the bottom inside the enclosure. Next, I’d like you to put the unit against the wall, aiming to insert the hooks on the Cooling unit (show them) into the bracket (show it) without letting it hang down (we’re not actually mounting the unit in this test). Instead, unhook the Cooling unit and readjust your hands to the initial lifting position, where they’re side by side (again, the first person goes first). Lower it back on the stand for the next angle iteration. So to summarize, in each interaction I’d like you to pay attention to how a given handle tilt angle in combination with the knob assist you in completing the tasks. Do you have any questions?”
2. **Pre-test questions** | Participants were asked to fill out one question concerning their height.
3. **Main tasks** | Participants were asked to perform the sequence of Coo-

ling unit lifting and mounting tasks described in the introductory paragraph above. As the moderator was changing the handles in between experiment sets (the handles were inclined away from the participants to align with the natural wrist position), participants were asked to fill out a few questions pertaining to the handle tilt that they just worked with. This sequence repeated three times corresponding to the three handle tilt angles under investigation.

4. **Post-task tasks** | Once participants tried out all three handle tilt angles, they were asked to fill out the last few questions in the Google Forms survey pertaining to the Cooling unit lifting and mounting experience overall. In the meantime, the moderator prepared for the next part of the experiment by attaching the sleeve to the Cooling unit.

Part 2 | DC unit insertion

1. **Test part introduction** | Participants were first read the following paragraph out loud: "The second part of the experiment simulates the insertion of the Data Center (or DC) unit into the Cooling unit. As you can see I added an additional piece to the Cooling unit, which I call a sleeve (point at it/touch it). One of the main functions of this part is to help an installer align and guide the DC unit in. In this part of the experiment, I'll ask you to pick up the DC unit from the floor; I'd suggest the following hand positioning (show them). I'd like you to then use the wing guides on the sides to start sliding the DC unit down. As you can see, there's also a back slit on the sleeve that you need to align with the rib in the back of the DC unit in order for it to slide in. We'll be again testing 3 different handle angles, which I'll be switching out between the runs while I ask you to fill out a few questions about the angle that you just experienced. Any questions?"

2. **Main tasks** | Participants were asked to perform the sequence of DC unit insertion tasks described in the introductory paragraph above. As the moderator was changing the handle tilts (which were again pointed away from the participants to align with the natural wrist position) in between experiment sets, participants were asked to fill out a few questions pertaining to the handle tilt they just experienced. Again, this sequence repeated three times corresponding to the three handle tilt angles under investigation.

In both parts of the experiment, the angles were changed from the smallest (5 degrees) to the largest (15 degrees). This was done due to the hypothesis that the 15-degree tilt angle, corresponding to a more natural wrist position in both scenarios, will be preferred, so participants will have less trouble completing the tasks in each part for the third and last time with this tilt angle.

The experiment concluded with participants reflecting on overall EMDC interaction via Google Forms and answering a few demographic questions. All questions asked during the experiment can be accessed via the link provided earlier in this appendix.

Data collection & analysis | During the experiment, data was collected using a Google Forms survey. The results were then exported to Google Sheets, where basic statistical analysis (mean and standard deviation values) was performed. Each experiment iteration was also recorded on a camera.

Results |

1. What tilt angle of the Cooling unit handles will yield the least straining lifting and mounting experience? 5 degrees - slightly lower average, yet also smaller standard deviation. When asked directly after experiencing all 3 angles, participants were tied in their preference between 5-degree and 15-degree tilt. A slight increase in the comfort of the 15-degree option was sacrificed for a more consistent and less variable user experience fro the 5-degree tilt.

- *If you had to do this sequence of tasks (squat lifting the unit and putting it against the wall) just once with your handle of choice, how physically straining would you find this task?* The data suggests that, on average, the task was perceived as relatively easy, but there is noticeable variability in how different people experienced the difficulty of the task. This variability is reflected in the standard deviation, which is moderately high compared to the scale (1-5). Interestingly, the participants who identified that they had professional experience in the tasks gave all the non-perfect scores.

- *On a scale from 1 to 5, how comfortable did the space between your fist knuckles and the unit enclosure feel to you?* 5/5 - proceed with

this spacing.

- *On a scale from 1 to 5, how comfortable did the space between your fists (the space between the handles) feel to you?* 5/5 - proceed with this spacing.

- *How physically comfortable did you find the suggested hand positioning (one hand on the handle, another one on the bottom of the unit) for aiming at the mounting bracket with the unit?* 3.67 average with a standard deviation of 0.52 indicates that participants consistently found this hand positioning acceptable, yet not perfect. Since no one gave a rating of 1 or 2, no comments were left with regards to how can this hand positioning be made better.

- *To what extent did the placement and size of the knob inside the Cooling unit assist you in placing it against the wall?* An average of 3.33 with a standard deviation of 1.21 (36% of average) indicated that while on average participants found the size and placement of the knob more helpful than neutral, there was some variation in opinions. One suggestion was to begin with the proposed hand position (one hand on the handle, the other grabbing the bottom of the unit) from the very start. Another suggestion was to design the knob similar to a door handle.

2. How hard do participants find it to align the mounting bracket on the wall with the Cooling unit's mounting hooks, given the proposed hand positioning on the Cooling unit? Overall a mean of 4 indicates that participants found it relatively easy to aim at the bracket, yet a high standard deviation (0.89, 22% of the mean) indicates that there was high variability across participants' perceptions. A concern over being even farther from the bracket in a real-life scenario was voiced, with a suggestion that the mounting bracket should protrude from the wall as much as possible.

- *On a scale from 1 to 5, how difficult did the height difference with your colleague make it for you to accomplish the tasks in this part of the experiment?* Mean was 1.33 and even though a standard deviation of 0.52 seems relatively high compared to the mean (over 50%), the fact that responses were consistent at 1s and 2s indicates that overall difference in height with a colleague was not a factor that leads to significant physical discomfort. No correlation between whether the taller or shorter person in the pairing experienced greater physical comfort was established. Still, minimizing the height difference between the installers would be recommended as participants from the group that had no height difference both gave the lowest score to this question, indicating that they 'didn't mind it/didn't notice it.'

- *Additional comments.* 2 out of 4 comments were centered on the transition between the squat lifting hand position to holding the bottom, with one suggestion to add a 'middle connection point' and another suggestion to decrease the distance between the bottom and the handles. Another relevant suggestion was to add a use cue on the bottom of the Cooling unit for hand placement.

3. What tilt angle of the Data Center unit handles will yield the least straining insertion experience? After experiencing all 3 handles, the majority of participants (67%) indicated the 10-degree tilt as the most physically comfortable to them. Looking at the rankings specific to each handle tilt also backs up this result. The 10-degree tilt has an overall highest average at 4.33. 5-degree tilt has a slightly lower average at 4.16. Variability was around the same, relatively insignificant level compared to the mean for both tilts. 15-degree tilt angle scored the lowest average (3.67) and had significant differences in perceptions of this option (1.21, 33%).

- *If you had to insert the DC unit just once with your handle of choice, how physically straining would you find this task?* With an average of 4.83 and very low variability in responses, it can be claimed that this task is easy to perform in terms of physical strain.

- *How physically comfortable did you find the suggested hand positioning on the handles?* Participants were allowed to come up with their own hand positioning. The average for this question was 4.67 (0.82, 17%), indicating that participants rather consistently found their selection of hand positioning to be nearly perfect for performing the task. These results suggest that no specific instructions in terms of hand positioning on the handles are necessary for this task.

4. Does the proposed sleeve design with slated sides and a back rib provide sufficient guidance and affirmation of the successful insertion of the Data Center unit into the Cooling unit?

- *To what extent did the sleeve aid you in guiding the DC unit into the Cooling unit?* As the sleeve had to be removed due to malfunctioning for the first 2 participants, these 2 data points were disregarded. For the 4 remaining data points, on average (3.25) it can be argued that participants found this feature to be slightly more helpful than not in guiding the Data Center unit in. However, variability of opinions was also relatively high (1.5, 46%). Looking at the comments of participants who gave lower scores, the back slit and rib were perceived to be helpful, while the side design can be improved by shortening the wings. The moderator also observed that typically one participant was struggling to understand how the insertion works on their first attempt, however once figured out, the next two attempts seemed smoother for them.

- *How uncomfortable/distracting did you find the paper attachments to the sleeve to completing the insertion task?* No participant had a problem with this feature.

- *What elements of the experience reassured you in the successful and complete insertion of the DC unit into the Cooling unit?* The feature that was the most helpful to participants was the back slit/rib (66.7%). 'Firm contact between the units at the end of insertion' and 'Following the sleeve side guides' only received 2 votes out of 6 (33.3%). However, it must be noted that the functionality of the side guidance of the sleeve was limited due to time constraints in prototyping.

- *How physically comfortable did you find the initial height of the sleeve/ Cooling unit for inserting the DC unit into it?* The average of 4.67 indicates that the initial sleeve height was perceived as very physically comfortable. The perception was rather consistent with only 1 response deviating from the maximum score of 5 (0.82, 17%).

Overall experience |

- *Imagine you're an installation professional and that you had to perform the entire EMDC installation (lifting and mounting the Cooling unit + inserting the DC unit) once. Given that all of your suggestions and feature choices would be implemented in the design, how physically straining would you find the entire EMDC installation procedure?* Overall, a mean of 4.33 indicates that the entire EMDC installation procedure was perceived as acceptable in terms of physical strain. The variability of responses was also relatively low (0.82, 19%), indicating consistency of this perception.

- *On a scale from 1 to 5, how clear/intuitive was the installation procedure to you after receiving the instructions?* A high mean of 4.5 suggests that the installation procedure felt very intuitive and straightforward to participants. Standard deviation analysis also shows that this opinion was highly consistent (0.55, 12%).

Final comments from participants |

- The side walls felt flimsy when guiding the DC unit and to me they felt superficial

- The mounting bracket could be redesigned a bit more, but the sleeves and ribs for mounting the DC unit onto the cooling unit is a good idea

Limitations |

- Uneven, unrealistic weight distribution/center of mass in the model (all the weight rested on the bottom of the units).

- Inaccuracies of the Cooling unit's handles tilt angles and other dimensions due to manual construction of the steel brackets (inaccuracies in drilling of the holes, etc.).

- Only half of the participants had professional experience in the task they were asked to perform, while people who would be performing this installation are professionals in it.

- Participants were not explained the meshing action that happens during unit's insertion, which might have influenced their ranking of the necessity of additional insertion affirmation features.

Data analysis and survey answers

Timestamp	How tall are you (cm)?	Height difference	**5-degree handle tilt |** On a scale from 1 to 5, how physically comfortable did you find this tilt angle for performing the tasks?	If you gave a score between 1 and 3 in the question above, please mention what physical discomforts you experienced in this scenario (think any undesired/unpleasant strain to your wrists, lower back, etc)? Please answer in 1-3 sentences.	**10-degree handle tilt |** On a scale from 1 to 5, how physically comfortable did you find this tilt angle for performing the tasks?	If you gave a score between 1 and 3 in the question above, please mention what physical discomforts you experienced in this scenario (think any undesired/unpleasant strain to your wrists, lower back, etc)? Please answer in 1-3 sentences.	**15-degree handle tilt |** On a scale from 1 to 5, how physically comfortable did you find this tilt angle for performing the tasks?	If you gave a score between 1 and 3 in the question above, please mention what physical discomforts you experienced in this scenario (think any undesired/unpleasant strain to your wrists, lower back, etc)? Please answer in 1-3 sentences.	Now that you have experienced all 3 handle tilt angles, which angle resulted in the best experience in terms of physical comfort for you?	If you had to do this sequence of tasks (squat lifting the unit+putting it against the wall) just once with your handle of choice, how physically straining would you find this task?	On a scale from 1 to 5, how comfortable did the space between your fist knuckles and the unit enclosure feel to you?	If you selected 1 or 2 in the previous question, how can this space be improved? Please be as specific as possible (e.g. increased by 3 cm)	On a scale from 1 to 5, how comfortable did the space between your fists (the space between the handles) feel to you?	If you selected 1 or 2 in the previous question, how can this space be improved? Please be as specific as possible (e.g. increased by 3 cm)	How physically comfortable did you find suggested hand positioning (one hand on the handle, another one on the bottom of the unit) for aiming at the mounting bracket with the unit?	If you selected 1 or 2 in the previous question, is there an alternative hand positioning that you can think of that would make this task easier for you? Please be as specific as possible.	To what extent did the placement and size of the knob inside the Cooling unit assist you in placing it against the wall?
8/12/2024 11:52:17	194		4		3	It felt a bit less natural than the 5 degree one	3	Again it felt less natural than the first one and more heavy on hand and wrist	5 degrees	3	5		5		4		2
8/12/2024 11:53:43	178	16	4		3	More pressure on the thumb side of the hand near the top.	3	More or less the same sensation as the 10° tilt, where there is more pressure on the top thumb side of the hand.	5 degrees	5	5		5		4		5
8/12/2024 14:35:54	185		3	It is quite difficult to get it from the ground due to the straight angle (lots of shear force). If it's from the ground, it works fine	4		5		15 degrees	2	5		5		3		4
8/12/2024 14:36:31	176	9	5		4		3	My wrists felt a little bit of strain due to the inward tilt of the handles	5 degrees	4	5		5		4		3
8/12/2024 15:31:56	165		4	I would give it a 2.5, as it is a tad bit harsh on the fingers while lifting	4	Was very easy and the work was done in seconds	5	Was the easiest of them all, had more control over the mounting procedure compared to the other grips	15 degrees	5	5		5		4		2
8/12/2024 15:35:42	165	0	3	Locking onto the mounting bracket felt a bit difficult towards the end. It just wasnt smooth.	4		5		15 degrees	5	5		5		3		4
			3.833333333				4								3.666666667		3.333333333
			0.7527726527				1.095445115								0.5163977795		1.211060142
															0.140835758		0.3633180425

If you selected 1 or 2 in the previous question, how can this feature be improved to be more helpful? Please be as specific as possible (e.g. increased in size twice, moved down by 1 cm, etc)	How easy did you find it to aim at the mounting bracket?	Comments about previous question	On a scale from 1 to 5, how difficult did the height difference with your colleague make it for you to accomplish the tasks in this part of the experiment?	If you have any other suggestions of how can Cooling unit lifting/mounting experience be improved in terms of physical ergonomics, please leave them here.	**5-degree handle tilt |** On a scale from 1 to 5, how physically comfortable did you find this tilt angle for performing the tasks?	If you gave a score between 1 and 3 in the question above, please mention what physical discomforts you experienced in this scenario (think any undesired/unpleasant strain to your wrists, lower back, etc)? Please answer in 1-3 sentences.	**10-degree handle tilt |** On a scale from 1 to 5, how physically comfortable did you find this tilt angle for performing the tasks?	If you gave a score between 1 and 3 in the question above, please mention what physical discomforts you experienced in this scenario (think any undesired/unpleasant strain to your wrists, lower back, etc)? Please answer in 1-3 sentences.	**15-degree handle tilt |** On a scale from 1 to 5, how physically comfortable did you find this tilt angle for performing the tasks?	If you gave a score between 1 and 3 in the question above, please mention what physical discomforts you experienced in this scenario (think any undesired/unpleasant strain to your wrists, lower back, etc)? Please answer in 1-3 sentences.	Now that you have experienced all 3 handle tilt angles, which angle resulted in the best experience in terms of physical comfort for you?	If you had to insert the DC unit just once with your handle of choice, how physically straining would you find this task?	How physically comfortable did you find suggested hand positioning on the handles?	If you selected 1 or 2 in the previous question, are there other ways you'd rather position your hands on the handles? Or perhaps even an alternative handle design in general? Please be as specific as possible.	To what extent did the sleeve aid you in guiding the DC unit into the Cooling unit?	If you selected 1 or 2 in the previous question, what kind of guidance would be more helpful to you for inserting the DC unit into the Cooling unit?	How uncomfortable/distracting did you find the paper attachments to the sleeve to completing the insertion task?
I think having to do 2 handles makes it harder also easier to lose grip. If it could be grabbed from the second position it might be easier to lift(like full process)	5		2	Maybe have a middle connection point. That helps you change positions without having to do a weird movement that can cause fatigue or injury	5		5		5		10 degrees	5	5		3		5
	5		1		4		5		5		10 degrees	5	5		3	The sleeve didn't allow for the unit to go in.	5
	3		1	Have a physical cue for the second hand that construction workers know they need to place their hand there. Maybe a hand grip with texture or one that slightly follows the shape of a hand.	4		3	The angle feels less natural than the 5 degree handle.	2	Orientation feels more difficult than the 5 and 10 degree handles	5 degrees	4	3		2	The guidance on the back and the slot were nice. However, the guidance on the side were in the way when inserting it. You have to be exactly in front of it will it insert correctly.	5
	3		2	Nothing that I can think of	5		4		3	I found it just a little bit hard to find the gap to slide it in. Other than that the handles made no difference.	5 degrees	5	5		2	I think keeping the arms a bit shorter (if possible), as it kind of obstructs the view	5
There can be a knob shaped like a doorknob which would've provided more stability and control over the cooling unit	4	Wrist bending in a weird way, causes strain	1	The distance between the handle and the bottom can be decreased	4		5		4		10 degrees	5	5		4		5
	4		1		3	There was no strain as such. But i prefer a inclined grip for the ease of lifting. The weight os light enough for there to be any discomfort.	4		3	Same reason as 5 degrees	10 degrees	5	5		5		5
	4		1.333333333		4.166666667		4.333333333		3.666666667			4.833333333	4.666666667		3.25		5
	0.894427191		0.5163977795		0.7527726527		0.8164965809		1.211060142			0.4082482905	0.8164965809		1.5		0
	0.2236067977		0.3872983346		0.1806654367		0.1884222879		0.3302891295			0.08446516354	0.1749635531		0.4615384615		0

What elements of the experience reassured you in the successful and complete insertion of the DC unit into the Cooling unit?	If you selected 'Other' or 'I didn't feel reassured' above, can you please elaborate on your answer? Please be as specific as possible and answer in 1-3 sentences.	How physically comfortable did you find the initial height of the sleeve/Cooling unit for inserting the DC unit into it?	If you selected 1 or 2 in the previous question, what physical discomforts did you experience (strain in your lower back/biceps, etc)? How can this height be changed to make the experience more physically comfortable for you? Please be as specific as possible.	If you have any other suggestions of how can DC unit insertion experience be improved in terms of physical ergonomics, please leave them here.	Imagine you're an installation professional and that you had to perform the entire EMDC installation (lifting and mounting the Cooling unit + inserting the DC unit) once. Given that all of your suggestions and feature choices would be implemented in the design, how physically straining would you find the entire EMDC installation procedure?	On a scale from 1 to 5, how clear/intuitive installation procedure was to you after receiving the instructions?	If you have any last-minute thoughts/suggestions/comments about this installation experience/interaction, please leave them here.	What was your start time?	What gender do you identify with?	How old are you?	Do you have professional experience in the kind of work that you were asked to perform today (aka have you been paid to do a job that involves lifting/installation work)?
Firm contact between the units at the end of insertion		5			4	5		11:00	Male	18-30	Yes
Catching the back slit with the rib		5			5	5		11:00	Male	18-30	No
Firm contact between the units at the end of insertion, Catching the back slit with the rib		3		Compared to the cooling unit, ergonomics matter less as the weight is way lower. The differences between the handle angles for the cooling unit were exaggerated because of the weight difference.	3	4	The side walls felt flimsy when guiding the DC unit and to me they felt superficial	13:45	Male	18-30	Yes
Catching the back slit with the rib		5			5	4		13:45	Male	18-30	Yes
Catching the back slit with the rib, Following the sleeve side guides		5			5	4	The mounting bracket could be redesigned a bit more, but the sleeves and ribs for mounting the dc unit onto the cooling unit is a good idea	14:45	Male	18-30	No

Appendix Q | Materials and manufacturing selection

Weighted criteria matrices

Core enclosure	Weight	1 - **Thermo**	2- **RTM**	3 - **FDM**
Mechanical strength	15	7	9	4
Weight	14	5	9	10
Desired aesthetics	12	10	10	7
Longevity | UV	11	10	8	10
Longevity | Scratch resistance	11	8	5	8
Double-sided features	8	4	10	8
Dimensional accuracy	8	5	10	8
Sustainability	7	5	10	5
Start-up costs	6	10	1	3
Post processing requirements	6	4	4	9
EU based manufacturing	2	10	5	9
Total weight	100	704	794	735

Sleeve	Weight	1 - **Thermo**	2- **RTM**	3 - **FDM**
Weight	15	8	4	10
Desired aesthetics	13	10	10	7
Sustainability	13	5	10	5
Start-up costs	11	10	1	3
Post processing	11	4	4	9
Longevity | UV	9	10	8	10
Longevity | Scratches	9	8	5	9
Dimensional accuracy	7	8	10	7
EU based manufacturing	6	10	5	9
Mechanical strength	6	7	9	4
Total weight	100	789	646	736

Material	**Tensile strength (MPa)**	**Izod impact strength (J/cm)**	**Elongation at break (%)**	**Density (g/cc)**
Polycarbonate (PC)	52	0.481-9.61	6.10-138	1.03 - 1.26
Carbon fibre composites	5000	8 - 15	0.43 - 11	1.15 - 2.25
Glass fibre composites	4600	Not found	4.8	2.54 - 2.6
Flax fibre composites	~1000	Not found	Not found	1.4 - 1.5

Figure 1 - Values of selected mechanical properties for the materials of interest (*MatWeb - the Online Materials Information Resource* (n.d.), *Overview of Materials for Epoxy/Carbon Fiber Composite* (n.d.), Mirdehghan (2021), Wpengine (2024), E-Glass Fiber, Generic (n.d.), Flaxcomp, (n.d.)).

Core enclosure criteria explanation and rankings

Criterion	Implied meaning
Mechanical strength | Desired performance based on such strength and impact resistance properties as tensile strength, izod impact strength, and elongation at break (Figure 1)	**Thermoforming (+) |** Comparatively large elongation at break value points at the fact that thermoformed PC parts deal with impact by flexing and bending that could potentially hurt internal hardware. Such ductile/flexible nature of thermoformed parts is also not beneficial considering enclosure installation where flimsy parts might cause significant difficulties in handling heavy weights. To exhibit more stiff behavior, thermoformed parts require careful design of internal rib reinforcement (*Empire West Inc. - Thermoforming Design Considerations*, n.d.). **RTM (++) |** RTM composites' higher values for the 3 properties of interest imply a more stiff and rigid enclosure without any further features, such as reinforcement ribs. **FDM (-) |** Intrinsic nature of FDM makes it considerably weaker in tensile strength due to layer adhesion property. While Epoxy coating might have minor positive effects on the print's strength, however, they are not significant.
Weight | Expected weight for the desired performance, especially considering IK10 rating	*(Assuming the same enclosure thickness across the 3 alternatives)* **Thermoforming (+) |** While PC has the smallest average density that would yield the lightest enclosure under the assumption stated above, it was reasoned that the actual weight would increase significantly due to the need for reinforcement ribs. **RTM (++) |** While the flax composite's density is greater than that of PC, this alternative was assumed to still yield a lighter enclosure since no additional reinforcement features are expected to be necessary. These results also have a relatively high degree of confidence in the performance of this material due to the high strength and lightness reputation of the composites (Fan et al., 2024). **FDM (++) |** FDM's intrinsic partly hollow infill structure is expacted to yield a lightweight solution (again also considering PC's relatively low density compared to the alternative); certain infill patterns are also known to provide significant strength and impact resistance properties improvements (All3DP, n.d.).
Desired aesthetics | Color, finish & texturing opportunities	**Thermoforming (++) |** Thermoforming is used for creating products from suitcases to car panels, which demonstrates an extremely wide array of detailing possibilities for this option. **RTM (++) |** In a similar vein, RTM is used from furniture making to car manufacturing. Various aesthetics of the reinforcement fabrics add an additional finish opportunity. **FDM (+) |** While FDM has a unique layered aesthetic, post-processing finishes are necessary to ensure that the print can be environmentally resilient and eliminate this aesthetic possibility by smoothening the print surface.

Longevity | UV degradation	**Thermoforming (++), FDM (++) |** PC exhibits UV resistive properties (Horesh, 2021). **RTM (+) |** Naturally sourced materials (such as flax and biobased resins) are generally more prone to UV degradation compared to synthetically derived materials (such as plastics) (Vedrtnam et al., 2022). However, all options are expected to exhibit comparable UV resistive properties if appropriate UV-resistant coatings are applied.
Longevity | Scratch resistance	**Thermoforming (+), RTM (-), FDM (+) |** Along the same reasongng thread as with UV resistance, synthetically derived PC is expected to have superior scratch resistance properties compared to a biobased composite. However, with appropriate surface treatments (e.g., hard coatings) all 3 alternatives are expected to exhibit comparable performance. RTM was given a lower rating for its inherently lower scratch resistive properties.
Double-sided features | Manufacturing method's ability to create features on both sides of the enclosure	**Thermoforming (-) |** While possible in some advanced types of thermoforming (e.g. pressure forming), implementing double-sided features is more challenging compared to the other 2 alternatives. **RTM (++) |** This manufacturing method is known and often chosen for its ability to create double-sided features. **FDM (+) |** 3D printing can arguably create any shape, however supports required to carry out more elaborate internal features might pose challenges and limitations.
Dimensional accuracy | The extent to which each manufacturing method is capable of producing dimensionally accurate parts	**Thermoforming (-) |** ±0.3 mm (*Thermoforming Vs. Injection Molding: What's the Difference? - Kemal*, n.d.). **RTM (++) |** The best dimensional accuracy performance is expected with RTM as this method uses a pressurized closed mold (ComposiTech, 2024). **FDM (+) |** Typically ±0.2 mm for industrial FDM printers (Additive3dasia, 2022).
Sustainability | Raw base materials sourcing	**Thermoforming (-), FDM (-) |** While many products have been incorporating recycled PC content in recent years, virgin material is still necessary, especially for applications requiring high mechanical strength and impact resistance. **RTM (++) |** Biobased resins and natural flax reinforcement are all naturally sourced materials.

Start-up costs | Expected costs of setting up a given manufacturing method	**Thermoforming (++) |** Thermoforming is known to be a cost-effective method and is expected to have a significant lead over the other 2 options in terms of start-up costs. **RTM (--) |** Expected to yield the highest start-up costs, primarily due to mold manufacturing that needs to be done from steel or aluminum. **FDM (-) |** Expected to be the second-highest option in terms of start-up costs with the majority of the price tag coming from high set-up costs of 3D printing.
Post-processing requirements | Additional operations required to be performed to obtain necessary features, such as holes, cuts, etc. Costs and resulting material waste are considered.	**Thermoforming (-), FDM (-) |** As both methods would yield a shell-like enclosure, various holes would need to be machined out, an expensive process that also leads to material waste. **FDM (+) |** While FDM is superior to the other 2 options in its ability to include necessary holes and other features in the enclosure, some material waste might occur from supports that are necessary to successfully create more elaborate features.
EU-based manufacturing possibilities | Opportunities to keep manufacturing in the EU zone as opposed to having to go overseas	**Thermoforming (++) |** Common and widely available manufacturing method in Europe. **RTM (-) |** Limited manufacturing capacity in the EU. **FDM (++) |** Great manufacturing capacity in Europe, with companies like MX3D showcasing it in the Netherlands.

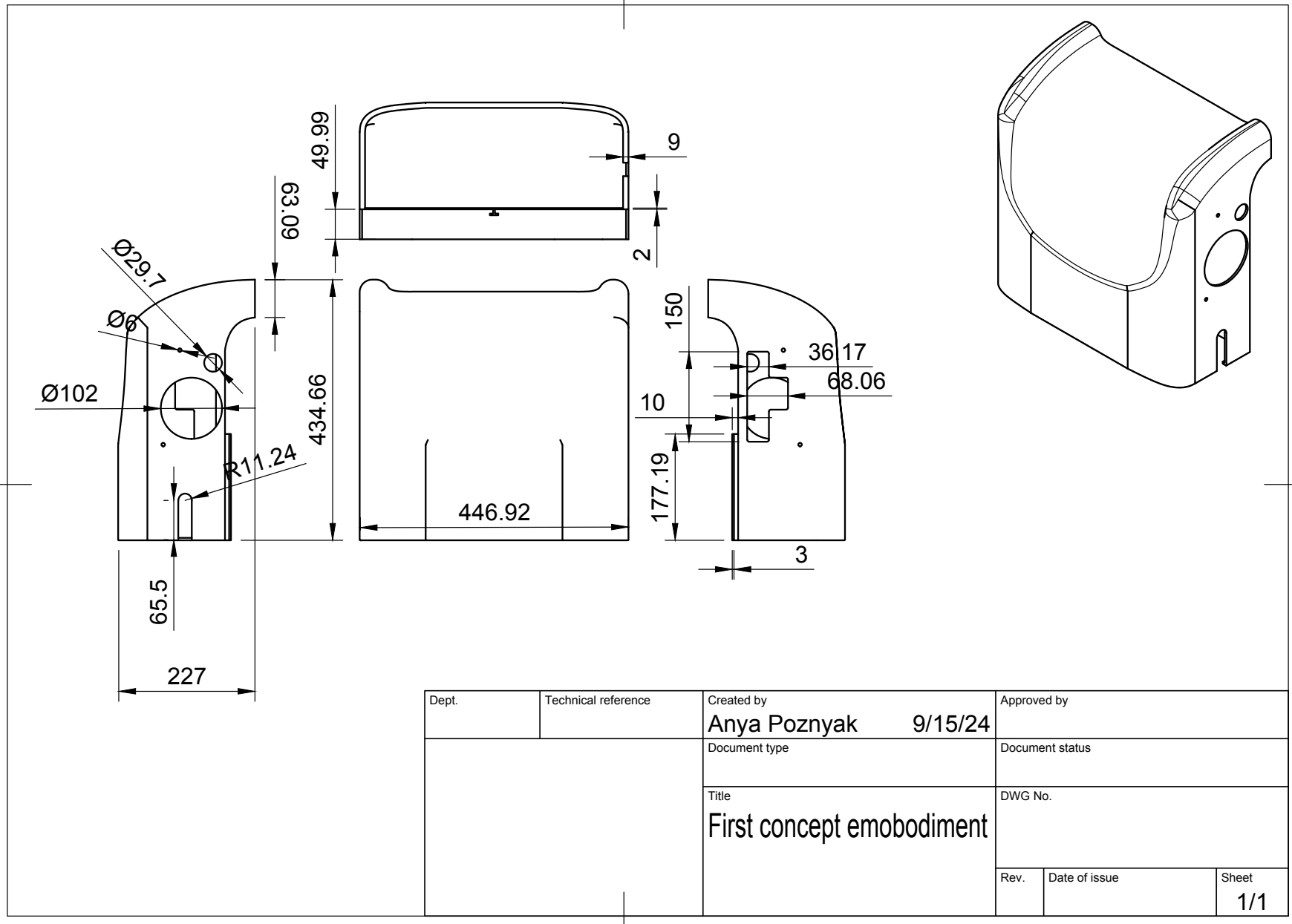
Customizable sleeve criteria explanation and rankings

Criterion	Implied meaning
Weight | Looking for the lightest possible solution as performance in terms of mechanical strength and impact resistance is of less importance for the sleeve	**Thermoforming (+) |** Expected to be the second lightest option, especially if the part is designed with thin walls. **RTM (-) |** As the density of the composites is on average higher than that of PC, RTM is expected to yield the heaviest past. While composites exhibit superb strength-to-weight ratios (especially when compared to metals), when strength is of less importance, their weight becomes relatively high compared to plastic alternatives. **FDM (++) |** Expected to yield the lightest part due to the ability to control infill density. Infill patterns can also be tailored to optimize the print's strength performance.
Desired aesthetics | Color, finish & texturing opportunities	**Thermoforming (++) |** Thermoforming is used for creating products from suitcases to car panels, which demonstrates an extremely wide array of detailing possibilities for this option. **RTM (++) |** In a similar vein, RTM is used from furniture making to car manufacturing. Various aesthetics of the reinforcement fabrics add an additional finish opportunity. **FDM (+) |** While FDM has a unique layered aesthetic, post-processing finishes are necessary to ensure that the print can be environmentally resilient and eliminate this aesthetic possibility by smoothening the print surface.
Sustainability | Raw base materials sourcing	**Thermoforming (-), FDM (-) |** While many products have been incorporating recycled PC content in recent years, virgin material is still necessary, especially for applications requiring high mechanical strength and impact resistance. **RTM (++) |** Biobased resins and natural flax reinforcement are all naturally sourced materials.
Start-up costs | Expected costs of setting up a given manufacturing method	**Thermoforming (++) |** Thermoforming is known to be a cost-effective method and is expected to have a significant lead over the other 2 options in terms of start-up costs. **RTM (--) |** Expected to yield the highest start-up costs, primarily due to mold manufacturing that needs to be done from steel or aluminum. **FDM (-) |** Expected to be the second-highest option in terms of start-up costs with the majority of the price tag coming from high set-up costs of 3D printing.
Post-processing requirements | Additional operations required to be performed to obtain necessary features, such as holes, cuts, etc.	**Thermoforming (-), FDM (-) |** As both methods would yield a shell-like enclosure, various holes would need to be machined out, an expensive process that also leads to material waste.

Longevity | UV degradation	**Thermoforming (++), FDM (++) |** PC exhibits UV resistive properties (Horesh, 2021). **RTM (+) |** Naturally sourced materials (such as flax and biobased resins) are generally more prone to UV degradation compared to synthetically derived materials (such as plastics) (Vedrtnam et al., 2022). However, all options are expected to exhibit comparable UV resistive properties if appropriate UV-resistant coatings are applied.
Longevity | Scratch resistance	**Thermoforming (+), RTM (-), FDM (+) |** Along the same reasongng thread as with UV resistance, synthetically derived PC is expected to have superior scratch resistance properties compared to a biobased composite. However, with appropriate surface treatments (e.g., hard coatings) all 3 alternatives are expected to exhibit comparable performance. RTM was given a lower rating for its inherently lower scratch resistive properties.
Dimensional accuracy | The extent to which each manufacturing method is capable of producing dimensionally accurate parts	**Thermoforming (-) |** ±0.3 mm (*Thermoforming Vs. Injection Molding: What's the Difference? - Kemal*, n.d.). **RTM (++) |** The best dimensional accuracy performance is expected with RTM as this method uses a pressurized closed mold (ComposiTech, 2024). **FDM (+) |** Typically ±0.2 mm for industrial FDM printers (Additive3dasia, 2022).
EU-based manufacturing possibilities | Opportunities to keep manufacturing in the EU zone as opposed to having to go overseas	**Thermoforming (++) |** Common and widely available manufacturing method in Europe. **RTM (-) |** Limited manufacturing capacity in the EU. **FDM (++) |** Great manufacturing capacity in Europe, with companies like MX3D showcasing it in the Netherlands.
Mechanical strength | Desired performance based on such strength and impact resistance properties as tensile strength, izod impact strength, and elongation at break (Figure 1)	**Thermoforming (+) |** Comparatively large elongation at break value points at the fact that thermoformed PC parts deal with impact by flexing and bending that could potentially hurt internal hardware. Such ductile/flexible nature of thermoformed parts is also not beneficial considering enclosure installation where flimsy parts might cause significant difficulties in handling heavy weights. To exhibit more stiff behavior, thermoformed parts require careful design of internal rib reinforcement (*Empire West Inc. - Thermoforming Design Considerations*, n.d.). **RTM (++) |** RTM composites' higher values for the 3 properties of interest imply a more stiff and rigid enclosure without any further features, such as reinforcement ribs. **FDM (-) |** Intrinsic nature of FDM makes it considerably weaker in tensile strength due to layer adhesion property. While Epoxy coating might have minor positive effects on the print's strength, however, they are not significant.

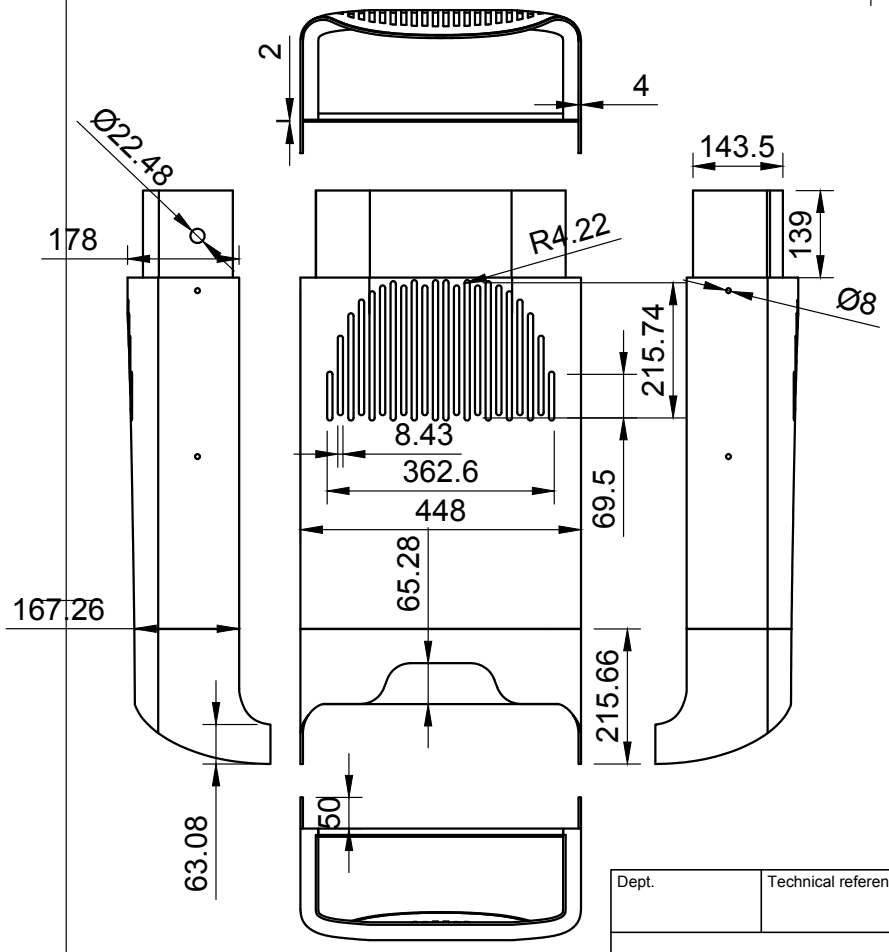
Appendix R | CAD embodiment dimensions

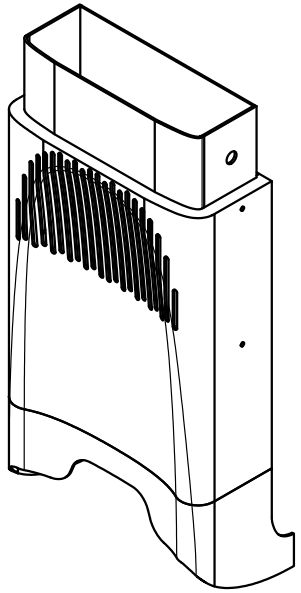
DC unit and back lid



Dept.	Technical reference	Created by Anya Poznyak 9/15/24	Approved by
		Document type	Document status
		Title: First concept emobodiment	DWG No.
			Rev. / Date of issue / Sheet 1/1

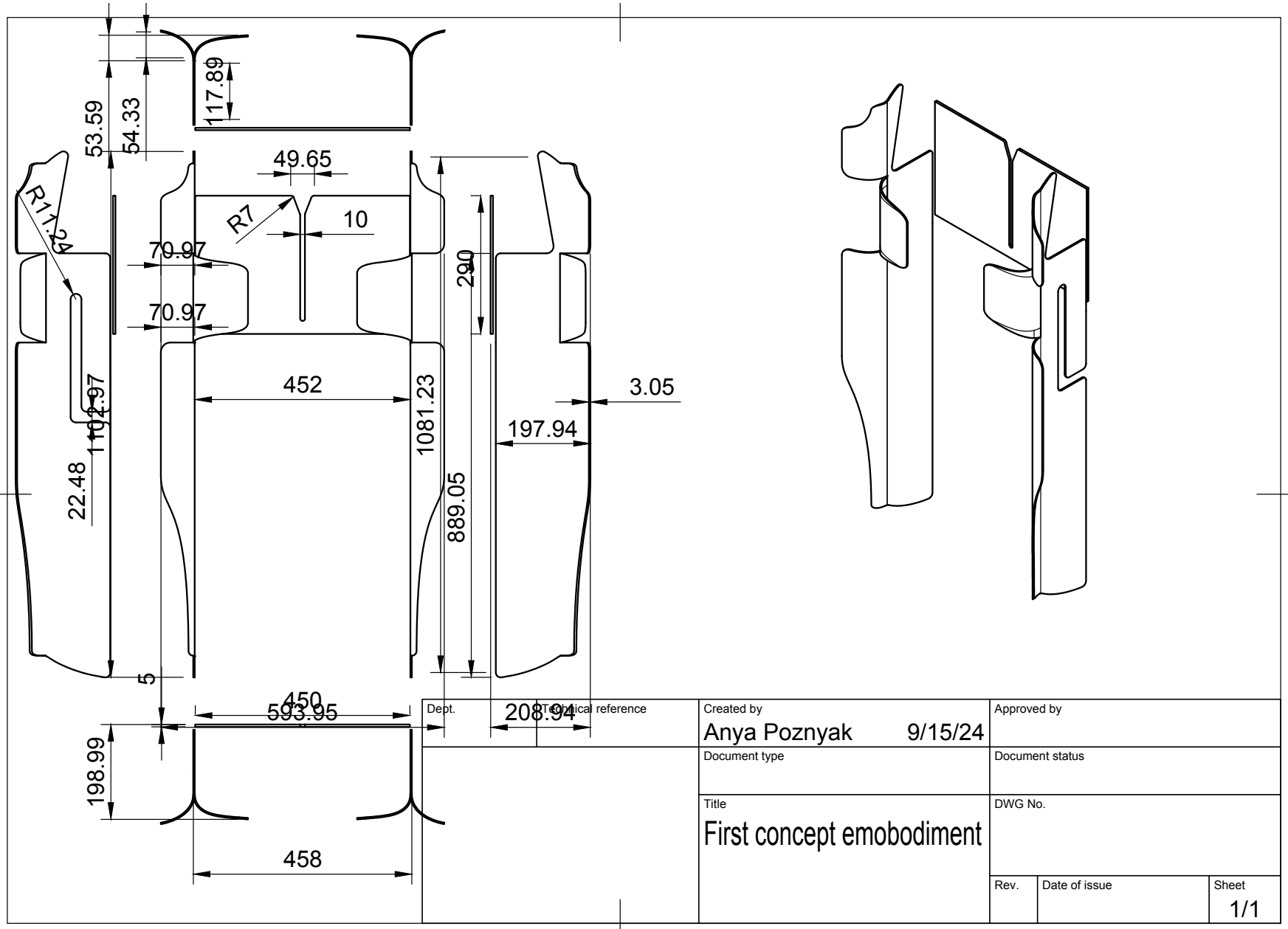
Cooling unit + back lid and Fans unit + back lid





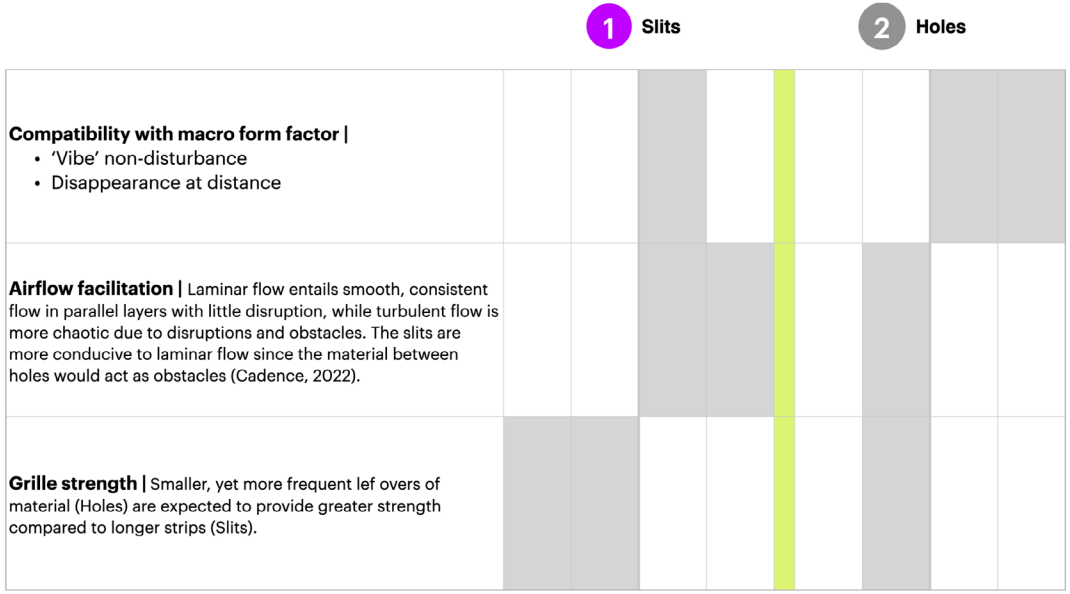
Dept.	Technical reference	Created by Anya Poznyak 9/15/24	Approved by
		Document type	Document status
		Title: First concept emobodiment	DWG No.
			Rev. / Date of issue / Sheet 1/1

Sleeve and its back plate



Dept. / Technical reference	Created by: Anya Poznyak 9/15/24	Approved by	
	Document type	Document status	
	Title: First concept emobodiment	DWG No.	
		Rev. / Date of issue	Sheet: 1/1

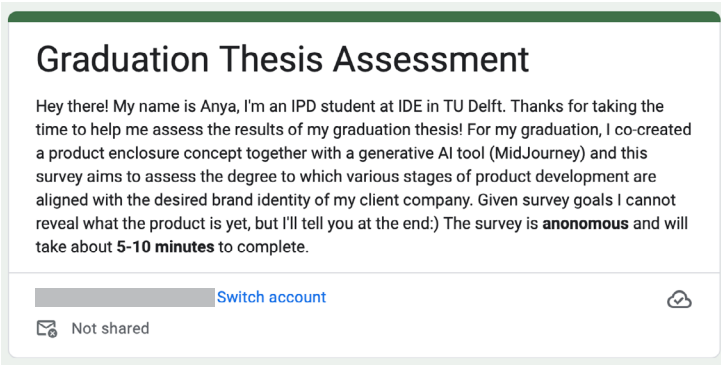
Appendix S | Front opening selection



	Weight	1 - Slits	2- Holes
Compatibility	40	7	9
Airflow	35	9	4
Strength	25	2	4
Total weight	100	645	600

Appendix T | Final feedback survey

Survey hyperlink | https://forms.gle/fUtmbdbYjFJZz9777



Graduation Thesis Assessment

Hey there! My name is Anya, I'm an IPD student at IDE in TU Delft. Thanks for taking the time to help me assess the results of my graduation thesis! For my graduation, I co-created a product enclosure concept together with a generative AI tool (MidJourney) and this survey aims to assess the degree to which various stages of product development are aligned with the desired brand identity of my client company. Given survey goals I cannot reveal what the product is yet, but I'll tell you at the end:) The survey is **anonomous** and will take about **5-10 minutes** to complete.

Switch account

Not shared

Timestamp	To what extent would you describe this design as **assertive**?	If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **assertive**.	To what extent would you describe this design as **elegant**?	If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **elegant**.	To what extent would you describe this design as **refined**?	If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **refined**.	To what extent would you describe this design as **empowering**?
9/9/2024 14:25:54	4		5		4		3
9/9/2024 14:29:49	5		5		5		5
9/9/2024 14:40:11	2	Make it less elegant	4		2	It's quite big and bulky, so that should be less	4
9/9/2024 14:40:52	5		5		5		5
9/9/2024 14:41:25	5		4		2	Lots of manufacturing splits still	4
9/9/2024 14:45:30	4		4		2	A bit blocky still, I feel the twists and curves don't fully break the shape of the enclosure	4
9/9/2024 14:47:15	4		4		3	it does not have a lot of details	3
9/9/2024 14:58:18	2	Bold colour, perhaps red	4		2	Refined to me means it fits contextually, while it is quite contrasting with the environment.	2
9/9/2024 15:21:23	3	It still feels subtle and blended in	4		4		4
9/9/2024 15:29:26	4		3	The gaps and lines in the shape make it a little rough.	4		5
9/9/2024 15:39:28	2	I'd like some clarity on the orientation and position of this object in relation to the user (and space). It does give a bit of cue in terms of the type of product though, something that feels ergonomic.	4		4		1
9/9/2024 16:01:02	4		4		2	Is not yet cost what it is about. Also it looks like an unfinished render.	3
9/9/2024 16:01:56	5		5		4		4
9/9/2024 16:02:19	4		2	To many screaming design elements	3	The curves are refined, but there is just to much going on to be really refined	4
9/9/2024 17:43:57	4		5		5		3
9/9/2024 20:26:55	2	I do not intuitively know what it will do, therefore i feel it is passive.	4		4		3
9/9/2024 22:05:59	5		4		4		5
9/10/2024 14:16:42	5		4		5		4
9/11/2024 10:43:59	3	Pointy shapes	5		5		3
Means	3.789473684		4.157894737		3.631578947		3.631578947
St devs	1.134261746		0.7647191129		1.164785451		1.065130473

If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **empowering**.	To what extent would you describe this design as **pioneering**?	If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **pioneering**.	What **general feeling** does this form evoke in you?	If you selected **'Unpleasant'** above, please explain in 1 sentence what detail(s) about this form evoke such feeling in you.
	4		Pleasant	
	5		Pleasant	
	3	I can't have an opinion about that because I don't know what it is	Pleasant	
	5		Pleasant	
	4		Pleasant	
	5		Neutral	
I am not sure what it is, so I would not feel sure to use it. Thus would not empower me inmediately	4		Pleasant	
Looks very cool, but I am missing the inspiring look that I require with empowerement.	2	Reminds me of a lot of concept car images, as a result it seems genericpy futuristic as I cannot see what the product actually is	Pleasant	
	4		Neutral	
	4		Neutral	
I don't think this screams "use me" or "I serve a purpose" or "I help you do something".	4		Pleasant	
It lacks a sense of meaning.	2	It's like cars. Fancy cars are not always pioneering. A lot of time is even negatively cheap looking.	Neutral	
	4		Pleasant	
	4		Unpleasant	It seems quite powerfull and a bit alien. Especially the top two horns/shoulders somehow make me feel a bit unpleasant
Maybe because I cannot see the size of the object, it seems quite small with the wooden floor background, it would be empowering if it was as big as a car for example	5		Pleasant	
maybe the placement against the wall makes it less empowering to me	4		Neutral	
	4		Neutral	
	2	something new	Pleasant	
I wouldnt know what an empowering shape would be	5		Neutral	
	3.894736842			
	0.9941348468			

Are there any **associations** that come to your mind when looking at this object? What does it remind you of (can be anything, some other product, animal, plant, etc.)? Please answer in 1-3 sentences.	To what extent would you describe this design as **assertive**?	If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **assertive**.	To what extent would you describe this design as **elegant**?
	3		5
Figure eight	5		4
Female body	3		2
A persons chest, as well as a butterfly.	1	Looks very held back now the shape should be more forward and the lines forming a pointing down arrow should also be gone	1
It reminds me of a car or car charger	4		2
If you put it horizontally, it feels like a fancy advanced concept car model	4		3
a bit of a butterfly and a cocoon.	3		2
Concept cars, smart materials and hospitals	3	Again bold colour, stance of the product is already better but could be angles more slightly to be more dramatic.	2
Some sort of plant / cell strucure, reminds me of bio-inspired architecture	4		3
Back rest, milk, hourglass	4		2
I think of a tanning bed, a sense deprivation tank or something related to healthcare (like something to put your head on)	2	I'm missing some cues on how to use this product, that would feel more straightforward.	2
A car.	3	It looks very utilitarian. Like a vacuum cleaner or a gardening tool.	2
Feminine shape, like gymnasts, and a sand clock	5		4
Sci-fi, alien, sci-fi robot	4		2
Computer mouse, space ship, waved textile, ocean	5		4
butterfly, flower (wallflower lol), service machine, I feel like i need to put my back in there?? fitness device?, contemporary art hihi	4		4
electric charger, something with water	3		2
butterfly, women, pure	2	organic shapes	1
Looks like modern car seating, or other shapes form the automotive industry	5		2
	3.526315789		2.578947368
	1.123902974		1.121298329

If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **elegant**.	To what extent would you describe this design as **refined**?	If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **refined**.	To what extent would you describe this design as **empowering**?	If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **empowering**.
	5		4	
	4		5	
	3		2	
It looks bulky now, so more slim shapes in variations in thickness would help	1	It looks bulky so anything that makes it more slim, some curves also	1	It looks unsure, because of the shape pointing outwards, like a shrug.
Harsh	4		5	
The resulted form factor has less smoothed transitions from elements to elements	3	Same as before, still get a bit of a "blocky" feel to it	5	
It feels somewhat buly and the shapes are not that elegant	4		3	also here not sure what it does, so it does not empower me at first
I think the lines feel a little random and incoherent. Too much is happening in the sides and they contrast the elegant interior with the holes	2	Same answer as above	4	I think it looks a bit like a Barnacle Boy from spongebob, so it is quite iconic and thus could symbolize empowerement in some way
The shapes feel a bit too blunt and geometric	2	It feels unfinished	4	
the edges seem quite sharp. make it more smooth	3	More smooth edges	4	
Feels like it will be made out of textured fiberglass	1	I'm missing some cues in terms of the materials to make an assessment on "how refined" it can be.	2	I have no idea how this can help me, maybe it is a component for something I use often.
Too complex and unpleasant to the eye. To many lines unconnected and going on all kinds of directions. No sense of style.	3	It looks like an actual product. But still maybe some sort of first generation device/prototype.	2	It's not inciting not empowering to interact with it in any way.
	4		4	
A bit to blocky elements with quite a lot going on	2		4	Feels like it resembles a strong posture on a human
I think the white colour makes it elegant as well	4		3	It seems cute, and small, it could be powerfull in a smart way, but not so much in a physical way. I think it misses a bit of large bulkyness to be powerfull, it is very refined
	4		4	
	2		3	
organic and cleaner lines	1	maybe its the lighting	1	everything
not very coherent	3	not very coherent	3	
	2.894736842		3.315789474	
	1.196974744		1.249561327	

To what extent would you describe this design as **pioneering**?	If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **pioneering**.	What **general feeling** does this form evoke in you?	If you selected **'Unpleasant'** above, please explain in 1 sentence what detail(s) about this form evoke such feeling in you.	Are there any **associations** that come to your mind when looking at this form? What does it remind you of (can be anything, some other product, animal, plant, etc.)? Please answer in 1-3 sentences.	To what extent would you describe this design as **assertive**?
4		Neutral			5
5		Pleasant		Wall sound system	5
3		Neutral		A shaver	2
1		Neutral		A shrugging person	3
2	More conservative than the other	Neutral		Looks like a radiator	4
4		Neutral		Definetly get a retro-futuristic concept car vibe from it	5
4		Neutral		It feels like an aid product for elderly people, but that might be the colour used	4
4	Never seen this form before in products, so in that sense it is quite pioneering	Unpleasant	It looks a little evil, as mentioned before like Barnacle Boy.	Barnacle boy, darth vader	4
4		Neutral		A platypus, a little	4
2	I don't know what it is so it is difficult to label it so	Neutral		grill, baby seat	4
3		Neutral		I think of a shaver or something to place a shaver	3
1	It's resemblance to cars does not make it stand out as is own innovating design.	Unpleasant	It feels cold and very hard. Pointy edges seem dangerous.	A car. Maybe a chr Toyota.	4
3		Neutral		Resembling a vegetable grinder.	5
2	Due to color, material and shapes	Neutral			2
5		Pleasant		Shaving machine, remote control, something to place on the wall like a thermostat, frog	5
4		Neutral		superhero, air refresher	3
4		Unpleasant			2
1		Neutral		bathroom, appliance, day-to-day	4
5		Neutral		looks like a medical chair, something you would see at the dentist	3
3.210526316					3.736842105
1.357241785					1.045737659

If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **assertive**.	To what extent would you describe this design as **elegant**?	If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **elegant**.	To what extent would you describe this design as **refined**?	If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **refined**.	To what extent would you describe this design as **empowering**?
	5		5		5
	5		5		5
	2		2		2
Still looks like an unsure person, it's the shape that points inwards that makes it not assertive	2	The contrast between the colors is too big	4		3
	3	The holes should be less big	3	Same as previous answer	4
	5		4		5
	4		4		3
	3	Again, quite a lot is happening. But it is better than previous version	4		3
	3	Maybe if it all was the same color it would feel more elegant	4		4
	2	Depends on the material. Not a fan of brown. But if leather then I would see it as more elegant.	4		4
Not sure what it allows me to do yet but says "feel me" lol.	2	I don't know about brown or brick color, I'd think it needed to look more "minimal" or one-toned.	4		4
	3	I think the lines, the grills and the colours do not strike a harmonious balance.	2	Same as before. Especially the area where the grills are.	3
	5		5		5
The subdued colors make it less assertivr	2	To much going on	2	To much going on	3
	4		4	It is refined, but in a modern way, the city centre is more refined in an historical way. This is a contrast	4
Im confused , i don't know what i think of it in relation to assertiveness	3	maybe if it is smoother and more one lined going down on the sides	4		4
	2		2		2
	3	different colors	2		1
pointy shapes	5		4		1
	3.315789474		3.578947368		3.421052632
	1.204280863		1.070606758		1.261207071

If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **empowering**.	To what extent would you describe this design as **pioneering**?	If you selected 1, 2, or 3 above, please explain in 1 sentence what is missing to you in this design to call it **pioneering**.	To what extent does this product **stand out** from the brick wall for you?	What are some elements of the design that make it stand out to you the most? Please, answer in 1 sentence.	To what extent does this product **blend in** with the wall?
	5		3		3
	5		3	The contract colors.	3
	3		3	The white and the shape	3
	3		4	The size of it and the white color	4
	4		4	The form factor, the curves	3
	4		2	It don't think it stands out	2
again not sure what it does or how to operate it, I lack information to know if it is empowering	4		3	The shape, the slots	2
Now it reminds me a little of a squid's head. It is definitevely iconic but not sure if it would empower me	5	Ver novel	2	Sformwise quite a lot, colourwise not so much. I would try to add a contrast colour that really pops	2
	4		4	The two different colors, the size (!), the fact that I don't know what it is	4
	2	Still	4		2
	5		5	The fact that an electronic is attached to a brick wall, I don't think I see that often or at all.	4
	3	A sense of naturally belonging to the environment.	2	If compared in size with the brick on the photo, the device looks as tall as a person. So, it's difficult to say it can stand out.	3
	5		2	White shape	2
	3		5	The eye grabbing shapes and that it is not clear what it is from viewing at it	5
	5		5	The different modern style, due to the organic shape.	4
	4		3	The holes in the middle, the shape, looks ergonomic	3
	2		3		3
colors	5		4	shape	2
Doesnt look strong	5		5	organic shapes and the disruption of the flow from the wall	5
	4		3.473684211		3.105263158
	1.054092553		1.073334423		0.9941348468

What are some elements of the design that make it blend in for you the most? Please, answer in 1 sentence.	What **general feeling** does this design evoke in you?	If you selected **'Unpleasant'** above, please explain in 1 sentence what detail(s) about this form evoke such feeling in you.	Are there any **associations** that come to your mind when looking at this form? What does it remind you of (can be anything, some other product, animal, plant, etc.)? Please answer in 1-3 sentences.	Imagine walking around Delft city center (or a historic city center of your choice) and seeing these objects about every other block. Do you feel the need to know **what** these products are?
	Pleasant			Yes
Brick color elements on the sides	Pleasant		Sand clock	Yes
The brown colour	Neutral			Yes
The red color	Unpleasant	It looks evil, like a cartoon character with a cloke that is up to no good	A villain with a cloke	Yes
The colour mostly	Neutral		Still a little bit radiator like, but also like an electric car charger	Yes
the choice of colour tone really is amazing at blending while not vanishing	Pleasant		It looks like an elegant piece of bark blended with some tech elements	Yes
colours	Pleasant		this time i do not have an association, I am just wondering what it is	Yes
Colour choice	Neutral		Squid	Yes
The color of the wall holder	Neutral		A grasshoper	Yes
	Neutral			Yes
the color	Pleasant		Looks like a lady in a dress.	No
Some areas, like in the Mediterranean, the incorporate small clay features, such as statues in brick walls like this. It could resemble that.	Neutral		Ancient Greek antefix, Cycladic figure.	Yes
Brown color of the box, flat shape	Pleasant		Butterfly , woman clothing/dress, wine glasses	Yes
Colors	Unpleasant	I wouldn't know what it is when seeing it in the city, while it had really strong shapes. A bit intimidating		No
Only the color	Neutral	I am quite fan of the historical look of houses in the city centre, therefore I am not sure if I would like to see such a modern device on all the houses. But it could be nice if it is on the side of houses, where there is just a brick wall	Space ship, vase, car	No
color	Neutral	im confused what it is	A camouflaged insect/animal (color changing, adapting, but not shape) , transformers, butterfly, air refresher, pillow, massage device	Yes
	Unpleasant	there is too much going on		Yes
color	Pleasant		intriguing	Yes
colour	Unpleasant	Such a modern looking object disrupt the old looking experience of the wall	Duo penotti	Yes

What would be your **guess** as to what this product is? You can mention something specific or a generic product category (e.g. kitchen appliances).	How old are you?	What is your occupation/study?	Which part of the world are you from?
	18-30	Business/finance	Europe
A new design of AC unit	51-60	Healthcare	North America
Safety	18-30	Engineering/technology	Europe
Some sort of info system, the grey stripes look like they could be speakers	18-30	Arts/design	Europe
Ev car charger	18-30	Engineering/technology	Europe
Something techy, like wireless antenna	18-30	Science/research	Europe
Based on the location a device which helps you around? maybe as a guide or assistant. Or if there is help needed, like an emergency device	18-30	Arts/design	Europe
It is a audio tour and ezplains to me what a specific building's history is	18-30	Arts/design	Europe
Electric car charging station?	18-30	Arts/design	Europe
An information thing?	18-30	Arts/design	Europe
Something you "get into"	31-40	Business/finance	North America
Air purifier, speaker, lamp	18-30	Arts/design	Europe
Sensors or network connectors.	51-60	Supply chain	Europe
Information thing?	18-30	Arts/design	Europe
I think a charger for electric cars	18-30	Arts/design	Europe
transferring air (chimney like), or a standing support (ergonomic standing ahah). A tourist talking device?	18-30	Arts/design	Europe
no idea	18-30	Arts/design	Europe
chill station, you can open it and st or lay over it	18-30	Arts/design	Europe
something to lean against, maybe massage chair	18-30	Arts/design	Europe

Mean							
	AI inspiration	Monochrome CAD	Color rendring			AI inspiration	Monochrome CAD	Color rendring
Assertive	3.79	3.53	3.74		Pleasant	57.9	10.5	36.8
Elegant	4.16	2.58	3.32		Neutral	36.8	73.7	42.1
Refined	3.63	2.89	3.58		Unpeasant	5.3	15.8	21.1
Empowering	3.63	3.32	3.42					
Pioneering	3.89	3.21	4					
	3.82	3.106	3.612					
St dev								
	AI inspiration	Monochrome	Color rendring					
Assertive	1.13	1.12	1.05					
Elegant	0.76	1.12	1.2					
Refined	1.16	1.2	1.07					
Empowering	1.07	1.25	1.26					
Pioneering	0.99	1.36	1.05					
	1.022	1.21	1.126					

Appendix U | Final concept assessment against set requirements

Requirements/Must-haves	Wishes/Nice-to-haves	Assessment
Enclosure interaction (I)		
IR 1 | All procedures with EMDC must require common tools only.		Ratchet lever for the clamping mechanism.
IR 2 | All procedures must be possible to do safely at en elevation.		More resolution needs to be obtained with regards to mounting the units on elevation (complications due to potentially unstable lift surface).
IR 3 | 1 person must be able to insert the Data center unit into the Cooling unit.		
IR 4 | 2 people must handle lifting and mounting of the Cooling unit.		
IR 5 | Client company must have a choice between conducting procedures themselves or opting out for assistance by a 3rd party service providers.		
IR 6 | Installer(s) must have clear guidance for each procedure with EMDC.		While installation procedure steps have been defined, communication way to the installers needs to be developed.
IR 7 | Enclosure elements cannot hurt installer(s) at any point during handling it (sharp edges, contact with electricity, etc.).		This aspect has been thought through to the best of ability given current product development level, yet further detailing and testing is necessary to ensure this requirement is met.
IR 8 | Mounting/demounting every unit must take 15 minutes or less.	**IW 9 |** Mounting/demounting should be as fast as possible.	Expected, yet testing required to verify.
IR 12 | The procedure of mounting/demounting all EMDC parts must have up to 7 steps (Baddeley, 1994).	**IW 12 |** Mounting/demounting procedure should be organized into meaningful groups (Baddeley, 1994).	
IR 12 | Only authorized staff must be able to interact with the EMDC.		Assuming that removable ratchet lever and mounting at elevation is sufficient to prevent unauthorized access, yet it needs to be determined in the next design iteration whether additional measures are necessary.
	IW 13 | Various procedures must provide feedback to reassure the user in their successful completion.	Ergonomics user testing pointed to proposed measures being sufficient for the current product development level.

Overall enclosure (E)		
ER 1 | Enclosure must provide adequate protection from outside environmental hazards • Enclosure design must aim for IPX4 watertightness level at all interfaces • Enclosure design must aim for IP5X solids protection level • UV resistance accounted for • Scratch resistance accounted for	**EW 1 |** Enclosure should aim for IP67 standard.	Required environmental protection is expected to be reached with the measures proposed, yet IP67 level requires further development.
ER 2 | Enclosure must prevent forced openings of the EMDC.		
ER 3 | Enclosure must **minimize** it **heating up** from the environment.	**EW 3 |** Enclosure should heat up from the environment as little as possible.	
	EW 4 | Enclosures design should optimize material usage/ MCO wrap up.	
ER 5 | Enclosure design must account for EMDC assembly.		
	EW 6 | Enclosure should minimize the amount of water that gets inside the Cooling unit through the front opening.	
	EW 7 | Core (non-customizable) parts should feature Hiro branding element(s).	
ER 8 | Enclosure surface finish must facilitate dirt and dust wash off with rain.		
Data center (DC) unit enclosure (D)		
DR 1 | DC unit enclosure must house 1 row of 11 servers.	**DW 1 |** DC unit enclosure design should be adaptable to accommodate 2 rows.	While 1 row/11 servers aesthetics has been addressed, 2+ rows design needs to be developed still.
DR 2 | DC unit enclosure must **protect internal hardware** from damage during shipment and installation.		
	DW 3 | 1 row DC unit enclosure aesthetics should be extendable to 2 rows of nodes.	
DR 4 | DC unit enclosure must take measures against bird perching.		

Hardware status indicators (I)		
IR 1 | Each node must have its own hardware status indicator.		
IR 2 | Hardware status indicators' incorporation into the DC unit's enclosure must be appropriate for the outdoors application.		
	IW 3 | Hardware status indicators design should account for the implementation of the second row of nodes.	Each row would have its own polycarbonate overlay.
IR 4 | Hardware status indicators must be positioned in the area surrounding the back PCB.		
IR 5 | Hardware status indicators must be visible... • in high UV context • from the ground level		
	IW 6 | Hardware status indicator's correspondence to its node node should be straightforward.	
	IW 7 | Hardware status indicators should obstruct water run off from the DC enclosure as little as possible.	
IR 8 | Hardware status indicators must avoid 'personification' of the EMDC.		
	IW 9 | Hardware status indicators design must avoid information overload as much as possible. • possibility to turn the lights off when not needed • adjustable brightness	While side placement of LEDs partly addresses this wish, further measures discussed in the report need to be implemented.
IR |10 Front opening design must be stylistically appropriate for the selected macro form factor.	**IW 10 |** Front opening design should preserve the 'monolithic' nature of the selected macro form factor.	Further design iterations are necessary.
EMDC powering (P)		
PR 1 | Power button incorporation into the DC unit's enclosure must be appropriate for the outdoors application.		
PR 2 | Power button must be positioned in the area surrounding the back PCB.		
PR 3 | Power button must be an off-the-shelf design.	**PW 3 |** Off-the-shelf solution should provide high degree of customization.	

Cable connectors (Ca)		
CaR 1 | The enclosure must accommodate 8 Ethernet cable and 1 power cable inlets.		Discrepancy with the number of Ethernet cable connectors needs to be addressed.
	CaW 2 | Cable connectors considered for sizing should be appropriate for outdoors applications. • IP67 compliant	Unclear whether proposed Ethernet connector meets this wish.
CaR 3 | Off-the-shelf solutions must be considered for the connectors.		
CaR 4 | Enclosure must account for the average sizing of existing capped cable connectors.		
CaR 5 | Considered power connector must meet desired performance metrics of current rating for 1.8-6 kW power delivery at 120V.	**CaW 5 |** Power connectro should have current rating for 1.8-6kW power delivery at 240 kW.	
	CaW 6 | Cables insertion and removal should be as ergonomic as possible.	Side placement might complicate this interaction, further testing is necessary to determine whether mitigations need to be put in place.
CaR 7 | Appropriate cable length must be achieved before insertion of the cables into EMDC cable connectors • Cable slack must be managed before hand		Assuming this will be done before cable insertion.
Cooling unit enclosure (C)		
CR | Total Cooling unit weight must be under 46 kg • 23*2 kg to be allowed to handle with 2 people		Internal hardware and enclosure design weight optimization required.
CR | Cooling unit enclosure must incorporate features that facilitate passive cooling through chimney effect.	**CW |** Cooling unit enclosure should remove 70% of heat through passive cooling.	Proposed vertical slits design is expected to be most optimal for airflow.
	CW | Enclosure should incorporate internal features that guide airflow along the desired path.	Still to be implemented.
	CW | Enclosure internal cross section shape should facilitate smooth airflow throughout the chimney.	Still to be implemented.
	CW | Enclosure internal shaft should be airtight • Facilitating chimney effect by preventing air leaks	Still to be implemented.
	CW | Enclosure walls should possess insulating properties • Cavities with air in the enclosure wall	Potentially unnecessary.
CR | Cooling unit enclosure must **protect internal hardware** from damage during shipment and installation.		

Front opening (O)		
OR 1 | Front opening design must have at least 70% of the designated opening area open.		
OR 2 | Front opening design must prioritize optimal airflow above aesthetics.		
	OW 3 | Front opening should let at little water in as possible.	
OR 4 | Front opening design must be stylistically appropriate for the selected macro form factor.	**OW 4 |** Front opening design should preserve the 'monolithic' nature of the selected macro form factor.	Further design iterations are necessary.
OW 5| Front opening design must yield satisfactory mechanical and impact resistance performance of the remaining enclosure material.		Verification required.
Fans unit (F)		
FR 1 | Fans unit attachment must take up 10 seconds less.		Expected.
FR 2 | Fans unit attachment must only require 1 installer.		
FR |3 Fans unit attachment method must support the estimated weight of the fans unit.		Verification with the supplier required.
FR 4 | Fans unit attachment solution must be suitable for outdoors use.		
FR 5 | Fans unit attachment must require little to no maintenance.		
FR 6 | Fans unit enclosure must provide means of securely grabbing it for attachment to the Cooling unit.		
FR 7 | Fans unit attachment method must prioritize visibility of actions and space accessibility.		Front-to-back sliding is expected to accomplish this.
FR 8 | Fans unit attachment method must utilize existing/off-the-shelf solutions.	**FW 8 |** Off-the-shelf solution should be easily adaptable/customizable.	
	FW 9 | Fans unit attachment method should be as light as possible.	
	FW 10 | Fans unit attachment should be as compact as possible.	

The sleeve (S)		
SR 1 | The DC unit must be properly aligned before entering the clamping mechanism area.		
SR 2 | The sleeve must ensure precise and sturdy guidance of the DC unit in with the accuracy of 2.5 mm (clearance between meshed plates).		
SR 3 | The sleeve must hide functional elements on the sides of the enclosures from viewed from the front.		
	SW 4 | The sleeve should facilitate the 'blending in' part of the design vision.	
SR 5 | The sleeve must the rigidly secured to the core enclosure.		(Irrelevant due to design change)
	SW 6 | Sleeve's weight should be supported independently.	(Irrelevant due to design change)
Clamping actuator, driver & interface (CI) | User-facing hardware necessary to set clamping mechanism in motion		
	CIW 1 | Clamping actuator should amplify user's force input as much as possible.	
	CIW 2 | Clamping actuator should require as small of force input as possible.	
CIR 3 | Clamping actuator must facilitate precise transfer of force.		Ratchet mechanism is expected to do so.
CIR 4 | Clamping actuator must be positioned to maximize **force transfer** to the clamping mechanism.	**CIW 4 |** Clamping actuator must be transferring as much force as possible.	Central positioning of the actuator on the side of the device is expected to do so.
CIR 5 | Clamping actuator must be appropriate for both right handed and left handed people.		It is expected that right-side positioning of the clamping actuator would yield a satisfactory experience to left-handed users.
CIR 6 | Clamping actuator must be hidden from the public eye • A person must be unable to tell what that feature is for	**CIW 6 |** Clamping actuator must only be accessible to 'authorized users.'	
	CIW 7 | Clamping actuator and driver should be off-the-shelf hardware.	
CIR 8 | Clamping actuator must be easily aligned with the driver in a tight space • must take 10 seconds or less • 135 mm vertical space corresponding to the overlap of the Cooling and DC units.		Further prototyping and testing required to verify.

Mounting solution (Mo)		
MoR 1 | EMDC must be mountable on all common (inside and outside) surface types.		Proposed mounting bracket and uneven mounting surface mitigation strategies and expected to do so.
MoR 2 | Enclosure mounting must be non-destructive to the surface it's put on.	**MoW 2 |** Enclosure mounting should affect the surface as minimally as possible.	Further mitigation strategies need to be develped.
	MoW 3 | An off-the-shelf mounting solution should be utilized.	
MoR 4 | Mounting solution must support up to 100 kg. • The weight of an EMDC up to 3 nodes rows		
MoR 5 | Off-the-shelf solution must meet IP66 standard.		Verification with the supplier required.
MoR 6 | Mounting solution must be appropriate for uneven surface (must avoid causing damage to uneven bricks surface).		
Mounting/insertion handles (H)		
HR 1 | The handles must feature safeguards preventing accidental dropping of the units.		Handles are closed off on both ends, securing installer's hand.
HR 2 | The handles must prioritize ergonomics over aesthetics.		
HR 3 | The handles must only detach at installer's intention (no accidental detachments).		
HR 4 | The handles must feature details that ensure optimal ergonomics in terms of force loadings in arms and wrists.		
HR 5 | Handles design must be appropriate for the weight they're supposed to handle.		Further verification required.

Design aesthetics (A)		
	AW | Enclosure design should be mindful of its coexistences with antennas.	
AR | Enclosure macro form factor must communicate Hiro brand identity • An independent viewer must use 3/5 Hiro brand identity keywords (or their synonyms) to describe the macro FF		Color Rendering scored above average for all 5 keywords in the final concept assessment survey.
	AW | Enclosure design should account for EMDCs' scalability • Possibility of multiple EMDCs 'co-existing' on the same facade	
AR | Enclosure design aesthetics must incorporate features that help it blend in with its environment in public perception.		The desired equal level os blending in/standing out (design vision) has been successfully achieved.
AR | Enclosure aesthetics must offer a solution that is the most advanced design possible, yet still acceptable by the public (MAYA principle).		
AR | Enclosure aesthetics must broaden public's view on the role that edge infrastructure can play in its environment • Edge infrastructure that can enhance the visual appeal of its environment • At least 50% of viewers should identity that EMDC enclosure would beatify their public spaces		Further design iterations are necessary to reach similar levels of pleasant/ neutral/unpleasant general feelings of AI Inspiration.
AR | Enclosure aesthetics must offer a 'signature' design, meaning that it looks appropriate across 3 placement contexts of interest • Urban, manufacturing, healthcare		Expected to be achieved with carefully chosen color offerings.
AR | Enclosure design must avoid personification trait • Being perceived as a person/creature		Personification concerns emerged during final assessment survey, further design iterations are necessary.
AR | Enclosure aesthetics must maintain its desired visual impact when viewed from a distance. • Distance from the ground to the 1st floor level or higher		
	AW | Enclosure aesthetics should be independent of such variable environmental factors as light angle and intensity • Maintain its sticking qualities regardless of possible environment limitations	

Sustainability (S)		
	SW | The enclosure material should have *at least* 25% recycled content in it.	Further material/manufacturing detailing is required to meet this requirement.
	SW | The enclosure material should be 100% recyclable.	Further material/manufacturing detailing is required to meet this requirement.
	SW | Enclosure materials should be bio-based.	
SR | Customizable enclosure part(s) must be 100% recyclable.		
Manufacturing & materials (M)		
MR 1 | Selected materials/manufacturing combination(s) must balance costs with not compromising on aesthetics.		Proposed material/manufacturing combination prioritizes aesthetics, yet cost optimization needs to be performed.
MR 2 | Selected manufacturing processes and materials must maintain essential form factor elements.		
MR 3 | Selected materials must allow for minimal dirt and dust accumulation.	**MW 3 |** Selected materials should be dust/dirt repellant.	
MR 4 | Selected material/manufacturing combination must be appropriate for outdoors placement in terms of common temperature differences.		
MR 5 | Selected materials/manufacturing combination must theoretically account for IK10 impact test.		Physical/digital simulations are required to verify.
MR 6 | Materials/manufacturing recommendations must be appropriate for the expected production volumes • 250-500 units/year		

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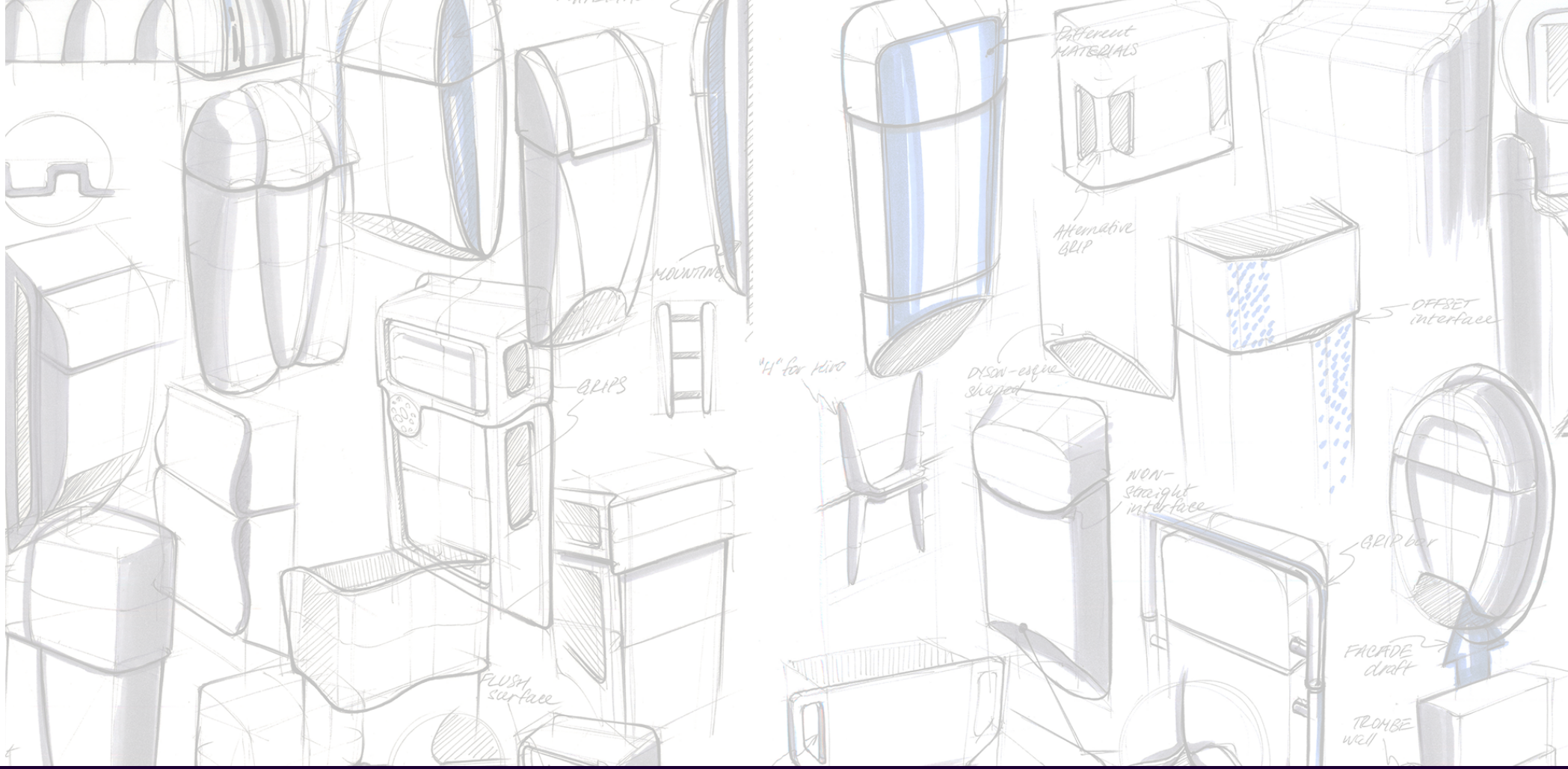
MOUNTING
GRIPS
FLUSH surface
Different MATERIALS
Alternative GRIP
OFFSET interface
"H" for Hiro
DYSON-esque shaped
NON-straight interface
GRIP bar
FACADE draft
TROMBE wall