

VEIL

From Multilayer Absorption Principles to Product Development, Design of an Outdoor Acoustic Panel for Temporary Events

Author: Matteo Segattini 10764274
Thesis supervisor: Riccardo Gatti
Co-supervisor: Marco Luigi Longana

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Abstract

Outdoor temporary events have become a common format for cultural and commercial activities, but they rarely provide good listening conditions. High sound exposure, reflective temporary structures, and the lack of enclosing boundaries often make acoustic control difficult. In practice, mitigation is usually limited to managing source levels, while few product solutions are designed to be deployed outdoors without disrupting the setting or the workflow of repeated assembly and disassembly.

This thesis aims to define and test a product oriented pathway for improving listening conditions in exposed event settings, by developing a deployable multilayer absorptive panel that functions both as acoustic device and spatial divider. The research combines contextual analysis of outdoor event scenarios, a review of the principal absorption mechanisms, and an iterative translation of constraints into requirements and decision criteria for design context.

The solution takes the form of a coherent multilayer architecture designed for sound absorption under the constraints of weather, transport, and repeated assembly.

A recycled carbon fibre nonwoven, Rymfelt, is integrated within the multilayer build up as a resistive element, supporting controlled energy dissipation while aligning the material choice with circularity goals. The configuration is conceived for double sided absorption and for protection against weather and handling, with a modular construction that suits temporary layouts. Beyond the concept stage, the thesis outlines an engineering development path by defining how the frame and its components can be produced and assembled, and it includes a simplified stability verification addressing wind related overturning risk.

Overall, the thesis contributes a structured method to move from outdoor event constraints to a buildable acoustic product concept, and it outlines design levers that can guide future deployable interventions where comfort must be improved without relying on permanent architecture.

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1. Introduction

1.1 Context and motivation

Temporary outdoor events, fairs, exhibitions, open air activations, pop up installations, and festival settings have become a common way to build social life and cultural visibility in contemporary cities (Figure 1). Their spaces are typically assembled quickly, configured for short time windows, and dismantled or re used in different layouts immediately after. This temporariness defines the operating conditions of the environment itself, where weather exposure, variable crowd density, changing sound sources, and limited control over surrounding surfaces combine into a setting that is dynamic, open, and only partially predictable.

Within this framework, acoustics is often treated as a secondary issue compared to logistics, safety, branding, and spatial layout. The result is a recurring condition that is familiar in many event environments: elevated background noise, reduced speech clarity at

short range, and a general sense of acoustic stress driven by the simultaneous presence of multiple sound sources (Berglund et al., 1995). Rather than aiming to reduce overall sound levels as such, acoustic interventions in event settings can focus on limiting avoidable reflections and improving local listening conditions, especially in the speech-relevant bands and in proximity zones where people gather and interact (Cox & D'Antonio, 2017). This shift can still produce tangible benefits for users: conversations require less effort, acoustic fatigue decreases, and the quality of the space is perceived as higher (Berglund et al., 1995).

This context defines a clear design opportunity. Acoustic comfort is repeatedly problematic in temporary event environments, yet the solutions typically used in architectural acoustics are often poorly compatible with the operational conditions of this scenario. Many high performance absorbers assume stable installation, protected indoor use, or integration into fixed building elements, while event infrastructures require components that can be deployed quickly, repositioned frequently, and stored efficiently, without losing performance or visual integrity over repeated cycles (Everest & Pohlmann, 2015). The opportunity is therefore to develop an acoustic element whose performance is

Figure 1: fuorisalone 2025



achieved within these constraints, rather than in spite of them. A further advantage, relevant but secondary to the core driver, is that event components are also expected to support communication and identity through branding and exhibition graphics, so an absorber that can operate as a clean, readable plane aligns more naturally with how event spaces are assembled and used.

Material and lifecycle aspects further reinforce the relevance of a dedicated solution. Temporary event components undergo frequent transport (Figure 2), rapid assembly, and repeated handling cycles, with a higher likelihood of impact, abrasion, dirt, and humidity exposure. These conditions can shorten service life and increase maintenance and replacement rates over time. At the same time, the growing availability of recycled, industrially produced fibre products creates a realistic pathway to integrate recycled content in a technically meaningful way, not as a symbolic gesture, but as a functional contribution within a system where acoustic performance, manufacturability, and durability must be balanced (RYMYC, n.d.; Sántha & Tamás-Bényei, 2025).

In summary, the context is defined by constraint driven environments where acoustic comfort is relevant yet under

addressed, and where solutions must remain compatible with modular deployment and the operational logic of temporary setups. This thesis responds to that gap by exploring a layered panel architecture intended for repeated use across temporary installations, with outdoor conditions treated as the most demanding reference.

1.2 Aim, objectives and contribution

The aim of this thesis is to develop and justify a structured approach to modular acoustic panels for temporary installations, with outdoor deployment used as the main driver to set performance and integration constraints.

To achieve this aim, the thesis pursues the following objectives:

- Define the application frame and translate it into design-relevant requirements and decision criteria, reflecting constraints related to deployment, handling, stability, exposure, maintenance, and visual integration.
- Establish the acoustic principles and evaluation parameters needed to inform design decisions for a layered absorber solution, focusing on what is directly actionable within the development process.
- Develop a functional layered architecture by defining explicit layer roles, constraints, and interfaces, and by clarifying how changes in configuration affect both acoustic behaviour and integration feasibility.
- Conduct material research mapped to functional roles and converge on a final layer set, with particular attention to testing and refining the role of Rymfelt within the layered assembly.
- Translate the research outcomes into a coherent product proposal, consolidating requirements, the final layer configuration, and integration choices into a clear direction for concept definition and engineering development in the subsequent chapters.

Figure 2: typical logistic event setup



1.3 Initial project premise: Rymfelt as an acoustic material

The project starts from a material led premise: the hypothesis that an industrially available recycled carbon fibre nonwoven could serve as an acoustic component for deployable absorber systems. The initial reference is Rymfelt, produced by the Italian company Rymyc, selected for its combination of acoustic potential, robustness under repeated handling, and recycled feedstock origin (RYMYC, n.d.; Sántha & Tamás-Bényei, 2025).

Unlike common porous absorbers in architectural acoustics, such as mineral wool, glass wool, open cell foams, or polyester nonwovens, Rymfelt belongs to a different material family (Everest & Pohlmann, 2015; Cox & D'Antonio, 2017). Its recycled carbon fibre origin (figure 3) suggests a fibrous porous morphology, potentially high internal surface area, and a structure that can remain mechanically coherent during repeated manipulation, which supports an initial assumption in which Rymfelt may contribute to sound absorption through viscous and thermal losses within its porous structure (Cox & D'Antonio, 2017).

However, from the outset, the project treats this premise as a starting point rather than as a predetermined solution. The material is carried forward into the thesis as a candidate to be positioned within a deployable system, and its most appropriate role is clarified only after the application requirements and the design logic of the absorber configuration have been established in the subsequent chapters.

In particular, the thesis keeps open the possibility that the most effective contribution of the material may emerge when it is combined with other layers that shape boundary conditions and airflow resistance, allowing the absorber behaviour to be tuned by configuration rather than fixed by a single material choice.

1.4 Method overview

The thesis adopts a method that narrows from an initial premise to a defined layered proposal through iterative alignment between requirements, acoustic reasoning, and material exploration. Requirements and decision criteria are established early to guide development and comparison between alternatives. A focused acoustic framework is then used to select the mechanisms and parameters that are most relevant for layered absorbers, providing a consistent basis for evaluating configurations (Cox & D'Antonio, 2017).

On this foundation, a functional layered architecture is developed by defining layer roles, constraints, and interaction logic, so that performance can be shaped through placement and interfaces rather than attributed to a single material. Particular attention is given to how resistive effects at or near the surface influence absorption and how these effects can be managed through stack design (Chevillotte, 2012; Segura-Alcaraz et al., 2018).

Material research is carried out within this architectural frame. Candidate materials are considered in terms of the role they can realistically fulfil within the layered assembly, while the initial premise around Rymfelt is progressively assessed and refined as the work develops. The outcome is a coherent layer set and a clear integration logic that provide a solid bridge to the chapters on application requirements, concept development, and engineering integration.

Figure 3: carbon fiber scraps



1.5 Scope, boundaries and assumptions

The thesis focuses on modular acoustic panels for temporary installations, with layered absorber architectures as the central object of study. The event and exhibition domain is treated as the primary reference scenario, including outdoor and semi outdoor conditions, in order to frame a demanding use case while keeping the resulting approach applicable to comparable indoor deployments.

The scope is bounded to the panel as a product component and to the integration logic that enables repeated deployment. The work does not provide a complete, site specific acoustic design for a single venue through calibrated simulations or compliance driven mapping, and it does not address large scale measures such as sound system tuning, crowd management, or urban noise mitigation. Technical documentation is developed to support feasibility and producibility; however, the thesis does not include a fully manufactured final product followed by an extensive standardized validation campaign across multiple test methods and conditions, as would be expected in a complete industrial qualification pathway.

The analysis assumes a local and pragmatic acoustic benefit, aimed at improving perceived comfort and speech related clarity in proximity zones rather than creating quiet environments (Berglund et al., 1995). Performance is treated as a result of configuration, with materials evaluated in their functional role and in interaction with adjacent layers rather than in isolation (Cox & D'Antonio, 2017; Chevillotte, 2012). Where full scale test facilities are not available, conclusions are drawn from literature grounded reasoning and targeted verification steps, with limitations stated explicitly when drawing conclusions.

2. Application scenario and requirements

2.1 Contexts and typical acoustic conditions

A temporary open-air or semi-outdoor event environment can be understood as a place that is assembled for a limited time and then removed, rather than a space designed to remain. It often takes shape in squares, courtyards, park edges, fairgrounds, or service yards that are temporarily opened to the public. What defines these settings is a non-permanent spatial condition: boundaries are transitional, circulation routes are adjusted, and functional elements are added to support the event, such as booths, light structures, fencing, signage, and technical areas (Figure 4).

Surfaces and obstacles are therefore heterogeneous and discontinuous: hard ground planes alternate with platforms, temporary coverings, and nearby façades or large objects that can locally act as reflective surfaces. As a result, sound does not behave as it would in a controlled indoor environment, or as it would in a fully unobstructed outdoor field. Instead, what people perceive is often shaped by a combination of direct sound and a small number of prominent reflections generated by the nearest surfaces, producing noticeable differences over short distances depending on local geometry, the presence of people, and partial shielding from stands or temporary partitions

Building on this spatial condition, the acoustic environment is rarely defined by a single stable source. Instead, it results from the overlap of contributors with different degrees of control and predictability. Some are intentional and often directional, such as public-address systems for announcements, guided presentations, or activity zones where sound is part of the programme. Others are distributed and emergent, including crowd noise, queuing, and circulation, which vary

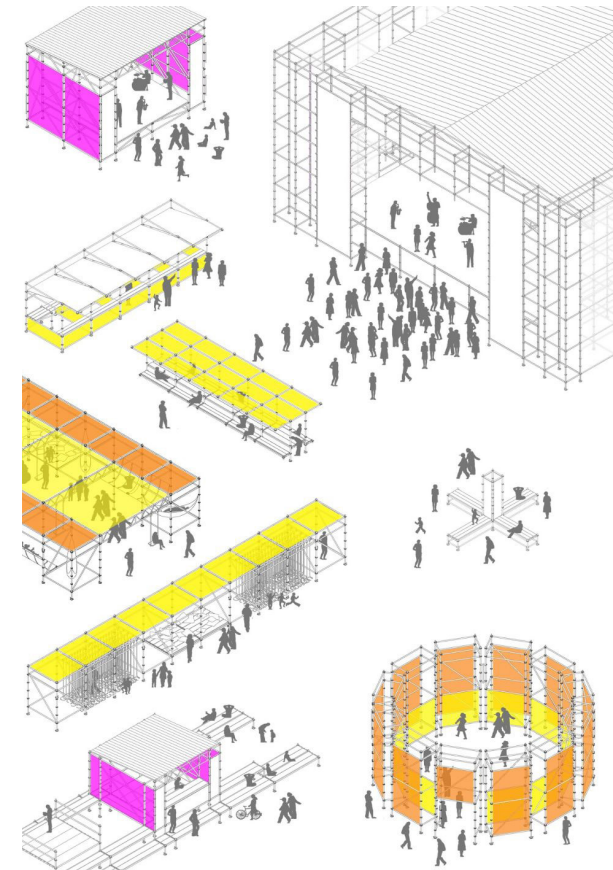
with density and movement.

Operational sources may also be present, for example service vehicles, generators, and temporary HVAC units. The outcome is a rapidly changing soundscape, where disturbance is shaped not only by average level, but also by peaks, repetition, and the duration of exposure (Berglund & Lindvall, 1995).

Outdoor and semi-outdoor conditions introduce propagation effects that are largely absent in indoor design problems, adding variability on top of an already complex mix of sound sources. In the absence of strong reflections, direct sound decays mainly with distance, and the inverse-square law tends to dominate this attenuation, meaning that sound energy spreads over an expanding area and level drops quickly as distance increases. (Figure 5)

Speech and signals can therefore become fragile as soon as background noise rises. In addition, the atmosphere becomes part of the propagation path: wind and temperature gradients can refract sound and bias how far it carries, producing differences in

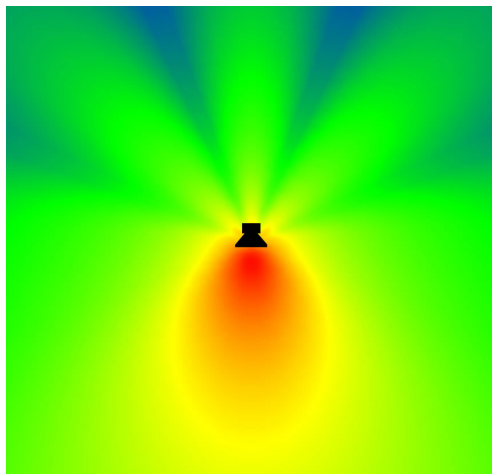
Figure 4: typical non-permanent event spatial condition



received level that are not explained by geometry alone. For this reason, established environmental-noise engineering practice specifies meteorological assumptions or reference conditions when estimating outdoor propagation and assessing levels in the field (International Organization for Standardization [ISO], 1996; ISO, 2017).

Spectral balance is equally important. Outdoor sound often contains persistent low-frequency components from traffic, machinery, or amplified systems, which propagate efficiently and can dominate perception at a distance. When these components dominate, annoyance tends to increase and speech becomes harder to follow due to masking (Berglund & Lindvall, 1995). Since everyday speech understanding depends primarily on mid frequencies, roughly from a few hundred hertz to a few kilohertz, design actions that reduce masking in this region can produce a clear improvement in communication and in the overall sense of acoustic order within the space (ISO, 2003).

Figure 5: Sound propagation in outdoor environment



2.2 Users and operational workflow

In this application scenario, the panel should be understood not only as an installed element, but as an object that repeatedly moves between two conditions: in service, when it is positioned and actively used within the event space, and in transition, when it is handled, transported, installed, removed, and stored. The lifecycle is therefore not defined by a single “final” state, but by the recurrence of these transitions, which become part of the normal operating context and shape how the system is experienced and maintained over time.

In practical terms, the operational sequence is relatively consistent across events. The panel is first transported to site and staged for deployment, then placed during installation (figure 6). It remains exposed during operation, in close proximity to people and to daily site routines, and is later dismantled, packed, and moved again. Because this cycle is repeated, the panel is continuously subjected to conditions that differ from those of a permanent installation: frequent handling, temporary resting and stacking, contact with uneven surfaces, and exposure to dust, moisture, and incidental impacts (European Committee for Standardization [CEN], 2015).

The main users align with the same two phases. During transport, setup, dismantling, and packing, the panel is handled by the

Figure 6: outdoor installation process



people responsible for deployment, where speed, clear handling, and safe assembly matter. During operation, responsibility can vary depending on the setting and the ownership model. The system should therefore behave predictably in use, remain compatible with circulation, and allow occasional repositioning when layouts or activity patterns change. Visitors and staff encounter the panel at close range while it is in service, so perceived safety, comfort, and robustness affect how naturally it is integrated into the environment. Taken together, these roles explain why the thesis addresses not only acoustic performance, but also deployment practicality, exposure, and repeated use (CEN, 2015).

2.3 Safety and compliance context in temporary public installations

Beyond its acoustic function, the panel is introduced into a temporary public setting where safety is a governing condition. Risk is not limited to the in-service state; it also emerges during handling phases, including installation, inspection, minor adjustments, and dismantling. For this reason, guidance and standards for temporary and demountable structures consistently treat competent design, clear procedures, and controlled erection and dismantling as core safety foundations, rather than organisational details (CEN, 2015).

A first implication is that temporary event components must remain checkable and verifiable across repeated cycles. This requires a clear assembly logic, limited ambiguity in intermediate states, and straightforward inspection after use and transport. Consistently with the lifecycle logic used in temporary-structure frameworks, safety expectations span design, manufacture, installation, operation, maintenance, and examination (CEN, 2015). The panel is therefore considered within the same lifecycle logic, not as an isolated product, but as a component of the temporary installation system.

A second implication concerns mechanical safety under environmental actions and public proximity. In outdoor and semi-outdoor use, wind actions must be treated as an explicit design condition. Acoustic effectiveness in open air typically requires a meaningful surface extent, which naturally increases exposure to wind pressure and the risk of overturning.. Stability therefore cannot be assumed and must remain verifiable within established structural design frameworks for wind actions and attached elements (CEN, 2005). In parallel, because the panel operates close to users, stability must remain credible not only under wind, but also under incidental contact, such as brushing, leaning, or unintentional impacts in crowded conditions. Surface and interaction safety therefore matters alongside global stability, including edge treatment, pinch and trap risks, and predictable behaviour under everyday contact in partially supervised environments (CEN, 2015).

Fire safety and material compliance should be integrated from the beginning because, in temporary public settings, the panel becomes part of the circulation space people rely on during an emergency. In these contexts, materials are assessed not only by functional performance, but also by reaction-to-fire behaviour, particularly flame spread, smoke production, and burning droplets. Within the European framework, reaction-to-fire classification provides a structured description of these behaviours through standardised testing, combining a main class with additional indices for smoke and flaming droplets (figure 7) (CEN, 2018).

This is especially relevant for acoustic applications because high absorption is often achieved with organic or polymer-based constituents. In those cases, the risk can involve dense smoke and hazardous decomposition products, which directly affect visibility and evacuation conditions (CEN, 2018). For this reason, acoustic effectiveness cannot be treated in isolation: material and surface-layer choices must be developed together with fire behaviour within a clear compliance pathway, so that performance and public-safety obligations are addressed through the same decisions (CEN, 2018).

2.4 Requirements and decision criteria

With the scenario and its operational realities now established, the observations made so far can be condensed into a clear reference point. The purpose of this concluding section is to bring these threads into a coherent picture, so that the subsequent chapters can build on an explicit and shared understanding of what matters most in this scenario.

From an acoustic perspective, the system is expected to support everyday spoken interaction in the areas where guidance and coordination occur. This implies acting on the local listening condition rather than on a single nominal “overall level”, since reliable speech depends on maintaining a favourable margin between speech and background noise (ISO, 2003; Berglund & Lindvall, 1995).

In addition, because outdoor sound often includes persistent low-frequency components with strong perceptual impact, the response should not be confined to a narrow band, but remain meaningfully effective across a broader and realistic frequency range (Berglund & Lindvall, 1995). Finally, because layouts and activity patterns

vary across sites, benefit should not rely on a single optimal placement; exposed absorbing surface is treated as a practical resource under changing source positions and geometries, and will later become a key basis for comparing design options.

Safety and compliance are treated as coupled criteria because the panel is a component of a temporary installation. This implies lifecycle-oriented safety expectations and defensible behaviour under both outdoor actions and incidental contact in crowded conditions (CEN, 2015). Wind is a primary stability driver for acoustically meaningful surfaces and requires explicit verification within standard design frameworks (CEN, 2005). Fire behaviour is integrated into material and surface-layer decisions through the European reaction-to-fire classification framework, following the EN 13501-1, and keeping acoustic ambition aligned with public-safety expectations through a clear compliance pathway (CEN, 2018).

Durability and maintainability complete the criteria set. Repeated handling and exposure require stable connections, inspectable assemblies, and performance that remains reliable across deployment cycles.

Figure 7: reaction to fire classification, overview

Definition	Grade	Smoke production	Flaming droplets	Description
Non combustible materials	A1	–	–	Materials that cannot contribute to a fire at any stage, including a fully developed fire, can be awarded class A1.
	A2	s1	d0	If a construction product produces no contribution to fire, but has the potential to produce some smoke or droplets, this falls into class A2.
Combustible materials very limited contribution to fire	B	s1	d0	Highly resistant materials always followed by additional classification for smoke and burning droplets, and all variations.
Combustible materials limited contribution to fire	C	s1	d0	Products that meet more stringent requirements than class D with limited contribution to fire, and all variations.
Combustible materials medium contribution to fire	D	s1	d0	Those with a contribution to fire, but greater resistance to flame, and all variations.
Combustible materials high contribution to fire	E	E, d2		Products that have a significant contribution to fire but resist a small flame for a short time.
Combustible materials easily flammable	F	–		If a product has not been tested or failed to meet class A1 to E requirements.

3. Acoustic and perceptual background for design decisions

3.1 Listening conditions in outdoor events: from noise to speech clarity

Outdoor events create listening conditions that differ from indoor spaces. Without enclosing walls, sound is less affected by persistent reverberation, but clarity is still challenged by the realities of public temporary settings: fluctuating background noise, dense crowds, moving sources, and large variations in distance between listeners and sound sources. In this thesis, speech clarity is used as a practical indicator of listening quality, because it captures whether information remains understandable in real use, ranging from everyday conversations between users within the area to announcements, wayfinding cues, and short instructions that support the event experience. (Berglund et al., 1995; Everest & Pohlmann, 2009)

Being outdoors does not make intelligibility less important. The listening condition is therefore treated as a design concern. It cannot be controlled in the same way as an indoor hall, but it can still be improved locally through choices that shape how sound travels, reflects, and competes within the layout.

To keep the discussion practical, the section relies on three simple ideas. Distance reduces the useful signal, background noise competes with it, and clarity depends on the balance between the two, especially in the frequency range most relevant for speech.

Before introducing these effects, two basic metrics are clarified. Sound level is commonly expressed in decibels, dB, a logarithmic measure referenced to a standard sound pressure in air, used because acoustic pressure spans several orders of magnitude and because the logarithmic scale makes level differences

manageable and directly comparable. In practice, decibels describe sound pressure level rather than perceived loudness, yet they provide the standard quantitative language to discuss attenuation with distance, the contribution of background noise, and the level differences that underpin signal to noise considerations.

Alongside level, when referring to acoustic absorption it is common to adopt the absorption coefficient, α , defined as the fraction of incident acoustic energy that is not reflected by a surface under specified conditions, with values ranging from 0 for a fully reflective surface to 1 for an ideally absorbing one.

The coefficient is widely used as a primary descriptor to evaluate and compare the absorbing performance of materials and assemblies, because it expresses how effectively a surface reduces reflected energy, and it is inherently frequency dependent, meaning that the same material can be highly effective in one band and less effective in another. For this reason, absorption is treated through frequency curves and standardised measurement contexts, rather than a single universal value. (Everest & Pohlmann, 2009; Cox & D’Antonio, 2017; ISO, 1998, 2003)

3.1.1 An outdoor audience is distance-limited

A defining feature of outdoor listening is that sound spreads without the support of room reflections. As distance increases, the level of direct sound decreases rapidly (figure 8): a useful rule of thumb is that level drops by about 6 dB every time the distance doubles. This immediately turns geometry into audibility. A listener at 20 m receives substantially less direct sound than a listener at 10 m, and this difference becomes critical when an audience footprint is deep. (Everest & Pohlmann, 2009)

This is one reason why outdoor events often feel uneven: without careful sound distribution, the back of a crowd is not “slightly” quieter, it can be meaningfully quieter. The consequence is not only lower loudness, but weaker intelligibility: as useful sound decreases, it becomes easier for competing sources and background noise to cover it. (Berglund et al., 1995)

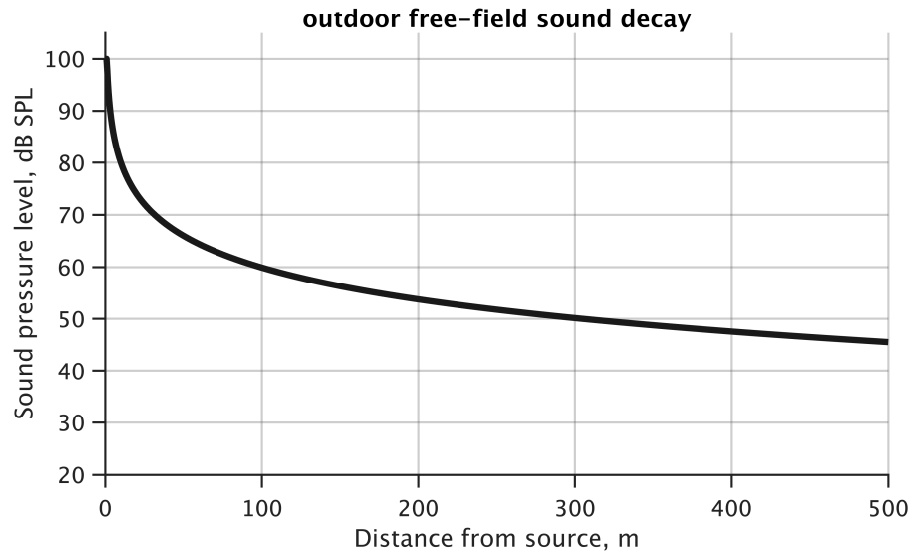


Figure 8: Graphical representation of outdoor free-field sound decay

3.1.2 From reverberation limits to signal strength limits

It is tempting to assume that outdoor environments are always clearer than indoor ones because there is less reverberation. This is only partly true. Indoors, long reverberation can blur consonants and reduce intelligibility, whereas outdoors this blurring is often reduced. However, as previously described, in open air the direct sound level can drop quickly with distance, so the limiting factor often shifts from reflections to the strength of the direct signal at the listener position. (Everest & Pohlmann, 2009)

This shift in what limits intelligibility is important for design. In outdoor settings, clarity depends not only on the direct signal reaching the listener, but also on the listening conditions created by the event layout, where people stand, how they move, where activities concentrate, and where competing sound persists. (Cox & D'Antonio, 2017)

Even in open air, events generate local acoustic situations in which nearby surfaces and crowd density shape what is heard, for example between booths, under canopies, along temporary corridors, near reflective elements, and in queueing areas. These micro-environments are where acoustic measures can produce a perceptible improvement in the overall experience.

3.1.3 Background noise and the concept of masking

In outdoor events, the main listening challenge is often not silence versus noise, but speech versus competing activity. Background sound is continuously present, and crowd noise is particularly influential because it is largely made of many voices at once. In this context, the key concept is masking. (Berglund et al., 1995)

Masking occurs when a competing sound makes speech harder to understand, not because speech is missing, but because relevant cues are covered. It becomes most severe when the interfering sound overlaps the same frequency region and the same temporal patterns that listeners rely on to decode speech. This is why crowd noise is so disruptive in practice. People may describe an area as loud, but the more direct problem is that spoken information becomes difficult to extract, even at short range. (Berglund et al., 1995; Cox & D'Antonio, 2017)

3.1.4 Balance between speech and noise

Because distance reduces the useful signal while background sound persists, the practical question is how much stronger the informative sound is than the competing noise at the listener position. This relationship is

commonly described as the speech to noise balance, often expressed as a signal to noise ratio (SNR), and it can be understood as the level difference between speech and the surrounding sound field. (Berglund et al., 1995)

The chart below (figure 9) visualises this balance by showing how the speech level decreases with distance while the background sound field remains approximately constant, highlighting how intelligibility depends on their relative separation at the listener position.

When speech is close to the background level, conversation and announcements may still be possible, but comprehension becomes effortful and mistakes become more likely. When speech clearly exceeds the background, understanding becomes easier and less fatiguing. This also explains why simply increasing loudness is not a reliable solution. In dense and active spaces, raising level can increase both the informative signal and the overall sound field. The design goal is therefore to improve the balance, not only the absolute level. (Berglund et al., 1995)

3.1.5 Wide-band frequencies

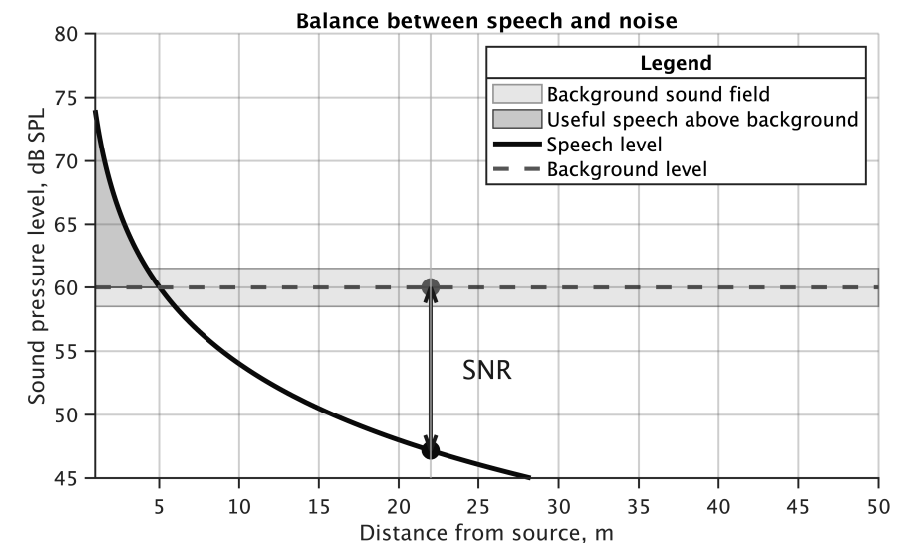
Spoken communication spans a broad portion of the audible spectrum, but intelligibility depends most strongly on mid

frequencies, where many of the cues that distinguish consonants are concentrated. A practical summary is that speech extends roughly from 100 to 6000 Hz, while the region most critical for comprehension lies approximately between 300 and 3000 Hz.

In outdoor conditions, however, the listening spectrum is not stable with distance. Mid and high frequency components are attenuated and disrupted more rapidly by atmospheric losses, scattering from people and small obstacles, and ground interaction effects, so the sound that reaches listeners tends to become progressively low frequency weighted as distance increases. (Everest & Pohlmann, 2009; Cox & D'Antonio, 2017)

This matters because several dominant outdoor noise contributors, including crowd babble, circulation, and operational equipment, also carry substantial energy in the same mid bands that support speech understanding. When speech cues and noise overlap in this region, clarity is primarily limited by masking rather than by absolute level. For this reason, a narrow band intervention is rarely sufficient in real event conditions. A more realistic goal is a response that remains meaningfully effective across a broader frequency range, supporting mid band clarity while also limiting the low frequency dominance that tends to persist outdoors. (Berglund et al., 1995; Cox & D'Antonio, 2017)

Figure 9: Graphical representation of balance between speech and noise



3.1.6 Intrinsic variability and listening quality descriptors

Event sound changes across both time and space. Two locations can have a similar average level but feel very different, for example one dominated by low frequency rumble, another by mid band babble, with different effects on speech understanding. For this reason, a single overall noise value does not describe listening quality well.

A more useful approach is to look at intelligibility related factors, in particular how favourable the speech to noise balance is in the most relevant frequency bands, and whether speech cues remain clear over time rather than being blurred by the environment. The aim is not to add complexity, but to describe clarity in terms that match how people actually understand, or fail to understand, speech. (Berglund et al., 1995; IEC, 2020)

3.1.7 Implications and local configurations

In this thesis, outdoor listening is treated as a balance problem distributed across space. Distance reduces the useful signal, background activity competes with it, and clarity depends on their relationship in the speech relevant bands. This explains why the same event can feel easy to follow in one spot and difficult only a few metres away. (Berglund et al., 1995)

Temporary layouts can also create local situations that behave like small acoustic pockets, even in open air. Corridors between booths, canopies, stands, and short sequences of rigid surfaces can add nearby reflections and short range sound persistence, which increases masking and reduces clarity in specific areas.

The practical consequence is that clarity can be improved without trying to control the whole outdoor sound field. Instead, interventions can focus on the local conditions in the zones where people queue, navigate, and exchange information. This sets the basis for the following sections, which introduce absorption mechanisms and evaluation parameters as tools for targeted improvements in these event micro

environments. (Cox & D'Antonio, 2017; Berglund et al., 1995)

3.2 Physical mechanisms for absorption

Outdoor events provide an acoustically open setting, yet listening can still be demanding. As described in Section 3.1, clarity degrades when speech competes with a strong and fluctuating background produced by multiple distributed sources, such as voices, music spill, machinery, and circulation.

Because masking is local and changes with distance, crowd distribution, and temporary layouts, improving intelligibility is less about controlling the overall outdoor sound field and more about shaping the micro environments where communication occurs.

Within this logic, absorptive interventions are not intended to silence an open field. Their role is to remove acoustic energy where it is most detrimental, reducing reflective clutter at short range and limiting the build up of mid and high frequency content from nearby sources. A deployable panel can be understood as a local boundary that increases dissipation near listeners, making the sound field more predictable in proximity zones without enclosing the space. (Chevillotte, 2012; Cox & D'Antonio, 2016)

This perspective links directly to absorption theory. If the design intent is a local improvement of speech to background conditions, the key question is how different absorber families dissipate acoustic energy (figure 10) and how their effectiveness depends on frequency, incidence, and configuration.

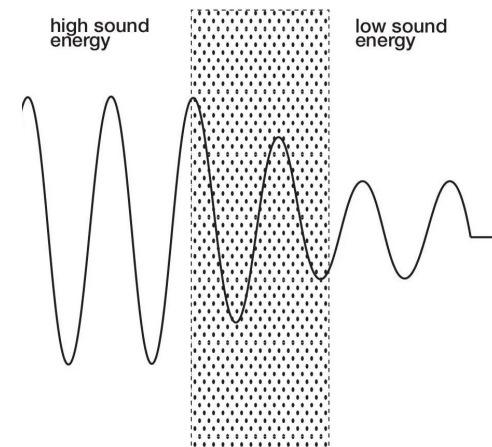
At a physical level, absorption is the conversion of sound energy into heat. This occurs either in a distributed way, when air motion is resisted through a structure, or in a concentrated way, when resonance amplifies motion around a specific frequency and losses become effective. In all cases, performance starts at the interface. Energy must enter the absorber instead of being reflected, meaning that the system must allow air to move, or a boundary to vibrate, and then dissipate that motion

through friction, thermal exchange, or internal damping. (Allard & Atalla, 2009; Cox & D'Antonio, 2016)

3.2.1 Porous absorbers

Porous absorbers rely on the fact that sound involves both pressure variation and particle motion. When a wave encounters an open porous structure, part of the oscillating air is forced through a network of narrow passages. Inside these pores, motion is resisted and energy is lost through two coupled mechanisms, viscous losses due to friction along solid surfaces, and thermal losses due to heat exchange between the air and the pore walls. The result is a gradual

Figure 10: sound energy dissipation



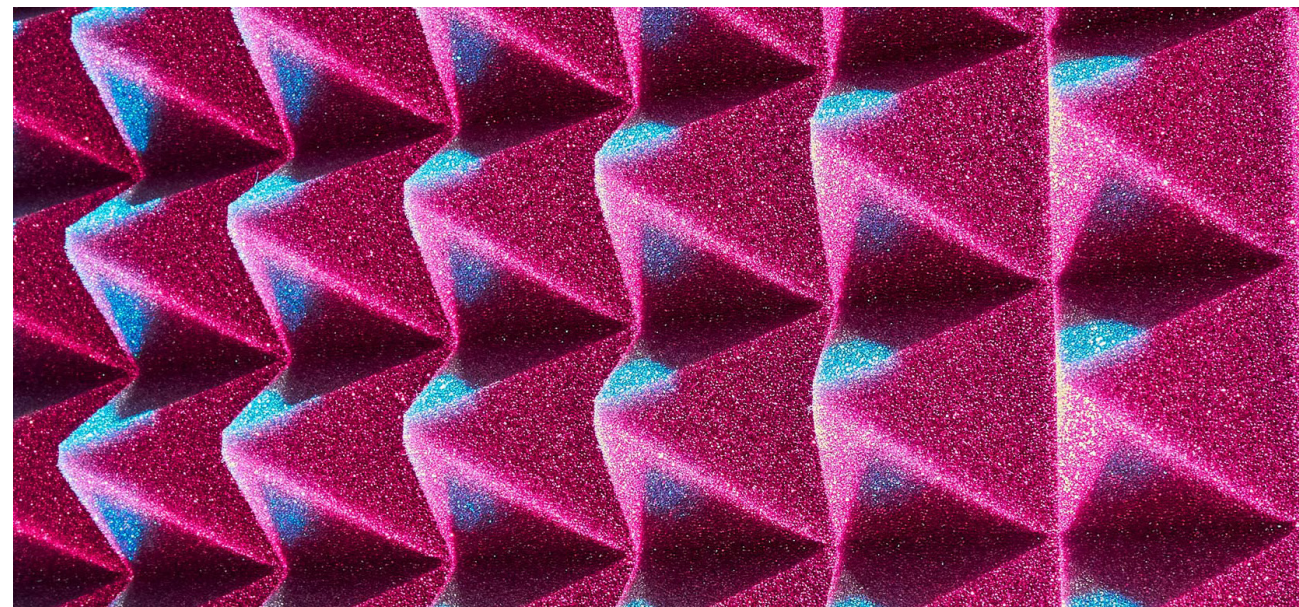
conversion of acoustic energy into heat as the wave penetrates the structure. (Allard & Atalla, 2009)

A key reason porous absorbers are widely used is that they are naturally broadband. They do not depend on a single tuned resonance. They provide losses across a wide range as long as sound can enter the material and interact with sufficient internal surface area. Their effectiveness depends strongly on how easily air can move through the structure. If it is too open, air moves with little resistance and losses remain limited. If it is too closed, sound struggles to penetrate and is reflected instead. (Allard & Atalla, 2009; Cox & D'Antonio, 2016). This balance is commonly described through parameters such as airflow resistivity and internal path complexity, which capture how resistive and how tortuous the air paths are.

Porous layers tend to be most effective in the mid and high frequency range. At lower frequencies a porous layer can still contribute, but it typically requires greater depth or a configuration that increases particle velocity in the material. Spacing behind the layer or a backing cavity can shift the velocity distribution and improve low frequency effectiveness without relying only on thickness. (Cox & D'Antonio, 2016)

A widely used product example of a porous absorber is the profiled panel often seen in acoustic treatments, where the surface geometry increases exposed area while maintaining an open structure, as shown in Figure 11.

Figure 11: acoustic pyramid foam panel



3.2.2 Resonant absorbers: Helmholtz type systems

Resonant absorbers concentrate motion around a tuned frequency. A Helmholtz type resonator can be described through a simple analogy. The air in an opening behaves like a moving mass, while the air trapped in the cavity behaves like a spring. When incident sound excites the system near its resonance, the motion in the opening becomes large and, if sufficient losses are present, a significant portion of the acoustic energy is dissipated. (Ingard, 1953; Cox & D'Antonio, 2016)

Dissipation occurs mainly through viscous and thermal losses in regions where velocity and gradients are high, typically near the opening and in boundary layers. Additional damping can be introduced by resistive elements, which increase losses and reduce the sharpness of the resonance. This step is what turns a resonator into an absorber, resonance increases motion, damping converts that motion into heat. (Chevillotte, 2012)

A fundamental characteristic of Helmholtz type absorption is a peak shaped response. A single resonator tends to produce strong absorption over a limited band. Broader behaviour can be achieved by combining resonators with different tuning frequencies, increasing damping, or designing configurations that create multiple resonances. (Cox & D'Antonio, 2016)

3.2.3 Spring mass resonators: membrane and panel absorbers

Another resonant family is based on the vibration of a membrane or a thin panel in front of an air cavity. In this case, the moving element is the surface itself. The panel provides mass, the enclosed air provides spring like compliance, and the system resonates when excitation matches the panel cavity dynamic. At resonance, motion is amplified and energy is dissipated through internal losses in the panel, friction at supports and edges, and damping elements placed in or near the cavity. (Cox & D'Antonio, 2016)

This mechanism is relevant because it can provide substantial absorption in frequency regions where a purely porous layer would

otherwise need impractical thickness. The response is again characterised by a resonance peak, while bandwidth can be increased when damping is introduced deliberately or when multiple elements with different resonance frequencies are combined. These devices borrow effectiveness from resonance, they rely on strong boundary motion rather than long propagation paths through a volume, and they dissipate that motion through losses. (Cox & D'Antonio, 2016)

3.2.4 Micro perforated and perforated panel absorbers

Micro perforated and perforated panels follow a hybrid logic. When backed by a cavity, they can behave as resonant systems, while dissipation is strongly linked to thermo viscous losses in many small apertures. When air oscillates through perforations, friction and heat exchange in thin boundary layers along the hole walls dissipate energy. Because this mechanism is distributed across many openings, the absorber can remain thin, durable, and geometrically controllable. (Maa, 1998; Li et al., 2014)

Performance can be shaped through geometric parameters, including hole diameter, perforation ratio, panel thickness, and the depth and structure of the backing cavity. These parameters control both the resonance frequency and the amount of damping. Thermo viscous effects within cavities can also influence the response beyond a single peak by reducing sharp contrasts in the curve and improving overall behaviour across a wider range.

A common example is shown in Figure 12.

3.2.5 Matching mechanisms to frequency ranges in practice

Although each absorber family has many variants, their typical behaviour can be linked to wavelength and to how losses are created. Porous absorbers provide their strongest effect when thickness and internal surface interaction are sufficient relative to the wavelength, which tends to make them increasingly effective at higher frequencies.

(Allard & Atalla, 2009; Cox & D'Antonio, 2016)

Resonant systems are often introduced when strong absorption is needed with limited depth at frequencies where porous thickness alone becomes inefficient. Helmholtz type devices concentrate motion in an opening and cavity, while panel and membrane devices concentrate motion in a vibrating surface. (Ingard, 1953; Cox & D'Antonio, 2016). In both cases, resonance amplifies motion and damping converts that motion into dissipation.

Micro perforated and perforated panels can be read as a geometrically controlled version of the same principle. They create many small regions where viscous and thermal losses are strong, and when combined with cavities they can provide resonant behaviour while maintaining a surface that can be structurally integrated. (Maa, 1998; Li et al., 2014)

The figure in the next page shows the typical absorption coefficient versus frequency behaviour of the main absorber families. Porous absorbers generally exhibit a broad response that increases with frequency, meaning that their useful α values are typically achieved over higher frequency ranges. Resonant systems, by contrast, tend to deliver high α over a narrower band, often centred at lower frequencies, where resonance concentrates motion and losses become effective. Micro-perforated follow a comparable resonance-driven pattern, but they commonly show a wider effective band and a shift of the peak region towards higher frequencies, depending on aperture geometry and cavity configuration.

This section has focused on physical mechanisms rather than design strategy. The translation of these mechanisms into robust design choices, and the reasons why broad band behaviour is often prioritised in variable event conditions, are developed later as a dedicated discussion.

Figure 12: microperforated panel

3.3 Design relevant parameters and evaluation methods

This section introduces the parameters and measurement notions needed to describe absorption in a way that remains comparable across different materials and configurations, and meaningful with respect to the listening objectives outlined in Section 3.1.

3.3.1 Design relevant parameters

Absorption should not be read as a single number because it changes with frequency. What matters is the overall shape of the absorption curve: which frequencies are effectively absorbed, how broad that useful range is, and how stable the response remains in realistic conditions. In event settings, a consistent broadband response is often more useful than a very high but narrow peak. (Cox & D’Antonio, 2016)

To relate this behaviour to an objective, a target band must be defined. Instead of asking whether an absorber is good in general, the comparison becomes whether it is effective in the frequency region where speech cues and typical masking sources overlap. (IEC, 2020)

Once the target band is established, performance must still be interpreted in relation to real boundary conditions. Absorption depends on incidence, so results can differ between near normal and multi angle fields, which matters outdoors where sources are distributed and arrival angles vary. It also depends on mounting and interfaces.

Backing rigidity, air gaps, cavity depth, edge constraints, and small assembly gaps can shift the response because they change how air motion develops at the surface and where losses occur.

For this reason, the design goal for a deployable panel is not only a favourable curve under ideal conditions, but a response that remains consistent under plausible variability in setup and surroundings. (Allard & Atalla, 2009; Cox & D’Antonio, 2016)

3.3.2 Common evaluation methods

Most absorption data used in design comes from laboratory measurements, because standardised methods make results repeatable and comparable. Two approaches are used most often. The first measures absorption on small samples under

a controlled incidence condition. The second estimates absorption from the behaviour of a large specimen in a room designed to approximate a diffuse field. (International Organization for Standardization [ISO], 1998, 2003)

The first approach is the impedance tube method (figure 14). It measures absorption under near normal incidence on relatively small specimens. It is widely used during development because it requires limited sample area, provides fine frequency resolution, and can also provide information related to surface impedance. Its main limitation is interpretive. Tube results describe a specific incidence condition and should not be treated as equivalent to results obtained under random incidence fields. (ISO, 1998; Cox & D’Antonio, 2016).

The second approach is the reverberation room method (Figure 15). It estimates absorption from the change in reverberation time when a large specimen, or an object, is introduced into a reverberant space intended to approximate random incidence. This method is widely used for product comparison and can also provide equivalent absorption area. Its limitations are mainly practical. It requires large samples, can show greater variability between facilities, and can be less reliable for strongly resonant systems with low damping. (ISO, 2003; ASTM International, 2022)

Because full frequency curves are not always easy to compare quickly, single number ratings are often used as summaries. They are convenient for communication and early sorting, but they remain secondary descriptors. By compressing frequency dependent behaviour into one value, they can hide differences that matter when the objective is tied to specific bands. (ISO, 1997; Cox & D’Antonio, 2016)

Alongside measurement, modelling tools are commonly used to explore sensitivity to geometric parameters and guide prototyping. Their role is not to replace measurement, but to support decisions by indicating which parameters most strongly shift the response before committing to large prototypes. (Allard & Atalla, 2009; Cox & D’Antonio, 2016)

3.3.3 Note on outdoor evaluation

In outdoor event contexts, no single laboratory number can fully represent in use performance, because incidence, source distribution, and local geometry vary continuously. A practical approach is therefore to use laboratory curves for controlled comparison, and, when needed, to complement them with simple checks in representative setups to confirm that the expected behaviour remains consistent under conditions closer to deployment.

Figure 13: sound absorption coefficient between absorber types

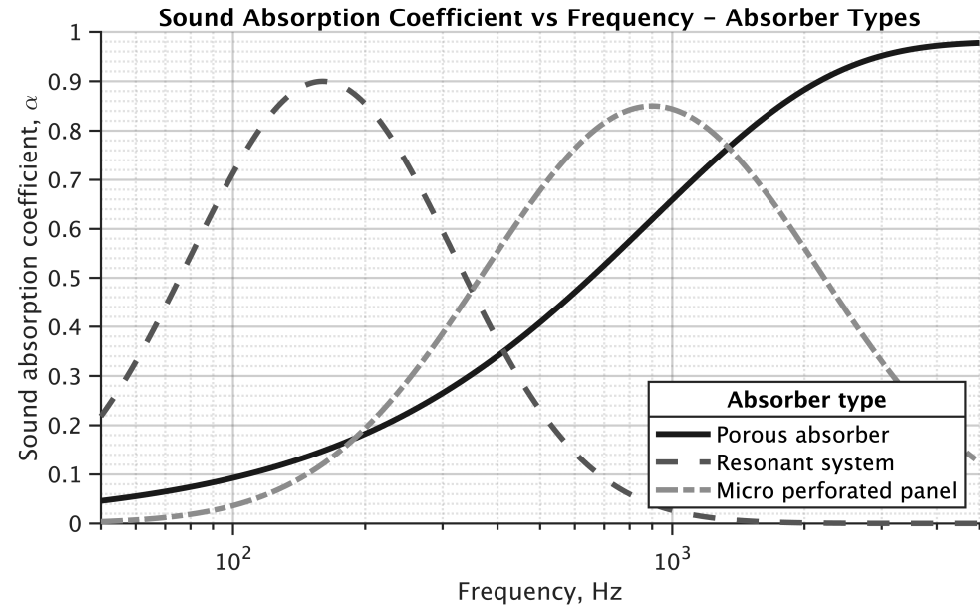


Figure 14: impedance tube method setup

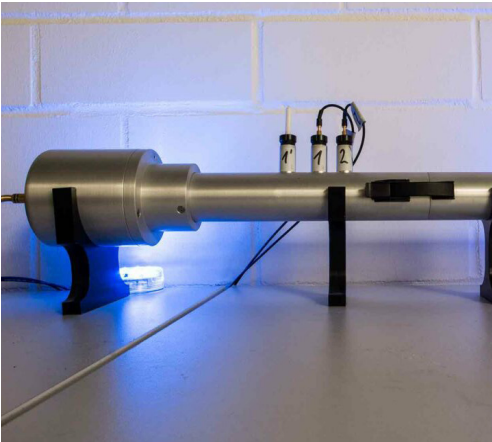


Figure 15: reverberation room method setup



3.4 Design implications

Listening quality in these settings depends on whether speech remains readable against a variable background that often overlaps in frequency. The aim is not to control an entire open sound field, but to improve listening locally in the zones where people communicate and coordinate. (IEC, 2020; Berglund et al., 1995)

This makes absorption a frequency dependent design problem. What matters is where the response is effective and how consistent it remains across a relevant band, not a single summary value. It also means performance must hold under changing conditions. In event layouts, sources are distributed, angles of arrival vary, and nearby temporary boundaries can introduce short range reflections, so the absorber should be configured and assessed with this variability in mind. (Cox & D'Antonio, 2016; ISO, 1996)

Surface area is another key lever. For any given mechanism, a larger active surface increases the overall effect, within the limits set by footprint and deployability. Finally, repeated use makes integration part of performance. Robust handling, protection of functional layers, and an assembly logic that supports consistent setup are required for the acoustic benefit to remain repeatable.

Taken together, these points frame the absorber as a deployable, broadband, and robust system that delivers a predictable local benefit across varied event layouts and repeated use cycles.

4. From monolithic absorbers to multi layer systems

4.1 Rationale for a layered acoustic assembly

The project began from a material led premise in which the absorbing function was initially associated with a single porous layer, used as the main dissipative element inside the panel. In principle, a single acoustic layer is an attractive starting point because it can be specified and compared in a relatively direct way (Everest & Pohlmann, 2009). However, in the intended application scenario of this thesis, the absorbing element cannot be treated as an isolated material choice. Its behaviour depends on how it is supported, protected, and coupled to the surrounding assembly, and it must remain effective under repeated deployment conditions.

This motivates a shift from a single layer absorption strategy to a multi layer acoustic assembly. Rather than relying on one porous layer to cover all acoustic functions, the absorber is treated as a set of coordinated layers with distinct roles (Cox & d'Antonio, 2017). In this logic, dissipation is combined with controlled surface interaction and stable boundary conditions, so that acoustic benefit remains the same across various handling, repositioning, and varied site layouts (Allard, Champoux, & Depollier, 1987).

A multi layer approach becomes relevant when the absorbing element must deliver a predictable effect within a constrained and repeatable configuration (Allard, Champoux, & Depollier, 1987). In temporary installations, the effective behaviour of an absorber is shaped by its boundary conditions, by what sits in front of it and behind it, and by how stable these conditions remain after transport and reassembly (Allard & Atalla, 2009). Treating absorption as a single layer property is therefore fragile, because performance depends on configuration as much as on intrinsic material behaviour

(Allard, Champoux, & Depollier, 1987). A layered acoustic assembly addresses this by separating roles. One layer can be optimised for porous dissipation, while other layers regulate how air motion enters the system, preserve the intended spacing or cavity depth, and stabilise the interface so that the same configuration is reproduced reliably (Chevillotte, 2012). The result is not complexity for its own sake, but a clearer control of the variables that govern performance in real deployment (Cox & d'Antonio, 2017).

4.1.1 Limitations of single layer absorbers under deployment constraints

A single porous layer is limited by its strong dependence on depth (Allard & Atalla, 2009). For porous absorption, meaningful action at lower frequencies generally requires substantial thickness, or an added air space that places the dissipative medium where particle velocity is higher (Everest & Pohlmann, 2009). Within the envelope of a deployable panel, this quickly becomes a constraint, because increasing depth increases bulk and mass and reduces practicality for transport, handling, and safe installation (Cox & d'Antonio, 2017).

Depth dependence also reduces controllability. When the porous layer is kept compact, its contribution concentrates mainly in the mid and high frequency range, while lower frequencies remain comparatively less affected (Allard & Atalla, 2009). Relying on a single porous layer would therefore imply either an increase in depth that conflicts with deployment constraints, or a performance compromise that weakens the purpose of the absorber (Everest & Pohlmann, 2009).

For these reasons, the project moved away from treating porous material as a standalone acoustic strategy. Instead, porous dissipation is treated as one role within a multi layer assembly, where depth, coupling, and surface interaction can be shaped through configuration rather than through thickness alone (Chevillotte, 2012; Cox & d'Antonio, 2017).

4.1.2 Layering as a design response

A multi layer absorber can be treated as an impedance shaped system rather than as a single material element (Allard, Champoux, & Depollier, 1987). Layering distributes acoustic function across complementary roles, so that surface interaction, damping, tuning, and protection are addressed explicitly instead of being forced into one layer (Chevillotte, 2012). This also allows product driven constraints, such as durability, cleanability, and printability, to be incorporated without undermining the acoustic concept (Rodríguez Vercher, del Rey, & Alba, 2025).

4.1.3 Consequences for evaluation and modelling

Once performance is approached at the assembly level, evaluation cannot rely only on the absorption curve of one layer. The relevant descriptor becomes the frequency dependent behaviour of the assembled absorber at its surface, because layer order, spacing, and backing conditions directly shape how energy enters the system and where dissipation occurs (Allard, Champoux, & Depollier, 1987).

This encourages modelling approaches that represent each layer through its acoustic contribution and combine them through transfer matrix logic, allowing configurations to be compared and refined before committing to large prototypes (Allard, Champoux, & Depollier, 1987; ISO 10534-2, 2023).

4.2 Functional layer roles and constraints

This section defines the functional roles that commonly appear within a multi layer absorber. The aim is not to describe specific materials, but to establish a role based vocabulary that links physical mechanisms to design constraints (Cox & d'Antonio, 2017). Each role is described in terms of what it contributes acoustically, and what must remain controlled to preserve performance under repeated deployment (Allard & Atalla, 2009).

4.2.1 Porous dissipative core

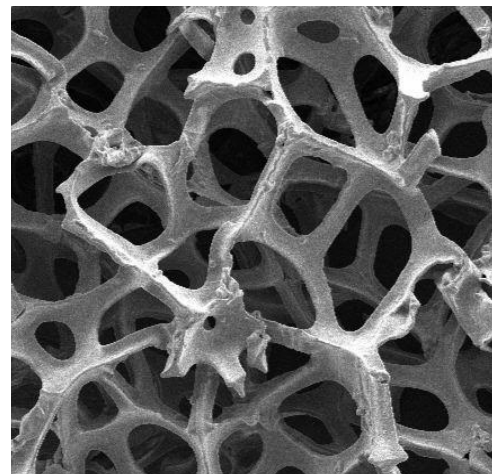
The porous core is the baseline dissipative element. As previously mentioned, its primary function is to convert acoustic energy into heat through viscous and thermal losses generated by oscillatory airflow within a tortuous microstructure (figure 16) (Allard & Atalla, 2009). It therefore provides broadband dissipation and stabilises the overall response, particularly in the mid and higher frequency ranges (Everest & Pohlmann, 2009).

Its constraints are closely tied to deployability. The material must tolerate repeated handling, intermittent compression during transport, and occasional moisture exposure without losing its internal structure (Allard & Atalla, 2009). It should preserve stable airflow resistivity over time and resist progressive clogging, since these changes can shift the effective behaviour of the entire assembly (Rodríguez Vercher, del Rey, & Alba, 2025). For this reason, a porous core cannot be described only through absorption curves, it must also be considered in terms of mechanical stability and environmental robustness (Allard & Atalla, 2009).

4.2.2 Resistive layer

A resistive layer is a thin element whose main acoustic contribution is resistance, meaning that it increases dissipative losses by raising the resistive part of the

Figure 16: porous microstructure detail, tortuosity



surface impedance seen by incident sound (Chevillotte, 2012). It can take the form of a resistive screen, a textile, a nonwoven sheet, or a perforated element designed to behave predominantly resistively within a target range (Chevillotte, 2012).

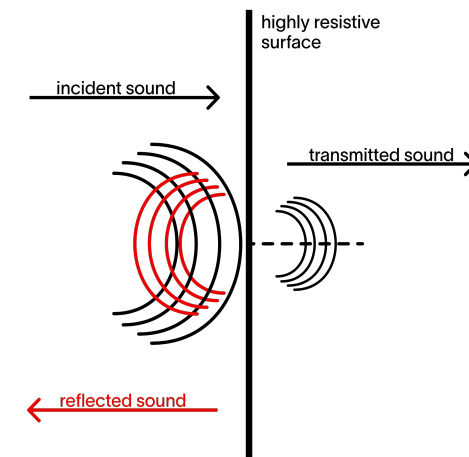
Resistive layers are introduced for two main purposes. First, they can improve coupling into the porous core by shaping the entrance condition, which can increase net absorption when resistance is tuned rather than added arbitrarily (Chevillotte, 2012). Second, they can act as damping elements for resonance driven subsystems, reducing sharp peaks and lowering sensitivity to tolerances by distributing losses across the assembly (Chevillotte, 2012).

The main risk is excessive resistance. If the surface becomes too resistive (figure 17), sound is reflected rather than admitted, and absorption decreases (Chevillotte, 2012). This also makes performance more fragile under contamination and ageing (Rodríguez Vercher, del Rey, & Alba, 2025).

4.2.3 Resonant interface layers

Resonant interface layers are introduced when low frequency relevant absorption must be extended within limited thickness. In compact assemblies, micro perforated panels are a common choice because their behaviour can be engineered through geometry and because they can produce high

Figure 17: graphic representation of reflected sound



absorption around a resonance when coupled to a compliant air volume (Maa, 1987; Cox & d'Antonio, 2017).

Two implications are especially relevant for deployable systems. The first is sensitivity. Perforation ratio, hole diameter, panel thickness, and effective cavity depth influence both resonance frequency and damping, meaning that manufacturing and assembly tolerances become part of the acoustic design space (Cox & d'Antonio, 2017). The second is bandwidth. A single resonance is naturally narrow, so resonant interfaces are most robust when integrated within a composite where porous and resistive layers provide distributed damping and broaden the effective response (Chevillotte, 2012).

4.2.4 Air volumes, cavities, and spacing layers

Air volumes within the assembly are functional elements rather than residual voids. They provide compliance, influence phase relationships, and determine how strongly other layers are excited (Cox & d'Antonio, 2017). When placed behind a micro perforated panel, an air volume acts as the compliant part of the resonant system and strongly influences tuning (Maa, 1987).

Air volumes also appear as spacing layers between elements, for example between a protective membrane and a stiffer interface, or between consecutive acoustic layers. In these cases, the purpose can include contact avoidance, protection of sensitive surfaces, and control of the entrance condition (Rodríguez Vercher, del Rey, & Alba, 2025). Even when a space is not intended as a tuned cavity, it still affects the surface behaviour by changing the effective impedance seen by incident sound and by influencing coupling between layers (Allard, Champoux, & Depollier, 1987).

For deployable products, these volumes introduce practical constraints. The intended spacing must be maintained under load, impact, and transport (Allard & Atalla, 2009). Leakage paths must be controlled, since unintended openings can alter the effective behaviour and reduce repeatability (Allard, Champoux, & Depollier, 1987). Air volumes are therefore design variables that

must remain stable across repeated cycles, whether they are used for resonance tuning or for controlled separation and coupling (ISO 10534-2, 2023).

4.2.5 Protective membrane

A protective membrane supports durability, surface protection, and containment of the internal layers, while providing an outer face that can be maintained over repeated use (Rodríguez Vercher, del Rey, & Alba, 2025). The membrane must be treated as acoustically active because it modifies the boundary condition at the surface (Rodríguez Vercher, del Rey, & Alba, 2025). Even thin membranes can affect absorption by adding resistance, altering end effects at perforations, and shifting dissipation toward the near surface region (Chevillotte, 2012).

Functionally, the membrane must protect the assembly while preserving acoustic coupling to the layers beneath. This requires controlled air and sound permeability, so that the oscillatory airflow associated with incident sound can enter the stack rather than being predominantly reflected at the surface (Rodríguez Vercher, del Rey, & Alba, 2025). Outdoor use makes this balance especially important because frequent handling and exposure to dust and humidity can change surface permeability over time, which would shift the effective surface behaviour and reduce repeatability.

4.3 Generic stack archetypes and interaction logic

Section 4.2 defined the functional roles that typically compose a multi layer absorber. This section translates those roles into recurring couplings and higher level archetypes, clarifying how configuration choices shape coupling, tuning, damping, and the practical use of available surface area. It first outlines common interaction patterns, then introduces two archetypal system logics, and finally presents the two project configurations as concrete instantiations.

4.3.1 Recurring layer couplings and configuration logics

Most multi layer absorbers can be understood as combinations of a limited set of recurring couplings.

A first recurring coupling is a porous layer paired with a resistive facing. In this configuration, the facing changes the entrance resistance and therefore the coupling into the porous network, which can improve net absorption if resistance is tuned rather than added arbitrarily (Chevillotte, 2012; Segura-Alcaraz et al., 2017). A second recurring coupling is a micro perforated (or finely perforated) panel combined with an air cavity, where the panel contributes a “mass-like” interface and the cavity provides compliance, enabling resonance-driven absorption and geometric tuning through perforation and cavity parameters (Maa, 1998; Song et al., 2016). A third coupling integrates both mechanisms: micro perforated panel plus cavity plus porous material. Here, porous material provides distributed losses that damp and broaden the resonant behaviour, making the response less concentrated around a narrow peak (Li et al., 2014; Sakagami et al., 2011).

A further extension is to distribute resonance contributions rather than relying on a single tuned cavity. This can be achieved by splitting the backing volume into multiple effective depths or by using series-parallel arrangements, with the intent of widening bandwidth and reducing sensitivity to a single

resonance condition (SheikhMozafari et al., 2024).

Across these couplings, the same design principle recurs: porous material supplies distributed losses, resistive elements regulate how energy enters the stack and add damping, micro perforated interfaces introduce resonance-driven low frequency relevance, and air volumes define the compliance conditions that enable tuning and interaction.

4.3.2 The main archetypes

The couplings above can be consolidated into two archetypal system logics, mainly distinguished by how the stack is terminated and, consequently, by how many faces are acoustically active.

Archetype A, one sided composite absorber. The system is designed around one active face and a defined rear boundary. The entrance condition is created on the exposed side, while the opposite side closes the assembly and stabilises the backing condition.

Archetype B, double sided symmetric composite absorber. The functional sequence is mirrored so that both faces are acoustically active. The system is orientation independent, and it aims to exploit both surfaces under real deployments where sound can arrive from multiple directions.

The following subsections describe the layer order logic that supports these archetypes, then introduce the two project configurations.

4.3.3 Layer order

Layer order is not interchangeable because each layer affects a different step of the same physical process. The first layers define the boundary condition and therefore how much energy is reflected at the surface versus admitted into oscillatory

airflow inside the assembly. The next layers shape this entrance interaction, determining whether the response is sharp and tolerance-sensitive or more damped and stable. The porous core then provides the main volume where admitted energy is dissipated through distributed viscous and thermal losses.

For this reason, the sequence follows a clear interaction logic.

The protective membrane is placed outermost because it is the exposed face in real use and must remain stable under handling and outdoor exposure, while staying air- and sound-permeable enough to preserve coupling into the layers beneath (Alba et al., 2025).

The micro perforated panel is placed close to the surface because it is the first engineered interface that structures near-surface airflow and enables resonance-assisted impedance shaping within compact depth. Its behaviour depends on perforation geometry and on how it is loaded by the impedance behind it, which makes its positioning and boundary definition part of the tuning logic (Maa, 1998; Song et al., 2016).

The resistive layer is positioned directly behind the micro perforated interface to add damping where particle motion is intensified by the interface mechanism. In this location, resistance can smooth peaks and widen the effective response, while also controlling the coupling into the deeper porous volume (Chevillotte, 2012; Li et al., 2014).

Finally, the porous dissipative core is placed deeper because it is the main broadband loss reservoir once energy has entered the system. In this position, it stabilises mid-high frequency absorption and provides additional distributed damping for the resonance-assisted contribution (Sakagami et al., 2011; Li et al., 2014).

Alternative orders are possible, but they typically shift the balance toward earlier reflection, narrower resonance dominance, or higher sensitivity to small assembly variations. For this reason, this sequence is adopted as the baseline logic for both one sided and double sided configurations.

4.3.4 Project configuration one

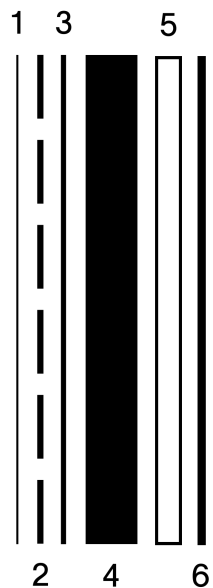
The initial configuration explored in this project follows the one sided logic of Archetype A. Its functional sequence is:

1. Protective membrane
2. Micro perforated panel
3. Resistive layer
4. Porous dissipative core
5. Rear air volume
6. Closed rear boundary condition

This configuration (figure 18) aligns with a compact resonance-assisted approach: the micro perforated interface and rear air volume define a resonance condition, while the resistive layer and porous core provide distributed losses that damp and stabilise the response (Pereira et al., 2021; Sakagami et al., 2011).

Its limitation follows from the one sided termination. Only one face is designed as an absorbing interface, while the opposite side primarily serves to close the system. In layouts where panels act as dividers and sound arrives from multiple directions, this leaves part of the available surface area acoustically inactive.

Figure 18: schematic layout of project configuration one



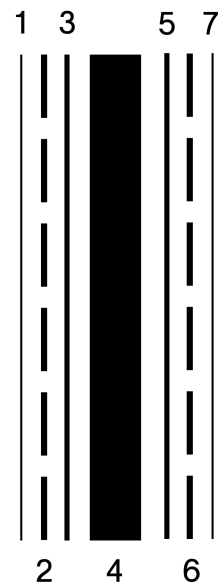
4.3.5 Project configuration two

The configuration adopted as the primary design choice is first introduced here, and it is then framed as an application of the double sided logic of Archetype B.

1. Protective membrane
2. Micro perforated panel
3. Resistive layer
4. Porous dissipative core
5. Resistive layer
6. Micro perforated panel
7. Protective membrane

In this symmetric layout (figure 19), the micro perforated interfaces are not tuned by a single dedicated rear cavity. Instead, their behaviour is governed by the impedance loading of the layers immediately behind, where resistive and porous layers supply distributed resistance and an effective compliance through their internal air volume. This shifts the interface contribution from a sharp cavity-tuned peak toward a more damped and broad mechanism, with dissipation occurring both near the perforations and within the porous network (Li et al., 2014; Sakagami et al., 2011).

Figure 19: schematic layout of project configuration two



This disposition is primarily driven by surface use. Compared to a one sided concept with a closed rear boundary, a double sided option makes it more likely that both faces contribute under real deployments, which is relevant when the panel functions as a divider and sound arrives from more than one direction.

Symmetry also improves practical use. With no privileged front face, the panel does not require orientation toward a specific source, reducing setup decisions and the risk of incorrect placement. Comparable behaviour on both sides supports repeatability across installations, since performance is less dependent on how the panel is rotated relative to the surrounding sound field.

4.4 Functional requirements by layer role

This section consolidates the layered architecture into a concise set of functional requirements. Requirements are stated first, then briefly contextualised by the role each layer plays in the stack. The layer order follows the physical stack from the exterior surface toward the inner core.

4.4.1 Protective membrane

The membrane shall remain air and sound permeable while providing a continuous protective surface. It shall tolerate repeated handling, cleaning, subtle abrasion, and outdoor exposure without tearing, puncturing, or progressive loss of permeability. It shall maintain stable surface behaviour under humidity and dust, avoiding sealing or clogging effects that would reduce coupling to the layers beneath. It shall support consistent graphic application and visual legibility without compromising permeability. It shall preserve dimensional stability in use, avoiding wrinkling or slackness that would introduce spatially non-uniform impedance.

4.4.2 Micro perforated resonant interface

The panel shall maintain geometric fidelity under handling and deployment, avoiding denting, warping, and local deformation. Perforations shall remain unobstructed in realistic outdoor conditions, and the surface shall be cleanable without systematic blockage. Manufacturing variability in hole diameter, perforation ratio, and thickness shall remain within a controlled tolerance band to preserve repeatable tuning. The panel shall interface repeatably with adjacent layers, avoiding micro-gaps, unstable seating, or edge leakage paths that alter effective impedance. The panel shall operate without unwanted noise such as buzzing or rattling when subject to vibration or incidental excitation.

4.4.3 Resistive layer

The layer shall provide controlled resistance without becoming an overly reflective barrier, meaning that its effective resistance shall remain stable under dust loading, ageing, and intermittent moisture exposure. It shall maintain continuity across the surface, avoiding tears, edge fraying, and local discontinuities that create leakage or uneven behaviour. It shall remain mechanically stable under repeated assembly, preserving consistent contact conditions and avoiding local compression set that would change effective resistance. It shall be compatible with a repeatable mounting method that does not introduce slackness, local detachment, or flutter.

4.4.4 Porous dissipative core

The core shall retain thickness and internal structure under repeated compression, transport loads, and handling cycles, limiting permanent compression set. It shall preserve stable airflow-related properties over time, avoiding drift due to moisture exposure, contamination, or fibre migration.

It shall resist progressive clogging and shall remain compatible with the cleaning and maintenance practices defined for the outer system.

It shall maintain consistent interfaces with adjacent layers, avoiding gaps, channel formation, or local densification that would produce non-uniform dissipation.

5. Material research: from literature landscape to the selected layer set

5.1 Literature landscape, acoustic materials and layered solutions

This chapter frames the material selection for the proposed multilayer acoustic panel by moving from a broad overview of commonly adopted absorber materials to a role based mapping of layer compatible options. Building on established absorber families and recent material developments, the discussion progressively narrows toward a set of candidates that can be credibly integrated within a deployable panel architecture. (Allard & Atalla, 2009; Cox & D'Antonio, 2017; Saha et al., 2025)

Across the absorber landscape, a limited number of material families recur in most panel constructions, including porous media, perforated and micro perforated skins, and hybrid assemblies that combine these constituents. Conventional cores remain dominated by mineral fibres and polymeric foams, while newer work expands the palette through bio based, recycled, and architected alternatives, often proposed in composite formats suitable for panel manufacturing (figure 20). As a result, absorber products are most often discussed as layered stacks, where different material families are assigned to specific positions rather than treated as standalone solutions. (Allard & Atalla, 2009; Cox & D'Antonio, 2017; Li et al., 2014; Saha et al., 2025)

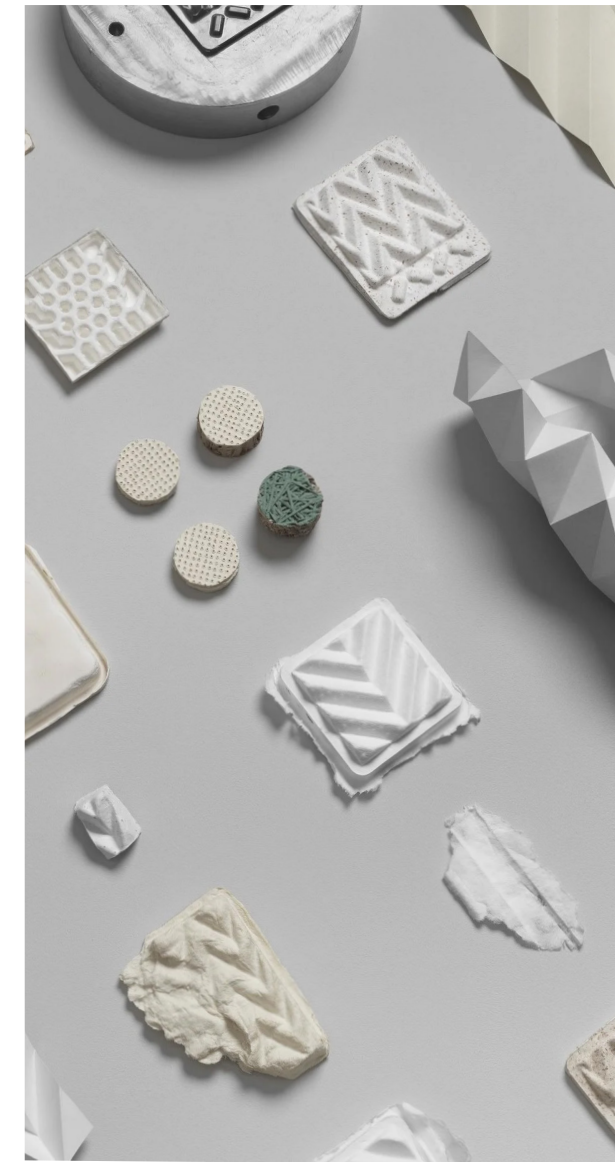
A final strand, increasingly visible in recent publications, concerns architected and additively manufactured porous structures, including lattice based absorbers. These approaches expand the palette of candidate "materials" beyond conventional foams and fibrous boards by treating geometry as a material property, enabled by additive manufacturing and simulation driven tuning

(Nakayama, 2024; Saha et al., 2025).

In summary, the literature outlines a consolidated range of conventional absorber materials, alongside a rapidly growing set of bio based, recycled, and architected alternatives (Allard & Atalla, 2009; Cox & D'Antonio, 2017; Saha et al., 2025).

Across these sources, layered solutions consistently emerge as the prevailing approach for combining different material families within panel assemblies that must remain compatible with practical requirements such as durability, handling, and integration.

Figure 20: BAUX Acoustic Pulp bio-based acoustic panel material



5.2 Options by layer function

In the following section, the material landscape is reorganised by layer function, translating the main material families into practical candidates for each position within the proposed multilayer panel.

5.2.1 Protective outer membrane and facing textiles

For panels intended to be handled, transported, and used in outdoor environments, the external layer is commonly implemented as a textile, mesh, or membrane that protects internal porous media from abrasion and contamination while remaining acoustically permeable (figure 21). In product practice, this role is frequently covered by coated meshes, architectural textiles, and technical fabrics, selected to balance durability, printability, and air permeability.

Within this category, woven and knitted facings are widely used, and their thread density and weave parameters can measurably influence the composite response of the panel, making the facing layer functionally relevant beyond appearance (Segura-Alcaraz, Segura-Alcaraz, Montava, & Bonet-Aracil, 2018). Woven fabrics are particularly recurring as acoustic facings because weave type, yarn diameter, and thread density provide a tangible design space for tuning permeability and mechanical robustness without changing

Figure 21: external acoustic membrane from Kvadrat



the underlying absorber (Cai et al., 2020). In deployable products, selection is further shaped by practical requirements related to handling, cleaning, UV exposure, tear resistance, and replaceability, which typically favours technical woven meshes and coated textiles over delicate interior fabrics.

5.2.2 Perforated and micro perforated panel common material choiches

Perforated and micro perforated panels define a cross material design space rather than a single material choice. Micro perforated concepts are reported in acrylic glass, plywood, metals, and plastics, which suggests that the substrate is most often selected based on fabrication compatibility, geometric accuracy, and the non acoustic requirements commonly associated with a panel surface (Cox & D'Antonio, 2017).

In general terms, wood based boards and metals are the two most recurring substrate families. Within wood based solutions, engineered boards, particularly MDF, are frequently adopted because they provide a uniform, stable, and easily machinable substrate for dense drilling and CNC based perforation patterns, while also offering predictable surface quality for finishing at architectural scale. Among metals, aluminium is often preferred in practice due to its favourable balance between formability and stiffness in thin sheet formats, and because it remains compatible with industrial perforation routes when high geometric repeatability is required, including punching, stamping, and

laser drilling.

The perforation scale further influences this choice. Conventional perforated panels with millimetre scale apertures are feasible across most substrates using standard tooling. As perforations move toward smaller diameters and denser patterns, the process window tends to narrow, favouring substrates and thickness ranges that remain compatible with precision drilling or laser based methods, while also limiting defect risks such as tearing, burr formation, local melting, or dimensional distortion. It can be concluded that material selection is typically driven by the interaction between target perforation geometry, panel thickness, and the feasible manufacturing route, rather than by the substrate material alone (Jaouen & Bécot, 2011).

Beyond material choice, perforated skins also offer a wide pattern design space. Hole diameter, pitch, staggering, and the use of graded or regionally varied perforation densities enable multiple visual and functional layouts within the same substrate. This variability is illustrated in Figure 22, which compares different perforation patterns and distributions across panel surfaces.

5.2.3 Resistive layer materials: nonwovens, meshes, and thin fibrous mats

Between perforated skins and porous cores, many layered panel products include thin resistive media, often implemented as nonwovens, fibrous mats, or woven screens. These layers can be realised with polyester nonwovens, glass fibre veils, technical felts, recycled textile fibres, and other sheet like fibrous products. Studies combining woven fabrics and nonwoven layers illustrate that even relatively thin fibrous sheets can be treated as a tunable component within a composite absorber construction (Chevillotte, 2012; Segura-Alcaraz et al., 2018).

From a selection perspective, this layer category is broad, and it is particularly compatible with circular materials, because it can be implemented with recycled fibre streams and engineered nonwovens. Wood and textile waste based composites are repeatedly discussed as candidates for absorber products when thickness, density,

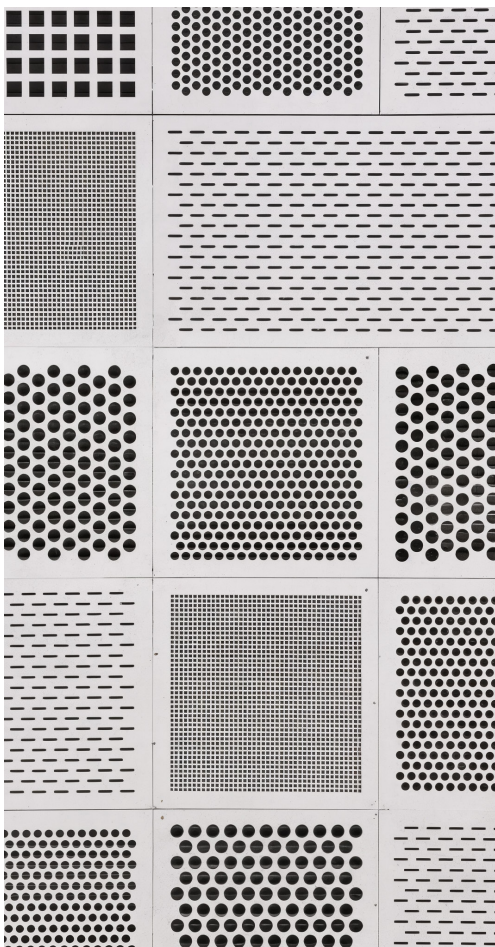
and binder content are controlled during manufacturing (Saha et al., 2024).

5.2.4 Porous dissipative cores

The porous core is usually the thickest material volume in a multilayer absorber, and it is where conventional supply chains remain strong. Common product choices include mineral wool boards and open cell polymer foams, largely adopted for their standardised formats, broad availability, and repeatable quality (Allard & Atalla, 2009; Everest & Pohlmann, 2009).

A second tier of candidates reflects sustainability and circularity goals, including natural fibre composites, bio filler reinforced foams, and absorbers derived from textile

Figure 22: alluminium microperforated panel patterns



waste streams. Within these families, acoustic performance is typically shaped through controllable manufacturing variables such as fibre composition, density, pore structure, and the selected processing route, which enables their development as engineered core materials rather than as purely craft driven alternatives (Berardi & Iannace, 2015; Saha et al., 2024).

Mycelium based blocks (figure 23) and panels can also be considered within the porous core landscape, particularly in applications where bio derived materials and low impact manufacturing are prioritised. In this case, the material family is often discussed in terms of how growth, drying, and finishing steps influence the resulting porosity, mechanical integrity, and long term stability, which are all decisive aspects when evaluating suitability for use as a core layer in panel products.

5.2.5 Synthesis of layer compatible material options

When considered together, the options outlined above show that multilayer acoustic panels are typically assembled by combining a limited number of material families, each selected for a specific layer position. Across the landscape, the most recurrent outcome is not a single preferred material, but a structured palette of candidates that can occupy each layer role.

This role oriented overview provides a practical basis for selection. It clarifies which material families are most commonly associated with each function, highlights where manufacturing compatibility and supply chain maturity become decisive, and frames the subsequent choices as a matter of assigning the right material to the right layer, rather than searching for a universal absorber solution.

The next sections build on this mapping by focusing on the recycled carbon fibre nonwoven, first as an initial core hypothesis, then through a refinement that relocates its contribution within the final layer set.



Figure 23: mycelium based panel from Myceen

5.3 Initial role hypothesis, Rymfelt as absorptive core

Rymfelt is a recycled carbon fibre nonwoven (figure 24), derived from carbon fibre containing waste streams, processed into a mechanically bonded sheet material whose fibrous network remains sufficiently open to interact with airflow while being stable in thin thicknesses.

In the early phase of the project, it was selected as a key candidate material because it offered a distinctive combination of technical identity and circular sourcing. Starting from this premise, it was natural to test the hypothesis of using it as the main absorptive core, by analogy with fibrous felts and wool based absorbers that are commonly adopted as porous volumes in acoustic panels.

This hypothesis was coherent at a conceptual level, since Rymfelt is a fibrous nonwoven and, in principle, fibrous media can provide sound absorption when used as a sufficiently thick porous volume. However, once the material was evaluated within the defined geometry and thickness allocation of the layered stack, the limitations of treating Rymfelt as the primary porous core became evident.

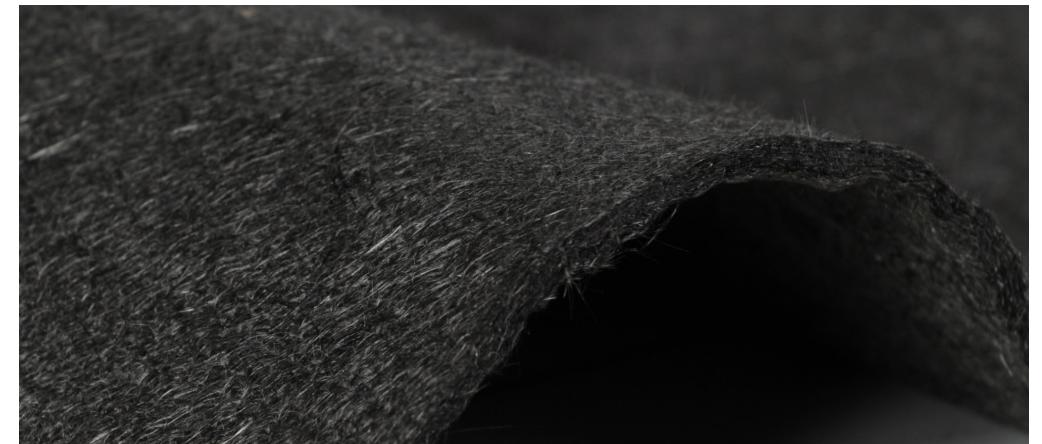
The first limitation concerns thickness efficiency in the relevant frequency range. A porous core must allocate significant depth to be effective at lower frequencies, while Rymfelt is most naturally used in thin sections and sheet like applications. Within the panel

depth budget, adopting Rymfelt as the main volumetric absorber would have shifted the acoustic outcome toward predominantly high frequency effectiveness, leaving the more relevant outdoor noise bands comparatively weak.

A second limitation concerns permeability and penetration. A porous core material is expected to admit the wave into the volume and dissipate energy progressively through depth. For Rymfelt, the nonwoven structure and the mechanical consolidation needed to maintain cohesion tend to increase flow resistance, meaning that part of the incident energy can be reflected or dissipated too close to the surface, rather than being distributed through a deep volume (Allard & Atalla, 2009). In practical terms, the material behaves as relatively “closed” when interpreted as a bulk absorber, which reduces the efficiency of using it as the main core.

A third limitation is structural intent. Many porous cores used in acoustic panels are engineered specifically for volumetric dissipation, through highly interconnected pore networks and microstructures that maximise internal path length and loss mechanisms (Allard & Atalla, 2009). Rymfelt, in contrast, originates as a technical nonwoven intended to act as a structural preform, therefore its fibre stiffness and its internal organisation are not primarily tuned to maximise volumetric acoustic dissipation. Under equal thickness and mass constraints, this makes it less competitive as a primary core compared to porous materials designed

Figure 24: Rymfelt carbon fiber nonwoven sheet



explicitly for absorption.

Taken together, these considerations indicate that using Rymfelt as the core would be an inefficient allocation of material and depth. It would place a technically valuable nonwoven in a role where its distinctive characteristics are under utilised, while still delivering a less reliable absorption outcome than mature porous cores (Everest & Pohlmann, 2009). For these reasons, the selection process shifted toward a role where the same physical traits, thin sheet format and relatively high flow resistance, become advantages rather than drawbacks. This leads to the refined hypothesis developed in the next subsection.

5.4 Role refinement, rationale for Rymfelt as resistive layer

The refined role assigns Rymfelt to the resistive layer position, placed upstream of the main porous core. This shift reframes the material from a depth dependent absorber to an interface layer that introduces controlled, localised flow resistance within the stack (Chevillotte, 2012).

In this position, thinness is not a limitation. A resistive layer is effective at millimetre scale thicknesses because its contribution is concentrated in the near surface region, where oscillatory particle motion is strongest and where viscous losses can be deliberately increased (Allard & Atalla, 2009). Rymfelt therefore matches the role by nature, it can deliver a significant resistive effect without requiring large thickness allocation.

The same parameter that penalised its use as a volumetric core, relatively high airflow resistivity, becomes the primary value driver as a resistive sheet. When placed ahead of the porous core and coupled to the perforated layers, the resistive sheet increases the real part of the surface impedance seen by the incident wave and improves the impedance transition between air, the perforated skin, and the downstream porous volume (Chevillotte, 2012; Sakagami, Kobatake, Kano, Morimoto, & Yairi, 2011). This helps suppress overly sharp resonant behaviour and supports a wider, more controlled absorption response

of the assembly, provided that the resistance remains within a suitable range.

In addition, the resistive sheet role allows the material to act as a dissipative filter before the wave enters the thick core. Rather than relying on deep penetration into the nonwoven, the design uses Rymfelt as a local loss element that pre conditions the incident field and stabilises the stack response. This makes the contribution of this material less dependent on large thickness, and more dependent on controllable sheet attributes such as areal weight class and stacking count, which can be specified and reproduced more reliably than a bulk packing state.

Finally, this reallocation is aligned with the outdoor and deployable context. When used as an internal resistive sheet, Rymfelt can be fully enclosed within the layered assembly, reducing handling exposure and protecting the nonwoven from abrasion and contamination. Its mechanical stability and relatively low sensitivity to humidity, compared with many bio based alternatives, further support its use as a thin internal layer in a panel intended for repeated transport, assembly, and use.

This role refinement preserves Rymfelt as a defining material of the project, but positions it where its physical traits and the panel requirements align most effectively. The next subsection focuses on the material itself in a more technical manner, detailing the relevant properties and integration notes that support its implementation within the final layer set.

5.5 Rymfelt, material focus and integration notes

Rymfelt originates from waste streams that contain carbon fibres, typically sourced from cured composite offcuts, end of life components, and production scrap (figure 25). In recycled carbon fibre streams, the main variability is not associated with carbon itself, but with matrix residues, coatings, and surface treatments carried by the incoming material. For this reason, recycling routes place strong emphasis on feedstock selection and on matrix removal. The recovery stage commonly relies on a thermal route aimed at removing

epoxy thermoset residues together with sizing and binder traces, followed by checks on surface cleanliness and on the mechanical integrity of the recovered fibres. In practice, recycling feasibility and output quality depend heavily on the incoming waste stream, since contaminants and non removable inclusions directly affect process efficiency and the consistency of the reclaimed fibre. This input sensitivity ultimately influences both the achievable openness of the resulting nonwoven and the repeatability of its behaviour once integrated as a sheet layer.

The conversion of recovered fibres into Rymfelt follows a conventional dry laid, mechanically bonded nonwoven route, as outlined in the following page in Figure 26. After the incoming material has been cleaned, cutted and stabilised through the recovery process, the fibres are first conditioned and mechanically opened to reduce agglomerates and promote a consistent feed. The opened fibres are then delivered to a carding stage, where they are disentangled, partially aligned, and formed into a thin, continuous web. To reach the required basis weight, this web is subsequently built up through a layering step, in which multiple webs are superimposed in a controlled manner until the target grammage is achieved. Mechanical consolidation is then performed by needle punching, where

repeated needle penetration entangles fibres through the thickness and provides cohesion without relying on chemical binders. Finally, the consolidated mat is trimmed as needed and wound into rolls, enabling transport, handling, and downstream cutting operations.

Within this process chain, the most relevant variables for design integration are the achieved basis weight, the uniformity of mass distribution along the roll, and the intensity of mechanical bonding, since these parameters govern both handling robustness and the effective openness of the fibrous network. Production is therefore commonly organised in batches, with upstream sorting of incoming fibre streams and adjustments of web build up and needling settings according to the specified grammage. Quality control typically relies on sampling along the roll, weighing, and categorising the material against tolerance targets, ensuring that the sheet properties remain consistent across production (Sántha & Tamás Bényei, 2025).

In this context, specification ranges and tolerances become part of the material definition rather than secondary procurement details. Rymfelt is supplied as a roll good with declared ranges that allow it to be treated as a parameterised component. The fibre length range is indicated as approximately 40 mm to 90 mm, and the product is offered across a

Figure 25: Incoming carbon-fibre composite waste stream used as feedstock for Rymfelt recycling.



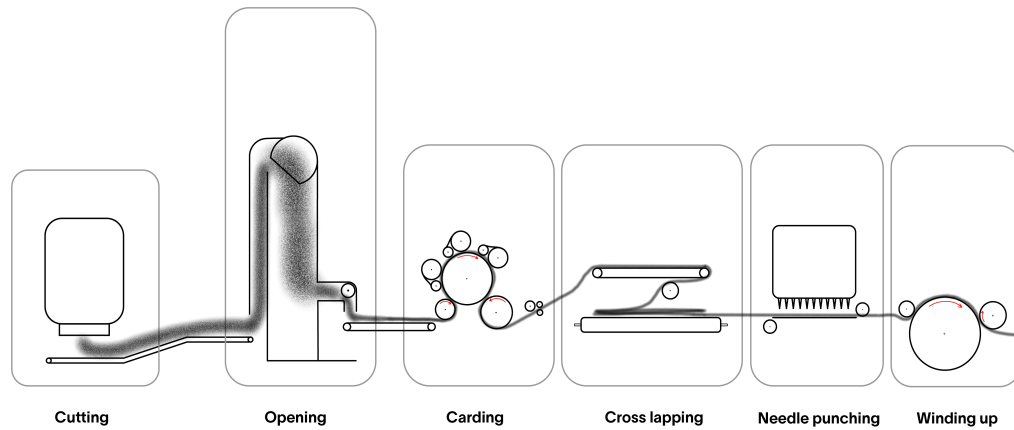


Figure 26: schematic overview of Rymfelt manufacturing process

wide areal weight window, approximately 180 g/m² to 1000 g/m². Tolerances tighten with increasing grammage, stated as ± 8 percent for 180 g/m² to 400 g/m², and ± 5 percent for 400 g/m² to 1000 g/m². The nominal fabric width is reported as 1250 mm. These parameters are practically relevant because they allow the resistive layer to be defined through procurement variables, areal weight class and number of plies, rather than through an uncontrolled bulk packing condition (figure 27).

At the microstructural level, Rymfelt can be described as a mechanically interlocked fibrous network composed predominantly of carbon fibres. Carbon fibre is based on a graphitic carbon backbone, associated with high stiffness and low moisture uptake, and it does not undergo the pronounced swelling behaviour often observed in natural fibres under humidity variation (Cantwell & Morton). In a nonwoven architecture, the fibres form a three dimensional web where pore space is defined by fibre diameter, fibre length, local orientation, and local packing density. The resulting medium is therefore not a foam like cellular structure, but a fibrous skeleton with interconnected inter fibre voids, which makes its interaction with airflow strongly dependent on how the web is formed and mechanically consolidated. This morphology has two direct implications for the panel integration.

The first is functional. As an engineered technical felt, relatively small changes in areal weight, ply count, and compression

state can shift the effective openness of the network and, consequently, the resistance that the layer introduces to oscillatory air motion. This provides a physical basis for using the material as a controlled resistive sheet within the layered assembly, where the design intent is to shape the boundary behaviour of the stack through thickness allocation and stacking, rather than to rely on deep volumetric penetration as a primary absorption mechanism.

The second implication concerns handling and containment, as a direct consequence of the same microstructure. A mechanically bonded fibrous web can release fine fragments and dust during cutting, trimming, or abrasion at exposed edges, particularly when fibres are stiff and brittle. For this reason, conversion operations are best treated as controlled workshop steps, and the panel architecture benefits from keeping the layer enclosed between adjacent materials across its full surface area, with perimeter containment strategies that limit fibre release during assembly and replacement.

Repeated deployment increases the importance of edge management. Even if the layer is enclosed, cut edges can fray under repeated rubbing or transport vibration if gaps allow relative sliding. Continuous boundary support, with sealing and alignment features that minimise layer movement, therefore becomes an integration requirement driven by the fibrous network structure rather than an external add on.



Figure 27: Rymfelt carbon fibre nonwoven samples with increasing areal weight, 250 g/m², 600 g/m², and 800 g/m²

5.6 Final material set and handover to concept

This subsection consolidates the final material set for the layered acoustic module and outlines, in practical terms, the rationale behind assigning each material to its respective layer role.

1. Protective printable membrane Mineral fibre woven fabric

The protective facing is defined as a technical woven fabric based on mineral fibres, selected to combine dimensional stability with a high degree of air permeability. As a mineral fibre weave, it provides a mechanically robust textile architecture that remains stable under outdoor exposure and repeated handling, while maintaining the open structure required for acoustic transparency. The facing is printable and treated to be water repellent, which supports outdoor use while keeping the surface breathable. Its role as the outer skin also enables straightforward replacement when needed, without disturbing the internal acoustic build up. A commercially available reference that embodies this material approach is the SoundMesh G8 product by Megasorber.

2. Micro perforated panel Aluminium sheet EN AW 5754

Aluminium was selected for the micro perforated panel because it combines good formability with stable sheet behaviour and is well suited to precise, dense perforation patterns. Compared with wood based boards and polymer sheets, it typically offers a wider and more controllable manufacturing window when perforations become finer and more closely spaced. Within aluminium sheet options, EN AW 5754 is a common grade supplied as flat stock and suitable for consistent cutting and drilling operations, while offering very good atmospheric corrosion resistance within the non heat treatable aluminium magnesium alloy family.

3. Resistive layer Recycled carbon fibre nonwoven

The resistive layer is implemented as a recycled carbon fibre nonwoven, specifically Rymfelt by Rymyc, building on the material rationale developed in the previous sections where this class of fibrous sheet media was positioned as a controllable, thickness efficient way to introduce flow resistance within the stack. In this role, the material contributes through a defined sheet behaviour rather than through volumetric dissipation, and it can be specified through procurement variables and integrated in a repeatable manner. The layer is kept enclosed within the layered assembly, which reduces handling exposure and limits risks related to dust generation during service operations.

4. Porous dissipative core Acoustic polyester wool

The core layer was assigned to a mature, specification driven porous absorber to maximise repeatability and reduce acoustic uncertainty. An acoustic polyester wool was selected because it represents an industrial porous core class available in stable, standardised formats, suitable for predictable volumetric dissipation within a defined thickness. This family is often positioned for moisture tolerant applications and can be specified for durability under repeated handling and replacement. A commercially available reference within this class is Megasorber P, which is presented as hydrophobic and as suitable for hot and humid conditions, with explicit positioning for outdoor exposure to the elements.

With the acoustic layer set defined, the project moves from material research to concept development. The next chapter translates the selected absorbing assembly into a product level solution, detailing how the stack is packaged, aligned, and protected, and how the system can be assembled, accessed, and reassembled with repeatable outcomes.

6. Contextual synthesis

6.1 Outdoor events as a constraint driven scenario

This chapter provides a brief synthesis that links the research phase to the design phase. Its purpose is to condense the main contextual implications into a clear set of constraints and requirement priorities, without reiterating previously discussed concepts or anticipating specific solutions.

As we have already established in the previous sections, outdoor and semi outdoor events provide a scenario where acoustic interventions are guided by changing conditions rather than by a fixed built space. Listening is not uniform across the site, open areas follow free field behaviour, while temporary elements such as booths, canopies, and partitions can locally change what people hear (Cox & D'Antonio, 2017). Since these environments are assembled and removed in short timeframes, the context also constrains what can be installed in terms of size, handling, placement, and repeatability across different venues (Hill, 2020). For this reason, the context analysis has been used to derive the project constraints, translating what the event environment demands into design conditions that keep the solution effective in real use.

6.2 Opportunity statement and final requirement priorities

The opportunity identified through the research is to improve perceived comfort and the ease of communication in event environments by acting on local listening conditions, rather than attempting global

noise reduction at the scale of the full site. This focuses the intervention on zones where speech comprehension, wayfinding, and short interactions concentrate, and where temporary semi enclosures make clarity more fragile (Hill, 2020; Everest & Pohlmann, 2009). From this opportunity, a small set of final requirement priorities emerges.

Acoustically, the system should address a broad frequency range, reflecting the heterogeneous noise content typical of temporary event environments. This includes an explicit focus on low frequencies, which in outdoor conditions tend to propagate over longer distances and remain perceptually persistent, as highlighted in the research phase. Because broadband performance cannot be achieved through porous absorption alone without impractical thickness, the requirement reinforces the need for the previously defined layered architecture, where complementary mechanisms are distributed across the stack to extend effectiveness while preserving deployability and manageable logistics (Allard & Atalla, 2009; Cox & D'Antonio, 2017; Rebillard et al., 1992).

Functionally, the system should remain predictable under repeated deployment, including handling, minor impacts, rain, and moisture exposure, since these factors can alter airflow resistance, clog apertures, or change surface impedance, with direct consequences on absorption (Allard & Atalla, 2009; Hill, 2020).

Operationally, the system should enable fast setup and preserve high freedom of placement within the designated area, so it can be positioned where it is most effective without imposing rigid layout constraints. Because it operates in public, high traffic environments, the product should also ensure lateral stability under incidental impacts and under wind gusts typical of temporary deployment. (Hill, 2020). Finally, it should align with sustainability and safety expectations for public events, through maintainable construction, reduced material waste across repeated cycles, and compatibility with standard fire and hygiene constraints (Hill, 2020).

7. Design brief and concept development

This chapter transitions from the research framework to the design phase, translating the acoustic evidence and the constraints of temporary events into a structured development path. It defines the final design brief, reviews relevant market and reference solutions, documents the concept exploration, and concludes with the selection and refinement of the final direction.

7.1 Final design brief

This section consolidates the key outputs of the previous chapters into a single design brief that steers concept generation and evaluation. It formalises the project intent, clarifies the scope as a deployable panel system for fairs and temporary events, and defines the priorities that connect acoustic performance, structural behaviour, and visual integration.

Design brief statement:

The project defines an outdoor acoustic panel system for fairs, exhibitions, and temporary events, where acoustic performance, structural stability, and visual clarity are treated as complementary design drivers. The design introduces a self supporting, modular architecture that enables rapid assembly and clean, continuous alignments, improving sound containment in environments where acoustic planning is generally absent. The system is conceived to deliver high stability with a minimal footprint, avoiding complex or semi permanent anchoring solutions, and turns acoustic mitigation into an active element shaping the spatial and acoustic identity of open air settings. A printable outer layer allows the panel to incorporate branding, signage, or exhibition graphics, giving the system a dual role as both an acoustic absorber and a communication surface.

Design objectives and requirements:

- 1. Acoustic objective, local containment and comfort**
The system shall improve perceived comfort and communication by acting on local listening conditions, especially in semi enclosed zones generated by booths, corridors, and temporary boundaries.
- 2. Broadband absorption within a deployable thickness**
The acoustic package shall provide broadband behaviour within a thickness compatible with transport and handling. Layer order and surface impedance shall be controlled so that sound can enter the system efficiently and losses can develop through the internal layers, rather than being limited by an overly reflective or overly resistive facing.
- 3. Self supporting stability with minimal footprint**
The panel shall stand safely as a free element in outdoor and semi outdoor settings, achieving high stability while keeping the base footprint compact. Stability shall be obtained through product level structural design and integration logic, avoiding reliance on complex anchoring, ground penetration, or semi permanent fixtures.
- 4. Rapid assembly and repeatable deployment**
The system shall support fast assembly, disassembly, and reconfiguration with a simple, robust sequence suitable for event timelines. The connection logic shall enable clean, continuous alignments and predictable spacing, allowing long runs, corners, and short partitions to be created with consistent visual and functional outcomes.
- 5. Modularity and continuous spatial definition**
The system shall be modular

through standardised, repeatable units. Repetition enables scalable deployment and consistent alignments, and supports spatial definition as a core functional output alongside absorption.

6. Outdoor durability and maintenance

The system shall tolerate handling wear, dust, humidity, and incidental contact. External surfaces shall be cleanable and suitable for repeated logistics cycles, and the acoustic layers shall be protected from direct damage without compromising permeability and absorption.

7. Visual clarity and communication role

The system shall include a durable, printable external membrane intended as a configurable communication layer. It shall accommodate event specific graphics, from branding and signage to exhibition content, supporting spatial legibility while preserving the acoustic function of the panel.

8. Manufacturability and scalability

The architecture shall enable scalable manufacturing and straightforward assembly, supporting prototyping and low volume production while preserving dimensional control and repeatable performance. Material selection and layer joining methods shall be compatible with robust tolerances, serviceability, and consistent acoustic behaviour across batches.

7.2 References and benchmark insights

This section positions the benchmark as a design instrument that supports concept development. The analysis surveys both outdoor and indoor product landscapes to build a comprehensive reference frame, then filters the findings through the constraints of

temporary events. The goal is not to identify a direct equivalent to the proposed system, but to understand how different sectors address similar sub problems, including stability, deployability, durability, acoustic principle, and visual integration, and to translate these observations into actionable implications for design.

7.2.1 Market landscape, outdoor mitigation archetypes and deployment logic

The outdoor sound mitigation market is dominated by two families that reflect different objectives and installation assumptions. A first family consists of absorbent sound barriers, which introduce dissipative materials to reduce reflected energy and lower the acoustic impact near the source. These systems are commonly conceived as mobile or semi mobile elements, because they are often used in temporary conditions such as construction sites, work zones, and short term machinery operations. Their product logic prioritises fast handling, robustness, and repeatable deployment over refined appearance.

A second family consists of reflective sound barriers, which primarily act by blocking line of sight propagation and redirecting sound away from receivers. These solutions are predominantly fixed infrastructures, typically associated with roads, railways, and other permanent sources. They are ground anchored, continuous, and non transitory by nature, and their performance is therefore coupled to site specific installation, foundation logic, and long term maintenance.

For the present project, this distinction is not only descriptive, but selective. The target scenario is intrinsically transitory, therefore fixed reflective barriers are relevant mainly as a boundary case that clarifies what is incompatible with temporary events, while mobile absorbent barriers represent the closest outdoor reference class in terms of deployment assumptions. At the same time, the outdoor absorbent class remains only partially transferable, because its formal language and integration priorities are typically shaped by construction aesthetics rather than by public facing event environments.

Echo barrier

Echo Barrier is a mobile outdoor noise control solution based on barrier blankets mounted to standard temporary fencing frames (figure 28). The system combines a robust, weather oriented outer construction with an absorbent core to reduce reflected energy and limit sound spill in temporary setups, and it is promoted for both construction environments and live event applications.

Its defining characteristics are the reliance on readily available site fencing as the load bearing structure, the resulting fast installation and cost efficiency, and a surface conceived for heavy duty use. The overall aesthetic is distinctly utilitarian and industrial.

KPIs

- Deployment mode: temporary, mobile
- Structural typology: fencing based barrier blanket system
- Materials: waterproof PVC outer skin, recycled absorbent composite core, mounted on temporary fencing frames
- Acoustic strategy: absorptive barrier
- Surface and visual layer: utilitarian, worksite coded aesthetic

Figure 28: Echo barrier acoustic panel system



NoiStop

NoiStop is an outdoor acoustic barrier fencing system conceived as a fixed, site installed solution built from modular fence panels (figure 29).

It is presented as a noise reducing boundary that combines shielding with absorption, using a pressed stone wool core inside a galvanised steel frame and retained by a highly durable polyethylene mesh. It is intended for applications such as roads, railways, and other outdoor noise sources where a permanent perimeter is required.

KPIs:

- Deployment mode: fixed, long term installation
- Structural typology: fence wall system based on modular panels
- Materials: galvanised steel frame, stone wool infill, polyethylene mesh
- Acoustic strategy: hybrid barrier plus absorption through mineral wool core
- Surface and visual layer: fence like appearance, outdoor infrastructure language

Figure 29: Noistop acoustic barrier



SOUNDEX Acoustic Curtain

Soundex is a temporary acoustic screening product conceived as a flexible barrier that can be suspended to create a continuous noise control line (figure 30). The curtain is described as a high absorption solution for screening around noisy activities, and it is designed for rapid setup through eyelets distributed along the edges, enabling straightforward hanging to temporary structures and perimeter frames.

The product has a wipe clean outer surface, a fold and lay flat handling logic for storage and transport, and integrated Velcro connections intended to minimise gaps between adjacent curtains and maintain continuity. Technical data report frequency dependent absorption and attenuation performance, and positioning the curtain as a certified, fire resistant, weatherproof resistant temporary barrier.

KPIs:

- Deployment mode: temporary, mobile
- Structural typology: hanging acoustic curtain, continuous screening through connections
- Materials: acoustic vinyl membrane, enclosed acoustic core, PVC containment construction, eyelets, and velcro fastening system
- Acoustic strategy: absorptive screening barrier
- Surface and visual layer: technical equipment aesthetic, wipe clean surface, continuity supported by edge linking

Figure 30: Soundex acoustic curtain



AcoustiGuard

AcoustiGuard Outdoor Sound Barrier Walls are an outdoor, site installed barrier system (figure 31). The product is made by a galvanized steel framing structure with lightweight, perforated PVC panels, filled with an acoustically absorbent mineral fibre.

The system is built around a full tongue and groove assembly approach, intended to create continuous, acoustically sealed runs, and it includes self draining rail detailing, with the absorbent mineral boards described as resistant to water and weather.

Typical application contexts include railways, generators, transformers, rooftop units, and inverters, as well as perimeter control for leisure and sports areas such as playgrounds, tennis or pickleball courts, and skating rinks.

KPIs:

- Deployment mode: fixed, long term installation
- Structural typology: fence like barrier wall with tongue and groove continuity
- Materials: galvanized steel framing, perforated PVC panels, mineral fibre absorbent infill
- Acoustic strategy: absorptive version and reflective version within the same wall family
- Surface and visual layer: neutral finished wall aesthetic, continuity driven surface, standardised appearance
-

Figure 31: Acoustiguard sound barrier



Flexshield

Flexshield Mobile Soundproof Panels are presented as industrial acoustic mobile screens intended to control noise by creating temporary partitions around sources or along work areas (figure 32). The product is described as a durable, high performing mobile panel system within Flexshield's Sonic System, a dedicated multilayer solution that guarantee sound absorption as well as sound barrier

The panel is made by a perforated steel sheet, mineral wool, and a back solid steel sheet. It is developed for flexible deployment rather than fixed installation, and positioned as an acoustic mobile soundproofing panel solution, for facilities that need reconfigurable noise management.

KPIs:

- Deployment mode: temporary, mobile, suitable for repeated repositioning
- Structural typology: rigid freestanding panels on swivel castors, typically with brakes
- Materials: high-density mineral wool core, perforated steel sheet
- Acoustic strategy: soundproofing oriented screening, intended to reduce transmitted noise and improve local containment
- Surface and visual layer: technical, industrial product language with a robust finish, prioritising durability over decorative integration

Figure 32: Flexshield mobile soundproof panel



7.2.2 Gap analysis for fairs, exhibitions, and temporary outdoor events

When the benchmark is focused on open air fairs, exhibitions, and temporary event layouts, a clear gap emerges. No established product category was found that translates outdoor noise mitigation into a coherent, event oriented system capable of meeting the combined operational and integration needs of these settings. Existing mobile outdoor solutions are largely shaped by pragmatic priorities and tend to offer limited visual and communicative integration.

This gap is not only a matter of appearance. It also concerns integration logic. Temporary events require solutions that can be placed on diverse ground conditions, assembled under time pressure, aligned into controlled sequences, and removed without traces. As a result, the event scenario remains underserved by products that treat acoustic mitigation as an integrated spatial component rather than as a purely technical barrier.

7.2.3 Why indoor references remain relevant

Although indoor conditions differ from the target scenario, selected indoor products remain useful references because they are designed as freestanding elements used in close proximity to people. They therefore prioritise aspects such as visual quality, clear proportions, easy handling, and repeatable placement, alongside acoustic performance.

For this reason, the benchmark includes indoor solutions only when they follow a transitory, self contained deployment logic. Systems that require attachment to walls, ceilings, or permanent building structures are excluded. The focus is instead on standalone partitions and panel based systems, which provide transferable insights on how acoustic function can be combined with a coherent surface language and practical requirements for repeated installation.

Unit

Lintex Unit is an indoor, freestanding acoustic divider designed as a mobile partition for open plan office environments (figure 33). It is designed to provide screening and sound absorption while also functioning as an active work surface, with configurations combining magnetic glass and textile, or textile on both sides.

The panel incorporates a sound absorbing polyester core and is designed to be repositioned through retractable wheels. The range is available in multiple sizes and surface options, enabling customisation through different colours and textile selections while maintaining a clean, furniture like identity typical of office partition systems.

KPIs:

- Deployment mode: temporary, mobile, indoor freestanding divider
- Structural typology: moveable wall on feet with retractable wheels
- Materials: aluminium frame, glass and textile surfaces, sound absorbing polyester filling
- Acoustic strategy: absorptive core integrated into a partition element
- Surface and visual layer: configurable surfaces, magnetic glass and textile options, designed as a clean office furniture element

Figure 33: Lintex Unit freestanding acoustic partition



Vank wall 3

Vank wall 3 is an indoor, freestanding acoustic wall system conceived as a lightweight screen that can be arranged as a single element or combined into multi wing configurations (figure 34).

The product is presented for home and office environments, with high partitions intended to create temporary separation while contributing sound absorbing surfaces.

The panels are made from recycled PET, upholstered in fabric, and connected to each other through zipper based fastening, while the system is stabilised through triangular plywood bases that can be dismantled for storage and transport.

KPIs:

- Deployment mode: temporary, mobile, indoor freestanding screen
- Structural typology: multi wing screen system, individual panels connect to form longer arrangements, detachable plywood bases
- Materials: recycled PET acoustic panels with fabric upholstery, triangular plywood bases
- Acoustic strategy: absorptive surfaces integrated into a partition element
- Surface and visual layer: textile upholstered surfaces with a clean furniture like identity, designed to act as a screen and background element

Figure 34: Vank wall 3 acoustic wall system



Vevor

Vevor acoustic panel is an indoor, freestanding room divider conceived as a folding screen made of three linked panels, intended to create quick separation within offices and domestic environments. (figure 35)

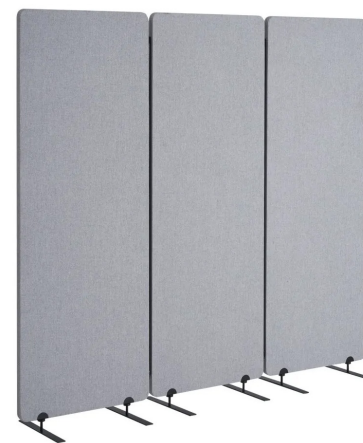
The product is marketed as a portable privacy divider that also contributes to acoustic comfort, using a PET based sound absorbing textile construction and a soft padded build to reduce disturbance and improve separation.

The three panel configuration defines a familiar screen archetype, where the divider is deployed as a single unit rather than assembled from independent modules, with integrated feet providing freestanding stability.

KPIs:

- Deployment mode: temporary, mobile, indoor
- Structural typology: folding room divider, three connected panels, paravento archetype
- Materials: PET based sound absorbing textile construction, padded build
- Acoustic strategy: absorptive soft surface intended to reduce ambient disturbance
- Surface and visual layer: plain textile finish, domestic and office oriented appearance

Figure 35: Vevor freestanding room divider



Baux Floor Dividers

Baux Felt Recycled PET Floor Dividers are indoor, freestanding acoustic screens designed as a modular floor solution for creating temporary separation in open plan interiors (figure 36).

The system is quick to configure and reconfigure, with a minimal number of hardware components and a small set of parts per unit, allowing different layouts to be assembled in minutes.

The divider panels are made from Baux Acoustic Felt Recycled PET, a GRS certified recycled PET material, and offered in a standard palette with additional colours available for custom orders. The overall product language is furniture oriented and minimal, relying on repeatable panel geometries, limited visible hardware, and a system logic that supports flexible arrangements rather than fixed installation.

KPIs:

- Deployment mode: temporary, mobile, indoor freestanding
- Structural typology: modular floor divider system, assembled from panels plus a minimal hardware set
- Materials: acoustic felt panels made from GRS certified recycled PET, metal and plastic hardware components
- Acoustic strategy: absorptive screen, acoustic felt surfaces
- Surface and visual layer: furniture aesthetic

Figure 36: baux floor divider modular acoustic screen



7.2.4 Discussion and implications for design

Across the reviewed references, the benchmark is synthesised through a two axis diagram that is shown below (figure 37). The vertical axis represents environmental readiness, ranging from controlled conditions to harsh outdoor exposure, while the horizontal axis captures aesthetic positioning, spanning from industrial to refined.

This representation makes the market gap legible. Solutions positioned toward harsh outdoor conditions tend to adopt industrial and infrastructure coded languages, while products with more architectural finishes and controlled visual integration are predominantly designed for controlled indoor environments.

The implication for the project is that the intended direction sits at the intersection between these two tendencies, aiming for a mobile system that is outdoor ready while maintaining an architectural and refined product language.

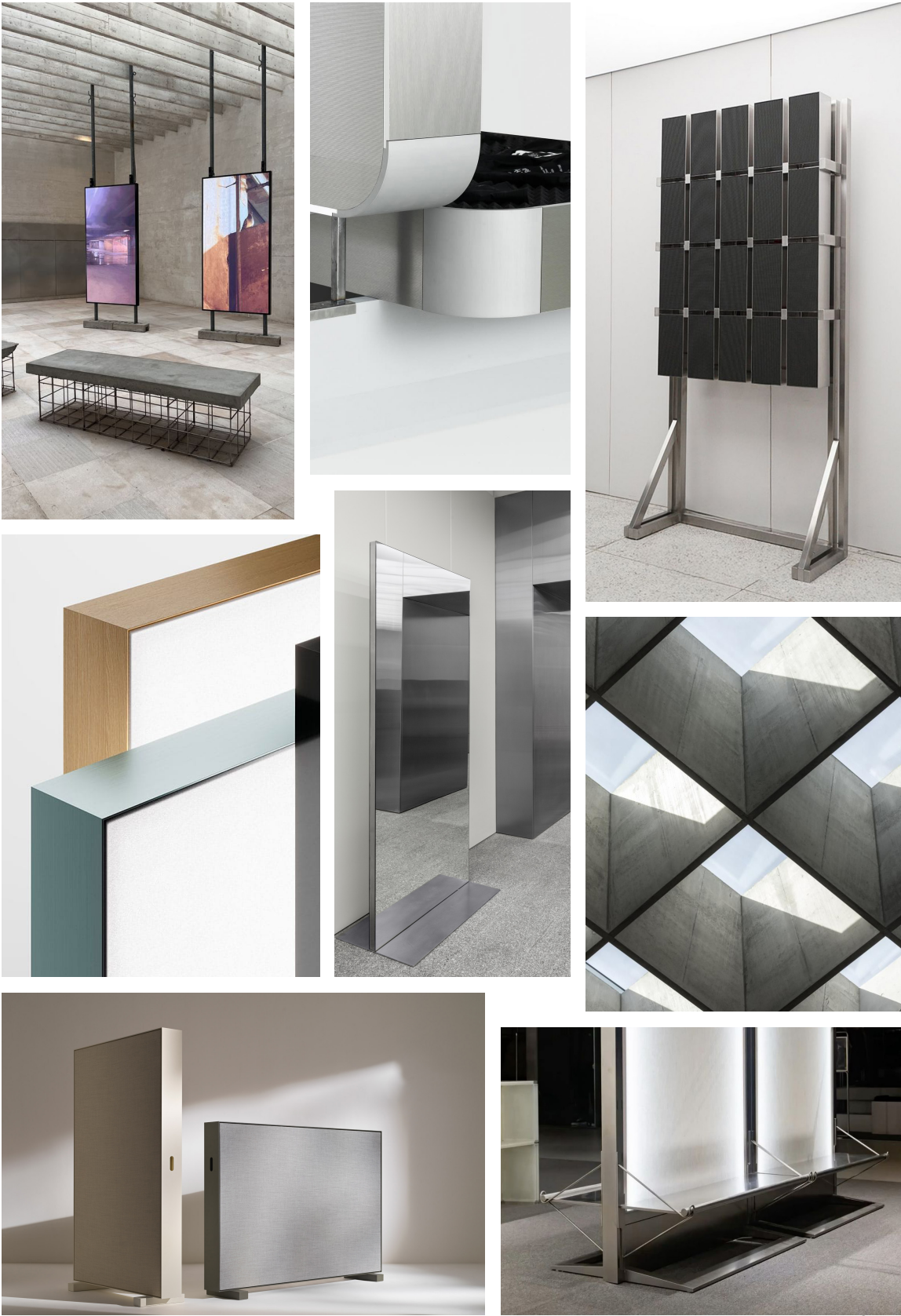
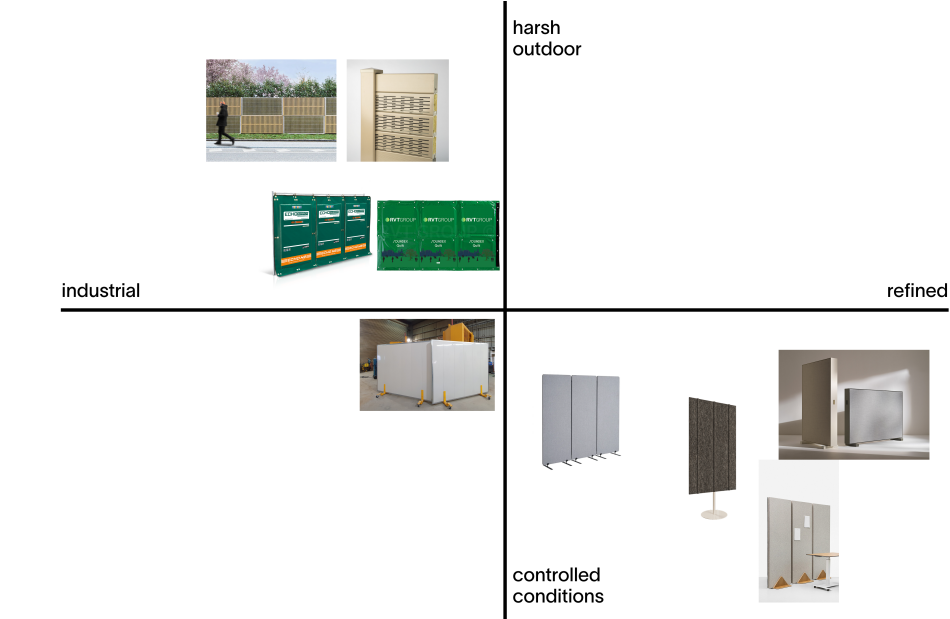
This synthesis provides a direct bridge to the next section, where concept exploration focuses on the structural and spatial architecture required to address this gap with a coherent product system.

7.3 Concept exploration and decision process

Concept exploration began by establishing a coherent visual and product reference frame through a moodboard, that is visible here on the right as figure 38.

This initial step was used to define the intended archetype and formal language, clarifying proportions, material cues, perceived robustness, and surface expression. Rather than prescribing a final form, it served to align the project around a shared aesthetic direction and a target level of refinement, ensuring that subsequent concepts would be evaluated not only for technical feasibility but also for consistency in how the system communicates its role as an outdoor deployable product.

Figure 37: Intended market positioning within existing product references.



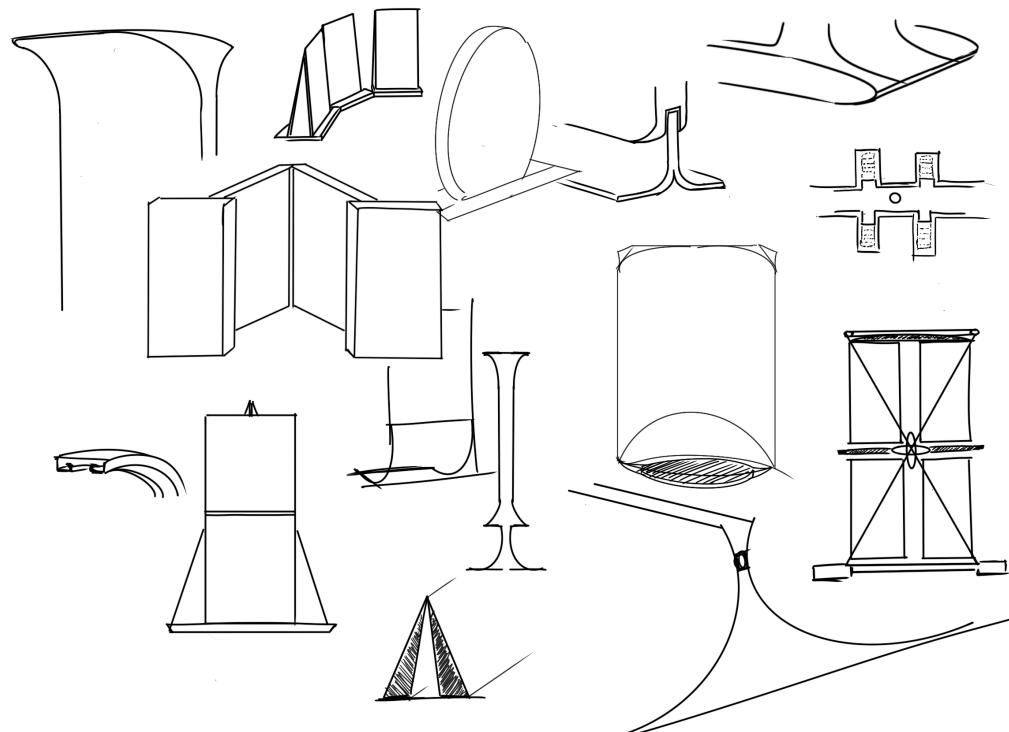
Early development was then articulated through a set of preliminary hand sketches (figure 39). These sketches capture initial hypotheses on shape, structure, assembly sequence, and base stability, exploring multiple options before committing to a single architecture. The intention was to identify an archetype that could combine stability with a clear, controlled presence, while remaining practical to deploy and handle repeatedly in temporary settings.

During this exploratory stage, the sketching activity also tested alternative geometries and more unconventional configurations that did not rely exclusively on a planar panel typology. These directions were useful to probe formal opportunities and to stress test different spatial and structural logics. However, when the proposals were filtered through the application constraints

and the requirements derived from the contextual and literature based research, the panel archetype emerged as the most robust foundation for further development, because it offered a clear balance between acoustic surface efficiency, deployability, and predictable stability.

From this point onward, three concepts were developed in parallel. Each one explored a different way of organising the acoustic body, the supporting structure, and the deployment logic, leading to distinct solutions in terms of stability, footprint, manufacturability, and overall visual presence. The next subsections present these alternatives and summarise the considerations that led to the final selection.

Figure 39: preliminary hand sketches

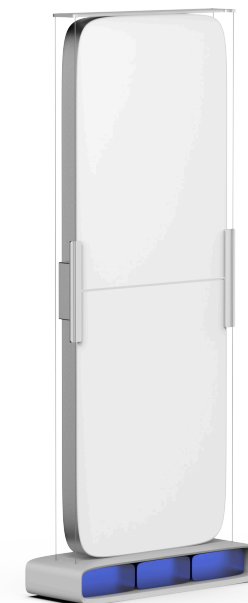


First concept

The first design direction explores a soft edged, modular panel conceived as a frame that encapsulates the sound absorbing body. The system is composed of two main modules that are brought together on site and locked through lateral engagement features, allowing the joint to remain visually thin and enabling a high proportion of exposed absorptive area. The overall geometry is characterised by rounded corners and continuous fillets, intended to communicate a controlled, product like presence while protecting the edges during handling.

Stability is addressed through a base designed as a coherent extension of the panel footprint, with the same softened geometric language. The base integrates dedicated ballast cavities that are conceived as empty volumes during transport and filled on site, for example with water or sand, to increase mass and lower the centre of gravity. In addition, the concept includes tensioning cables that connect the upper portion of the panel to the base, providing a secondary stabilisation path intended to limit sway and improve resistance to overturning in outdoor conditions.

Figure 40: concept n° 1



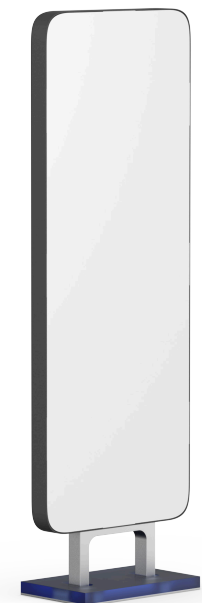
Second concept

The second concept develops a more controlled and geometrically defined language while retaining softened edges. The panel is conceived around a monocoque shell that wraps the absorptive body laterally and closes the rear side, creating a continuous and protective backside. This configuration frames the acoustic layer as a single uninterrupted surface on the front, with the sound absorbing material treated as one continuous element rather than divided into multiple modules.

The supporting structure combines a ballast base with arched legs that connect the panel to the ground contact plane. The base is conceived as a hollow volume intended to be filled on site, increasing mass and lowering the centre of gravity to improve stability. The system is completed by a thin sheet metal plate in contact with the ground, which acts as the interface between the structure and the supporting surface.

This direction prioritises compositional simplicity and product integrity, minimising the number of separate parts and promoting a cohesive overall form. The trade off is logistical, since the monocoque architecture

Figure 41: concept n° 2



is not divisible into smaller transportable sub assemblies, and therefore results in a bulkier unit. In addition, the closed rear shell inherently constrains the acoustic interaction to a single primary absorbing face, limiting the possibility of a double sided absorptive configuration.

Third concept

The third concept returns to a frame based archetype that encapsulates the sound absorbing body, while making the product decomposition more explicit. The panel is conceived as two main portions separated by a clearly legible split line, which supports assembly logic and clarifies the modular nature of the system. Lateral connector elements are used both to lock the two halves together and to enable side by side coupling, allowing multiple units to be aligned and mechanically linked into continuous runs.

A defining feature of this direction is the visual continuity between the upper panel and the base, achieved through a consistent geometric transition rather than treating the base as an independent accessory. The

Figure 41: concept n° 3



base is formed by two slightly curved sheet metal elements that extend downward from the panel and gradually widen outward, generating the required footprint for stability. These elements are constrained by a third component, a sheet metal plate that closes the geometry and contributes to stiffness and overall stability at ground level.

7.4 Final concept definition and development

This section presents the selected concept and documents the refinement process that led to the final product definition.

The third concept was chosen as the most coherent foundation, then progressively simplified through successive iterations to consolidate functionality and ensure alignment with the requirements established in the final brief. The development therefore focused on reducing structural and assembly complexity while preserving the intended acoustic role, stability performance, and overall formal coherence.

The selection was also informed by the logistical condition that is intrinsic to the project. While the system is expected to remain assembled and in use for extended periods during an event, its operational context is fundamentally transitory, meaning that transport, storage, and repeated handling become primary drivers alongside in use performance. For this reason, preference was given to a direction that preserves the possibility of disassembly and volume reduction, minimising bulk during logistics cycles. This rationale supported the continuation of a frame based archetype, where the external frame contains and protects the absorptive body while enabling a component logic compatible with packing efficiency and repeated deployment.

The final product definition resulting from the refinement process is presented in figure 43, showcasing VEIL, with its overall architecture, proportions, and integration logic of the system.

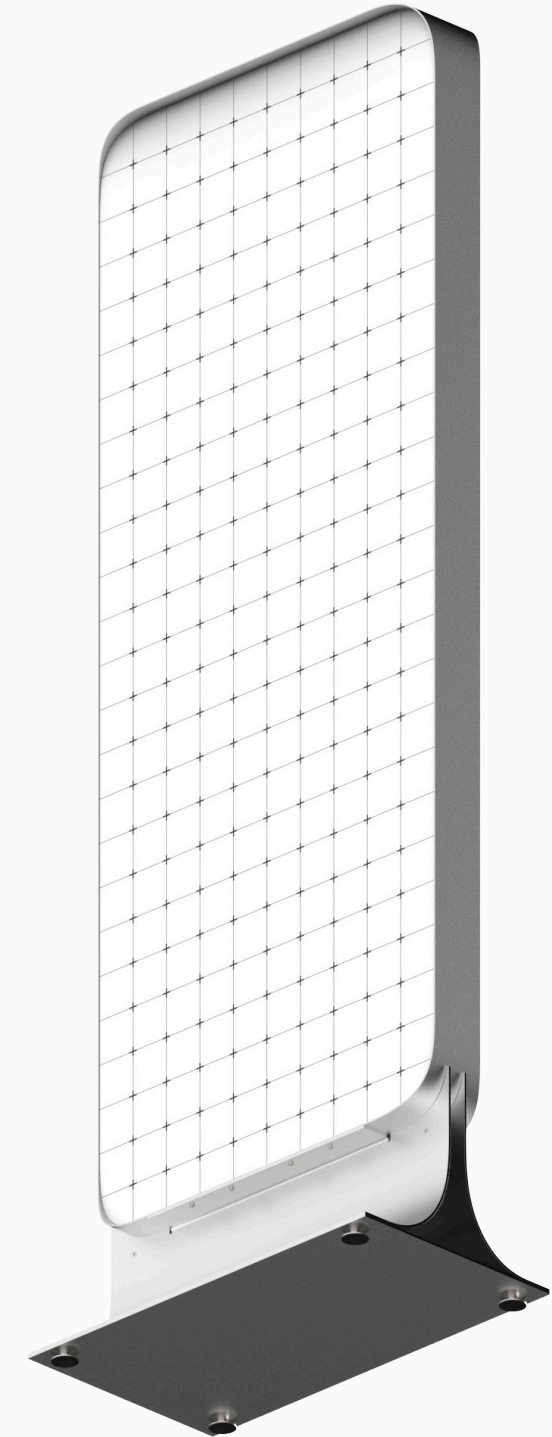


Figure 43: VEIL final product

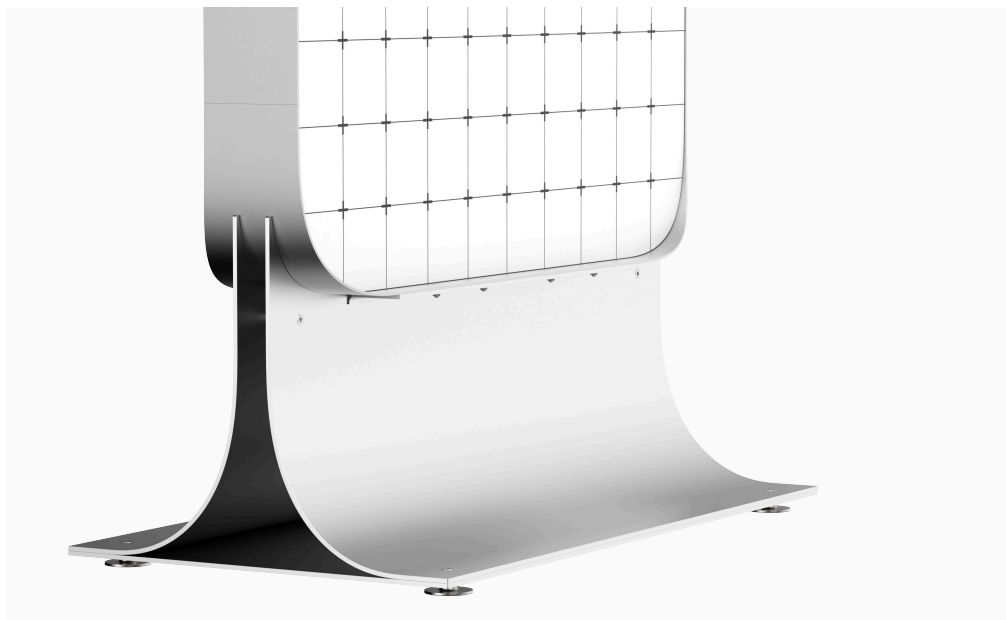
A first key step was to move away from a two part panel assembly and converge toward a single continuous body. This decision removed the need for a split line and eliminated the associated lateral connection elements, improving both visual continuity and practical robustness. In parallel, dimensional and material choices were revisited to optimise stability through the intrinsic mass distribution of the base. Unlike the other explored directions, the selected concept did not rely on an on site fillable ballast volume, and this approach was intentionally maintained during development. By concentrating mass in the base through dense metallic materials rather than low density fill media such as water or sand, the design could achieve the required weight and a lower overall centre of gravity with a more compact footprint, supporting overturning resistance while reducing bulk and visual encumbrance (figure 44).

Further refinement introduced differentiated frame depths across the upper, lower, and lateral elements. The upper and lower frames share the same extrusion profile and are both subtly accentuated (figure 45). The upper member suggests a protective canopy and reinforces outdoor readiness, while the lower member increases the



Figure 45: profile detail

Figure 44: compact footprint base detail



available contact area, providing a larger and more stable interface with the base structure. Together, these adjustments improve the perceived depth of the product language, reduce overall visual heaviness, and support a more integrated relationship between the acoustic body and the supporting structure.

The overall dimensions of VEIL are the outcome of a scale definition process that balances contextual constraints with functional intent (figure 46). On the one hand, the concept benefits from maximising the active surface, since the intervention is conceived as a local acoustic measure operating through strategic surface placement

within temporary outdoor layouts. On the other hand, the transient nature of events imposes strict requirements on logistics, handling, and repeated transport, which argue for a compact and manageable envelope. The final size therefore reflects a deliberate compromise between acoustic coverage and deployability, and it is further consolidated by the decision to frame the product as a single, self contained unit rather than a multi part assembly. Finally, the external membrane, intended not only as protection but also as a potential communicative surface, contributes to the definition of a clear, readable frontage, reinforcing the selected proportions and overall format.

Figure 46: general dimensions expressed in mm

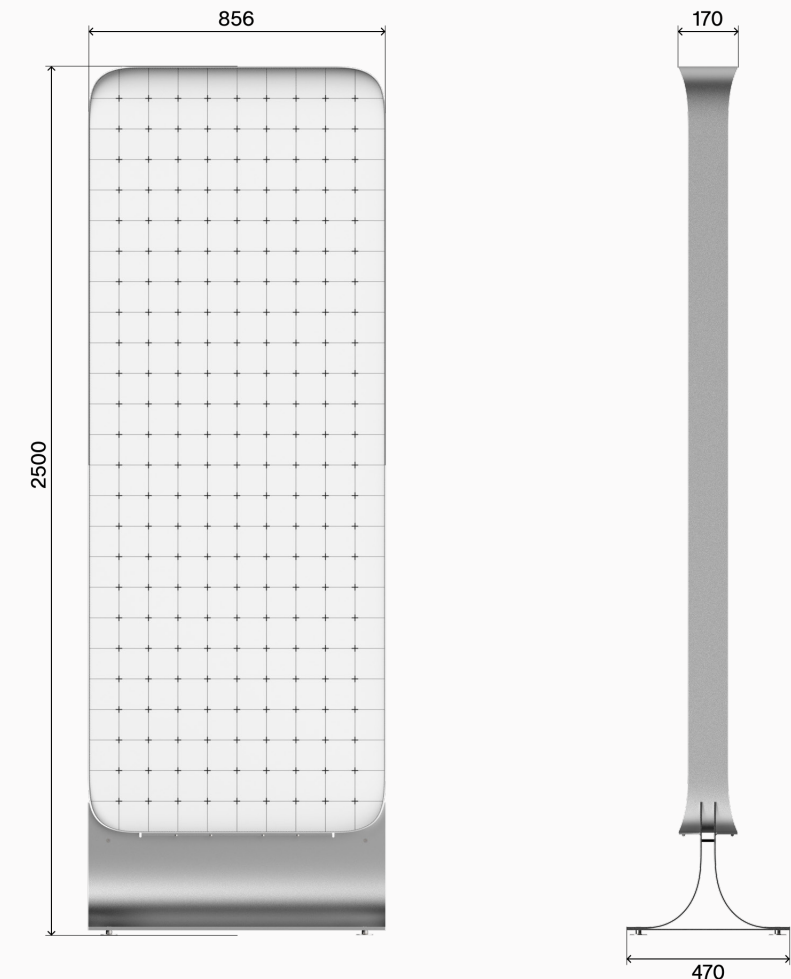




Figure 47: contextual render of VEIL in a temporary event setting

8. Engineering and manufacturability

This chapter brings the project into an engineering phase, clarifying how the proposed panel can be realised as a reliable product for temporary outdoor deployment. Building on the acoustic rationale and the context driven requirements established earlier, the concept is consolidated into practical solutions for layer integration, assembly, and manufacturing. The focus is therefore on feasibility, repeatability, and robustness, showing how material and architectural choices are carried through into a buildable system that can be assembled on site, handled safely, and maintained across multiple event cycles.

8.1 Layer integration and frame architecture

Building on the layer set defined in Chapter 5, the step from an acoustic configuration to a deployable product requires a small number of practical conditions to be kept under control. Once assembled, the stack must remain consistent in thickness and alignment so that the intended acoustic response is preserved rather than altered by local gaps, sliding interfaces, or unintended air paths. The internal layers must also be held with a controlled and repeatable compression, sufficient to keep contact between interfaces, but limited enough to avoid excessive compaction of the porous core and the resulting drift in behaviour. In addition, the

assembly must protect the acoustic materials from handling damage and outdoor exposure, particularly at the perimeter, where edges and terminations are most vulnerable.

As defined earlier, the absorbing core is organised as a symmetric multilayer stack (figure 48). From the exterior to the interior, each side is composed of a protective membrane, a micro perforated panel, and a resistive nonwoven layer, followed by the porous core at the centre and mirrored by the same sequence on the opposite side. In the adopted configuration, nominal thicknesses are as follows, protective membrane 1.0 mm, micro perforated panel 1.5 mm, resistive layer 2.5 mm per side, and porous core 66 mm. This distribution maintains a compact overall depth while preserving the intended functional roles of the layers, namely protection and acoustic transparency at the surface, impedance control through the resistive interface, repeatable geometry through the perforated layer, and broadband dissipation within the porous volume.

The integration strategy is intentionally simple but robust. The acoustic core is captured within a perimeter frame made of aluminium extrusions (figure 49), which define the panel envelope and provide the structural reference for layer seating and alignment. The specific frame profile design provide dedicated internal bearing faces, which constrain the stack and define the reference depth, as shown in Figure 50, keeping the porous core, the micro perforated layers, and the resistive layers in position without adhesives or mechanical fastening across the active area. In this way, the extruded frame controls boundary conditions and compression through its geometry, ensuring that clamping is repeatable and not dependent on bonding thickness or user applied tightening.

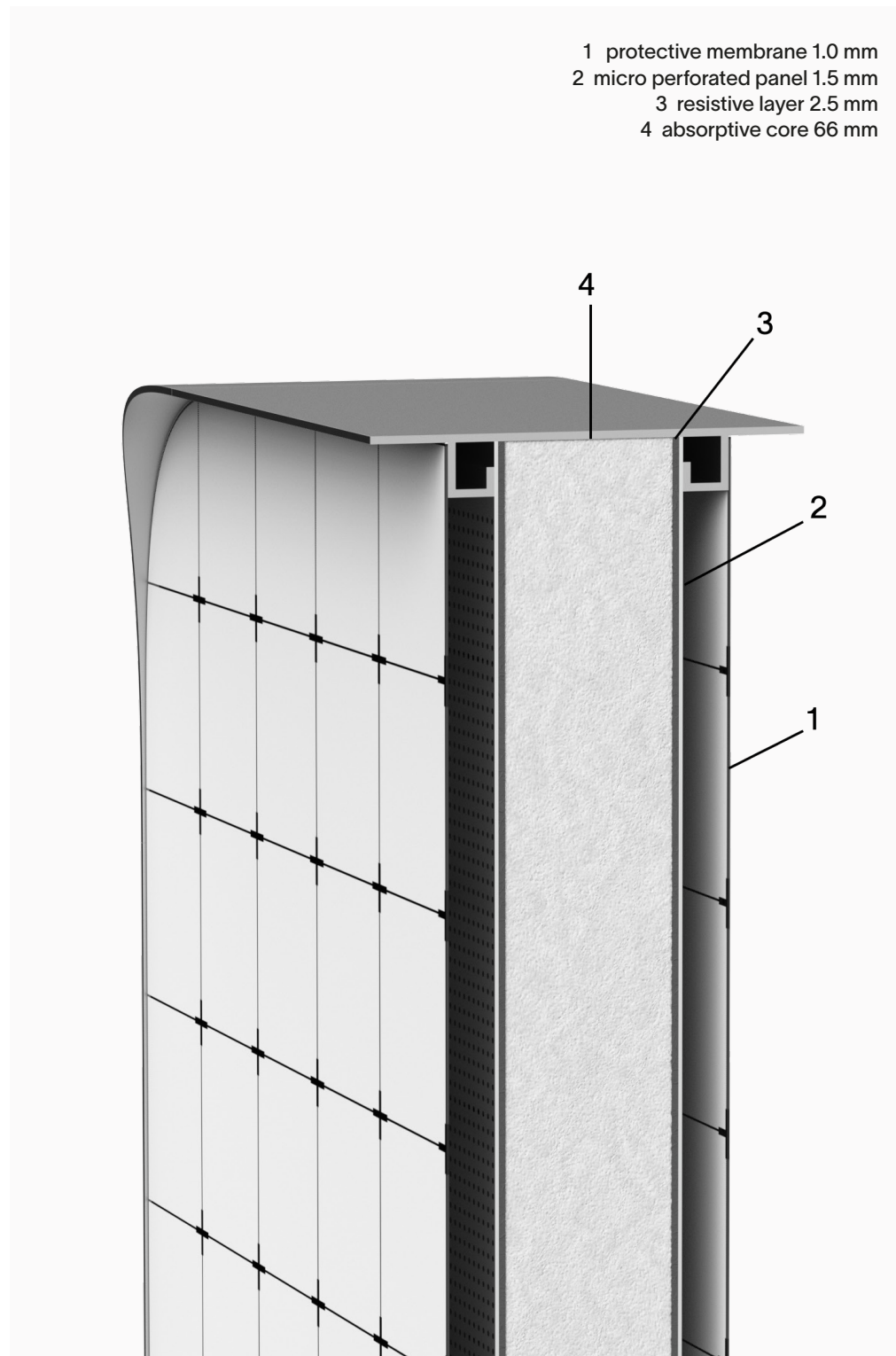


Figure 48: section view and layer integration



Figure 49: perimeter frame



Figure 50: frame section geometry defining the internal bearing surfaces.

At the perimeter, the same extruded frame also acts as a protective boundary and as the interface for environmental sealing. An external rebate provides a continuous contact surface for the protective membrane, which is bonded only along the perimeter through an adhesive strip. This interface is intentionally serviceable, and the membrane is conceived as a printable outer skin that can be replaced between events if a renewed communicative surface is desired, or substituted in case of cuts, tearing, or wear (figure 51 & 52). Overall, the extruded frame is therefore not an accessory component, it is the key architectural element that preserves the acoustic intent while enabling a repeatable, maintainable, and durable product integration.

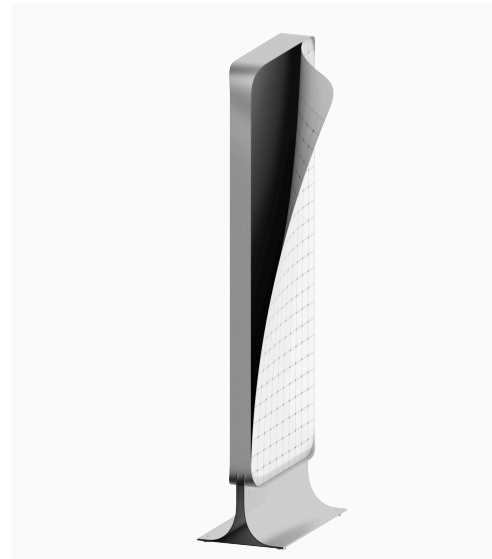


Figure 51: replaceable protective membrane



Figure 52: examples of protective membranes printed on request

8.2 Assembly logic and connections

Given the temporary nature of the intended context, the assembly strategy is driven by two coupled requirements. The first is the ability to minimise the product volume for transport, enabling frequent relocation from one event site to another. The second is operational speed, since set up and dismantling must remain compatible with short installation windows and repetitive handling. The resulting solution adopts a demountable configuration where the product is organised into two main subassemblies, the panel frame (figure 53), which encloses the acoustic stack, and the base (figure 54), which provides ground support and stability. This separation keeps each part manageable while allowing a clear and repeatable assembly sequence.

Assembly starts from the base. Two curved sheet metal elements are positioned onto the main base plate and fixed through M8 screws, with height adjustable feet integrated to compensate for uneven ground and to set the working attitude of the unit. To further increase stability and prevent relative movement between the curved elements, additional M6 screws combined with spacers connect the two plates, creating a stiffened structure that maintains geometry under service loads and handling actions.

The frame is formed by four extruded members, an upper, a lower, and two lateral profiles, whose continuity is completed through dedicated corner elements. These elements define the corner geometry and close the perimeter, while integrated locating features guide the fit with the ends of the adjacent profiles and keep the members aligned during assembly. Once all four corner elements are seated, the frame geometry closes and the perimeter is fully defined, enabling final fixation. The junctions are then secured through M5 screws, which pass through the holes in the extruded profiles and engage into the integrated blocking features of the corner elements, locking the assembly while maintaining full demountability. This approach ensures consistent alignment and a robust, repeatable connection between the extruded segments.

The outer protective membranes are applied as the final step. Each membrane is bonded along the external rebate of the frame through a continuous perimeter adhesive.

After panel completion, the unit is placed onto the base through the dedicated contact surface and secured using M5 screws. On the opposite side, the fasteners are locked with hex nuts, providing a reliable clamping connection while keeping the joint fully demountable. This completes the assembly into a stable, deployable configuration that can be dismantled in reverse order for transport.



Figure 53: frame subassembly

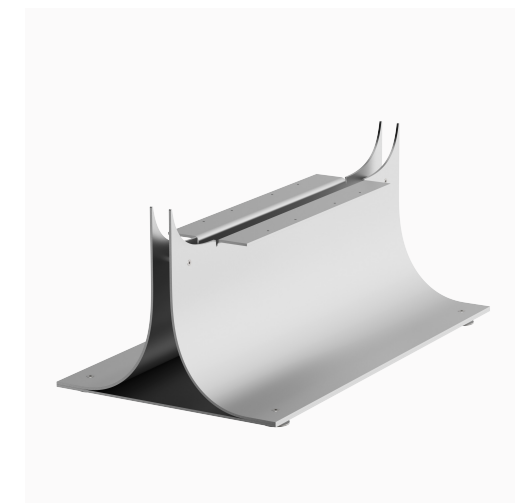


Figure 54: base subassembly

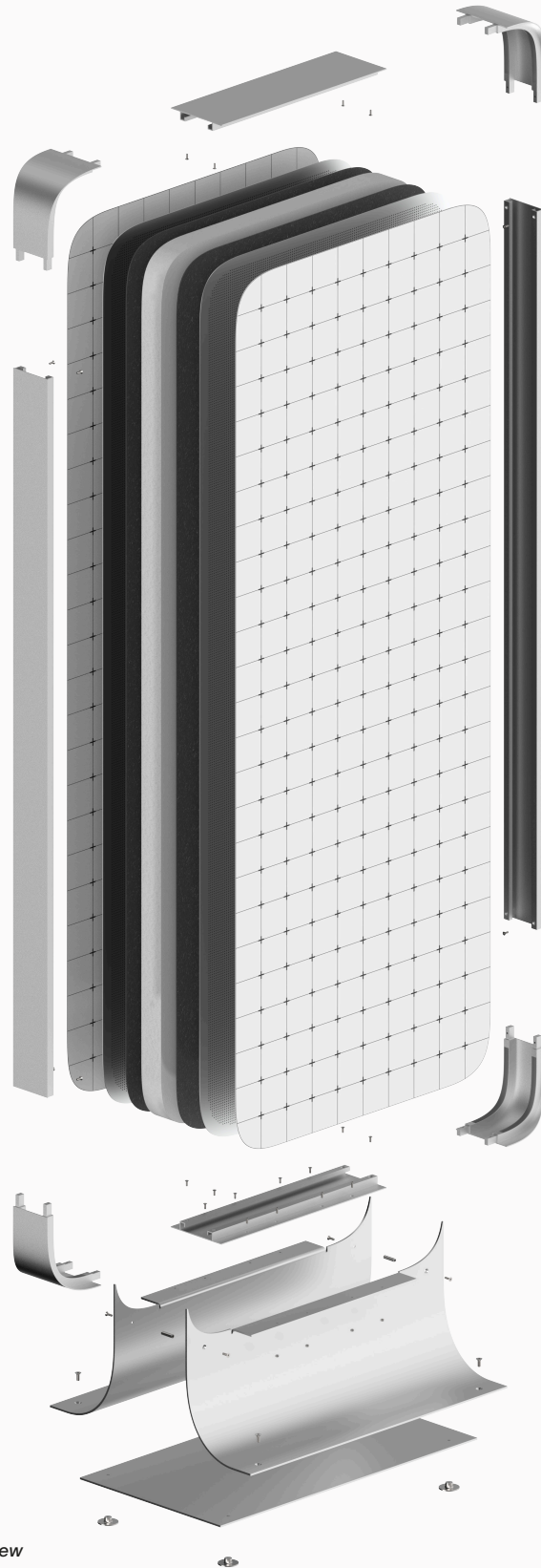


Figure 55: VEIL exploded view

8.3 Manufacturing strategy

The manufacturing strategy is defined to keep the main structural parts simple, repeatable, and compatible with established industrial processes. The frame is based on aluminium extrusions in alloy 6063 (figure 56), selected to enable cost effective profile production and reliable surface finishing. The profile geometry is intentionally kept straightforward and the wall thickness is set to 3 mm, balancing stiffness, manufacturability, and weight. After cutting to length and machining of the required features, the aluminium extruded members are anodised to improve corrosion resistance and surface durability, while also providing a consistent aesthetic finish across repeated deployments.

The corner components (figure 57) complete the perimeter of the frame and are manufactured through aluminium sheet metal forming operations, the alloy 6063 has been selected again to maintain material continuity with the extrusions. The main corner body is produced from 3 mm aluminium sheet, first cut to shape and then stretch formed to obtain the required geometry. Two pairs of interface rails are then laser cut from 1.5 mm aluminium 6063 sheet. These rails are connected to each other by welding two additional end components, positioned at their extremities, which create the engagement features that couple with the internal rail geometry of the extruded profiles. Once the rail subassembly is formed, it is welded onto the previously stretch formed corner body to obtain the complete corner component. The corner assemblies are then anodised, ensuring corrosion protection and a uniform finish across all frame parts.

The base (figure 58) adopts a similar process logic, relying on cutting and bending operations to obtain stiffness and repeatable geometry. It consists of two symmetric side panels in stainless steel AISI 304, each 5 mm thick, which are cut from sheet and subsequently bent to achieve the desired curved profile.

The third base element, also in 5 mm AISI 304, is produced through flat cutting and functions as the ground plate to which the two side panels are connected during assembly.



Figure 56: aluminium extruded frame component



Figure 57: corner component

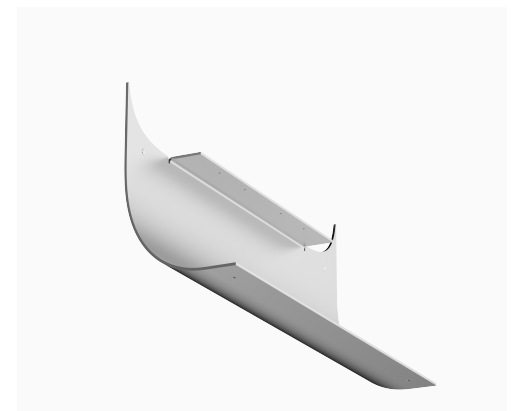


Figure 58: base panel

8.4 Structural stability

Structural stability is a primary feasibility condition for the proposed panel, since the product is intended to operate in open air and semi outdoor event layouts where exposure to wind cannot be controlled. In this context, lateral stability becomes a safety critical aspect that directly informs the base design, the panel to base connection, and the overall mass distribution of the system. The following calculations therefore assess the panel under a representative wind induced lateral load, translating an assumed pressure acting on the exposed surface into an equivalent horizontal force and overturning moment. This verification is used to determine whether the adopted footprint provide an adequate stability margin against sliding and tipping in typical deployment conditions.

Figure 59 provides a concise list of the parameters used in the calculation and the corresponding values adopted, while the right page presents the calculation steps and results.

The results should be read as a simplified stability check, intended to confirm the plausibility of the proposed configuration rather than to provide a detailed site specific assessment. Within this scope, the obtained safety margin is considered reasonable for a deployable panel operating in typical outdoor event conditions, where moderate wind exposure is expected and installation layouts are managed. In practice, when exceptional wind levels are forecast or measured, events commonly adopt operational thresholds beyond which temporary structures and loose elements are removed or dismantled to restore overall safety.

Finally, potential accidental impacts were also considered qualitatively, but they were not developed into formal calculations, since their likelihood is lower and the resulting lateral actions are expected to remain below the representative wind induced load used as the governing case in this verification.

Figure 59: symbols, parameters and values adopted in the overturning verification

Symbol	Description	Value	Unit
m	Total mass	95	kg
g	Gravitational acceleration	9.81	m/s ²
B	Base width, overturning direction	0.470	m
E	Lever arm of weight to pivot	0.235	m
H_{tot}	Total exposed height, panel plus base	2.5	m
b	Exposed width	0.85	m
z_w	Wind resultant height	1.25	m
A	Exposed area	2.125	m ²
μ	Friction coefficient, medium assumption	0.4	—
ρ	Air density, standard condition	1.225	kg/m ³

$$W = mg = 95 \cdot 9.81 = 931.95 \text{ N}$$

Overturning verification

The stabilising moment is provided by the weight acting through the lever arm E . The overturning moment is generated by the wind resultant F_w applied at height z_w .

$$M_{res} = WE = 931.95 \cdot 0.235 = 219.01 \text{ N m}$$

$$M_{ot} = F_w z_w$$

At the overturning limit, moments are equal:

$$M_{ot} = M_{res} \Rightarrow F_{w,lim} = \frac{M_{res}}{z_w} = \frac{219.01}{1.25} = 175.21 \text{ N}$$

The corresponding mean equivalent pressure on the exposed area is:

$$p_{ot,lim} = \frac{F_{w,lim}}{A} = \frac{175.21}{2.125} = 82.45 \text{ Pa}$$

Sliding verification

Sliding resistance is estimated via Coulomb friction:

$$F_{sl,lim} = \mu W = 0.4 \cdot 931.95 = 372.78 \text{ N}$$

$$p_{sl,lim} = \frac{F_{sl,lim}}{A} = \frac{372.78}{2.125} = 175.42 \text{ Pa}$$

Since $F_{w,lim} < F_{sl,lim}$, overturning governs with respect to sliding under the assumed interface condition.

Equivalent wind speed

To express the result as an interpretable wind magnitude, the mean pressure is approximated as dynamic pressure:

$$p \approx \frac{1}{2} \rho v^2 \Rightarrow v = \sqrt{\frac{2p}{\rho}}$$

Overturning equivalent wind speed:

$$v_{ot,lim} = \sqrt{\frac{2 \cdot 82.45}{1.225}} = \sqrt{134.6} = 11.6 \text{ m/s} \approx 41.8 \text{ km/h}$$

Sliding equivalent wind speed:

$$v_{sl,lim} = \sqrt{\frac{2 \cdot 175.42}{1.225}} = \sqrt{286.4} = 16.9 \text{ m/s} \approx 60.8 \text{ km/h}$$

Under the stated assumptions, the limiting condition is overturning, occurring at a lower equivalent wind speed than sliding.

8.5 Durability and lifecycle

Durability is treated as a core feasibility condition, because the panel is expected to be assembled, used, dismantled, and transported repeatedly across different event sites. For this reason, the design relies on corrosion resistant metals for the structural parts, combined with protective surface finishing, so that the frame and base can tolerate outdoor exposure, handling abrasion, and incidental impacts over multiple deployment cycles. In parallel, the perimeter frame geometry protects the internal layer terminations, which are typically the most vulnerable areas during transport and installation, and reduces the likelihood of local damage propagating into the acoustic core.

A second driver is the serviceable integration logic. The acoustic stack is mechanically captured rather than permanently bonded into a single laminate, which limits irreversible failure modes and allows the system to be opened for inspection if required. Wear is concentrated on predictable elements, such as fasteners, contact interfaces, and adjustable feet, which can be replaced without affecting the functional layers. The protective membrane

follows the same logic. Since it is bonded only along the perimeter, it can be substituted between events if a clean surface is needed, and it can be replaced quickly in case of cuts, tearing, or progressive surface degradation, while leaving the internal acoustic layers intact.

From a lifecycle perspective, the project also retains the material rationale developed earlier in the thesis. The acoustic core includes a nonwoven layer derived from recycled carbon fibre feedstock, which is reintroduced here as part of the product feasibility narrative, not only as a performance enabler but also as a responsible material choice aligned with repeated use scenarios. At end of life, the panel can be dismantled into distinct subassemblies, supporting maintenance during use and facilitating material separation.

Structural metal parts can follow established recycling streams, while the internal layers can be managed according to their composition and disposal route. Overall, the durability and lifecycle approach reinforces the chapter's engineering intent, ensuring that the panel remains reliable across repeated deployments and recoverable through straightforward disassembly when it reaches the end of its service life.

9. Conclusions and future work

9.1 Key outcomes and contributions

The insights from the literature review, the contextual analysis of outdoor events, and the technical benchmarking of absorber typologies converge to show that improving acoustic comfort in temporary venues is less a matter of global noise reduction, and more a matter of locally shaping what people hear in critical interaction zones. In these contexts, listening conditions are unstable and spatially non uniform, therefore the designer's contribution lies in translating acoustic principles into solutions that remain deployable, robust, and repeatable across changing sites.

The study shows that broadband improvement, especially when extending performance towards lower frequencies within a compact thickness, is not achieved through a single material choice, but through the orchestration of complementary mechanisms. Porous absorption provides the baseline dissipation, while resistive and microperforated elements enable surface impedance control and targeted enhancement, resulting in a layer logic that is both acoustically grounded and compatible with outdoor constraints such as handling, weather protection, and maintenance. In this sense, the work contributes a consolidated rationale for a feasible multilayer architecture, linking absorber theory to a coherent and deployable solution that remains consistent with the operational conditions of temporary events.

The final design proposal embodies these insights in product form, defining the panel as a modular component where acoustic performance and deployment requirements are designed together. Integration is treated as a deliberate choice and a performance condition, because the realised effect on site depends on positioning, protection from exposure, transport, and repeatable assembly.

Accordingly, the contribution extends beyond the acoustic stack itself and includes a set of integration principles that support structural stability, durability, and lifecycle oriented reuse. Within this framework, the recycled carbon fibre based nonwoven layer is a central element of the concept, because it anchors the absorber architecture in a circular material strategy and translates recycled high value fibres into a functional acoustic layer within an outdoor ready, reusable system.

However, the panel alone cannot fully determine the perceived outcome at an event. Its impact depends on being embedded in a broader operational approach that considers placement logic, proximity to sources and listeners, and the spatial definition of semi enclosed zones where communication is most fragile. In this perspective, the panel provides a practical and scalable building block for local acoustic improvement, while the overall effectiveness remains contingent on how it is deployed as part of a wider event layout and sound management strategy.

9.2 Limitations

The main limitation is that the validation remains bounded to a design and engineering assessment, rather than a full scale acoustic verification in representative outdoor conditions. Outdoor performance is strongly affected by placement, local geometry, wind, humidity, ageing, and by the spectral and directional characteristics of real sources, therefore any predicted absorption advantage from layered strategies would need controlled measurement campaigns to quantify the effect on speech metrics and perceived comfort.

A further limitation concerns the trade space between thickness, weight, and low frequency performance. While the selected configuration aims for broad band behaviour in a compact form, fundamental constraints remain, especially when the target includes low frequencies where wavelengths are large and resonant mechanisms become dominant. This means that the panel can realistically improve local conditions, but it cannot be interpreted as a universal or site independent solution to low frequency noise at event scale.

9.3 Future developments

Future work should prioritise experimental validation and refinement through iterative prototyping. Impedance tube measurements and in situ trials can be used to calibrate the multilayer design, assessing how sensitive the response is to airflow resistance in the resistive layer, microperforation geometry, and cavity configuration. This would strengthen the link between design parameters and performance targets, and would help define acceptable variability in the key acoustic features of the system.

In parallel, the project could investigate more compact high performance configurations emerging from recent studies on microperforated systems with engineered cavities, including coiled or parallel cavity concepts that increase the effective acoustic path without increasing external thickness, while exploiting thermo viscous losses. These approaches are promising for extending absorption bandwidth in space constrained assemblies, and they remain consistent with the ambition of a deployable, product oriented solution.

Future development should also address lifecycle and field robustness through longer term testing, focusing on weathering, cleaning, moisture management, and the stability of acoustic behaviour over time, together with modular repair and replacement strategies. This would support the transition from a defined concept to a validated product system that can be reliably deployed across multiple events and reused over repeated cycles.

Bibliography

1. Alba, J., del Rey, R., Ramis, J., & Sanchis, V. (2025). Indirect acoustic characterisation of membranes for the control of sound absorption. *Buildings*, 15, 1249. <https://doi.org/10.3390/buildings15081249>
2. Allard, J.-F., & Atalla, N. (2009). *Propagation of sound in porous media: Modelling sound absorbing materials* (2nd ed.). Wiley.
3. ASTM International. (2022). ASTM C423-22: Standard test method for sound absorption and sound absorption coefficients by the reverberation room method. ASTM International.
4. Berardi, U., & Iannace, G. (2015). Acoustic characterization of natural fibers for sound absorption applications. *Building and Environment*, 94, 840–852.
5. Berglund, B., Lindvall, T., & Schwela, D. H. (Eds.). (1995). *Guidelines for community noise*. World Health Organization.
6. Cantwell, W. J., & Morton, J. (1991). The impact resistance of composite materials, a review. *Composites*, 22(5), 347–362.
7. Chevillotte, F. (2012). Controlling sound absorption by an upstream resistive layer. *Applied Acoustics*, 73, 56–60. <https://doi.org/10.1016/j.apacoust.2011.07.005>
8. Cox, T. J., & D'Antonio, P. (2017). *Acoustic absorbers and diffusers: Theory, design and application* (3rd ed.). CRC Press.
9. European Committee for Standardization. (2005). EN 1991-1-4: Eurocode 1—Actions on structures—Part 1-4: General actions—Wind actions. CEN.
10. European Committee for Standardization. (2015). EN 13782: Temporary structures—Tents—Safety. CEN.
11. European Committee for Standardization. (2018). EN 13501-1: Fire classification of construction products and building elements—Part 1: Classification using data from reaction to fire tests. CEN.
12. Everest, F. A., & Pohlmann, K. C. (2015). *Master handbook of acoustics* (6th ed.). McGraw-Hill Education.
13. Hashemi, Z., Monazzam Esmailpour, M., Nasirzadeh, N., Farvaresh, E., Beigzadeh, Z., & Salari, S. (2022). Estimation of sound absorption behavior of combined panels comprising Kenaf fibers and micro-perforated plates below 2500 Hertz. *Journal of Health and Safety at Work*, 12(4), 872–894.
14. Hill, A. J. (Ed.). (2020, May). *Understanding and managing sound exposure and noise pollution at outdoor events* (AES Technical Document AESTD1007.1.20 05). Audio Engineering Society.

15. Huang, C. H., Lin, J. H., & Chuang, Y. C. (2014). Manufacturing process and p sound absorbing and thermal insulating polyester fiber, polypr polyurethane composite board. *Journal of Industrial Textiles*, 43(4), 627–640.
16. Ingard, U. (1953). On the theory and design of acoustic resonators. *The Journal of the Acoustical Society of America*, 25(6), 1037–1061. <https://doi.org/10.1121/1.1907235>
17. International Electrotechnical Commission. (2020). IEC 60268-16: Sound system equipment—Part 16: Objective rating of speech intelligibility by speech transmission index. IEC.
18. International Organization for Standardization. (1996). ISO 9613-2: Acoustics—Attenuation of sound during propagation outdoors—Part 2: General method of calculation. ISO.
19. International Organization for Standardization. (1997). ISO 11654:1997 Acoustics — Sound absorbers for use in buildings — Rating of sound absorption. <https://www.iso.org/standard/19583.html>
20. International Organization for Standardization. (1998). ISO 10534-2:1998 Acoustics — Determination of sound absorption coefficient and impedance in impedance tubes — Part 2: Transfer-function method. <https://www.iso.org/standard/22851.html>
21. International Organization for Standardization. (2003). ISO 354:2003 Acoustics — Measurement of sound absorption in a reverberation room. <https://www.iso.org/standard/34545.html>
22. International Organization for Standardization. (2003). ISO 9921: Ergonomics—Assessment of speech communication. ISO.
23. International Organization for Standardization. (2017). ISO 1996-2: Acoustics—Description, measurement and assessment of environmental noise—Part 2: Determination of sound pressure levels. ISO.
24. International Organization for Standardization. (2018). ISO 9053-1:2018 Acoustics — Determination of airflow resistance — Part 1: Static airflow method. <https://www.iso.org/standard/69869.html>
25. Jaouen, L., & Bécot, F. X. (2011). Acoustical characterization of perforated facings. *Journal of the Acoustical Society of America*, 129(3), 1400–1406.
26. Li, J., Chang, D., Liu, B., & Tian, J. (2014). Improving sound absorption bandwidth of micro perforated panel by adding porous materials. *Applied Acoustics*, 85, 107–114.
27. Maa, D.-Y. (1998). Potential of microperforated panel absorber. *The Journal of the Acoustical Society of America*, 104(5), 2861–2866.
28. Megasorber. (n.d.). Megasorber P (Product data sheet).
29. Megasorber. (n.d.). SoundMesh G8 (Product data sheet).
30. Min, H., Lou, H., Rong, N., & Zhao, Y. (2025). Acoustic performance of micro-perforated panel sound absorbers with paralleled coiled-up cavities for noise reduction in traffic tunnels. *Building and Environment*, 278, 113003.
31. Nakayama, R., et al. (2024). Acoustic metamaterials based on polymer sheets, from material design to applications as sound insulators and vibration dampers. *Polymers*, 16(12), 1686.
32. Pereira, A., Gaspar, A., Godinho, L., Amado Mendes, P., Mateus, D., Carbajo, J., Ramis, J., & Poveda, P. (2021). On the use of perforated sound absorption systems for variable acoustics room design. *Buildings*, 11, 543. <https://doi.org/10.3390/buildings11110543>
33. Rymyc. (n.d.). RYMFELT safety data sheet (Rev. 2.0) [Safety data sheet].
34. Rymyc. (2023). Rymyc presentation [Company presentation].
35. RYMYC. (n.d.). RYMFELT (recycled carbon fibre nonwoven) and company information. Retrieved February 3, 2026, from <https://www.rymyc.it/>
36. Saha, S., Sonawwanay, V., Patel, S). A short review of recent innovations in acoustic materials and panel design, emphasizing wood composites for enhanced performance and sustainability. *Polymers*, 17(2), 197.
37. Sakagami, K., Kobatake, S., Kano, K., Morimoto, M., & Yairi, M. (2011). A systematic approach to the design of multi layer microperforated panel absorbers. *Applied Acoustics*, 72(11), 852–860.
38. Sántha, P., & Tamás-Bényei, P. (2025). [Express Polymer Letters article referencing Rymfelt supply and processing route]. *Express Polymer Letters*, 19(11), 1202–1213. <https://doi.org/10.3144/expresspolymlett.2025.88>
39. Segura-Alcaraz, P., Bonet-Aracil, M. A., Gisbert-Payá, J., Montava, I., & Díaz, J. (2017). Sound absorption of textile material using a microfibras resistive layer. *IOP Conference Series: Materials Science and Engineering*, 254, 072022. <https://doi.org/10.1088/1757-899X/254/7/072022>
40. Segura-Alcaraz, P., Segura-Alcaraz, J. G., Montava, I., & Bonet-Aracil, M. (2018). The use of fabrics to improve the acoustic absorption: Influence of the woven fabric thread density over a nonwoven. *AUTEX Research Journal*, 18(3), 269–280. <https://doi.org/10.1515/aut-2018-0006>
41. Segura-Alcaraz, P., Segura-Alcaraz, J. G., Montava, I., Bonet-Aracil, M., & Jorda, J. (2021). The effect of the combination of multiple woven fabrics on the sound absorption coefficient of recycled polyester nonwoven fabrics. *Journal of Industrial Textiles*, 50(8), 1253–1273. <https://doi.org/10.1177/1528083720916322>
42. SheikhMozafari, M. J., Hashemi, Z., & Mohsenian, A. (2024). Numerical optimization of microperforated panel absorbers: The impact of series-parallel configuration, air gap, and porous materials on the sound absorption bandwidth. *Journal of Health and Safety at Work*, 14(4), 772–795.
43. Song, B., Peng, L., Fu, F., Liu, M., & Zhang, H. (2016). Experimental and theoretical analysis of sound absorption properties of finely perforated wooden panels. *Materials*, 9, 942. <https://doi.org/10.3390/ma9110942>
44. Tayong, R. B., Dupont, T., & Leclaire, P. (2013). Sound absorption of a micro-perforated plate backed by a porous material under high sound excitation: Measurement and prediction. *International Journal of Engineering and Technology*, 2(4), 281–292. <https://doi.org/10.14419/ijet.v2i4.1421>

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