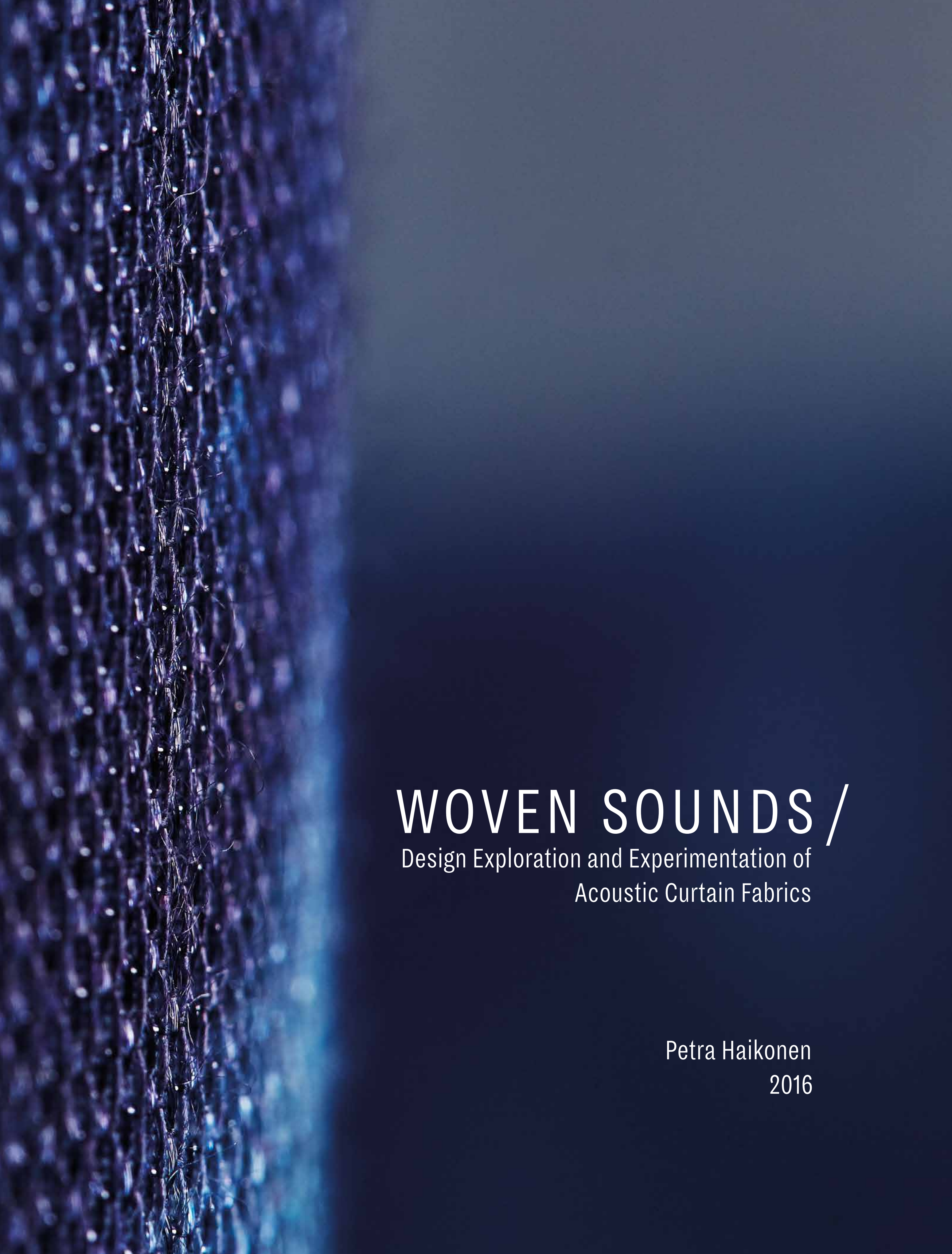


WOVEN SOUNDS /

Design Exploration and Experimentation of Acoustic Curtain Fabrics

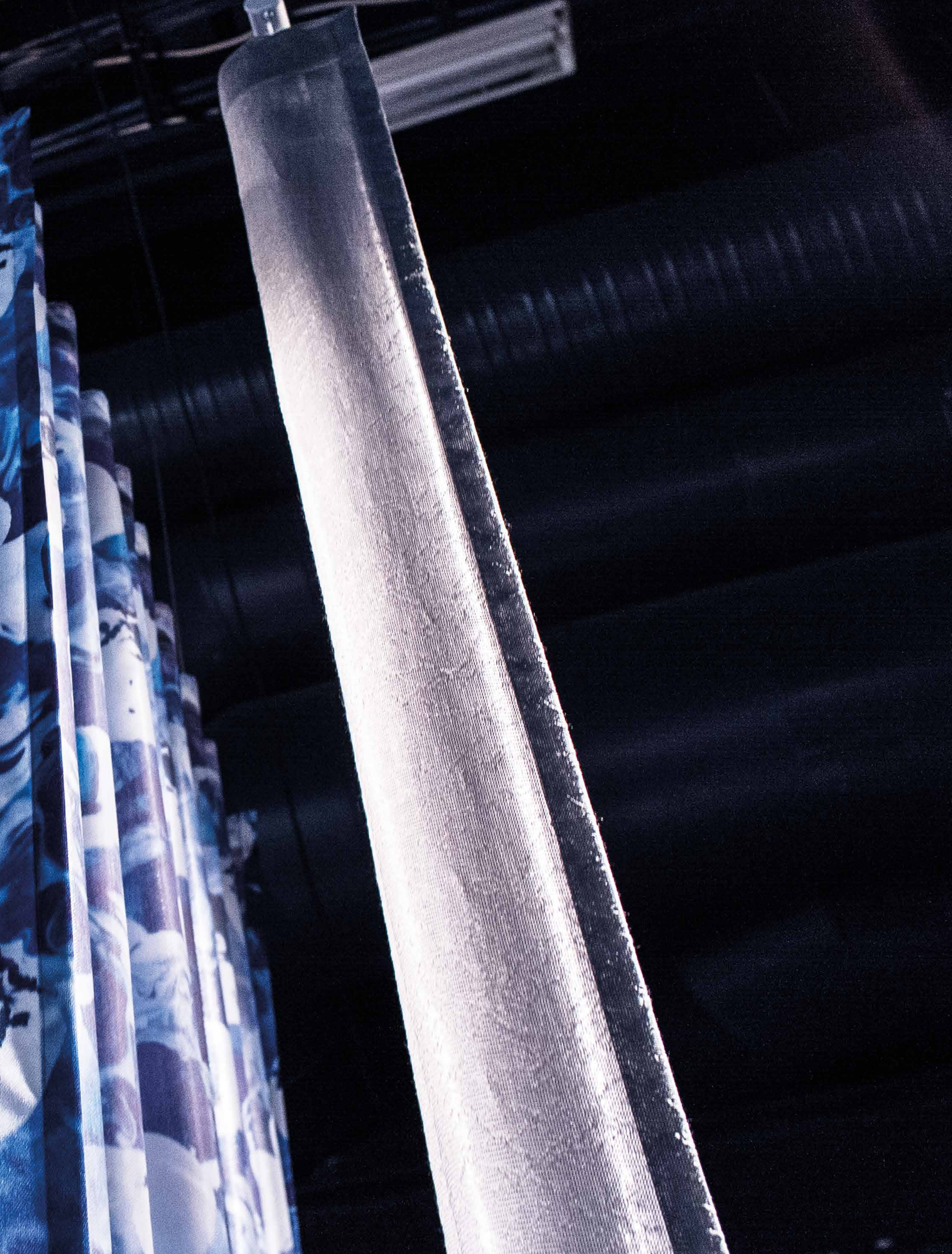
Petra Haikonen

2016

Woven Sounds /
Design Exploration and Experimentation of Acoustic Curtain Fabrics

Petra Haikonen / 2016
Master of Arts Thesis – Aalto University
School of Arts, Design and Architecture – Department of Design
Fashion and Collection Design

Supervisors /
Maarit Salolainen, Adjunct Professor, Department of Design
Kirsi Niinimäki, Associate Professor, Department of Design



ABSTRACT

Sound conditions are a top priority when it comes to designing an indoor space, since good sound conditions enhance the purpose the space is built for. There are several solutions for improving room acoustics, and one of the newest inventions in the market are lightweight acoustic curtains. This thesis examines such woven curtain fabrics, that have the appearance of conventional lightweight curtains, but that are able to absorb medium and high frequency sounds. Acoustic curtains belong to the group of functional textiles, where a particular function is integrated as a primary design criteria for adding value to otherwise conventional textiles.

The goal of this practice-based research is to understand how and why lightweight acoustic curtain fabrics are designed and produced, and to adapt that knowledge in a design process of acoustic curtain fabrics. The work is done in collaboration with an Italian weaving mill Lodetex and their clients. The design process is based on a thorough background research, and a comprehensive ideation and conceptual design work. The aim of the design work is to create a versatile set of prototype fabrics in order to find the best possible design solutions for sound absorptive fabrics.

The theoretical research provides the necessary information for understanding the basics of sound and acoustics. Sound is the concept of the work, and it acts also as an inspiration and a sketching tool in the visual design work. The theoretical research also covers a review on lightweight acoustic curtains and what are the factors that influence the sound absorption properties of those fabrics. Lastly the theoretical research is utilized in the design practice of experimental development work of woven acoustic curtain fabrics.

Since the work is a practice-based research, the documentation of the design process is as important outcome as the presented idea collection of the designed prototype fabrics. The prototypes were created within two development cycles that included phases of prototyping, testing, analyzing and developing. The work reveals the complexity of designing sound absorbing fabrics. There are several microstructural factors that affect the sound absorption performance both individually and as a combination. Therefore the design work of woven acoustic fabrics should be based on several prototyping and testing phases in order to discover the most suitable material and structural solutions.

This work establishes a design practice, that combines a thorough technical exploration and a creative experimentation. The relevance of this work is to provide new knowledge of functional acoustic fabric design to the manufacturing company Lodetex and to their clients. The presented idea collection offers a variety of fabric designs that possess a potential for even highly performative acoustic curtain fabrics. This practical study is a starting point to a development work, that most likely continues as a more advanced design practice in the future with some of Lodetex's clients.

TIIVISTELMÄ

Hyvät ääniolosuhteet tekevät tilasta monikäyttöisemmän, ja siksi huoneakustiikka on tärkeää sisätilojen suunnittelussa. Äänen absorbointiin on useita ratkaisuja, joista yksi uusimmista on ohuiden akustoivien verhokankaiden käyttö sisustuksessa. Tämä opinnäyte tarkastelee tällaisia kudottuja verhokankaita, jotka eivät ulkonäöllisesti juurikaan eroa tavallisista verhokankaista, mutta jotka kykenevät absorboimaan keskitaajuuksien ja korkeiden taajuuksien ääntä. Akustoivat verhokankaat ovat funktionaalisia tekstiilejä, joiden suunnittelussa toiminnallisuus on tärkein kriteeri. Tämä myös nostaa tekstiilin arvoa entisestään.

Practice-based-tutkimustyön tavoitteena on ymmärtää miksi ja miten ohuet akustoivat verhokankaat on valmistettu, ja sitä kautta toteuttaa akustoivien verhokankaiden suunnittelu- ja kehitystyö. Opinnäyte on tehty italialaiselle kangaskutomolle Lodetexille sekä heidän asiakkailleen. Suunnitteluosuuden pohjana on laaja tutkimus aiheesta sekä kattava ideointi- ja konseptuaalinen suunnittelutyö. Suunnittelutyön tarkoituksena on luoda kokoelma erilaisia prototyyppikankaita, joista käy ilmi akustisesti toimivimmat suunnitteluratkaisut.

Työn teoreettinen osuus kattaa äänen ja akustiikan perusteet, mikä on olennaista akustoivien verhokankaiden toiminnallisuuden ymmärtämisessä. Ääni toimii työn kokonaiskonseptina, eli se on myös inspiraation lähde sekä luonnostelutyökalu visuaalisessa suunnittelutyössä. Teoreettinen osuus kattaa lisäksi ohuiden akustoivien verhokankaiden tarkemman tarkastelun ja osoittaa muun muassa, mitkä tekijät kankaan rakenteessa vaikuttavat äänen absorbointikykyyn. Teoreettista tietoa heijastellaan opinnäytteen kokeellisessa suunnitteluosuudessa.

Työn lopputuloksena toimii practice-based-tutkimuksen tapaan sekä prosessin tarkka kuvaus että esitelty ideakokoelma suunnitelluista prototyyppikankaista. Kankaat on suunniteltu ja valmistettu Italiassa kahden erillisen kehitysjakson aikana. Kehitysjaksot sisältävät protokankaiden valmistuksen, niiden testaamisen, testitulosten analysoinnin sekä mallien jatkokehityksen. Työssä käy ilmi akustoivien verhokankaiden suunnittelun monimutkaisuus. Monet kankaan rakenteelliset tekijät vaikuttavat äänen absorbointikykyyn sekä itsenäisesti että toistensa yhteisvaikutuksesta, mikä vaikeuttaa kankaan suunnittelua huomattavasti. Siksi akustoivien verhokankaiden suunnittelun tulee olla pitkäaikainen prosessi, jotta saadaan selville toimivimmat materiaaliyhdistelmät sekä niitä tukevat rakenteelliset ratkaisut.

Opinnäytteessä toteutuu suunnittelutyö, joka yhdistää laajan teknisen tarkastelun sekä luovan kokeilun. Työ tuottaa uutta tietoa funktionaalisen akustoivan kankaan suunnittelusta ja valmistuksesta sekä kutomo Lodetexille että heidän asiakkailleen. Esitelty ideakokoelma tarjoaa kattavan valikoiman verhokankaita, joilla on potentiaalia toimia akustoivina verhokankaina. Opinnäyte toimii lähtökohtana kehitystyölle, joka todennäköisesti jatkuu tulevaisuudessa kutomon asiakkaiden kanssa.

THANK YOU

my thesis supervisors /
Maarit Salolainen
Kirsi Niinimäki

all the experts and professionals who shared their knowledge and passion /
Lodetex
Shahrokh Farhanghi
Luca Farhanghi
Davide Bonsignore
Marie van Landeghem
Fabrizio Brignoli
Alberto Colombo
staff of Lodetex

Kvadrat
Johanna Apelgren
Anne Højgaard Jørgensen
Anne Elisabeth Kargaard
Stine Find Osther
Anna Wilhelmine Ebbesen
Lea Nordström

Innofusor
Toni Oinonen
Joni Nisula
Mikko Hyppölä

Silent Gliss
Markus Brugger
Anne Jacobsén

Vallila Contract / Création Baumann
Piia Iso-Kuortti

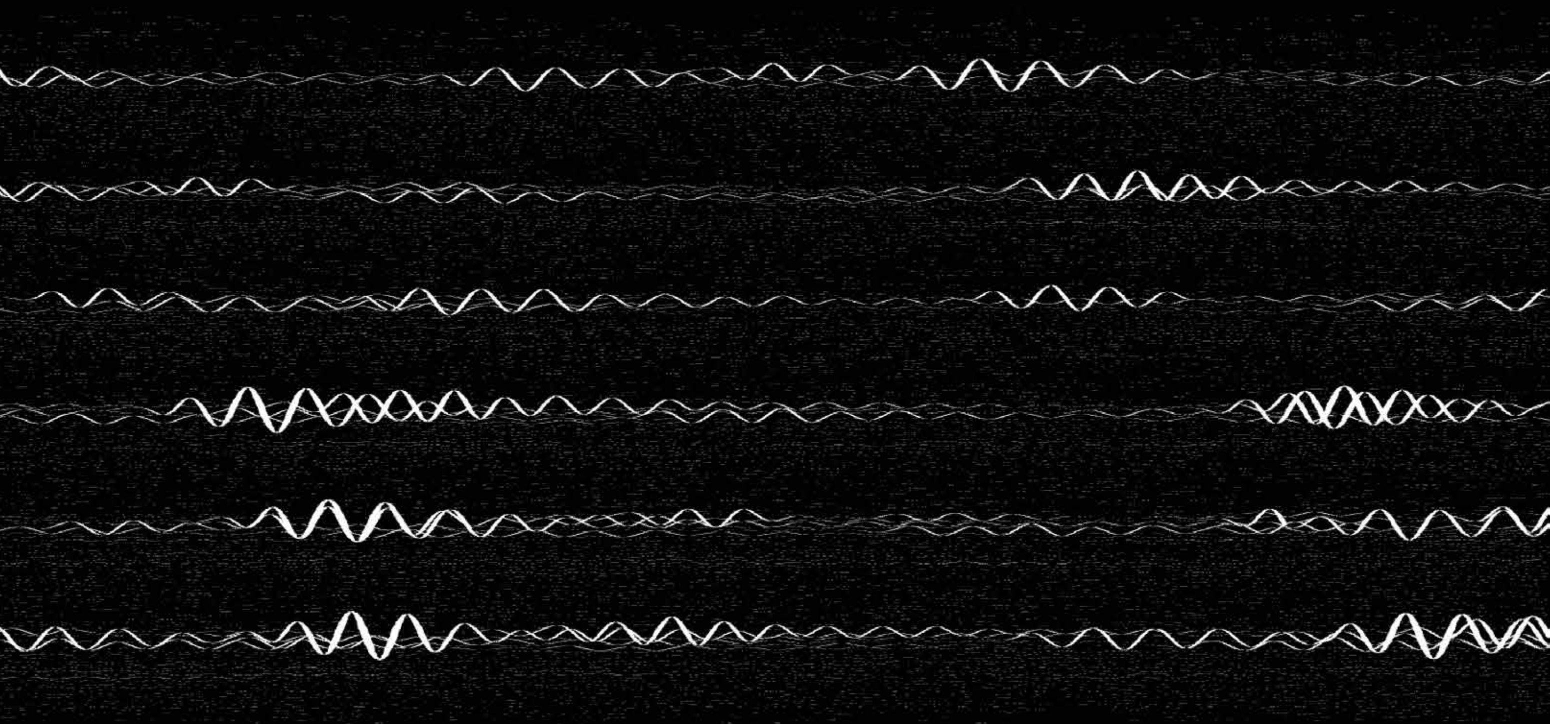
Tapio Lokki

my partner with visuals and in life /
Jouko Saastamoinen

the talented photographer /
Ilkka Saastamoinen

my family and friends for all your support

TABLE OF CONTENTS



1 INTRODUCTION

This thesis is a practice-based research of woven acoustic sheer and lightweight curtain fabrics that improve the sound environment of the indoor spaces. The purpose of the work is to uncover some of the factors that need to be taken into account when designing woven acoustic curtain fabrics for a textile manufacturing company. The work is divided into three sections; first two sections contain the theoretical background of the work and the last section contains the design work. The first section Concept / describes the functional and visual concept of the design process, that is sound. It also opens up the basics of room acoustics. The second section Case / deals with acoustic curtain fabrics; how they are structured and what kind of examples there are in the current market. The third section Design Practice / is a documentation of experimental development process of acoustic curtain fabrics that was done for an Italian weaving mill Lodetex.

BACKGROUND AND COLLABORATION

During 2015 I did an internship for an Italian weaving mill Lodetex, where I was fortunate to learn a lot about textile production from the manufacturing perspective. Lodetex is a weaving mill working in a medium-high market producing interior fabrics, mainly curtain fabrics but also blankets and bed covers, and additionally some fabrics for high fashion. For the most part Lodetex works in the contract textile market, and they sell fabrics to textile editors and other textile companies all over the world. Lodetex has a relatively small staff with altogether 35 people working in the design department, office, and the weaving and finishing departments (Lodetex 2012). After the first months of my internship I discovered that the company had a demand for acoustically functioning fabrics — meaning that the fabric is designed to absorb sound — but no one in the design department was able to fully focus on the subject, so I requested to study the topic as a master's thesis. The management of Lodetex and also their two major clients, European textile companies Kvadrat and Silent Gliss, were excited to launch the development work of acoustic fabrics with me as the project designer.

Lodetex is specialized in producing sheer and lightweight flame retardant curtain fabrics for contract market, so they already possess the needed equipment, materials and clients for developing lightweight fabrics with acoustic qualities.

With the massive pressure coming from Asia, it is forcing European and American textile manufacturers to act in order to keep up with the competition. One solution is to add value to the manufactured products, either by emphasizing the value of materials and production, or by coming up with innovative products. Creating new and innovative products means that the company has to undertake a product development process, which can be full of risks. (Büsgen 2012, 133.) Lodetex produces all of their fabrics in their premises in Italy from weaving to dyeing, digital printing, and finishing. They too have their competition at medium-high market with companies that are able to lower their prices and quality, so adding value to curtain fabrics with acoustic functionality is a risk worth taking. Lodetex possesses also a competitiveness with their production machinery compared to other manufacturing companies of acoustic curtain fabrics in the current market. That is their knowledge in jacquard weaving and digital printing. Emphasizing those techniques in the acoustic fabric design can help them to stand out from other concurrents.

The topic of acoustic fabric design felt inspiring to me, since I was able to expand the concept of sound to the visual design process as well. I had been doing some digital sketching experiments with audiovisual programming in collaboration with a programmer Jouko Saastamoinen during my previous studies, so it felt natural to continue the audiovisual sketching with him in the master thesis project as well.

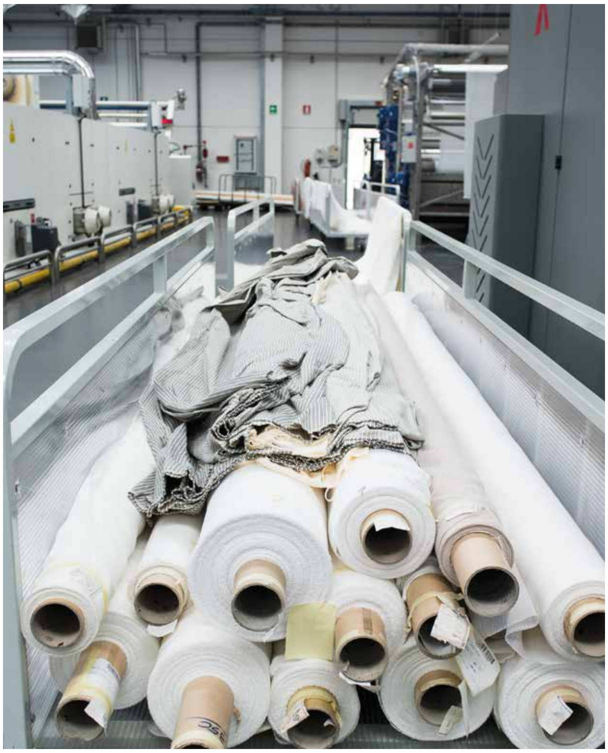


Fig. 1.1 & 1.2 Weaving and finishing departments at Lodetex.

During the project I found out also other sketching methods for visualizing sound than just digital programming. Although the visual design part is important, the focus of the work is still on creating a versatile structural collection of prototype fabrics.

CONTEXT AND RESEARCH QUESTIONS

This thesis is a practice-based study where an artifact or a product is the research outcome and the contribution to knowledge. Within practice-based research the knowledge arises also from materials, forms, applied technologies and techniques, and the context of use. Documentation and an analysis of the practice is highly important part of practice-based research. (Candy 2006, 1–3.) The main focus of this work is in the development process of acoustic curtain fabrics, so therefore it can also be referred as a production-based research. The goal of a production-based research is to share the applied design expertise, and to document the design explorations, creations and reflections (Selinger & Hahn 2015, 28).

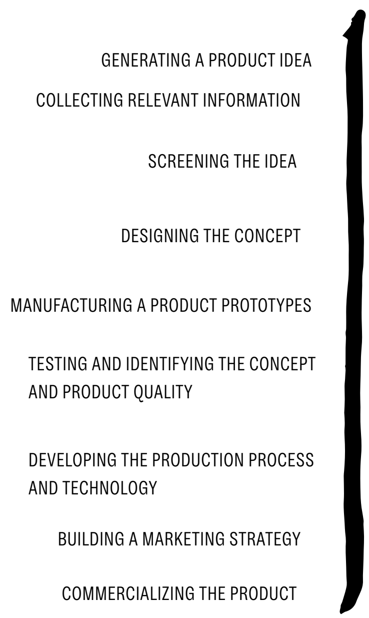
The research problem is focused on the design process of acoustic fabrics. Since the topic is relatively new, the knowledge about designing acoustic curtain fabrics is quite inadequate, and probably kept as a secret within the manufacturing companies. Therefore the most obvious research problem was whether I can collect enough data to gain a deeper understanding of what are the key factors that can be influenced in the design process of woven acoustic curtain fabrics. Another problem, that occurred right in the launch of the process, was whether I even manage to design fabrics that possess the needed requirements of sound absorbers. I also started to ponder if it would be possible to attach sound as a visual concept as well. That kind of multilevel conceptual thinking inspires and challenges me the most, so for that reason I decided to build this work on two merging frames; the main frame being sound, and the defining frame being acoustic curtain fabrics.

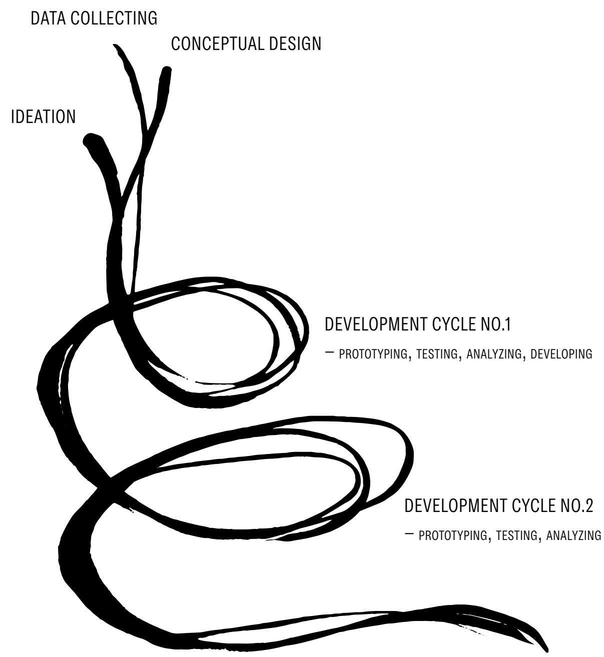
The main research question of the work is:

- How to design a functional and visually versatile set of curtain fabrics with a common concept of sound?

The defining research questions for the theoretical background are:

- Concept / What are the different aspects of sound and acoustics in relation to acoustic textiles?
- Concept / Can sound be visible?
- Case / What kind of functional textiles acoustic curtains are?
- Case / What are the key factors that influence the sound absorbing abilities of woven fabrics?





The productive section of the work is based on interior textile product development process presented by Büsgen (2012). Büsgen's model is built with following steps: generating a product idea, collecting relevant information, screening the idea, designing the concept, manufacturing a product prototypes, testing and identifying the concept and product quality, developing the production process and technology, building a marketing strategy, and finally commercializing the product. This kind of procedure is usually followed in large companies with extensive resources and marketing strategies, whereas smaller enterprises concentrate most likely on the most necessary steps, including the technical and conceptual aspects. (Büsgen 2012, 134, 150.) Since Lodetex is a relatively small manufacturer, and I am the only one working full-time with the project, I am adapting Büsgen's model in a way that fits the character of this work. I am emphasizing the experimental aspects of the design work, so instead of Büsgen's linear process, I have modified the process to be cyclic and organic with ideation, data collecting, and conceptual design work happening simultaneously creating two development cycles.

Acoustic fabrics are functional textiles, and similarly to how Watkins and Dunne (2015) have written about functional clothing design, functional textile design is a combination of science and art. Creativity and intuitiveness together with a disciplined research and engineering create the backbone of the functional design process. (Watkins & Dunne 2015, 1, 3.) Even though certain design requirements might narrow down the freedom of the design process, problem solving can actually increase creativity and inspire to a new way of design thinking. Designing acoustically functioning textiles is a complex work with a sensibility to all factors of the fabric construction acting both independently and in an interaction.

The methodological choices of the work follow the steps of the development process. The scientific research about sound absorption performance of woven fabrics is quite limited, because the emphasis of the acoustic research is mainly in non-woven textiles (Soltani & Zarrebini 2013, 1012). Due to that, the information to the theoretical part is gathered with various methods including literature review, discussions with experts and a small-scale benchmarking of some of the acoustic curtain fabric examples on the market. All that information supports the design process with an added data coming from an initial inquiry sent to two clients of Lodetex, and also from a documentation of the whole experimental design process.

Even though the work is done mainly for contract textile market, the emphasis of this work is in the acoustic performance excluding the full requirements of the contract textiles, such as flame retardancy and color fastness. Additionally a proper collection thinking is excluded from the design work, since at this stage the importance is in the discoveries of structural solutions that stand out from versatile prototype fabrics. One of the main tasks of a textile designer in a manufacturing company is not to build solid collections but to present a variety of ideas on structures and patterns for clients, who can then buy individual items for

Fig. 1.3 Büsgen's development model vs the applied model.

their own collections. Therefore I am presenting the tangible outcome as an idea collection of prototype fabrics with versatile looks, structures, patterns and uses.

POSITIONING AND PREVIOUS WORK

For centuries people have used textiles not only for creating pleasing and comfortable interiors but also for reducing noise, and to cover and protect items. Due to that acoustically functioning textiles have existed for a long time, but integrating a technical functionality as a design criteria is a relatively new phenomenon. Technical and innovative functional textiles, with a focus on performance, are becoming more popular not just within fashion but within interior textiles as well (Büsgen 2012, 133; Sinclair 2015, 534). Consumers, interior designers, and architects may choose whether they want to emphasize the functional, aesthetic, or sustainability aspects when choosing the textiles for the interiors.

Within this thesis, I am focusing on a particular group of hanging fabrics, that I am referring as curtain fabrics. Curtains do not need to be just a decorative part of the room when they can contain important functions as well. Today with increased window sizes, curtains are used to protect from UV light, heat and glare, but they can also act as sound absorbers. Also sheer, translucent fabrics can soften the daylight, absorb sound and provide daytime privacy without blocking the natural light or the views from the windows. They soften the modern architecture without darkening the indoor space or making the space feel heavy. (Nielson 2007, 182–184.) The advantages of curtains as sound absorbers are their lightweight nature, relatively cost effective manufacturing, easy maintenance, and due to their convertibility, they enable changes within the room acoustics (Iso-Kuortti 27.10.2015; Pieren 2012, 864).

There are several previous Aalto University's theses about woven contract textiles, though none of them focuses particularly on acoustic textiles. A couple of theses are made for Lodetex, for example Tiina Paavilainen's (2015) thesis, that concentrates on a specific fil coupé technique and its possibilities and limitations in the fabric production. Carmen Brecheis's (2013), Victoria Fislage's (2012) and Aoi Yoshizawa's (2014) master's theses focus on contract textile market and its restrictions in the design process from different point of views. Brecheis focuses on product development process of functional contract textile. Fislage has her emphasis on the public spaces from the textile designer's perspective. Yoshizawa's work includes contract textile design and a bit of curtain fabric design as well but without any specific functionality. Nanako Tani (2015) covers the topic of acoustic control in architectural spaces generally in her master's thesis but without going deeply into the technical requirements or design solutions. Considering these works, this thesis brings a new aspect of functional interior textile design process to master theses done in Aalto University, and an addition to already existing contract textile design theses.

2 CONCEPT / SOUND AND ACOUSTICS

Sound surrounds us everywhere and all the time. It is an auditory experience connected to individual perceptions. Sound can be tied to an object or a space that creates the sound, or it can as well be a subjective phenomenon, such as tinnitus. Acoustics turn the perceptual and subjective phenomenon into physical. In acoustics sound appears as a wave, as a mechanical vibration that is transmitted by a medium, such as air. A sound event can stir emotions and memories when it reaches the psyche. The nature of sound is invisible in our everyday lives, and yet sounds have individual shapes and forms that can be revealed visually.

This section covers the technical and visual concept of the thesis work. First it opens up the meaning of sound and how sounds affect people. After that the chapter continues to cover how sound behaves in a space, ergo acoustics. There the focus is in room acoustics and acoustic absorbers. Due to the complex terms and definitions of sounds and acoustics, this chapter also includes a terminology list. Lastly the section shifts from technical content to an artistic view with paragraphs about visualizing sound. That part builds a ground for the visual concept of the actual design work.

WHAT IS SOUND?

The definition of sound contains both an auditory sensation that we recognize in our ears, and a disturbance in a medium that triggers the sensation. Sound travels as waves in both solid, liquid and gas. As sound waves travel in air, the air pressure changes, and those changes are what our ears and microphones detect as sounds. (Rossing, Moore & Wheeler 2002, 3–4.) Sound waves can travel both longitudinally, vertically and diagonally, so if a sound wave is moving inside a closed space with minimized absorption, one could describe the bouncing patterns from surface to surface as disorderly and chaotic.

Casati and Dokic (2010) reveal that in philosophy, sound has many other natures than just the physical wave. Sounds are so connected to the temporal and spatial perceptions, that they could also be considered as individuals, events, or properties of the object that creates the sounds, depending on how sounds are to be located. Sounds can be where the hearer is, or as in acoustics, sounds can be located as a wave in a medium between the sound source and the hearer. Or sounds can also be located where the sound source is. (Casati & Dokic, 2010.) Considering sounds as spatial perceptions is interesting, and also well related to this work. Even though the main consideration within this work is in acoustics, also other aspects of spatiality can be attached for example to the visualization of sounds, and to the use of sounds as emotional stories in the creative work. If a sound stirs memories of a certain location, is it then not located both in the physical space and in the emotional space?

Interesting opposite aspects of sound are noise and silence. It seems that we often notice sound really only when it is too loud for us or if it is completely missing. At least I feel that I fully comprehend the sound environment that I am used to only when I am surrounded by silence, while standing on top of an arctic hill or in the middle of forest. Schafer (1994) writes that in Western civilization silence is often seen as a negative aspect. It is a reminiscent to death, not a humane state. But silence should gain a positive status once again in our modern life, since silent periods are just as important ways for humans to gain energy as sleep. (Schafer 1994, 253–254, 256.) Even though absolute silent spaces could be worth creating for energy storing and meditation, it is not a focus of this work. Instead, noise control in an interior space is what can be reached within this topic.

Noise is an aspect of sound that has several meanings, as Schafer (1994) lists; acoustically examining noise is referred as unwanted and disturbing sounds. The term can be used generally from any loud sound. Noise can also mean unmusical sounds created electronically, such as white noise. Forth meaning, that is not related to sound, is a disturbance in a signaling system, for example the snow effect in an old analog television. People react differently to noise, and it might be partly due to how much time we spend outdoors. Northern inhabitants can be more disturbed by noise than people living in southern countries, who spend more time outdoors due to warm climate. (Schafer 1994, 182, 217.) It is clear that a space affect sound just as equally as sound affect a space.

SOUND IN SPACE

Since the nature of sound is to travel across the air, it reacts to the space it travels in. In an open space with no blockage, sound waves can move freely, but in an indoor space surrounded by walls, a floor and a ceiling, sound waves are constantly colliding and reflecting back and forth from the surrounding surfaces. In order to have a pleasing sound environment in the indoors, one must be able to control the reflecting behavior of traveling sound waves. The science of sound, acoustics, is a wide term containing all aspects of studying sound phenomenon whether it is in physics, engineering, music, psychology, or architecture (Borenius, Jauhiainen, Lampio, Nuotio, Pesonen & Pyykkö 1985, 10–11; Rossing et al. 2002, 3). In the next paragraphs I am referring only to architectural acoustics and room acoustics in particular.

Sound conditions are a top priority when it comes to designing an indoor space, since good sound conditions enhance the purpose the space is built for. Sound environment in a space affects directly how people experience that space. (RIL 243-1-2007, 9.) Therefore acoustics need to be carefully planned by architects, engineers, acoustic engineers, and interior designers. It is important to improve the audibility of positive sounds, for example a speech in a lecture room, and to minimize negative sounds, that are referred as noise (Borenius et al. 1985, 11). There are structural ways to either isolate sounds

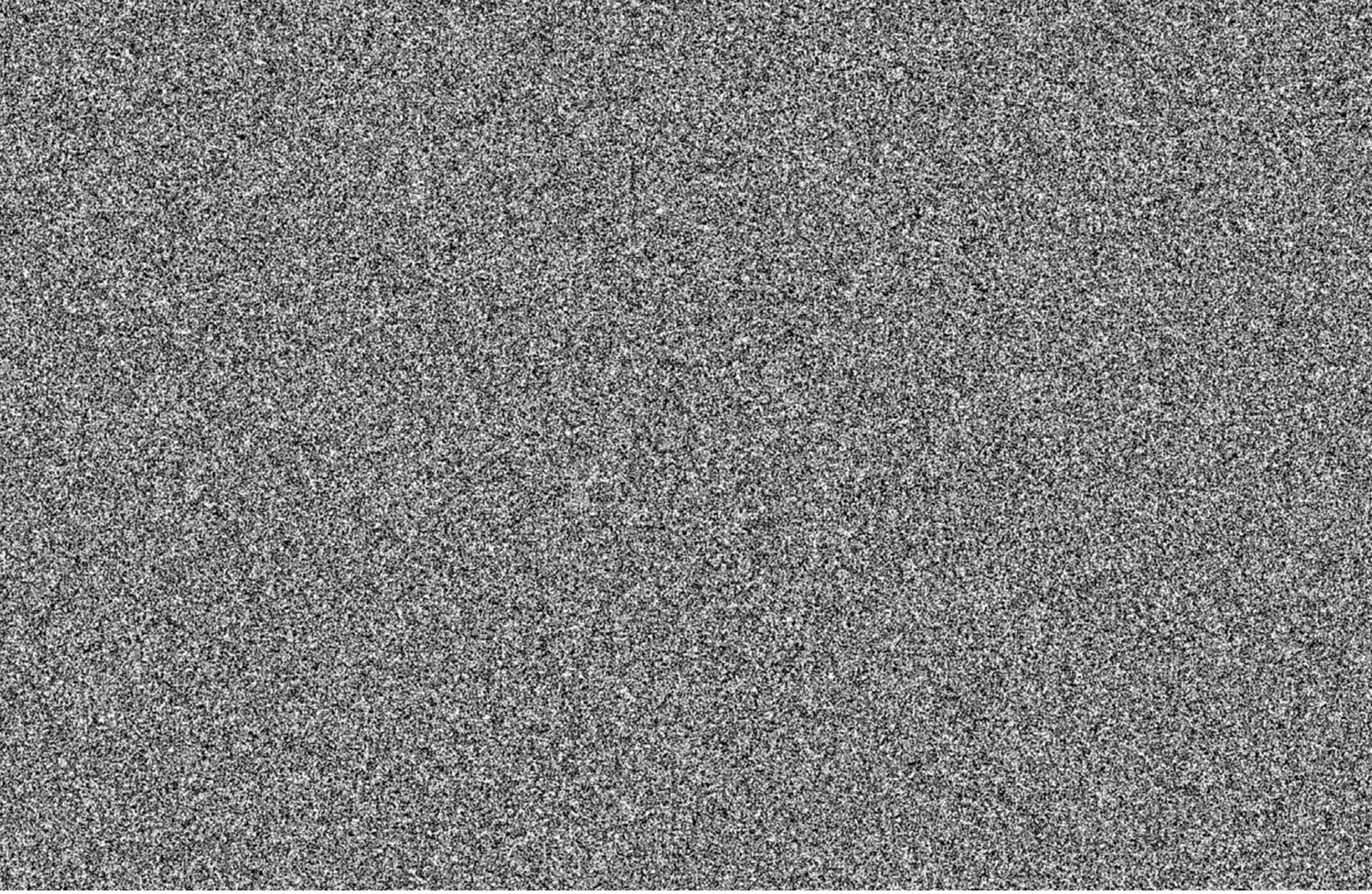
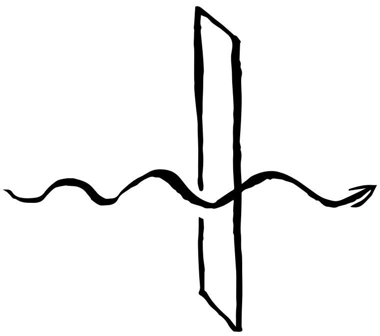
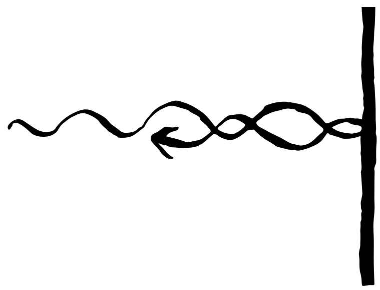


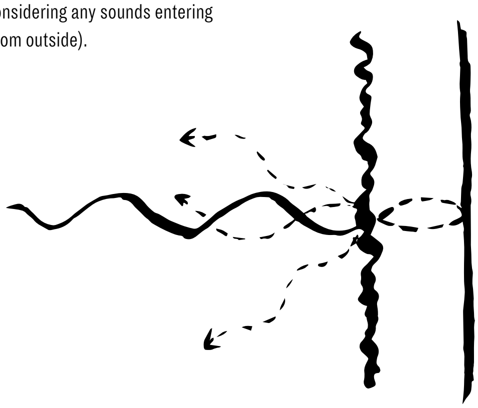
Fig. 2.1 Generated noise pattern.



Full absorption: when a sound wave enters an open window, none of it returns to the room, making the space silent (not considering any sounds entering from outside).



Full reflection: when a sound wave enters a hard surface, e.g. a concrete wall, almost all of it reflects back to the space, resulting a chaotic sound environment.



Absorption ability of a porous material: when a sound wave enters a porous material, a part of it reflects back, and a part of it is absorbed within the material. A part of the wave goes through the material, but if there is a hard surface behind the porous material, the sound wave bounces back from it and gets absorbed again. The sound environment becomes more pleasant with less reflection.

Fig. 2.2 Illustration of sound absorption and sound reflection.

that enter the space from outside, or to absorb sounds that are created inside the space. This work focuses only in the absorption of the indoor sounds.

Room Acoustics

Room acoustics studies the behavior of sounds inside a closed space, ergo a room. The purpose of room acoustics is to design an interior where the positive sounds — the sounds that are meant to be heard in a space — are enhanced, and where the negative sounds are at least partly reduced. (Borenius et al. 1985, 60.) There are three types of sounds that arise inside a room and that can be effected with acoustic planning. First type is airborne sounds, that radiate directly to the air, for example when people are talking or typing. The second type is surface sounds, that originate from surfaces, for example the sound of steps coming from the floor. The third type of sounds is impact or structurally born sounds, that are triggered by a structural vibration of an action, for example jumping or hammering. (Willbanks et al. 2014, 271.) There are also external sounds coming from outside, but those are usually blocked by sound insulating systems within the structures of the building.

The trend in interior architecture nowadays, especially with public and office spaces, is to have vast open spaces and to use hard materials over soft. That complicates the acoustic planning, since its goal is to reduce the reflection of sounds from surfaces, and to control the movement of sound waves. So how to attenuate sounds within a room? It can be done either by surrounding the source of sound with barriers, by eliminating other ways for sound to transmit, or most importantly, by absorbing sound energy with the use of absorbers (Rossing et al. 2002, 731–732). When a sound wave hits a surface, some of it reflects back, some of it continues through the surface, and some of it absorbs inside a material. Absorption happens when sound energy transforms to another form of energy, like heat. (Borenius et al. 1985, 52, 54.) Air absorbs sound to some amount, especially at high frequencies over 1 kHz and in large spaces, as well as also humans who use the space (Grueneisen 2003, 59).

Heavy textiles, such as carpets and panels, are often used in sound absorption, since thick and porous materials are effective sound absorbers especially at low frequencies. However, also very thin textiles can absorb sound, if the structure and the use of the fabric is designed for that particular purpose (Pieren 2012, 864). The key is to understand that all acoustic absorbers have different qualities and uses, so one should not compare thick panels with translucent curtains, but to build a composition of different elements to complement each other. Lightweight fabrics are not effective absorbers at low frequencies, and therefore should not be used as the sole acoustic elements in concert halls, recording studios, or anywhere where acoustics is a top priority. However in spaces, such as offices, where natural light is important, and where disturbing noise occurs at medium to high frequencies, lightweight acoustic fabrics are highly usable together with other porous materials that also absorb sound.

The frequencies of human speech ranges somewhere in between 300 to 3000 Hz, although the basic voice frequency is around 100–200 Hz for men, and 200–400 Hz for women (RIL 243-1-2007, 54; Rossing et al. 2002, 727). Then again, for example in open offices, the sound frequencies that ought to be absorbed range somewhere between 1000 to 5000 Hz (Lokki 12.11.2015). It is always the matter of case, which frequency ranges should be absorbed from a particular space and with what absorption solution. Within the development process of acoustic fabrics, I have been focusing on the absorbing coefficient of the frequency ranges of 600–4000 Hz, since public spaces and open offices are closest to the target spaces of my prototype fabrics, and since it has been proven to be the most effective frequency range for lightweight acoustic curtains.

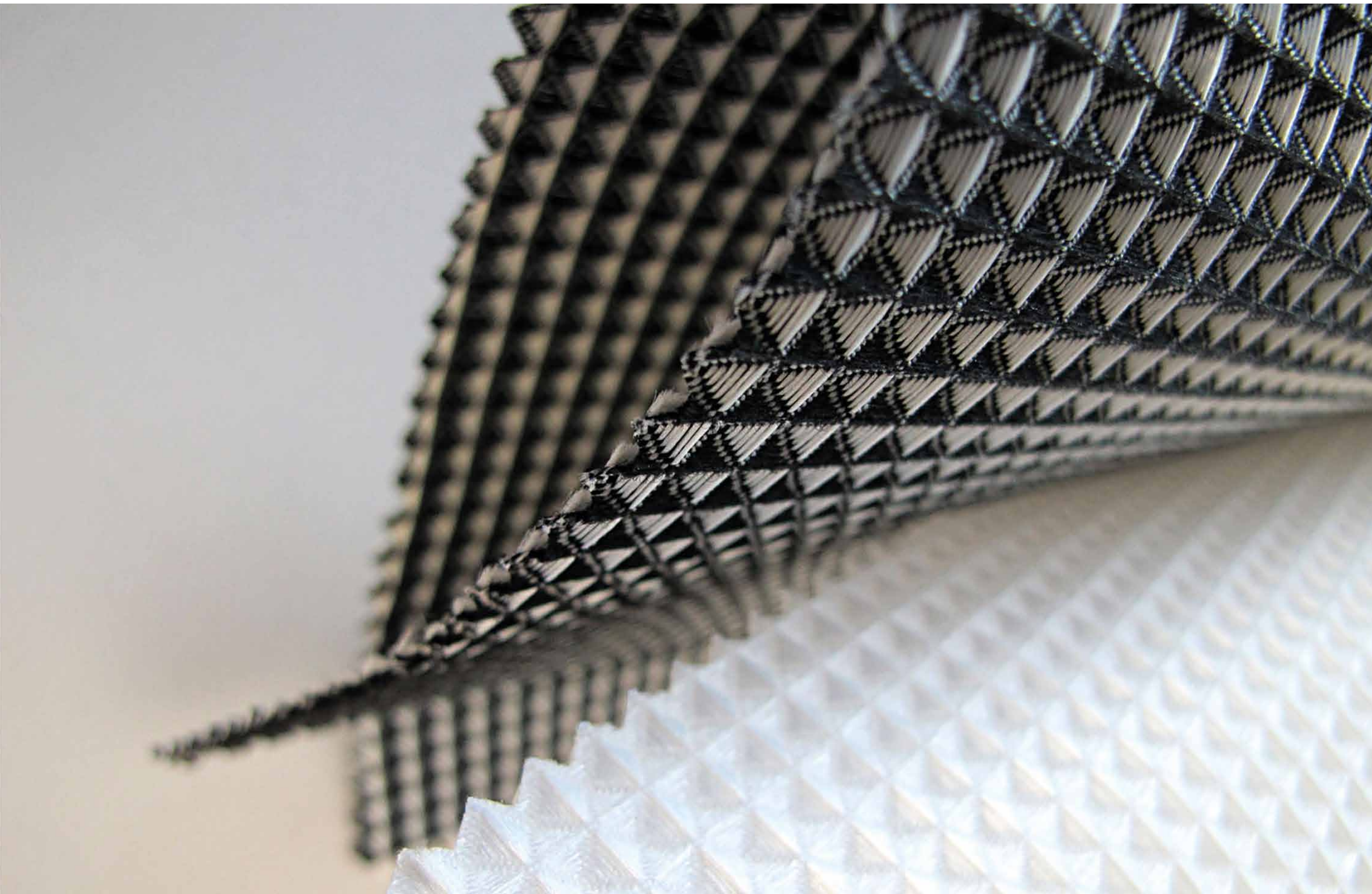
Porous Sound Absorbers

Sound absorbers play an important role in room acoustics. It is usual and most effective to combine different absorbing materials in a room to create an acoustically pleasant environment. Porous materials, such as textiles, acoustic ceiling tiles, panels made of glass fiber or mineral wool, acoustic plaster, and open-cell foam, are the most commonly used as sound absorbers. Porous materials are used to absorb mostly mid to high frequencies. The thickness and the installation method impact on what range of frequencies the material is able to absorb, since the thickness or the distance from the wall should be one quarter of the absorbed wavelength. For example, a sound with 32 Hz has a wavelength of around 10.5 meters, so in order for a porous material to absorb that sound, the thickness or the airspace between the material and the wall should be around 2.6 meters. Since achieving that is impossible in most cases, there are other solutions for low frequency absorption, such as diaphragmatic absorbers. They are specially built reactive structures similar to a speaker cabinet, that resonate at the tuned frequencies. (Borenius et al. 1985, 53; Grueneisen 2003, 60; Rossing et al. 2002, 581.) Another example of active low to mid frequency absorber, created by a Danish company Flex Acoustics, was explained by Tapio Lokki (12.11.2015), an associate professor and researcher on virtual acoustics at Aalto University. It is a rubber structure that is placed either at the ceiling or to the sides of the space, and the rubber tubes and mattresses are then filled with air depending on the frequencies to be absorbed. Those structures have been used for example in the Eurovision Song Contest 2014 arena. (Flex Acoustics; Lokki 12.11.2015.) In this work I am only focusing on porous absorbers, since acoustic curtains belong to that category.

So how do porous materials absorb sound? It is called a viscosity resistance, and it means that when a sound is forced to pass the porous material, the sound pressure triggers the air between the fibers of the material to vibrate, and that movement of air converts the sound energy into thermodynamic energy. The energy of sound wave is so small that no measurable change in the temperature occurs, even though the absorbed sound produces heat. (Rossing et al. 2002, 740–741; Soltani & Zarrebini 2012, 876.) Also the airspace between the porous material and hard surface can affect to the sound absorption coefficient, especially at low frequencies, if the width of the airspace is around one quarter of the air wave length. In that case the sound wave reflecting from a surface back to the porous material has its maximum speed where the porous material is, which makes the air molecules vibrate rapidly, and the friction pushes sound energy to change to heat. (Borenius et al. 1985, 54; RIL 243-1-2007, 149.)

Sound absorption coefficient of a surface material expresses how much sound is absorbed. A sound absorption coefficient of 1 means that all of the coming sound energy is absorbed, and a sound absorption coefficient of 0 means that the sound is completely reflected from the surface. The sound absorption coefficients of porous materials are tested in a certified laboratory, and they are given a classification of A, B, C, D, or E. Materials in class A have a high absorption coefficient (0.9–1), whereas class E materials have to lowest absorption coefficient (0.15–0.25). The sound absorption coefficient is dependent on the size of the surface area. If a square meter of material with a sound absorption coefficient of 0.5 is doubled in size, the sound absorption coefficient should be equal to a square meter of material with a sound absorption coefficient of 1. (RIL 243-1-2007, 157; Rossing et al. 2002, 531.) The optimum sound absorption class of lightweight acoustic fabrics varies between B to D, as it is revealed later in the benchmarking of examples of acoustic curtain fabrics in the current market.

Fig. 2.3 aQflex sound absorbers, FlexAcoustics.
Fig. 2.4 Woven three-dimensional acoustic textile by Trevira.



TERMINOLOGY OF SOUND AND ACOUSTICS

The terminology of sound and acoustics is complicated and easily misleading. For example the terms soundproof and silencing are often used in advertisements of sound absorbing materials, even though the purpose of them is not to eliminate all sounds but to reduce undesired noise to a level that is healthy and pleasing. (Rossing et al. 2002, 731.) Also the terms sound insulating and sound absorbing both refer to the qualities of the used materials, but insulating materials block sounds coming from outside the space while absorbing materials impact the level of sounds generated inside the space (RIL 243-1-2007, 46). This simplified terminology includes the important sound and acoustics terms used within this work.

Sound

A pressure variation in a medium, such as air, that moves as a longitudinal wave, and that causes an auditory sensation. The physical vibration of molecules is also called sound waves. A wavelength (λ) is the distance between two subsequent peaks of a sound wave. At 20 Hz the wavelength is around 17 m while at 20 kHz the measure is around 17 mm. A waveform of sound is a graph of sound pressure versus time. (Acoustic Glossary; Grueneisen 2003, 46–47; Rossing et al. 2002, 3–4, 14.)

Noise

Unwanted sounds are referred as noise. Noise can be both a physical phenomenon, such as a loud sound, or it can be a subjective experience of a listener. In both cases noise affect negatively to the sound environment especially in the workplace or places of relaxation. (RIL 243-1-2007, 10.) Noise may also refer to electronically generated aperiodic sounds, like white and pink noise, that are random signals whose values are not dependent on each other (Acoustic Glossary).

Frequency

The amount of vibrations occurring during one second measured in hertz (Hz). Humans can hear sounds within the range of 20 Hz to 20 kHz (20 000 Hz). Infrasonic frequencies below 20 Hz are sensed as vibrations, whereas ultrasonic frequencies above 20 kHz cannot be sensed at all. An average speaking voice of a man is around 100–200 Hz, and an average speaking voice of a woman is around 200–400 Hz. (Grueneisen 2003, 48; RIL 243-1-2007, 35, 54.)

Decibel

A value of sound intensity level presented in a logarithmic decibel (dB) scale. 1 dB change is still inaudible, but 3 dB change can be heard. 5 dB difference is clearly heard, and 10 dB higher sound seems to double with the intensity level. If two machines, that generate the same sound pressure, are used together in a closed space, the sound pressure level put together is three decibels higher than the sound pressure level with just one machine running. (RIL 243-1-2007, 37.)

Acoustics

The science of sound, that can include aspects of physics, engineering, music, psychology and architecture. Room acoustics deals with sound environment in a closed space, and the goal of acoustic planning is to enhance the positive sounds and to decrease noise. Those can be achieved both with sound insulation and sound absorption. (Borenius et al. 1985, 10–11,60; Rossing et al. 2002, 3.)

Sound Absorption

Instead of sound insulation, that reduces sound transmission to a room, sound absorption reduces sounds that are born inside a room. When sound is absorbed, the energy of sound transforms into another form, such as thermodynamic energy. Sound absorption impact to the reverberation time (the echo effect) and the volume of the sound. Sound absorption happens in all porous surfaces, such as textiles, furnitures and humans. Sound absorption depends on the frequency range, so for choosing the right acoustic absorber, the frequency level of the absorbed sound has to be known. (Grueneisen 2003, 59; RIL 243-1-2007, 46–47.)

Sound Absorption Coefficient

Sound absorption coefficient (alpha α) is a measure of a material's sound energy absorption capacity at a given frequency. Alpha values vary between 0 and 1, where 1 equals a full absorption (for example an open window) and 0 equals a full reflection (for example a hard concrete wall). Materials with alpha value over 0.5 are considered absorptive, and materials with alpha value less than 0.2 are considered either reflective or so thin and loose, that the sound just passes through. (Grueneisen 2003, 59; Rossing et al. 2002, 531.) Absorptive materials sold on the market have a sound absorption class and one weighted alpha value (α_w), that is a calculated average value of the measured alpha values in different frequency ranges.

sound absorption classes and weighted alpha values (frequencies 200–5000 Hz):
- A 0.90–1.00 α_w
- B 0.80–0.85 α_w
- C 0.60–0.75 α_w
- D 0.30–0.55 α_w
- E 0.15–0.25 α_w
- 0.00–0.10 α_w Not classified

Noise Reduction Coefficient

Noise reduction coefficient (NRC) is a simplified single number average of a material's weighted alpha value, that is often used in the English-speaking countries (Création Baumann 2015a). Within this work I will only refer to sound absorption coefficient (α), since that is more commonly used in Europe.

Airflow Resistance

Airflow or flow resistance (R_s) is a measure, that describes how much air is passed through a tested material (Pa s/m) (Müller-BBM 2016a). The lower the value, the more air goes through the material. Highly absorptive materials usually have R_s values of 600–1000. Airflow resistance is the first measurement calculated from the tested acoustic materials, though the R_s value only gives an estimate whether the material is suitable for sound absorbing.

Reverberation Time

Reverberation time (T) describes how quickly a sound pressure level drops to 60 dB, when the source of sound is turned off. If the reverberation time is really short, the space sounds dead, and if the reverberation time is too long, the sounds keep on mixing together for a long time resulting a cacophonous sound environment. (Grueneisen 2003, 62; RIL 243-1-2007, 50.) The reverberation time is used for measuring the sound absorption coefficients.

VISIBLE SOUND

Sound is an intriguing subject since it's basic state of matter is invisible. Yet it surrounds us everywhere constantly. We all have learned how to describe sounds in writing, from quiet whispers to ear bursting bangs. But visualizing sound is not a universal rule, and it is most often fictitious and dependent on the interpreter (Schafer 1994, 123, 127). Musicians have adapted notation as a tool to visualize sounds, and technicians and engineers are able to read different graphs drawn by computers and machines that render sound. Because of the physics of sound, it is also possible to create visual patterns with sounds in mediums, such as liquids, due to the vibration of sound. That phenomenon is called cymatics.

So why bother trying to visualize something invisible? Maybe one reason, as Reas and McWilliams (2010) mention, is that people are good with reading visual images. Even the most abstract information is easier to understand when it is drawn. (Reas & McWilliams 2010, 121.) Another reason occurred in arts, especially in audiovisual art, is the emotional side. In audiovisual art sound and images together add value to each other, which changes the way we see and hear them (Correia 2013, 59). Audiovisual artists play with the synergy of sounds and images, and that way they influence the emotions and associations of the audience.

People with one form of synesthesia connect visuals, most commonly colors, with heard sounds. As an example Correia (2013, 50) notes that, "the sound of a flute may be pastel lemon color". Synesthesia is a complicated phenomenon, since images connected to sounds are individual with all synesthetes, and due to that I am excluding its deeper research from the thesis work. But aside from the phenomenon, associations between sounds and colors are intriguing, since also some non-synesthetes are able to associate sounds with colors, as Correia (2013) writes. Musicians and artists have applied the connection of the two in both ways; Hungarian composer Franz Liszt have known to direct his orchestra musicians based on colors in the 19th century, and several famous painters, such as Wassily Kandinsky, tried to capture sounds and music in his abstract art. (Correia 2013, 51–52.) Since synesthetes perceive sounds intuitively, the synergy of sounds and visuals in arts should not be associated with synesthesia, as there it is merely an interpretation of an artist.

The following paragraphs addresses two types of sound visualizations: cymatics and audiovisual art. They both share the same vision of revealing the secret world of visible sound but from very different perspectives. Cymatics plays with intermediating material mediums, that are manipulated by sounds. Audiovisual art on the other hand relies purely on digital tools for connecting sounds with visuals. Both types of visualizations are shortly described by example artists and their works.

Fig. 2.5 Wassily Kandinsky's woodcut White Sound from his book from Klänge (Sounds), 1913.

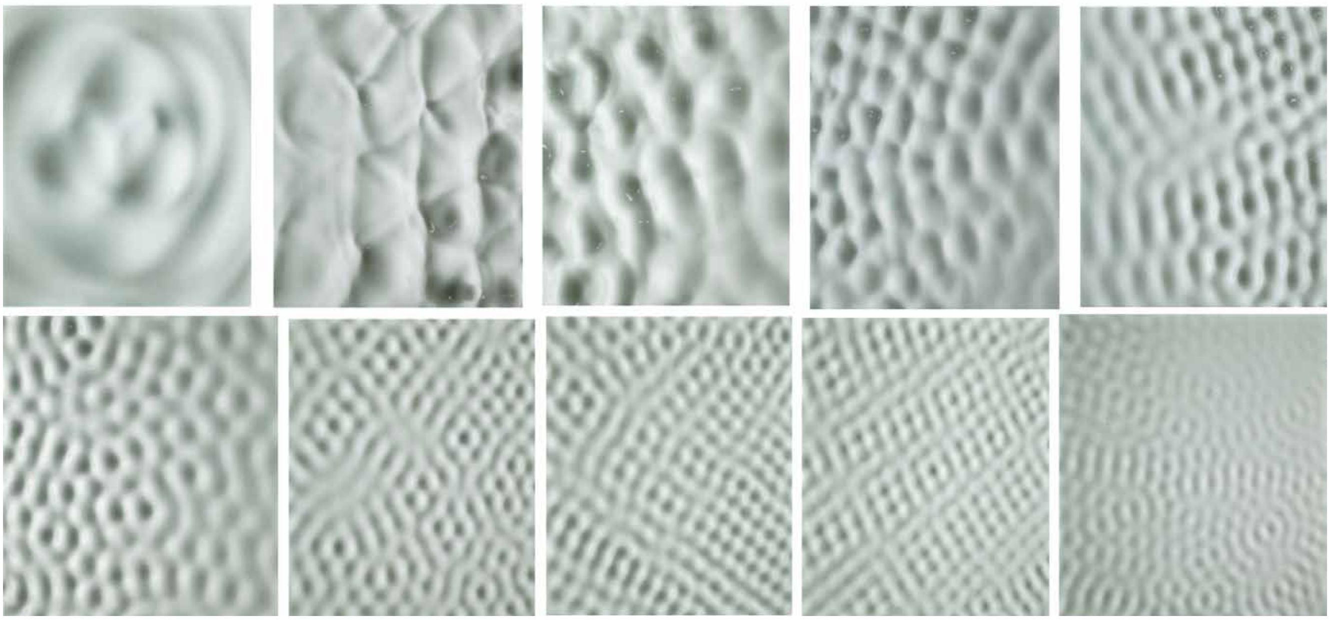
Cymatics

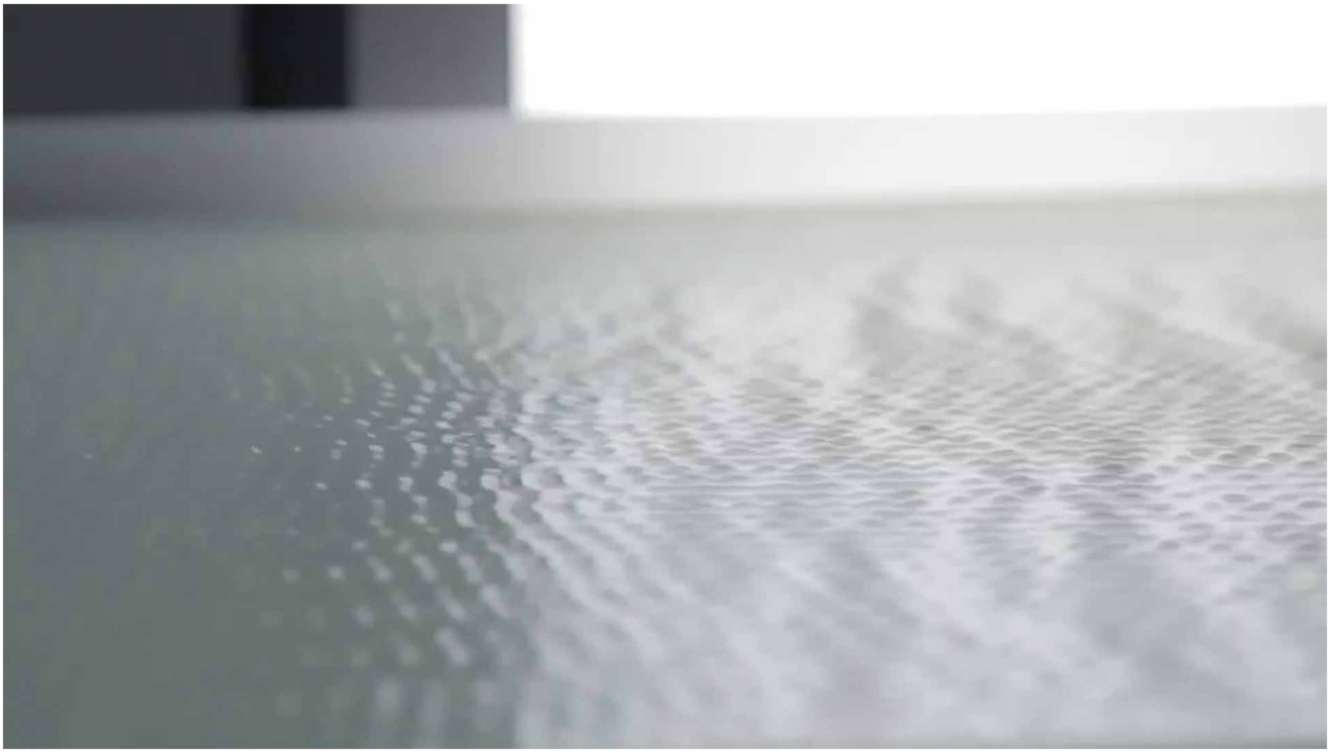
Cymatics is a phenomenon where a vibration of sound triggers medium, such as liquid or sand, to cluster in patterns and to create visualizations of sounds. Creative technologist Evan Grant (2009) states, that cymatics can be seen as “a looking glass into a hidden world, that unveils the substance of things”. Chladni patterns, invented by Ernst Chladni in 1787, are the most common examples of cymatics. Chladni patterns are created when small particles of for example sand are sprinkled on top of a metal plate, and the plate is then vibrated with for example a violin bow. The particles cluster to areas where vibration is minimal, and that triggers intriguing patterns of clustered particles to appear. The increase in the played sound frequency increases also the complexity of the patterns. (Grant 2009; Rossing et al. 2002, 33; 38.) It is possible to say, based on cymatics, that nature is full of hidden data that can be revealed. It also proves that all sounds have different and unique forms.

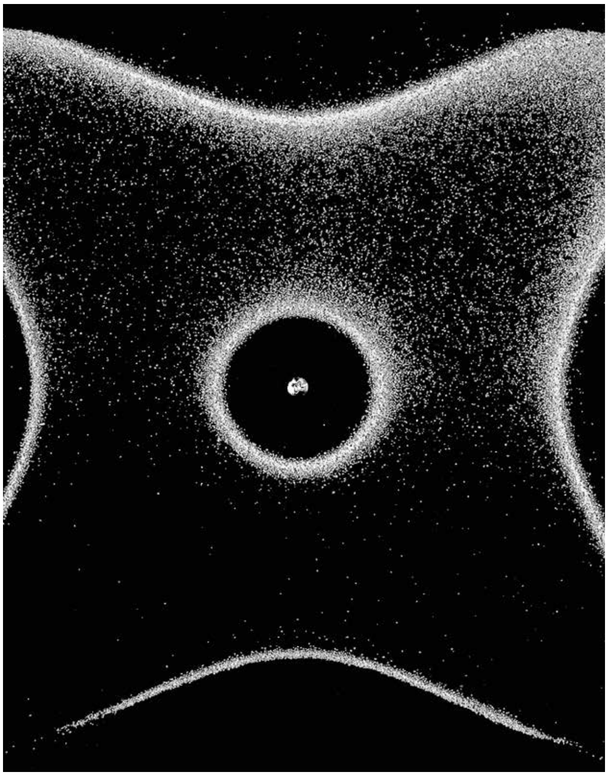
Carsten Nicolai

In arts cymatics is used as a media to visualize the hidden world of sounds, and the cymatics artists work with the material and tactile nature of sound. German musician and visual artist Carsten Nicolai has been exploring the possibilities of cymatics in his art. His work Wellenwanne (2001) is an installation of large trays exhibiting cymatics patterns that appear on water surface through sound vibration. Also his other work Milch (2000) exploits the same principle of vibrating liquid in a form of photographs taken from the cymatics experiments. Somaini (2011) describes Nicolai’s cymatics works as fingerprints to the individual sounds that vibrate the liquids, and he also refers cymatics art to archaeology. (Somaini 2011, 212.) In a way I can relate to that, since there is something mystical in exploring and digging up the movement in otherwise still surface with sounds. But what appears in the surface is not past, as it is with archaeology, but it is present.

Fig. 2.6 Carsten Nicolai’s cymatics photograph series Milch, 2000.
Fig. 2.7 Carsten Nicolai’s cymatics installation Wellenwanne, 2001.







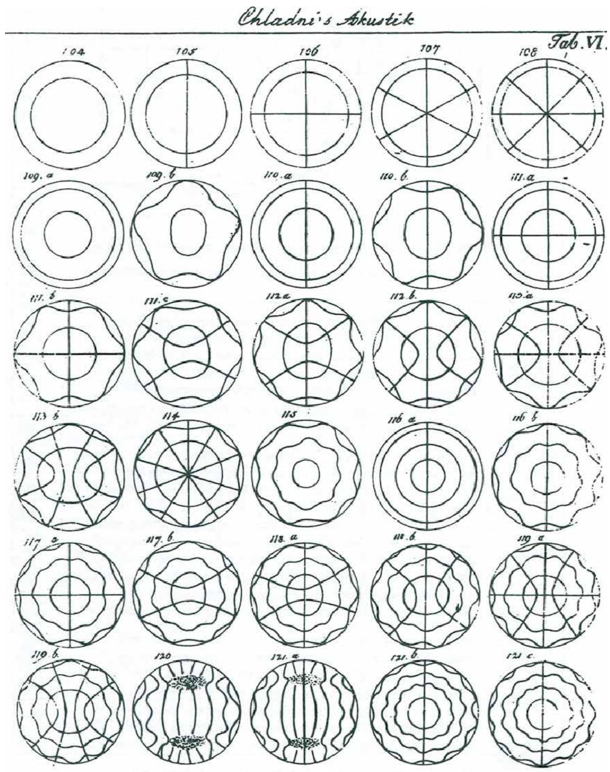
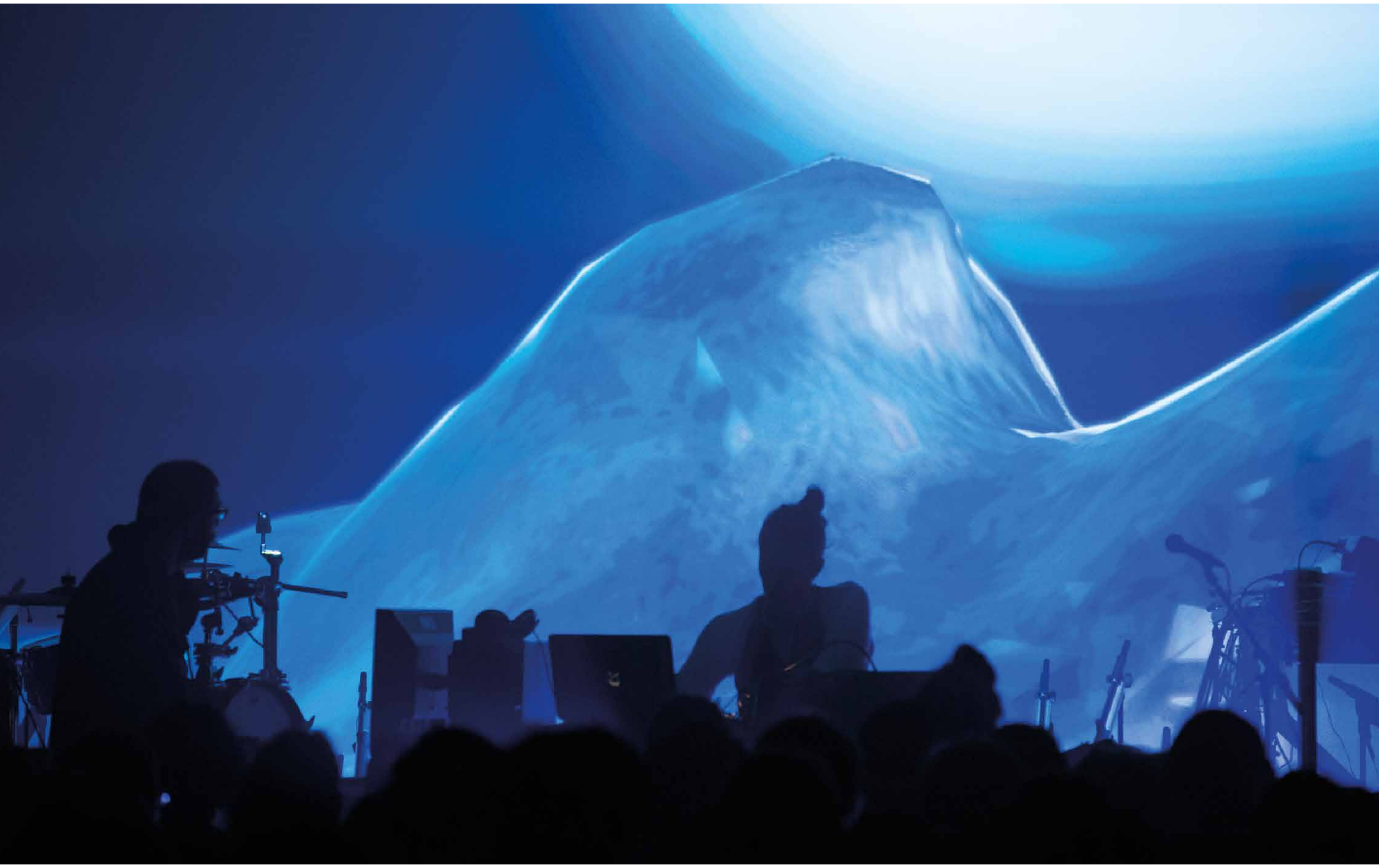

Chladni's Akustik
Tab. VI.
104
105
106
107
108
109. a
109. b
110. a
110. b
111. a
111. b
111. c
112 a
112. b
113. a
113. b
114
115
116 a
116 b
117. a
117. b
118 a
118. b
119 a
119 b
120
121. a
121. b
121 c

Fig. 2.8 Chladni figure created with sand.
Fig. 2.9 Chladni figures drawings by Ernst Chladni, from his book Die Akustik, 1802.
Fig. 2.10 Cymatics experimentation with vibrating water.



Audiovisual Art

Unlike cymatics, that explores the visualizations of sound through a material substance, audiovisual art is purely a digital playground for connecting sound and visuals. Audiovisual art is often related to VJ (video jockey) culture, where visual material is applied to improve the spatial music performance and to put "weight to sound" (Correia 2013, 48–49). While audiovisual art is commonly adopted in electronic music and club culture, it is also a complex genre of art including visual music, and performance and installation art as well. It is merely about synchronizing visuals and audio together as a one unity.

Creating audiovisual art requires an understanding of coding, where one creates a series of instructions and operations called algorithms or programs, for the computer to follow. Computer can be seen as a tool for more efficient production work, but it can also act as an intellectual collaborator in the creative process, if randomness and the self-organizing nature of programming are utilized. (Reas & McWilliams 2010, 13, 25.) With random values it is possible for example to generate visuals with unexpected compositions, and that genre is commonly referred as generative art. Another interesting way to create visuals by programming is called transcoding, where a file data, such as an audio file, is applied as a raw material for a program that normally operates with images (Reas & McWilliams 2010, 49). The outcome can be something completely new and interesting. Audiovisual artists may apply all kinds of ways possible to create visuals through sound, either by generative art, transcoding or other methods.

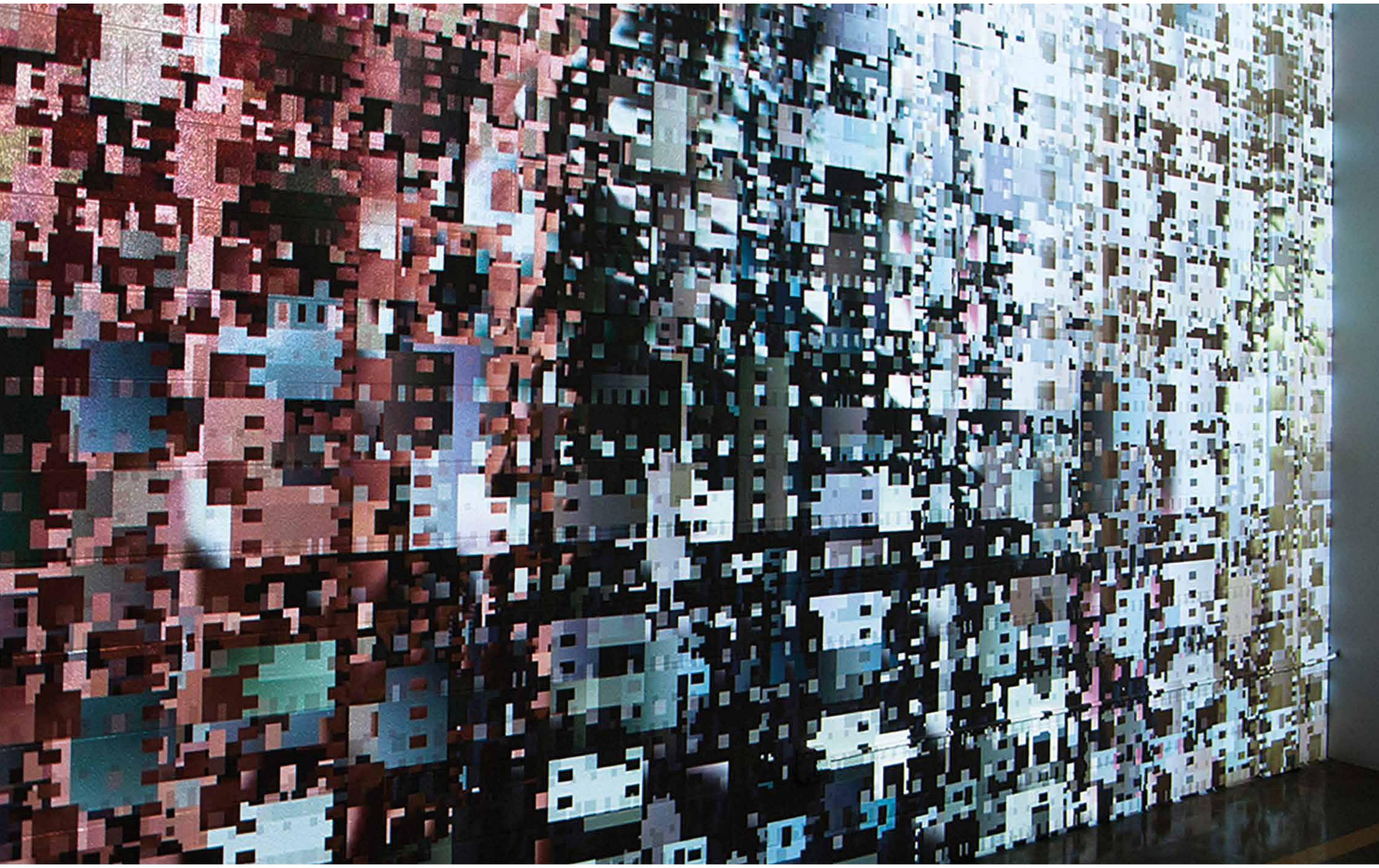
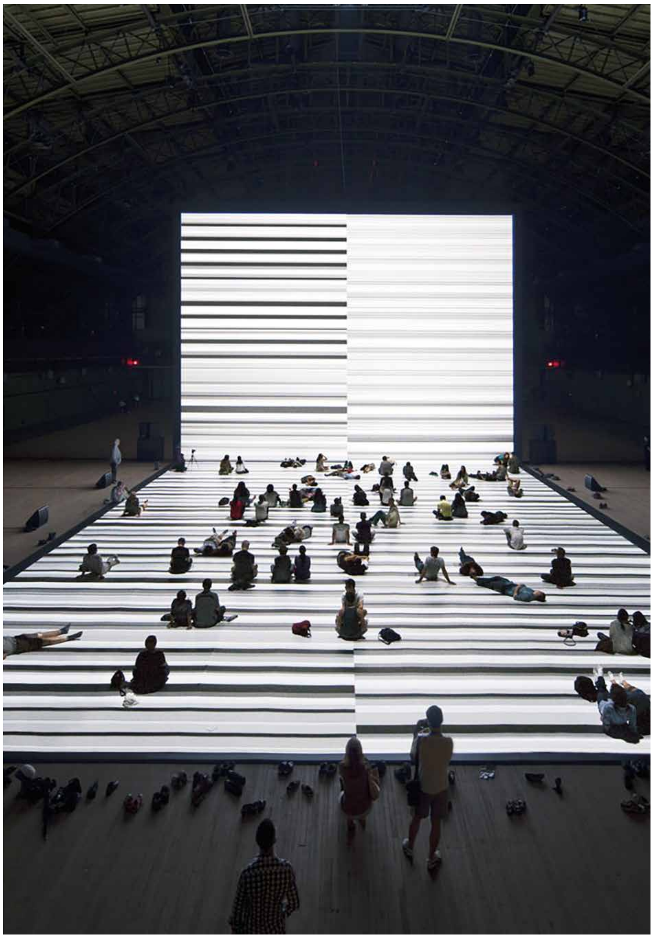


Fig. 2.11 Audiovisual performance at MUTEK festival Montréal, 2015.
Fig. 2.12 KNBC by Casey Reas, 2015. Audiovisual installation made of distorted television signals.

Ryoji Ikeda

Ryoji Ikeda is a Japanese multimedia artist working with music and audiovisual installations. His work is somehow mathematical and matrix-like, and, as Herbert (2011) puts, “it feels like it was assembled under a microscope”. Ikeda works with basic elements of sound, like sine waves and white noise, and due to that essence he also uses only raw white light against a black background in his audiovisual installations. (Herbert 2011, 162.) His ongoing work test pattern (2008–) is a system of transforming data (text, photos, sound or video) into binary barcode patterns. The name test pattern comes from the fact that his system manipulates data so fast, that it tests the performance capability of the devices and also the limit of viewer’s perception. (Herbert 2011, 162–163; Ikeda; Reas & McWilliams 2010, 81.) I would describe Ikeda’s work as ultrafast, raw, and even though it is somehow trialling, it captures the essence of synchronization of audio and visuals. Ikeda’s music and his audiovisual performances of test pattern feels like a morse coding of some particular data. Similarly to cymatics, it feels that Ryoji Ikeda is trying to unveil a hidden data in a form of audio and visual art. And actually, as Herbert (2011, 162–163) uncovers, Ikeda is using data, such as his emails, as a raw data to create his encoded messages.



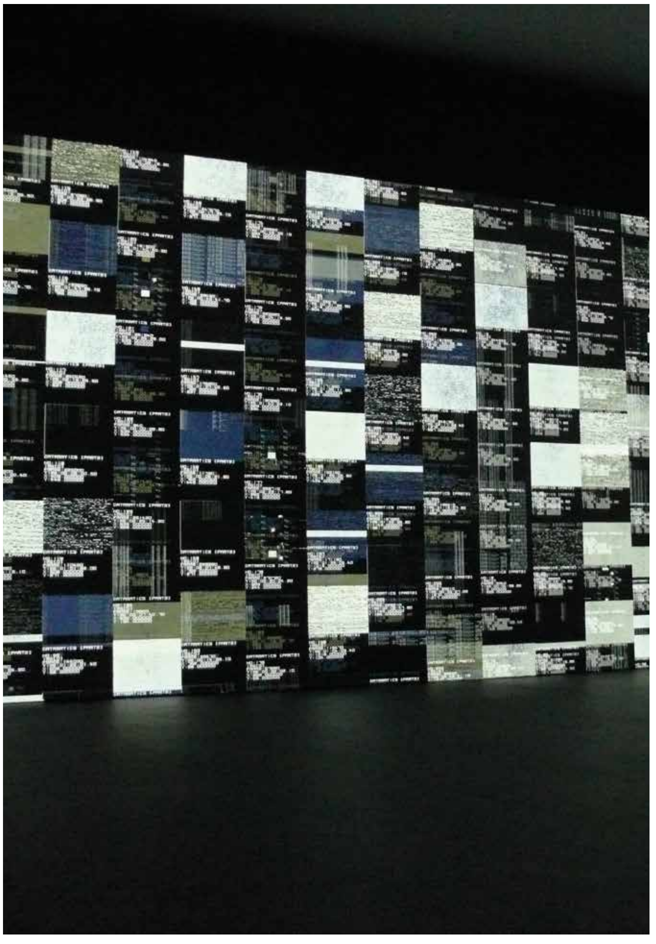


Fig. 2.13 supercodex (live set). Audiovisual performance by Ryoji Ikeda, 2013.
Fig. 2.14 Ryoji Ikeda's Data.Tron [8K enhanced version]. Audiovisual installation, 2010.
Fig. 2.15 Ryoji ikeda's test pattern (enhanced version). Audiovisual installation, 2011 at Park Avenue Armory, New York.
Fig. 2.16 test pattern no. 5, audiovisual installation by Ryoji Ikeda, 2013.

CONCEPT / SUMMARY

- Concept / What are the different aspects of sound and acoustics in relation to acoustic textiles?
- Concept / Can sound be visible?

This chapter covered the themes of sound and acoustics, and it revealed both the technical and visual framework of the design process. It opened up the basics of sound and acoustics, and the used terminology. It also explained the synergy of sounds and visuals, and how to visualize sound in arts.

Sound can be observed from aspects of physics, philosophy and psychology. This work focuses mainly in the physics of sound, that is acoustics. Although different perceptions of sound widens the interpretation of the topic, and adds a new perspective to the work. The different perceptions of sounds and feelings appear in the design practice section as the sound stories, that are the inspirations of the designs.

Acoustic interior planning may be used for several purposes. In a concert hall the main purpose of acoustic planning is to improve the whole audible experience. Then again some spaces, for example a recording studio, require a total soundproofing with powerful damping structures. The area of interest within this work is in spaces where the excessive noise is not dampened completely, but it is toned down for a more pleasing sound environment. Porous sound absorbers are efficient acoustic elements in such spaces, especially when different absorbing materials are combined. Acoustic curtain fabrics belong to the category of porous sound absorbers, so the functionality is very similar to a porous acoustic panel, though the range of frequencies absorbed varies. Lightweight acoustic curtain fabrics are most effective within the frequency range of 600–4000 Hz, which is close to the noise range of an office for example.

The synergy of sounds and visuals can affect how the sounds are experienced emotionally. The paragraphs of visible sound explained the different aspects of that synergy, whether considering people with synesthesia visualizing sounds intuitively, or an artist capturing the essence of electronic music with digitally created visuals. The focus of visualizing tools were in cymatics and audiovisual art, since those methods are used also within the design practice of this work. Both of those methods essentially try to reveal the hidden world of sounds, but with just different mediums. Cymatics artists experiment with material mediums like sand, liquid, or even fire, that are manipulated with the vibration that sound waves create. Audiovisual artists use only the digital medium, though with a wide range of approaches, whether subjecting the played audio to a wanted visual shapes and forms, or letting the audio data to generate a random visualizations itself.

3 CASE / SOUND ABSORBING CURTAINS

Acoustics has become an important quality both in residential and public interiors. Whether it is due to the wide and open indoor spaces, that emphasize the need for acoustic planning, or the increased awareness and sensitivity to noise, it is hard to tell. But when it comes to improving the sound environment in interiors, using textiles that are especially designed for acoustic purposes, is a practical solution. Although aesthetics is an important part of textile design, functionality is raised to the primary focus in the design process of acoustic textiles. The basic considerations, whether the fabric hangs and drapes well, how it feels, and how heavy or lightweight the fabric is desired to be, have to be taken into consideration during the design process. But there are several factors that influence the acoustic performance, and those have to be researched and considered primarily. The performance requirements have to be tested and fulfilled as a part of the design process. The design should be a balance between the function and the look of the fabric, while at the same time holding on to high quality.

This next section covers the case of the thesis, that is woven acoustic curtain fabrics. There are many acoustic textile solutions in the market, from the textile interiors of cars to felted panels in concert halls and heavy velvet curtains in theaters, but the focus of this work is on relatively lightweight woven acoustic fabrics that absorb high frequencies, and that are applied as curtains. The chapter explains first the basic functions and the advantages of acoustic curtains. Then it opens up the factors affecting the sound absorbing ability in a fabric's micro-structural level and with the use of the curtain fabric in a space. After that it explains the required acoustic tests for the sound absorbing fabrics, and finally the section ends with showcasing some examples of lightweight acoustic curtain fabrics that are for sale in the current market.

FUNCTIONAL CURTAINS

Sound absorbing curtains can be categorized as functional textiles. In fact all interior textiles are functional, since their purpose is to cover and protect (Sinclair 2015, 534), but in this thesis work functional textiles are referred to textiles that are designed with a particular functional quality in mind — in this case the sound absorbing quality. The curtain market is full of sheer fabrics, that though soften the light coming from outside, do not have any other functions. There is nothing wrong with those kind of curtains being merely decorative, but as functional textiles, sheer and lightweight acoustic curtains can offer both the decorative value of the soft and airy look, and the functional value of the sound environment improvement of the space.

The scientific research of acoustic textiles show that, even though woven fabrics have lower sound absorption coefficient than many nonwoven textiles, such as needle-felted fabrics, the application of woven fabrics can improve the absorption performance. If there is a sufficient airspace behind the fabric, the ability to absorb sound is greatly

enhanced. (Pieren 2012, 864; Soltani & Zarrebini 2013, 1011.) When woven acoustic fabrics are used as curtains, the mounting in front of the window or a wall creates an airspace to the back of the fabric, therefore resulting an efficiently working sound absorber. The application of acoustic curtains is not tied only to cover windows or walls, but they can also be placed in the middle of a space as a room divider, if the sound absorption coefficient of the fabric is high enough.

There are many advantages of acoustic curtains compared to other sound absorption solutions. Woven acoustic curtains are relative cost effective, easy to maintain, and by draping and moving the curtains, it is easy to change the sound conditions of the room flexibly (Iso-Kuortti 27.10.2015; Pieren 2012, 864; Pieren & Heutschi 2015, 27). Unlike other acoustic absorbers, that are placed as an addition to the interior, woven acoustic curtains can replace conventional curtains without the need for adding vast quantities of extra acoustic elements to the interior. People are used to having curtains in the interiors, so acoustic curtains should fit to almost any interior without problems.

Some performance requirements need to be noticed if the acoustic curtain fabric production is for the contract market. Qualities, such as flammability and colorfastness, need to be tested and approved according to standards before textiles can be applied in public spaces (Nielson 2007, 112). Since this thesis work is done for a manufacturer of contract textiles, those performance requirements have to be taken into consideration. But as the work is still in a prototyping phase, the focus remains with the acoustic performance. If the prototype fabrics were to be sold and produced for the contract market, it should be relatively easy to adjust the qualities of the fabrics to reach the requirements of contract textiles without changing the acoustic performances too much.

Fig. 3.1 Création Baumann's acoustic curtains used in a private home in St Gallen, Switzerland.

FACTORS AFFECTING THE ACOUSTIC PERFORMANCE OF WOVEN FABRICS

There are studies of the sound absorption performance of woven fabrics and what effects it, but still the common consensus of general factors of woven acoustic fabrics is lacking. It was reported already in the 1970s that the sound absorption of curtains depends on the draping, the mounting distance from the wall, the airflow resistance, and the surface mass density of the curtain fabrics. During the 1990s it was also proved that fabric's microstructure has a significant influence on the sound absorption coefficient. (Pieren & Heutschi 2015, 27.) What seems to be the common observation in all research within the field of acoustic textiles, is the complexity of the textile structures, and that while particular factors are influencing the absorbing performance independently, also the combination and interaction of different factors is crucial.

The following paragraphs list factors that I have selected from the published literature of acoustic performance of woven fabrics. However it is impossible to prove, that if this list is followed in the design process of a woven fabric, the outcome would be a perfectly functioning sound absorbing fabric. It seems that, due to the effect of different variables as a whole, changing just one factor can alter the sound absorbing performance completely. Therefore the following list of factors should be taken merely as a guideline for finding the best solutions for acoustically performative fabrics. The factors are placed in two categories: fabric microstructure and fabric application. Fabric microstructure is more relevant to this work, because those factors can be altered in the design process of a woven fabric. Fabric application is equally important, though a fabric designer cannot directly influence to those external factors.

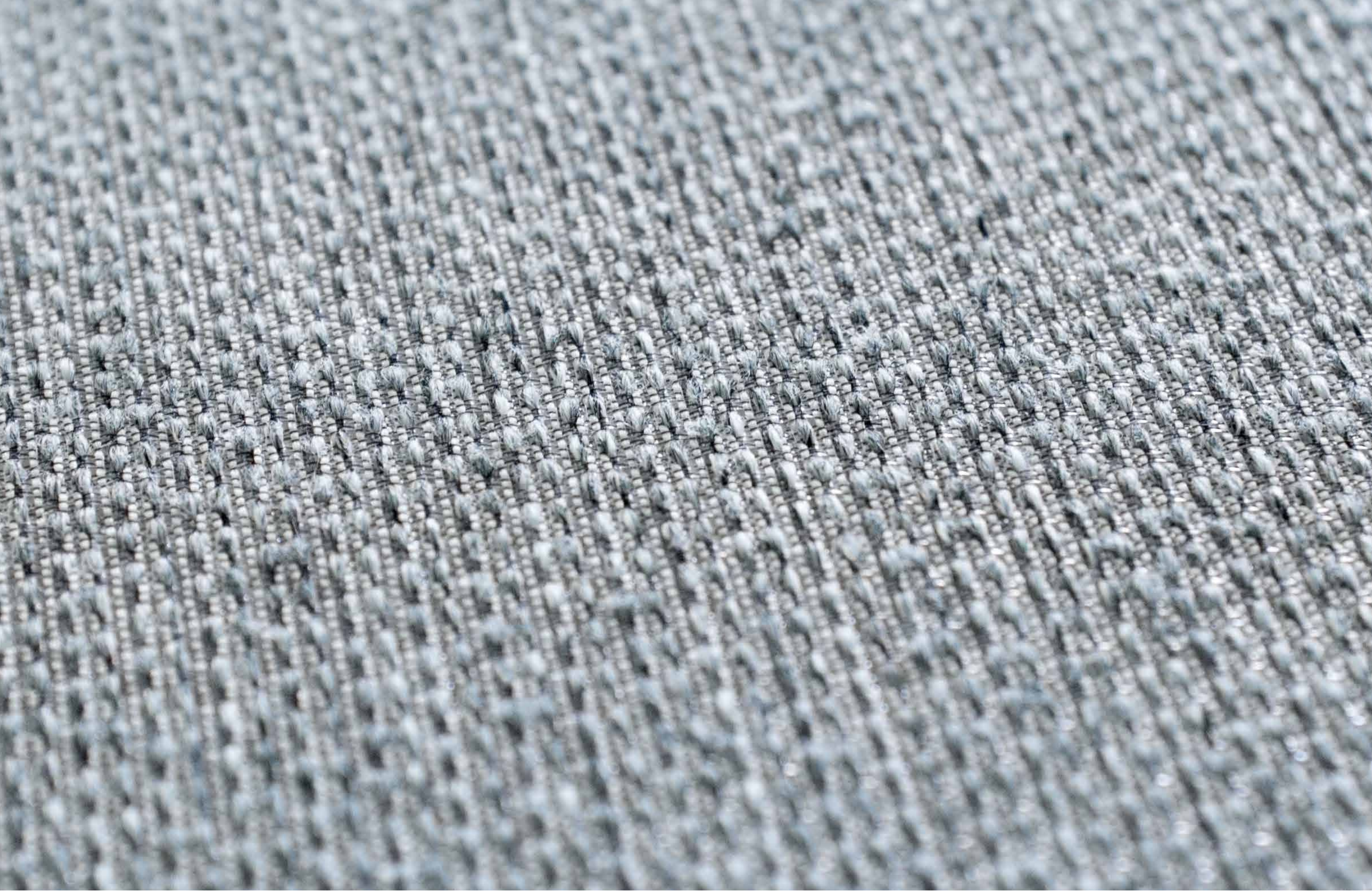
Factors – fabric microstructure

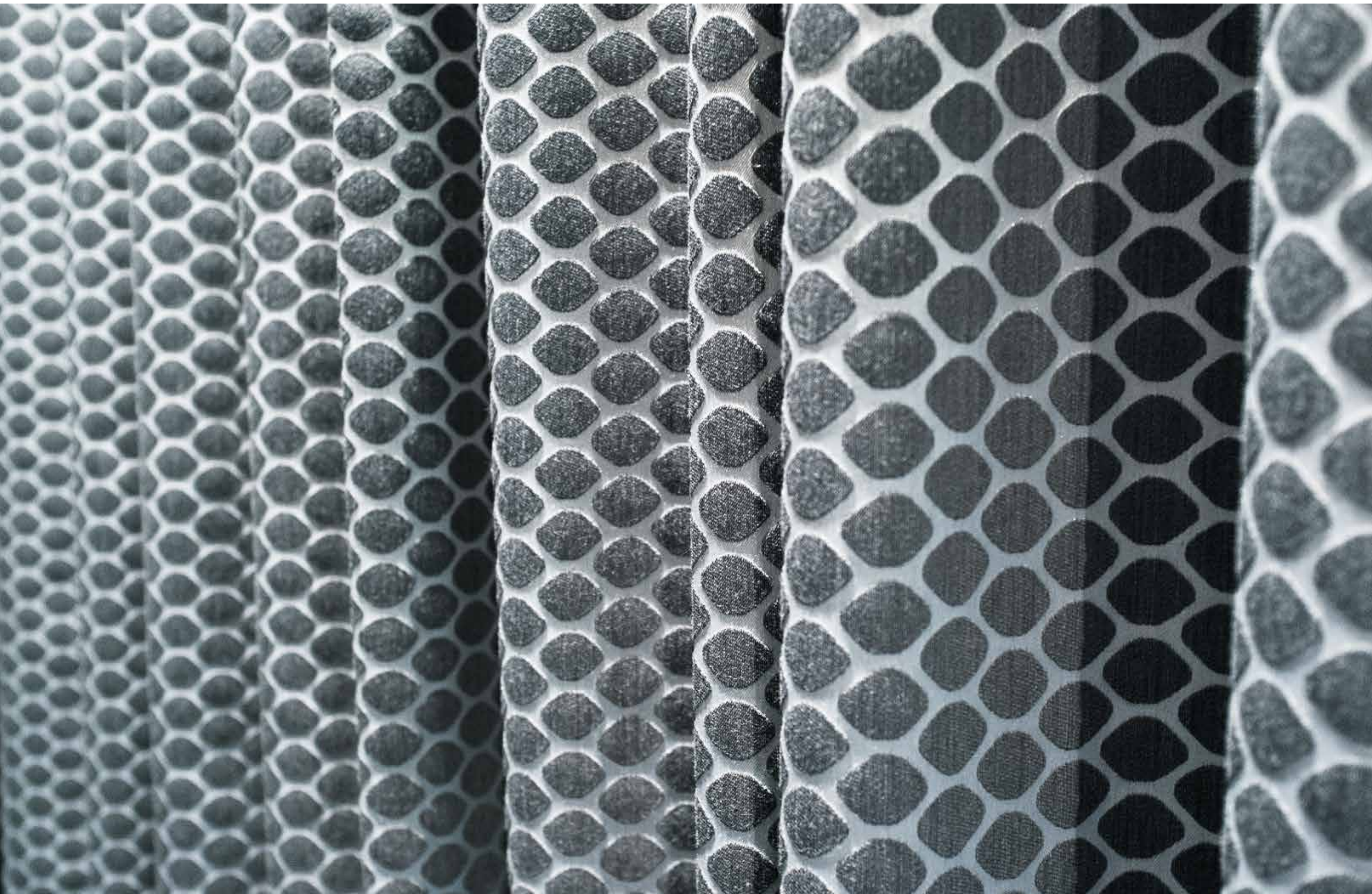
- density
- woven structures
- structures of yarns and fibers
- thickness
- layering
- finishing techniques
- vibration

Factors – fabric application

- airspace on the back of the fabric
- draping
- placement in the room

Fig. 3.2 Close-up of a surface of a prototype fabric 23361.
Fig. 3.3 Prototype 23379 hanging at the Tekstiili16 exhibition in Helsinki.





Fabric Microstructure

Fabric microstructure describes the inherent factors of a fabric, such as the types of yarns and the structures used (Pieren & Heutschi 2015, 35–36). All factors within the fabric microstructure create the fabric cover and the surface area, that impact significantly to the sound absorbing performance of a fabric. It is apparent that the fabric cannot be too open, or the sound just passes through it. In addition the fabric cannot be too densely covered, so that the sound just reflects from the surface. Tapio Lokki (12.11.2015) also emphasized the importance of large surface area created with three dimensional woven structures for increasing the absorbing surface area of the fabric. As mentioned already in the paragraph about porous sound absorbers, the sound absorption coefficient is dependent on the size of the surface area. Within woven textiles the surface area does not consist of only the size of the fabric but also the microstructural three dimensional composition.

Density

Density is one of the most important factors influencing the sound absorption performance of a fabric. Density in different references can mean either the warp and weft yarn pick densities of a woven fabric (yarns/cm), or a ratio of the fabric weight to fabric volume (g/cm3). Higher pick density increases the absorption up to a point where fabric is so dense, that it just reflects sound waves. Low pick density on the other hand means that the fabric structure is so open, that sound can just pass through the fabric. (Soltani & Zarrebini 2012, 878; Soltani & Zarrebini 2013, 1013.) The influence of density varies in different sound frequencies. Dense fabrics seem to absorb more sound waves at high frequencies than in low frequencies. However, the low frequency absorption is proved to be difficult with thin fabrics anyhow, since it requires a greater thickness from the absorbing material. Soltani and Zarrebini (2012, 879) have shown that a fabric density of 0.32 g/cm3 would be the optimum density for woven fabrics, since it absorbs most efficiently the whole range of sound frequencies. However, since I would need a laboratory equipment to measure the fabric densities, I cannot compare or test them from my prototype samples, and so I cannot prove or discredit that optimum density.

Woven Structures

A fabric surface is created when warp and weft yarns are interlaced as a woven structure. That has an impact both to the fabric cover and to the surface area, but also to the feel and the drape of the fabric. (Jackman, Dixon & Condra 2003, 143.) Soltani and Zarrebini (2012) discovered, that woven structures result to different sound absorption coefficient values. According to them, plain weave, due to its most intersection points, has the best sound absorption coefficient value, and that 2/1 twill, 3/1 twill, 2/2 twill, rib, and satin were ranked beneath the plain weave in that order. (Soltani & Zarrebini 2012, 878.) The reason, why the amount of intersection points affects the sound absorption coefficient, is when a sound wave enters the fabric, the yarn intersection points act as frictional elements that resist the sound wave from passing through (Soltani & Zarrebini 2013, 1015). Soltani's and Zarrebini's research only presented the simplest of weave structures with conventional materials, but experimentation with different woven structures and material choices may reveal more complex results than their study. And since woven structures have an effect also on the feel and the drape of the fabric, different structural and material combinations have to be tested for finding out what gives the best overall result.

Structures of the Yarns and Fibers

The structures of yarns affect the acoustic performance of a fabric, especially with lightweight fabrics. The covering effect should not increase the weight of the fabric too much, so therefore the fabric cover should be created with the use of certain yarns. Differently shaped fibers have their own covering abilities. For example round cross-sectional fibers cover the surface less than flat-shaped fibers. Also multidimensional fibers cover better than straight fibers. (Willbanks et al. 2014, 52–53.) Due to the effective covering ability of flat fibers, it is usual to see synthetic film yarns, such as unsupported and transparent Lurex film yarns, used in lightweight acoustic curtain fabrics. Film yarns provide an efficient covering effect and a translucent appearance to the fabric.

The twist of the yarn also influences the acoustic performance in a way that the yarns with lower twist absorb sound more efficiently (Soltani & Zarrebini 2013, 1011, 1015). Low twisting yarns contain more surface area, because the fibers are not too packed, and due to that the fabric cover increases. Soltani and Zarrebini (2012) have studied also how different spinning systems affect the sound absorption coefficient. They found out that rotor-spun yarns have better absorption coefficient than ring-spun or compact-spun yarns. Since the structure of rotor-spun yarns is bulky and more hairy, the air viscosity is improved, and the sound absorption is more efficient. Ring-spun yarns, on the other hand, are less bulky and possess less resonance. In compact spinning the hairiness of the yarn is purposely reduced, which impacts negatively to the fabric cover and surface area. (Soltani & Zarrebini 2012, 880–881.)

Thickness

Low sound frequencies require thickness from the absorbing materials (Lokki 12.11.2015). The thickness of a porous absorber should be one-tenth of the wavelength of the sound (Seddeq 2009, 4612), and with low frequencies the thickness should be even one quarter of the wavelength (Grueneisen 2003, 60). For example a sound wave of 100 Hz in 20 degree celsius has a wavelength of around 340 cm, so in order to absorb that frequency sounds, the absorber should have a thickness of 35–85 cm. At higher frequencies, however, thickness does not have that significant effect on the absorption capacity, but instead the airspace behind the fabrics becomes more important (Seddeq 2009, 4612, 4615). Due to that, lightweight acoustic curtains provide a practical solution in spaces where particularly mid to high frequencies should be absorbed.

Layering

Having multiple layers of acoustic fabric changes the sound absorption coefficient. The increase of layers adds also the thickness and the fabric cover, and that results to significantly higher values of sound absorption coefficient. The entrapped air between the layers also improves the sound absorbing performance. When multiplying the fabric layers, the density of the layers should be relatively lower than with just one fabric layer, otherwise the added layers can lead to too dense surface that just reflects the sound wave. (Soltani & Zarrebini 2013, 1014–1015.) With woven structures it is possible to design layered fabrics with pockets. So layering can be achieved either in the microstructural level with woven structures, or with the fabric application, if for example a layered panel curtain system is used.

Finishing Techniques

I was not able to find any scientific research of the influence of different finishing techniques, though it is possible to alter the fabric microstructure with finishings similarly than with woven structures or with yarn types. From analyzing the test results of my own prototype fabrics, I realized that different finishes influence the airflow resistance values, so ultimately they affect also the sound absorption coefficient. I noticed that fabrics with an air-drying and ironing finish had higher airflow resistance than the same fabric with only ironing. I assume it is because the air-drying opens the yarn fibers even more, and that contributes to the increase of fabric cover and the surface area. Another finishing technique, that may have an effect on the absorbing ability, is printing. As Tapio Lokki (12.11.2015) also mentioned, printing may either increase the porous surface area, or it might act as a glue that hardens the fabric and clogs the pores. Based on the experimental test I conducted, digital printing with reactive colors resulted a relatively small decline of the absorbing abilities, so it should not have as significant effect as for example air-drying has.

Vibration

Sound-induced vibration is a factor worth considering with lightweight fabrics. If a fabric can move freely, the sound wave passing through the fabric triggers a fabric vibration to occur, which can reduce the sound absorption coefficient. (Pieren 2012, 867–868.) However, since it is impossible to tell whether a designed fabric will have a fabric vibration or not, that factor cannot be influenced within the design process. It can only be assumed, that the vibration in lightweight fabrics might reduce the sound absorbing performance to some level.

Fabric Application

In addition to fabric microstructure it is also important to understand how an acoustic curtain fabric is used in a space. Since the application is most commonly a hanging curtain, the following factors need to be considered: to what distance the curtain is mounted from a wall or from a window, how the fabric is draped, and how the curtains are placed within a room. Even though these factors affect the sound absorption abilities, they cannot be fully controlled by the designer of the acoustic curtain fabric, since it is up to the end-customer to decide how they want to hang the curtains. Therefore I will call these factors as external factors.

Airspace behind the Curtain

Freely hanging curtains are almost always placed in front of a window or a wall so that there is an airspace between the fabric and the hard surface. That airspace is meaningful with thin acoustic fabrics, because it increases the ability of absorbing mid to high frequencies (Seddeq 2009, 4615; Soltani & Zarrebini 2013, 1011). Then again, a larger airspace at the back does not necessarily mean better absorption coefficient, but an airspace with the width of one quarter of the wavelength should be an optimal distance (Borenius et al. 1985, 54; RIL 243-1-2007, 149). For a 1 kHz frequency with a wavelength of approximately 35 cm, the efficient airspace would be around 9 cm. The usual curtain mounting provides an airspace close to that width.

Curtains placed in the middle of a room as a space dividers can work perfectly as acoustic absorbers also, if they are placed in the diffuse field of a room. That means a part of the room where the sound pressure level is uniform, for example an area where a reflected sound is dominant (Acoustic Glossary). Pieren and Heutschi (2015) revealed, that fabrics placed in the diffuse field of a room had the same capability to absorb sound with even a larger frequency range than fabrics placed near a hard surface. The study showed even better results with low frequencies for free hanging fabrics in the diffuse field. (Pieren & Heutschi 2015, 37.) So it is possible to have lightweight acoustic curtains as space dividers as well, if the sound absorption coefficient of them is high enough.

Draping

Draping of a fabric influences directly to the absorbing surface area. If a curtain is 100% folded, meaning that for a 1 meter wide space there are 2 meters of draped fabric, also the surface area is doubled, and the overall sound absorption coefficient is doubled as well. Since 5 m2 of fabric with a sound absorption coefficient of 1, 10 m2 of fabric with sound absorption coefficient of 0.50, and 20 m2 of fabric with a sound absorption coefficient of 0.25 all have the same equivalent sound absorption area of 5 m2, draping the acoustic curtains can multiply the absorbing ability (Création Baumann 2015a, 16). Acoustic fabrics are tested both as flat and as 100% folded for the sound absorption coefficient in a reverberation room, and the alpha value presented in the market is always the result of the 100% folded fabric.

Fabrics applied as free hanging curtains should be drapable. Cover factor of a fabric usually impacts to the drape and stiffness of the fabric (Sinclair 2015, 728). Therefore it might be difficult to produce an acoustic curtain, that has a sufficient fabric cover, and that drapes softly, so therefore many lightweight acoustic fabrics do not drape as nicely as conventional lightweight curtain fabrics.

Placement in the Room

It matters where to place sound absorbing materials within a room. Seddeq (2009) writes, that it has been discovered that absorbers placed near corners in a rectangular room are more efficient than if they are placed elsewhere. The ideal situation would be to place different types of absorbers in walls, floors, and ceilings to cover both horizontal, vertical and diagonal directions, and most importantly not to have two surfaces without absorbers to face each other. (Seddeq 2009, 4613.) Acoustic absorbers should be situated at head height, though acoustic curtains are usually mounted either from the top of a window or from the ceiling to the floor, so they cover almost the whole height of the room.

REQUIRED ACOUSTIC TESTS

In order for a fabric to reach the requirements of a sound absorber, it needs to be tested according to standards. Testing acoustic qualities from a fabric is similar to all standardized textile testings, such as flammability, color fastness or abrasion resistance. Since the test methods are standardized, the whole procedure with test conditions, calculations to be made and so forth, are dictated within each method. Tests are designed to simulate the conditions of a real application of the textiles. (Willbanks et al. 2014, 31.) Testing is usually provided either by governmental laboratories or by independent testing laboratories (Nielson 2007, 117), such as the German test laboratory Müller-BBM, that tested the prototype fabrics within this work. Standardized test results are needed for quality control, and for comparing different manufacturers' products with each other, if the products are classified by their performance.

There are at least three different test methods for sound absorption that are either directional or explicit. The first method, flow resistance, is the initial test for all fabrics intended to be tested acoustically. It does not measure the sound absorption coefficient, so the results from that are only directional. The last two methods, the impedance tube method and the reverberation room method, measure the sound absorption coefficient. The impedance tube method measures the sound absorption coefficient only from a small sample with a directional sound, so even though the result is the absorption coefficient, it cannot be applied for comparing the results of the reverberation room test. The reverberation room method is the most accurate of the methods, since it measures the absorption coefficient from a large piece of hanging fabric with a reflecting sound, so the test conditions are closest to the reality.

Flow Resistance

The flow resistance (or the airflow resistance) method DIN EN 29053 measures the amount of direct airflow passing through a porous material sample (Pa s/m). Air pressure is measured both in front and behind the test sample, and the specific airflow resistance (R_s) is then counted. The R_s value is then compared with the surface density and the thickness of the fabric, and an evaluation of the sound absorption performance is given. The R_s values between 600–1000 refer to good sound absorbers. The evaluation can be applied for selecting the most promising samples for sound absorption coefficient tests, or for monitoring the production of acoustic products in the market. Flow resistance test is relatively inexpensive, since the size of the test sample is only 100 mm diameter. (Müller-BBM 2015a, Appendix B, Page 1; Müller-BBM 2016a.) The evaluation based on the R_s value though might be sometimes misleading, since the analysis of the current market examples presented later on revealed, that even though the R_s values were low, the sound absorption values were still high. Because of that, I am a bit hesitant to rely only on the R_s values within my work, even though those are the main test results from the prototype fabrics at this stage.

Impedance Tube Method

The impedance tube method DIN EN ISO 10534-2 measures the sound absorption coefficient with a perpendicular sound. The test is done inside a tube, and the material sample is attached to the one end of the tube and a speaker to the other. A sound is played from the speaker, and microphones inside the tube measure the maximum and minimum pressures of the standing wave. From those measurements it is possible to count the sound absorption coefficient values of the material sample in different frequencies. The impedance tube method is mostly applied with the scientific studies that compare different samples with each other. It can also be applied directionally for determining the sound absorbing performance of a porous material, if the reverberation room method cannot be used. The advantage of tube test compared to reverberation room test is, that it is faster and more affordable due to its small sample size of around 30–100 mm diameter. (Borenius et al. 1985, 53; Müller-BBM 2016b; Soltani & Zarrebini 2012, 876.)

Reverberation Room Method

The reverberation room method DIN EN ISO 354 measures the sound absorption coefficient (α_w) in a large echoing room (approximately 200 m^3) with a diffuse sound. The reverberation time is measured both with and without the material sample. From the reverberation time it is possible to count the sound absorption coefficients in different frequency ranges. For testing acoustic fabrics, the sample material is hanged from the ceiling with a distance of 10 cm from the reflective wall. The material is then tested both as a flat arrangement and as 100% folded. The sound absorption coefficient values, that are presented with the acoustic fabrics, are the values received from the 100% folded samples. The advantage of the reverberation room method is its large scale, so it is possible to measure the sound absorption coefficient also from large furnitures or even from people. But the downside is that the test is relatively expensive, and it acquires a large piece of sample material, usually around 10–12 m^2. There are also smaller chambers available for material samples of 1 m^2, but those are applied mainly for product development and not for the final acoustic test. (Borenius et al. 1985, 53; Müller-BBM 2015b, 4, Appendix C, Page 1; Müller-BBM 2016b.)

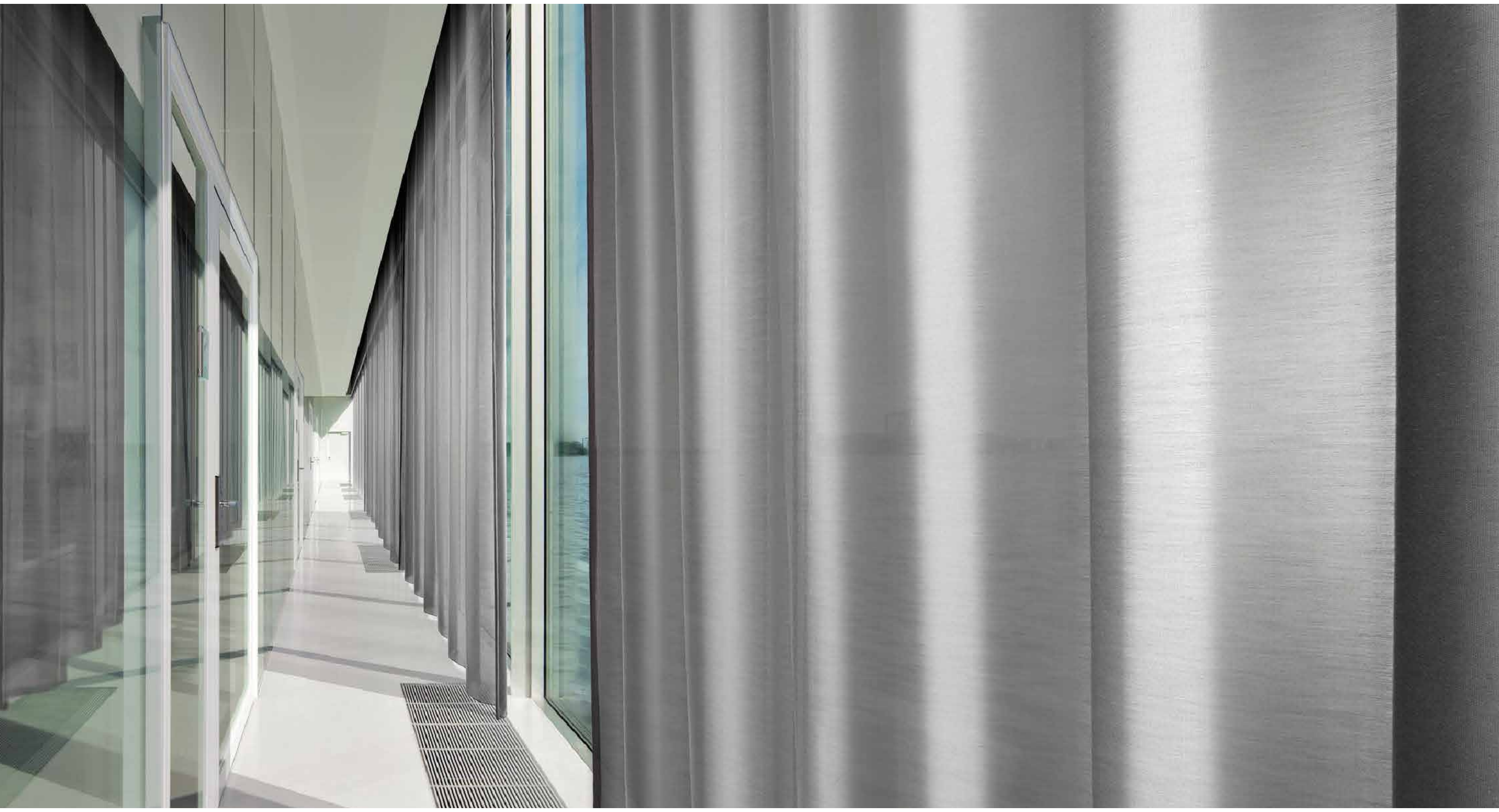
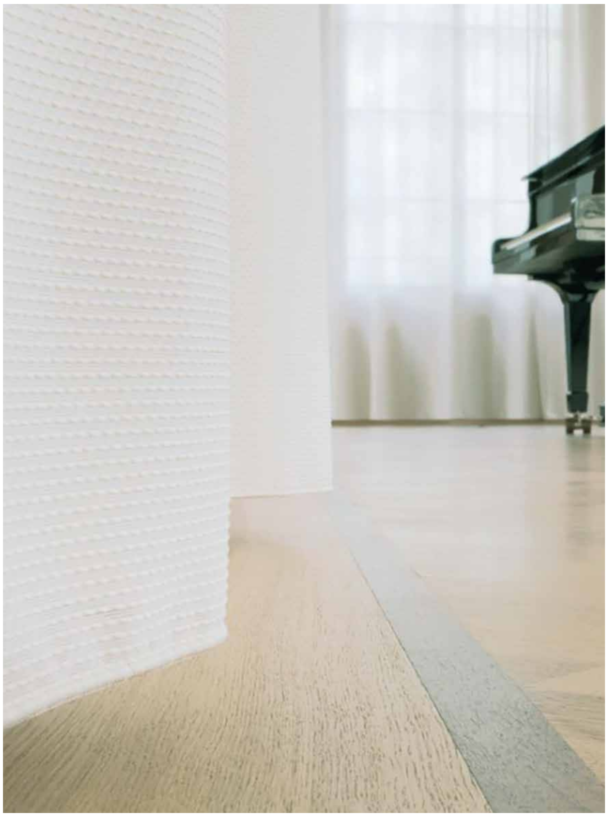


Fig. 3.4 Vescom's acoustic curtain Marmara.

EXAMPLES OF ACOUSTIC CURTAIN FABRICS IN THE CURRENT MARKET

The range of lightweight acoustic curtain fabrics has been widening within the past couple years, although the market it still quite small-scale. An important aspect in the development process of a new product, as Büsgen (2012, 135) writes, is to analyze competitor products. Watkins and Dunne (2015, 5) also add, that a market survey is a good way to find trends within the field, and to come up with novel design solutions instead of redesigning what has already been done. The aim of this benchmarking is to compare the test results and the structural differences in order to understand the basis of constructing woven acoustic fabrics, and to come up with novel ideas.

The examples presented here are the most well-known manufacturers and editors of acoustic curtain fabrics in Europe, and most of their products are comparable in weight, translucency and the used materials. All the presented fabrics are flame retardant and Öko-Tex Standard 100 certified, and the purpose of all of these curtains is to blend in with the interior, and to bring light into the space while providing a maximum sound absorption. It seems that all of them claim to be the first ones to come up with an innovative use of transparent film yarn and a specific weaving technology for creating sheer acoustic curtain fabrics. Although I was not able to discover any specific weaving technologies from any of the examples other than the same industrial dobby weaving.



Annette Douglas Textiles

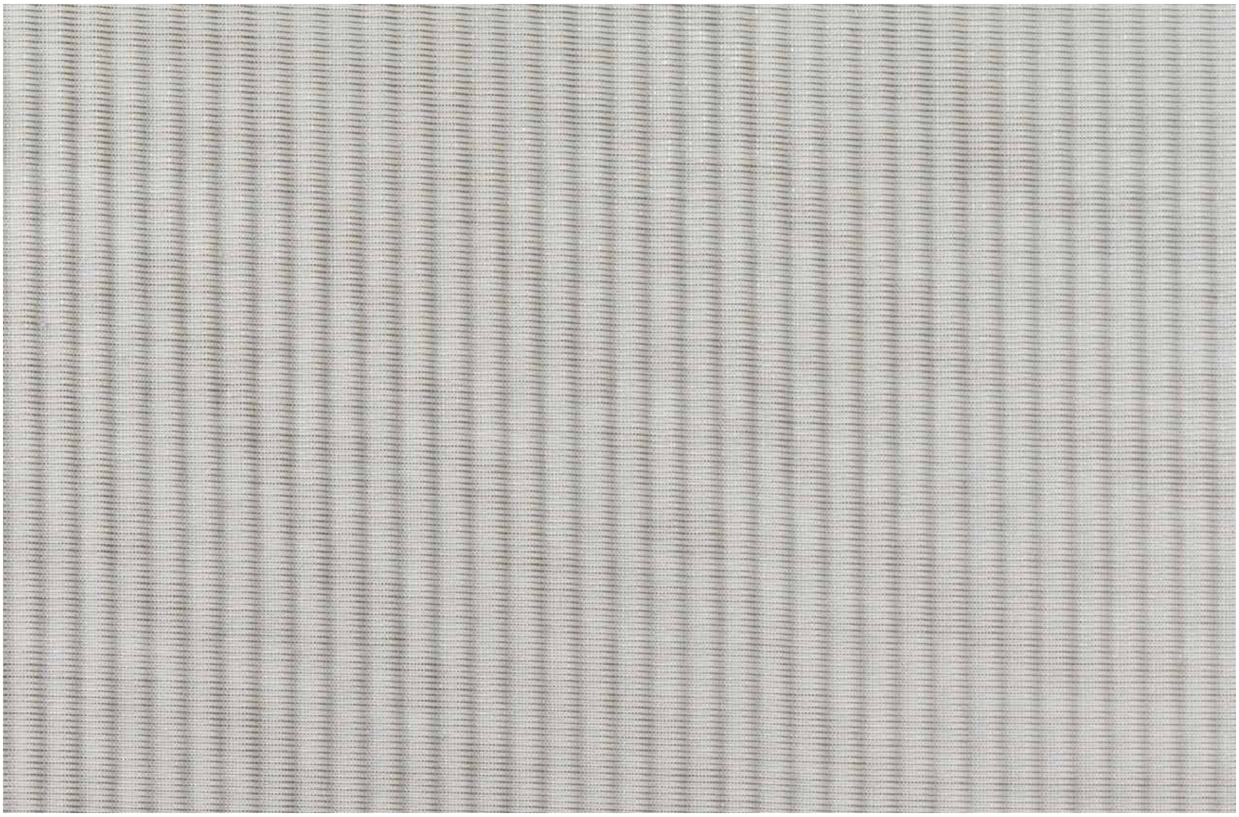
Swiss-based textile designer Annette Douglas states of being the first to discover the potential of lightweight curtains as acoustic absorbers. She works both with her own brand Annette Douglas Textiles and for textile editors, such as Vescom. Douglas's "Silent Space Collection" was launched in 2011, and she has continued developing the collection throughout the years in close collaboration with EMPA Swiss Federal Laboratories for Materials Science and Technology. Annette Douglas has won several awards, such as Swiss Design Award in 2011, with her acoustic curtain fabric collection. (Annette Douglas Textiles.)

All of the five curtain fabrics of the Silent Space Collection are very lightweight Trevira CS fabrics with alpha values of 0.5–0.8. Compared to other brands' fabrics, Silent Space Collection is highly competitive with the sound absorption coefficient results. All fabric colorways are classical with whites, greys, beiges, and browns. I was not able to get any actual samples from the fabrics, so therefore it is difficult to analyze the visual look or the draping of the curtain fabrics, but according to the images found online, the structures seem quite plain with flat transparent film yarn on the background and thicker yarns on top.

Silent Space Collection, 5 curtain fabrics
α_w= 0.50–0.80, weights 88–149 g/m²

- **Streamer classic** – TCS, 133 g/m², R_s 323, α_w 0.80, class B, 3 colors
- **Streamer pro** – TCS, 149 g/m², R_s 373, α_w 0.80, class B, 8 colors
- **Whisper classic** – TCS, 102 g/m², α_w 0.50, class D, 4 colors
- **Whisper air** – TCS, 86 g/m², R_s 158, α_w 0.60, class C, 3 colors
- **Liquid classic** – TCS, 88 g/m², α_w 0.50, class D, 2 colors

Fig. 3.5 Streamer classic col. 100.
Fig. 3.6 Silent Space Collection.



Vescom

A Dutch-based interior company Vescom produces three translucent acoustic curtain fabrics developed and designed by Annette Douglas. All three fabrics are flame retardant due to the use of both Trevira CS and flame retardant polyester (FR). Vescom promotes the fabrics to have sound absorption abilities up to five times higher than conventional translucent curtain fabrics due to the porosity and the special weaving technology used in their production. (Vescom 2012; Vescom 2013.)

Vescom's online page (Vescom 2016) offers descriptions to each of the curtain fabrics. All of the fabrics seem to have transparent film yarn on the ground for a translucent look and for a dense background surface. Carmen has a three dimensional surface with a rib binding on top. Marmara is a plain fabric with a matte weft yarn on top and a transparent film yarn on the ground, resulting a shiny background. Formoza has a transparent film yarn on the ground and thicker yarns on top for creating structure and surface volume. Also these acoustic curtain fabrics have simple aesthetics and plain colorways for the use in modern architectural spaces. I did not get swatches from these fabrics either, so therefore it is difficult to analyze the drapability or the feel of the fabrics.

Annette Douglas / Vescom, 3 curtain fabrics
α_w= 0.50–0.60, weights 91–133 g/m²

- **Carmen** – TCS/FR, 91 g/m², α_w 0.50, class D, 4 colors
- **Marmara** – TCS/FR, 104 g/m², α_w 0.50, class D, 4 colors
- **Formoza** – TCS/FR, 133 g/m², α_w 0.60, class C, 3 colors

Fig. 3.7 Close-up of Vescom's acoustic curtain Carmen.

Création Baumann

Though Swiss textile company Création Baumann sells over 90 fabrics as acoustic, eight of them are marketed as translucent acoustic curtain fabrics. Création Baumann, as well as other sheer acoustic curtain editors, states to be one of the first to come up with an innovative method of using a new thread and a weaving technique for creating translucent acoustic fabrics. (Création Baumann 2015b.)

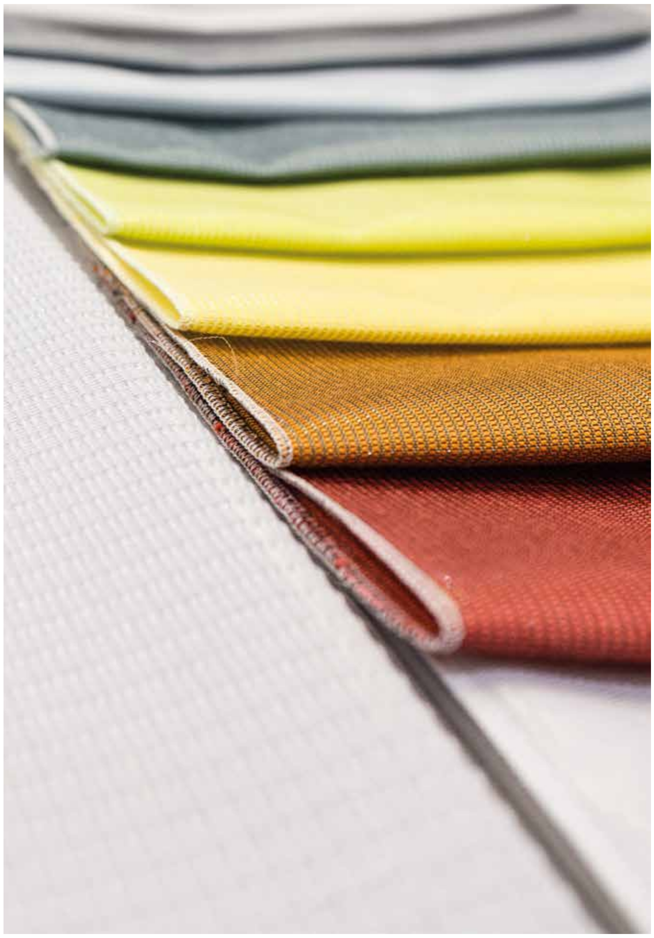
All of the Création Baumann's translucent acoustic curtain fabrics are created with transparent film yarn mixed with softer yarns. It seems that at least the majority of the presented sheer acoustic fabrics are woven as one weft system fabrics with simple structures, such as rib and plain weaves. That creates a shiny look, since the film yarn is visible to the front side of the fabric. Deltacoustic and Primacoustic seem to be woven as two weft system where the transparent film yarn stays on the backside of the fabric resulting a more softer feel and a less shiny look. I do not have fabric samples of Primacoustic or Terzacoustic, but it is highlighted on Création Baumann's online page, that they have a special matt look compared to other translucent acoustic fabrics. Piia Iso-Kuortti (27.10.2015), the representative of Création Baumann Finland in Vallila Contract, explained that Alphacoustic and Gammacoustic will have matt versions in the future, and it seems that Primacoustic and Terzacoustic are now those new versions. Reflectacoustic seems to also be one of the newest incomers in their lightweight acoustic fabric collection. Reflectacoustic is a multifunctional curtain fabric with both a sound absorption ability and a glare and heat protection. The reverse side of the fabric reflects sun light even though the fabric is still translucent. The colorways of Création Baumann's acoustic curtain fabrics are wide and versatile from Betacoustic's grey tones to Deltacoustic's earthy and colorful choices. (Création Baumann 2016; Iso-Kuortti 27.10.2015.)

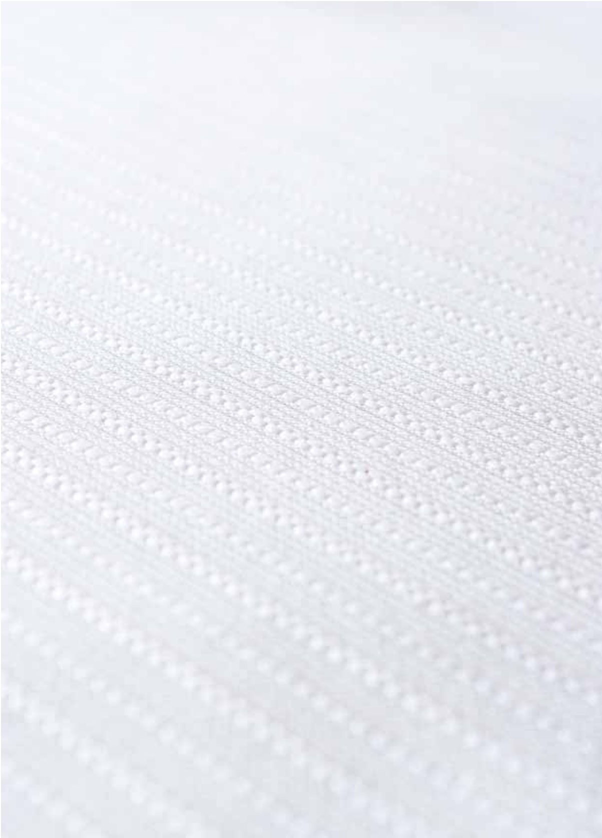
Transparent Acoustics, 8 curtain fabrics
α_w= 0.50–0.65, weights 70–134 g/m²

- **Alphacoustic** – TCS, 115 g/m², R_s 228, α_w 0.60, class C, 16 colors
- **Betacoustic** – TCS, 125 g/m², R_s 163, α_w 0.65, class C, 8 colors
- **Gammacoustic** – TCS, 74 g/m², R_s 118, α_w 0.50, class D, 10 colors
- **Deltacoustic** – TCS, 125 g/m², R_s 218, α_w 0.60, class C, 17 colors
- **Zetacoustic** – TCS, 134 g/m², R_s 212, α_w 0.65, class C, 10 colors
- **Primacoustic** – TCS, 125 g/m², R_s 218, α_w 0.60, class C, 7 colors
- **Terzacoustic** – FR, 70 g/m², R_s 91, α_w 0.50, class D, 7 colors
- **Reflectacoustic** – TCS, 134 g/m², R_s 199, α_w 0.60, class C, 5 colors, light transmission degree 27–45%, light reflection degree 24–43%

Fig. 3.8 Transparent Acoustics collection.
Fig. 3.9 Zetacoustic.
Fig. 3.10 Reflectacoustic with a glare and heat protection.
Fig. 3.11 Color variations of Alphacoustic.


DIE TRANSPARENTEN AKUSTIKSTOFFE FÜR DEN PERFEKTEN RAUMKLANG
TRANSPARENT ACOUSTIC FABRICS FOR PERFECT AMBIENT SOUND
GAMMACOUSTIC COL. 46
ALPHACOUSTIC COL. 26
VORDERSEITE I FRONT SIDE
ETACOUSTIC COL. 12
VORDERSEITE I FRONT SIDE
COUSTIC COL. 85
VORDERSEITE I FRONT SIDE





Silent Gliss

Silent Gliss is a Swiss-based curtain company specialized in complex curtain hanging systems for draped panel curtains. They also have their own collection of curtain fabrics. According to Silent Gliss's key account manager in Finland Anne Jacobsén, the company offers both a soft and a stiff versions of the same fabric quality for either draped curtains or hardened blinds or panel curtains. That stands out from the other compared companies. Their fabric collection includes two translucent acoustic Trevira CS fabrics. (Jacobsén 23.3.2016; Silent Gliss 2013; Silent Gliss 2015.)

The structures of the two translucent acoustic fabrics are similar to previous examples with transparent film yarn used for creating a transparent effect and a dense surface. In addition to the film yarn, Silente 10 has three other weft yarns with different thicknesses for creating a three-dimensional surface. Silente 20 has a simple structure with a film yarn and a thicker Trevira CS yarn running as a plain weave. Since these fabrics are woven as one weft system, the transparent film yarn is visible to the front side of the fabric, resulting a shiny effect to both of the fabrics. Silent Gliss offers the two acoustic curtain fabrics in three colors; white, light beige and light grey. The feel of the fabrics is dry and quite stiff due to the use of the film yarn.

Acoustic curtain collection, 2 curtain fabrics
α_w= 0.60–0.65, weights 131–160 g/m²

- **Silente 10** – TCS, 160 g/m², α_w 0.65, class C, 3 colors
- **Silente 20** – TCS, 131 g/m², α_w 0.60, class C, 3 colors

Fig. 3.12 Silente 10 col. 1.
Fig. 3.13 Silente 20 col. 2 & 3.

CASE / SUMMARY

- Case / What kind of functional textiles acoustic curtains are?
- Case / What are the key factors that influence the sound absorbing abilities of woven fabrics?

This section contained the case of woven acoustic curtain fabrics. It answered why acoustic curtains are a part of functional interior textiles, and what factors have an effect to the sound absorbing ability and how. The chapter also went through the different standardized testings for acoustic fabrics. Lastly it showcased some of the most known examples of lightweight acoustic curtains that are for sale in the current market.

Acoustic curtain fabrics are functional, since they possess active functions other than being merely decorative. Acoustic curtains are able to compete with other sound absorption solutions, since it is easy to just replace conventional curtains to acoustic ones without the need of excessive elements. They are also more easily convertible with the needs of the required sound environments by just draping or relocating the curtains. Designing functional textiles acquires a vast research to the topic, to the requirements, and to the variables that affect the performance. Also conducting a market survey reveals important data of the trends and the needs of the functional textile market.

The case research done for this work revealed many factors that ought to be considered before the design process of acoustic fabrics. I have divided them into internal microstructural factors and external fabric application factors. Internal factors are the ones that are modifiable via the fabric design process, and that have an effect on both the fabric cover and the surface area. Those elements should be kept in mind while designing a woven acoustic fabric. External factors, ergo the application of the curtains, are the ones that are usually managed by someone else than the designer of the curtain fabric. Often it is an interior designer, an architect or an acoustic expert, but it can also be a regular consumer. While professionals may understand the importance of the mounting or the draping of the acoustic curtains, it might be useful to have some kind of guidelines for the end-users of the most effective application of the acoustic curtains.

The small benchmarking done at the end of this chapter revealed the similarities of all those examples, and with that it clearly showed the opportunities that are still lacking in the current market. All of the examples compete with similar target users with their similar looks. They all use the transparent film yarn, that creates a shiny look to the fabric. Even though the examples are well designed and high-performative acoustic curtain fabrics, none of them stands out with for example a bolder visual look. That seems to indicate a niche in the market, a stepping stone for functional and yet visually interesting collection of curtain fabrics.

4 DESIGN PRACTICE / DEVELOPMENT PROCESS OF ACOUSTIC CURTAIN FABRICS

The creative part of the work consists of an experimental development process of woven sound absorbing curtain fabrics done for the Italian weaving company Lodetex. The goal of this chapter is to document and share the design discoveries. I have divided the design process into six steps: ideation and conceptual design, product development cycle no.1, creating visuals, product development cycle no.2, presenting the outcome, and finally the possible marketing and commercialization of the curtain fabrics. Ideation and conceptual design covers the starting point, and the goals and the restrictions of the project. Product development cycle no.1 includes the first prototyping phase, collecting and analyzing the completed test results, and developing ideas further. The visual design work that came after development cycle no.1 focuses on the visual concept of the work, and how different sketching methods were utilized. Product development cycle no.2 contains the latter prototyping, testing and analyzing phases. The last part of this chapter covers how the project may continue with two different clients.

APPLIED DESIGN PROCESS MODEL

The design process of acoustic curtain fabrics is loosely based on Büsgen's (2012) model of product development process of interior textiles. The model is built on basic steps following each other from generating the idea, collecting relevant information, screening, building a concept, manufacturing prototypes, testing, developing, marketing, and finally commercializing the product. (Büsgen 2012, 134.) Since following that particular order accurately would have been quite linear for my work flow, and since I am the only designer working fully with this project, I decided to create my own model based on the most relevant steps from Büsgen's model. I am referring the process as experimental, since experimentation is the key aspect both in technical and visual design processes.

My applied process is built on ideation, data collecting, and conceptual design work that as a core create cycles, that contain the actual design work. Each development cycle is built on the phases of prototyping, testing, analyzing, and developing. I planned a rough process from the early stage forward to clarify the needed steps from the first prototype round to the second, and all the data gathering and analyzing that was necessary. The first prototype development cycle was planned as an experimental tryout round, where different structures and material combinations could be tested and developed later. Since the design work was more technical than visual, I had to modify my own design thinking. Instead of merely focusing on the aesthetics and the feel of the fabrics, I now emphasized the technical problem solving over the visual aspects. But even still I wanted to create a visual story behind the whole work, and therefore I decided to create a visual concept for the second cycle prototypes. Due to the time limitations the design work was finished after the second stage, though the development process may continue later on depending on the interested clients.

The model is only partial, since I am referring to the marketing and commercialization only briefly at the end of this chapter. That is because the product development stage was not fully completed during this project, and also because marketing and selling the fabrics is not included to the work assignments of a designer in a fabric manufacturing company.

Since Lodetex is a manufacturer of woven fabrics, the role of a designer is different to the role of a designer in their clients' companies. According to textile professor of Aalto University Maarit Salolainen (15.6.2016), the creative team in a manufacturing company works quite freely when it comes to innovating new design ides. Usually they work with a broad idea collection that includes a wide range of fabric qualities and styles for the diverse client base. Designing woven fabrics for a manufacturer is usually based on already made fabric qualities (structures and used materials), but novel designs are created for new innovative techniques or projects, such as this work. (Salolainen 15.6.2016.) Since I am working with a design task organized by the manufacturer, I am not targeting the fabric qualities or the visuals to any particular client, but treating the set of prototypes as a collection of structural ideas and visual experimentations. The prototypes were designed with the support of the textile technician Fabrizio Brignoli and the design staff of Lodetex.

The design process of functional products have to include a round of tests after each prototyping phase. Lodetex commissioned a certified German laboratory Müller-BBM to execute the required flow resistance tests for the majority of prototype fabrics produced for this project (see Appendix 3). In addition to those tests I wanted to create my own tentative acoustic test. The benefits of doing home testing is its minimum costs and quick results. The test is based on a method, where a frequency sweep is played and recorded with and without a fabric sample placed in between a speaker and a microphone, and those results are then compared in order to see if there is any difference. If the sound environment stays around the same during the whole testing procedure, it is also possible to compare the results of all the prototype fabrics together. The program FuzzMeasure was used in the measuring of the prototype samples, and the results were presented as graphs.

Fig. 4.1 Digital print 23132 being tested at home.
Fig. 4.2 FuzzMeasure plays a frequency sweep and draws a frequency response graph for comparing the results of with and without the tested fabric.


Impulse Response
PreSonus
AudioBox 22VSL

STEP 1 – IDEATION AND CONCEPTUAL DESIGN

Ideation, data collecting and conceptual design are in the essence of the whole process, and therefore they follow and evolve during other steps as well, even though they form the first step of the project. They create the building blocks that are examined and experimented with until they unite as a new design solution. According to Büsgen (2012), ideation can be a result of a thorough research on the topic, but it can also be a flash of genius. Conceptual design is needed for clarifying how the developed product will work, and how to achieve its performance requirements. It is about searching for the best solutions from different variations and alternatives, and making decisions of which design direction should be followed. Selecting from a set of solutions is vital during the whole product development. (Büsgen 2012, 135–137.)

Initial Ideation and Goals

The whole idea of developing acoustic curtain fabrics originated from a realization, that Lodetex has a demand for acoustic fabrics, but no one was able to fully focus on the subject. As a designer I like to receive challenging design tasks, so therefore the topic suited me fine. Also I had been working with audio responsive digital sketching before, so I thought if it would be possible to combine the visual sound to functional sound in a design process of acoustic curtains. The management of Lodetex engaged to the project quickly.

The ideation work started with setting the main goal for the project, which was to create a versatile set of prototype fabrics with different weights, although having an emphasis on sheer and lightweight drapable fabrics. It was agreed, that I would focus on quantity at this prototyping stage instead of merely quality, since it was crucial to understand the factors that affect the sound absorption abilities, and to discover different options and the most practical solutions for designing woven acoustic fabrics.

Visual Concept

Curtains may be used either as a silent background for other bold interior choices or as a dominant part of otherwise simple interior (Willbanks et al. 2014, 26). Based on the market study I realized, that the majority of acoustic curtains belong to the first category with their really simple structures and unobtrusive colorways. It seems that the curtain companies do not even want to give any visual attention to this great functionality that is incorporated into the fabrics. I understand that in the contract market simpler textiles are easier to produce and sell, but since my approach was experimental, I wanted to incorporate also a visual statement into the curtain fabrics.

Acoustic curtain design included an intriguing thought of using the same concept of sound in many levels. Somehow the almost philosophical idea of creating visible and tangible sound to fabrics, whose essential role is to take in as much sound as possible, was really interesting. Also the emotional side of sound perceptions felt inspiring. Could I evoke sound memories of a certain time and space with just visualizing sounds? Could viewers hear the sounds in their minds if the visualization would be connected to a sound story?

The visual concept was based on digital and material sketching, where sound would act as a tool for creating structures and patterns. Sounds were also used as structural and emotional inspirations for simpler fabrics without clear patterns. Even though the visual concept was attached to the topic from the project's early stage, I decided to focus on the visuals with the second cycle prototypes, and to use only simple structures in the first prototyping fabrics.

Client Data

Since Lodetex is a manufacturer working for several clients, I also wanted to collect data from their clients. I created an initial inquiry which was sent to Danish textile company Kvadrat and to Swiss curtain company Silent Gliss. The inquiry was answered by Johanna Apelgren from Kvadrat and project manager Markus Brugger from Silent Gliss (see Appendix 1). Their answers about the requirements and the needs were quite similar, and the results of the inquiry were included with the overall goals of the project. The noticeable thing from both of the company representative's answers was the need to find solutions to the unpleasant shiny look of the acoustic fabrics. As was seen in the benchmarking also, the current lightweight acoustic curtain fabrics are all done with the shiny film yarn, and with structures that do not cover the film yarn that much.

Fig. 4.3 Prototype 23362 with natural matt look.
Fig. 4.4 Prototype 23347 is sheer and drapable.

Requirements and needs Kvadrat

- overall performance requirements of contract textiles
- alpha value over 0,6 (R_s 600–1000)
- transparency (as sheer as possible, easy to cover a lot of space)
- soft hand
- drapes nicely
- simple structures in sheer colors like white, light grey and light beige
- interested in using film yarns but avoiding the stiffness and shine that usually comes with it

Requirements and needs Silent Gliss

- flame retardant
- good light and energy values
- availability in soft and stiff version
- good hanging behavior
- big width
- influence in reverberation time
- transparency (customers do not want to hang a “carpet” in front of the window
- fabrics without patterns
- colors white, off-white, beige, grey and black
- looking for fabrics that are not shiny since working already with shiny film yarns

Conceptual Design

A conscious choice was made to focus merely on the acoustic qualities of the prototype fabrics at this stage of the design process, and to leave other contract textile requirements aside except with some of the material choices. All the used materials were selected based on their structural factors, that emphasize the sound absorbing abilities. The used materials are mainly flame retardant, since majority of yarns used at Lodetex are either flame retardant polyester (PES FR) or Trevira CS (TCS). Some yarns used in the prototypes, for example the flat Lurex film yarn (PES), are not flame retardant due to lower production costs. Although those yarns can be changed to flame retardant versions, if the designs were to be sold for production. I also wanted to create some prototypes with natural fibers, because of their bulky nature that should improve the sound absorption performance.

Lodetex has around 50 different weaving machines with about half of them dobby and leno looms, and the other half that are jacquard looms (Lodetex 2012). Dobby looms produce fabrics with either basic weaves, such as plain, satin, and waffle weaves, or small designs with usually less than 25 different warp arrangements. Jacquard looms are complex computer-operated machines, where every warp yarn is controlled individually. Therefore jacquard fabrics can have multi-colored and picture-perfect large scale patterns. Leno looms differ from the previous two in that it has warp yarns as pairs, where one warp yarn crosses over the other before the weft yarn is inserted. The leno weave has an open and lace-like structure. (Jackman et al. 2003, 99.) For the acoustic project I decided to focus only with the dobby and jacquard looms, leaving the leno weave out. The density of the leno looms at Lodetex would have been too loose for the acoustic purposes, and therefore it was not worth doing tryouts. All the looms in Lodetex are double in width, meaning that the full width is 330 cm, and the curtain fabrics are usually produced so that the weaving width is actually the curtain length. It means that the horizontally woven weft yarns are then set vertically in the hanging curtain. So even really wide acoustic curtain fabrics can be woven at Lodetex as one piece without any seams lengthwise.

Fig. 4.5 Yarn samples of thin Trevira weft yarns used at Lodetex.
Fig. 4.6 & 4.7 Dobby and jacquard machines at Lodetex.

STEP 2 – PRODUCT DEVELOPMENT CYCLE NO.1

The first product development cycle started while I was still doing my internship at Lodetex. It proceeded quite intensely with quick prototyping within a few weeks, where by the end we had produced around 15 prototype fabrics with different structural and material tryouts. All the prototypes were tested with the airflow resistance test and also with my own tentative test. After the tests I analyzed the results and developed the upcoming cycle no.2.

Prototyping

The prototyping phase started with modifying five previously produced hard-set qualities that were designed by Lodetex and their designer Anna-Mari Leppisaari into acoustic hard-set prototypes (see Appendix 2). Since one of the key factors of an acoustic fabric is to have a compact surface, hard-set fabrics that are used for example as roller blinds, should be effective absorbers. The glue used as a stiffening in hard-set yarns spreads when the fabric is heated and closes excessive air gaps within the microstructure of the fabric. I discussed with a weaving technician Fabrizio Brignoli, and we decided to add a flat Lurex film yarn (PES) on the background of each fabric for even denser outcome.

In addition to the developed hard-sets I wanted to create a set of versatile prototypes, where the main ideas consisted of layered structures and different material try-outs. I ended up designing 11 novel fabrics (see Appendix 2). The majority of the novel designs were woven as two weft system structures, where the background wefts create a dense surface, and the foreground wefts form a soft and porous surface. Almost all of the novel prototypes had Lurex film yarn (PES) as the background weft yarn, since that same solution was used in all of the example fabrics on the market. Only two designs were made without the film yarn, and I tried to create a dense but thin background with other material choices. The used warps were chosen because of their varied thicknesses and structures for receiving wide range of results.

Fig. 4.8 Modified hard-set fabrics 23115, 23112, 23111, 20109 and 23120, designs by Lodetex.
Fig. 4.9 Novel designs.

Fig. 4.10 All cycle no. 1 prototype fabrics.
Fig. 4.11 Two designs (23182 & 23183) without the Lurex film yarn.

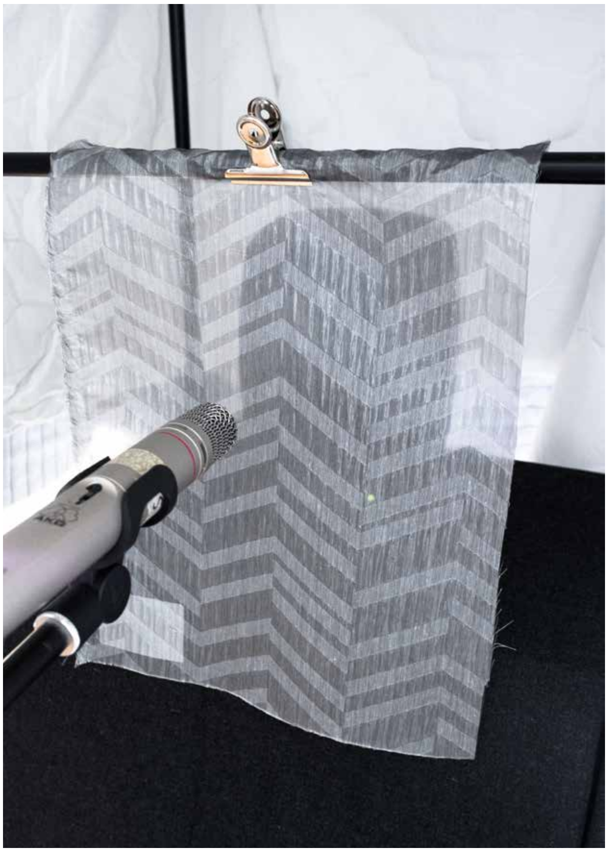


Fig. 4.12 Testing design 23178 at home.
Fig. 4.13 Kvadrat's choices from development cycle no.1.

Testing

All the prototype fabrics from the cycle n.1, except for one developed hard-set fabric, were tested in the certified test laboratory Müller-BBM in Germany after the prototyping phase (see Appendix 3). As with all acoustic tests, the laboratory did only the preliminary flow resistance testing, and the results were then analyzed and estimated. Only five of the tested fabrics had good or average results. Within the top five prototypes were two modified hard-set fabrics and three novel designs.

Results from Müller-BBM (from best to worst):

- 23111 – 143 g/m², R_s 869, medium high
- 23131 (air blow + ironing) – 177 g/m², R_s 828, medium high
- 23131 (ironing) – 172 g/m², R_s 702, medium high
- 14957 (print ground with Lurex film yarn) – 36,5 g/m², R_s 556, medium
- 23132 (air blow + ironing) – 101 g/m², R_s 417, medium
- 23132 (ironing) – 99,8 g/m², R_s 367, medium
- 23109 – 209 g/m², R_s 268, low
- 23183 – 211 g/m², R_s 236, low
- 23182 – 138 g/m², R_s 177, low
- 23181 – 69,2 g/m², R_s 149, low
- 23179 – 69,2 g/m², R_s 115, low
- 23112 – 87,6 g/m², R_s 93, very low
- 23180 – 69,9 g/m², R_s 60, very low
- 23138 (air blow + ironing) – 158 g/m², R_s 58, very low
- 23138 (ironing) – 161 g/m², R_s 50, low
- 23178 – 55 g/m², R_s 43, very low
- 23174 – 73,9 g/m², R_s 37, very low
- 23175 – 89,6 g/m², R_s 35, very low
- 23120 – 198 g/m², R_s 32, very low

Before receiving the airflow resistance results from Müller-BBM, I created my own tentative test method to see whether it would be possible to test acoustic performance at home. Since I did the testing in my living room, I was not able to create standardized test conditions, but still I managed to get comparable results. Based on the tentative test results I was able to rank the first prototypes roughly, and once I received the airflow resistance results from Müller-BBM, I realized that my results correlated with the laboratory results. Even though the tentative test only records sound that passes through the prototype fabric — meaning that it does not show whether the sound absorbs within the fabric or just reflects from the surface — the airflow resistance results revealed that none of the prototype fabrics should reflect sound that much. The reflection of sound occurs if the airflow resistance value (R_s) rises well over 1000.

Later on Kvadrat wanted to have the acoustic tests done for four of their chosen fabrics from the first prototypes (see Appendix 4). Müller-BBM tested both the flow resistance values and the sound absorption coefficient values from those prototypes. The tested prototypes were one modified hard-set fabric (23112), and three novel designs (23175, 23178, and 23181). The sound absorption coefficient results were unsatisfying, though it was known already from my tentative test that those fabrics would not achieve any high results.

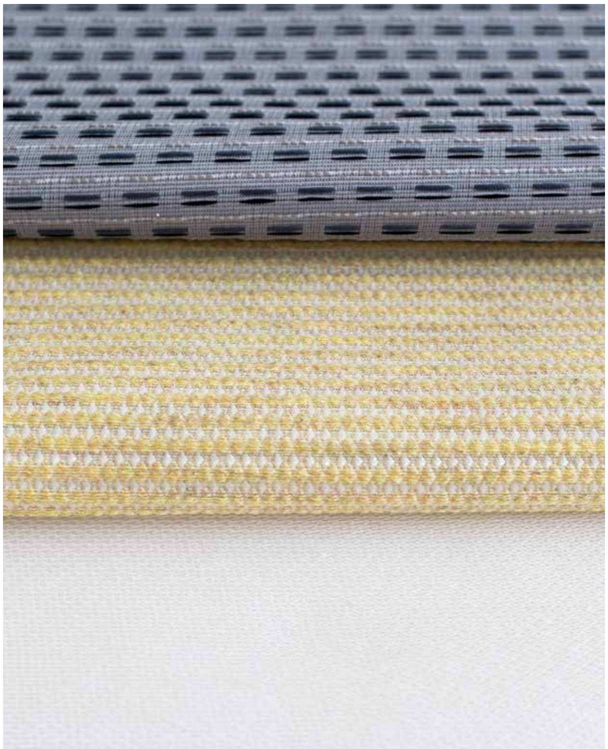
Kvadrat results from Müller-BBM (from best to worst):

- 23181 – 68 g/m², R_s 117, α_w 0.45, class D
- 23112 – 86,6 g/m², R_s 70, α_w 0.40, class D
- 23178 – 66 g/m², R_s 48, α_w 0.30, class D
- 23175 – 100 g/m², R_s 34, α_w 0.25, class E

Design 23181 showed the best result out of the four prototypes. With the given alpha values, I was able to compare it with the example acoustic fabrics from the market. Example fabrics all have an alpha value of 0.50, which is only 0.05 higher than the alpha value of 23181, but none of those fabrics achieve as low weight as 23181. So even though the feedback from the results was negative, I still consider that the design 23181 is a fairly well performing acoustic fabric in that weight range.

23181 compared to some example fabrics in the current market:

- 23181 – 68 g/m², R_s 117, α_w 0.45, class D
- Annette Douglas' Liquid classic – 88 g/m², α_w 0.50 D
- Vescom's Carmen – 91 g/m², α_w 0.50 D
- Création Baumann's Gammacoustic – 74 g/m², R_s 118, α_w 0.50 D
- Création Baumann's Terzacoustic – 70 g/m², R_s 91, α_w 0.50 D



Analyzing

I analyzed the combined results of the airflow resistance test and my own tentative test together with associate professor in virtual acoustics at Aalto University Tapio Lokki. We realized that the samples with the highest results have bigger surface area due to three dimensional surface created with weave structures and different weft yarns thicknesses. The designs 23111 and 23131 had the highest results and clearly bigger surface area than other prototypes. Design 23132 also had a good result considering that it is more translucent than several other prototypes. The surface of that fabric seems to be dense but still porous with a lot of air cavities. From the analyzed data Tapio advised to focus on increasing the surface area through structural and material choices. He also pointed out, that with layered structures the surface should have some kind of tension or stiffness in order to create a working air pocket structure. All of the layered prototypes had too porous surfaces for creating any effective air pockets in between the layers.

One important point, that was realized from the test results, but that had not come up in the literature research about woven acoustic fabrics, was the influence of the fabric finishings to the absorption ability. Three of the novel designs were tested with two different finishings to see whether finishings would affect the results at all. The tested finishings were air blow drying with ironing and only ironing. The results showed that all of the fabrics with air blow and ironing had clearly better airflow resistance values, which I believe is caused when the fibers open during the air blow, and that increases the microstructural surface area.

- 23131 with air blow & ironing – 177 g/m², R_s 828
- 23131 with only ironing – 172 g/m², R_s 702 (R_s difference of 126)
- 23132 with air blow & ironing – 101 g/m², R_s 417
- 23132 with only ironing – 100 g/m², R_s 367 (R_s difference of 50)
- 23138 with air blow & ironing – 158 g/m², R_s 58
- 23138 with only ironing – 161 g/m², R_s 50 (R_s difference of 8)

Clearly most of the samples failed in the tests due to too low surface density. Though that failure was expected, since the development work had started from zero. All the fabrics with the best results were woven with Linda warp, which is the thickest of the thin Trevira CS warps used at Lodetex. It seems that this particular warp creates a bit denser surface, which is needed for the acoustic curtain fabrics.

Comparing the client inquiry requirements given by Kvadrat and Silent Gliss (see Appendix 5), designs 23132 and 23181 ranked as the best ones. Both of those designs had all the qualities, that the clients were looking for, although only design 23132 had an average acoustic performance. Those two designs were chosen for further development in the second product development cycle.

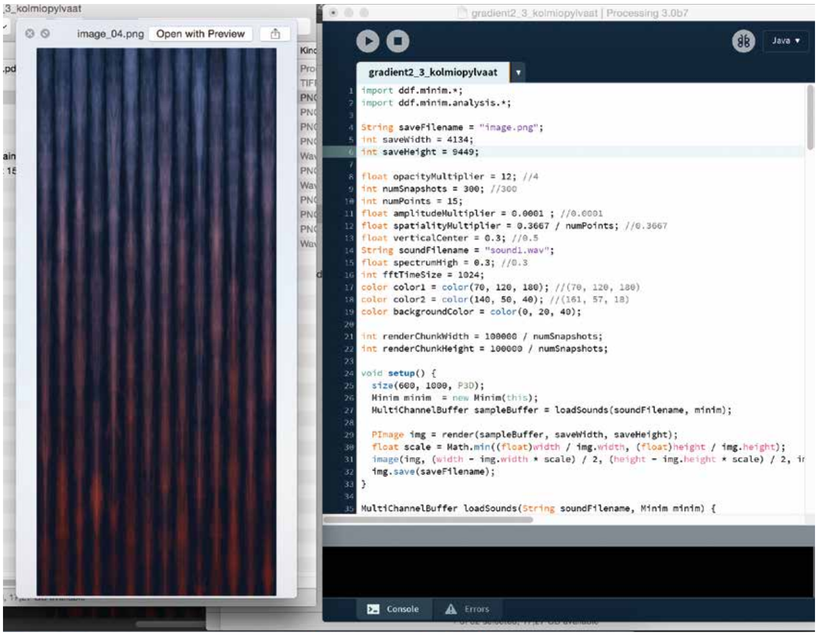
Fig. 4.14 Designs 23111, 23131 and 23132 with highest results.
Fig. 4.15 Design 23181 ranked as one of the best according to the client inquiry requirements analysis.

Developing

Based on the analysis I created a list of qualities that seemed to work, and that should be developed further. I also went through all of the prototypes and figured out what would be the best way to develop each of them. Additionally I listed the most suitable weft yarns to be used with different thicknesses and structures. The created yarn list included flat film like yarns, flat and open (not twisted) yarns, flat and open hard-set and shrinking yarns, hairy yarns, porous natural yarns, and thicker special yarns. For the second cycle I wanted to incorporate also digital printing, since I had not been seeing that used in any acoustic curtain fabrics. I decided to use at least two working designs from the first prototyping phase (23132 and 23131 modified as polyester) as digital print grounds for the second cycle.

Good qualities to focus on during the second development cycle:

- increased surface areas with material choices and weave structures
- dense surfaces with right weaving densities and background bindings in two weft system structures
- air blow finish whenever possible
- layered structures with denser surfaces
- thicker warps
- flat open yarns for the background wefts, and heavier porous and hairy yarns on top for adding the surface area



STEP 3 – CREATING VISUALS

I have been interested in digital sketching for a couple of years now, so I wanted to incorporate that into the work. The latest digital sketching method involved audio responsive animation, where visuals are created by the played audio. Therefore it felt natural for me to continue with those, and to create the whole visual concept from sound. In the end I decided to use two different sketching mediums: digital sound responsive computer sketching and material cymatics sketching. All created sketching tools and programs were made in close collaboration with a programmer and an audio enthusiast Jouko Saastamoinen.

Since my workflow was experimental and intuitive, I decided to create a very loose visual concept without too restricting collection thinking. The chosen color map was quite loose, because the work did not include any proper collection thinking. I chose a color map based on the natural tones, that appeared in the initial client inquiry answers with some additional stronger colors.

Digital Sound Sketching

All digital sketching programs were made with a software called Processing. Processing is a development environment and a programming library specialized in producing and manipulating sound and visuals. Processing is built especially for visual artists, designers, and architects to create visual material with coding. (Processing.) All the small programs were written by Jouko Saastamoinen out of visual ideas and instructions that I gave to him. As Jouko (21.6.2016) explained, the programs analyze different aspects of the sound input, such as the frequency spectrum and the wave shape, and transform that analysis into shapes and colors. We created four different programs for versatile sketching. The first two program variations (Waves and Noise) render the visuals real-time from the played audio, so the visual appearance is an animation that the played audio directs. The latter two program variations (Interference and Color Gradient) draw one still image from an audio file that is linked to the code.

Fig. 4.16 Sketching with Processing.

Waves

- visual idea – would it be possible to create a sound landscape?

These programs draw the sound wave shapes from audio that is played real time. The scenery effect is created when the most recent sound clip is rendered at the bottom of the screen, and the previous ones move upwards and on top of each other on every frame. The line thicknesses are modulated by the changes of the volume. (Jouko Saastamoinen 21.6.2016.) I did tryouts with several different sounds, including classical music, techno, and nature sounds.

- created – five woven jacquard patterns and one digital print pattern

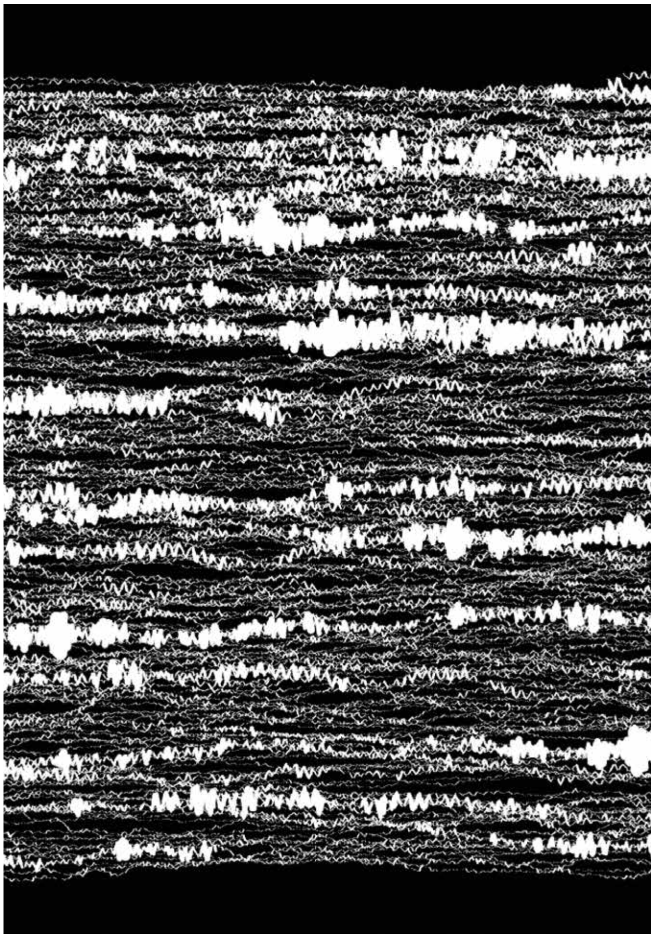
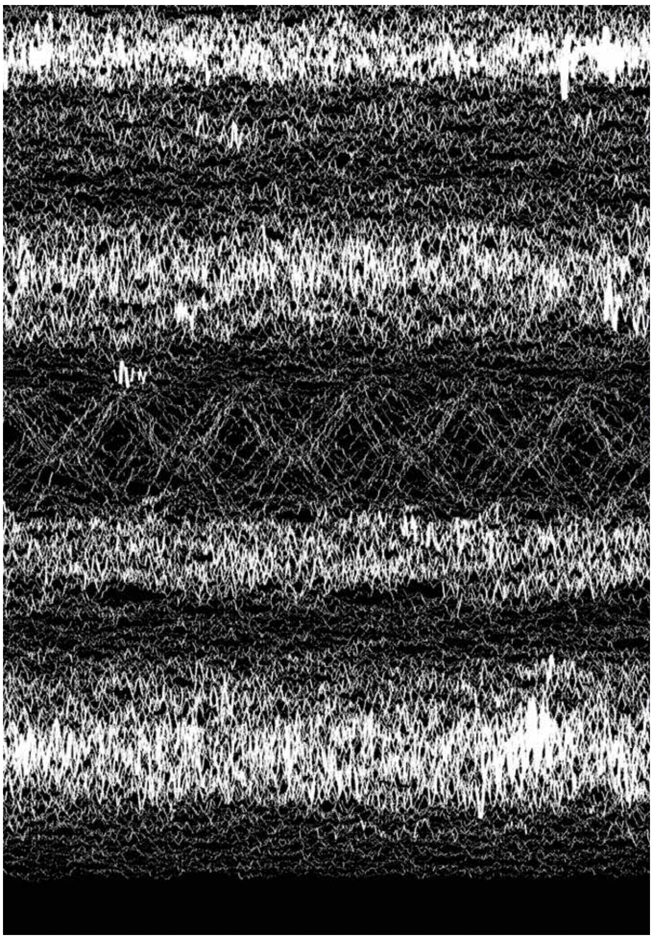
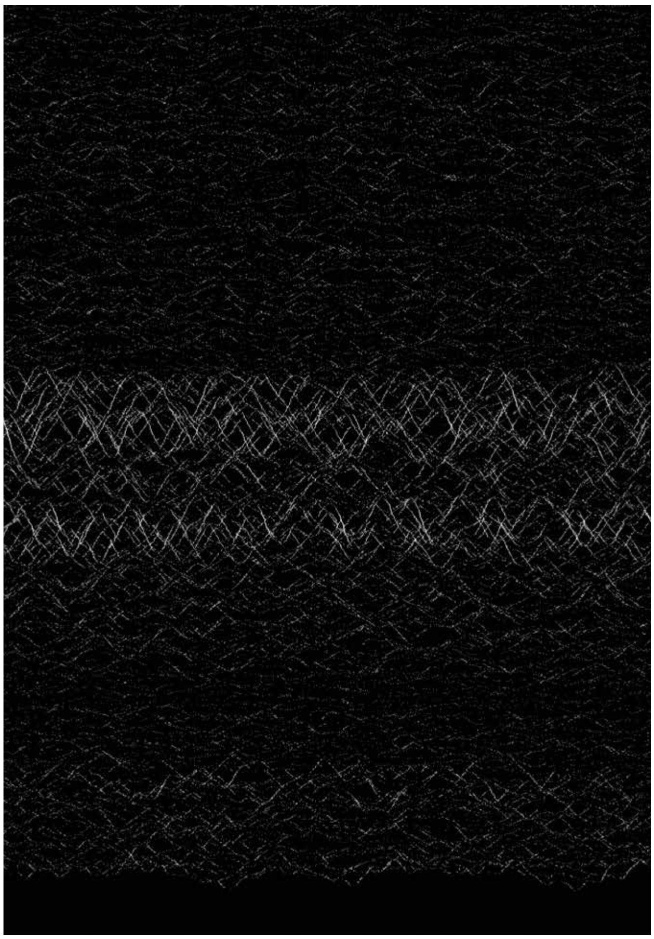
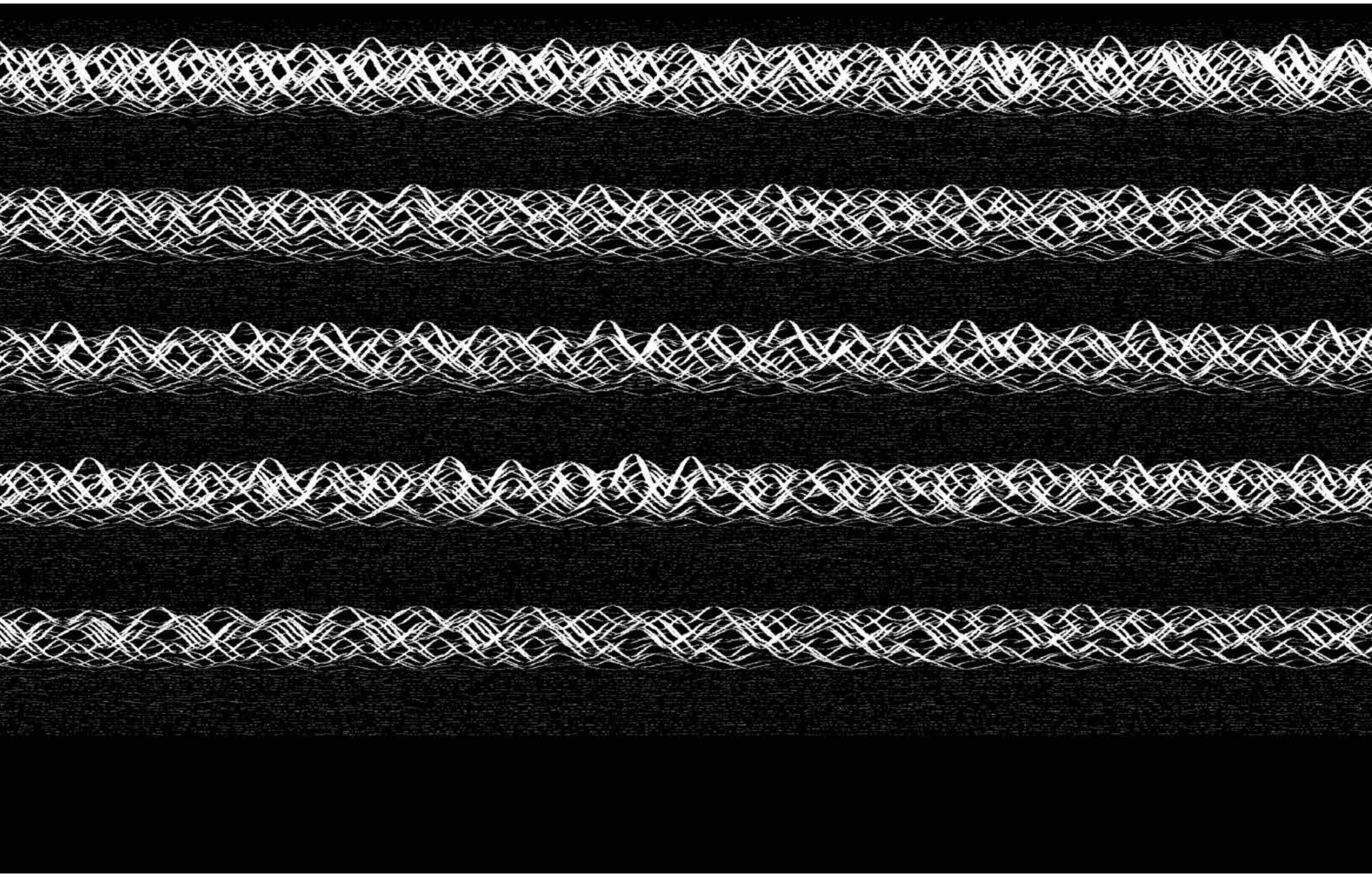


Fig. 4.17 Waves created while playing techno.
Fig. 4.18 Ocean and whales waves.
Fig. 4.19 Waves from Mozart’s Requiem in D Minor.







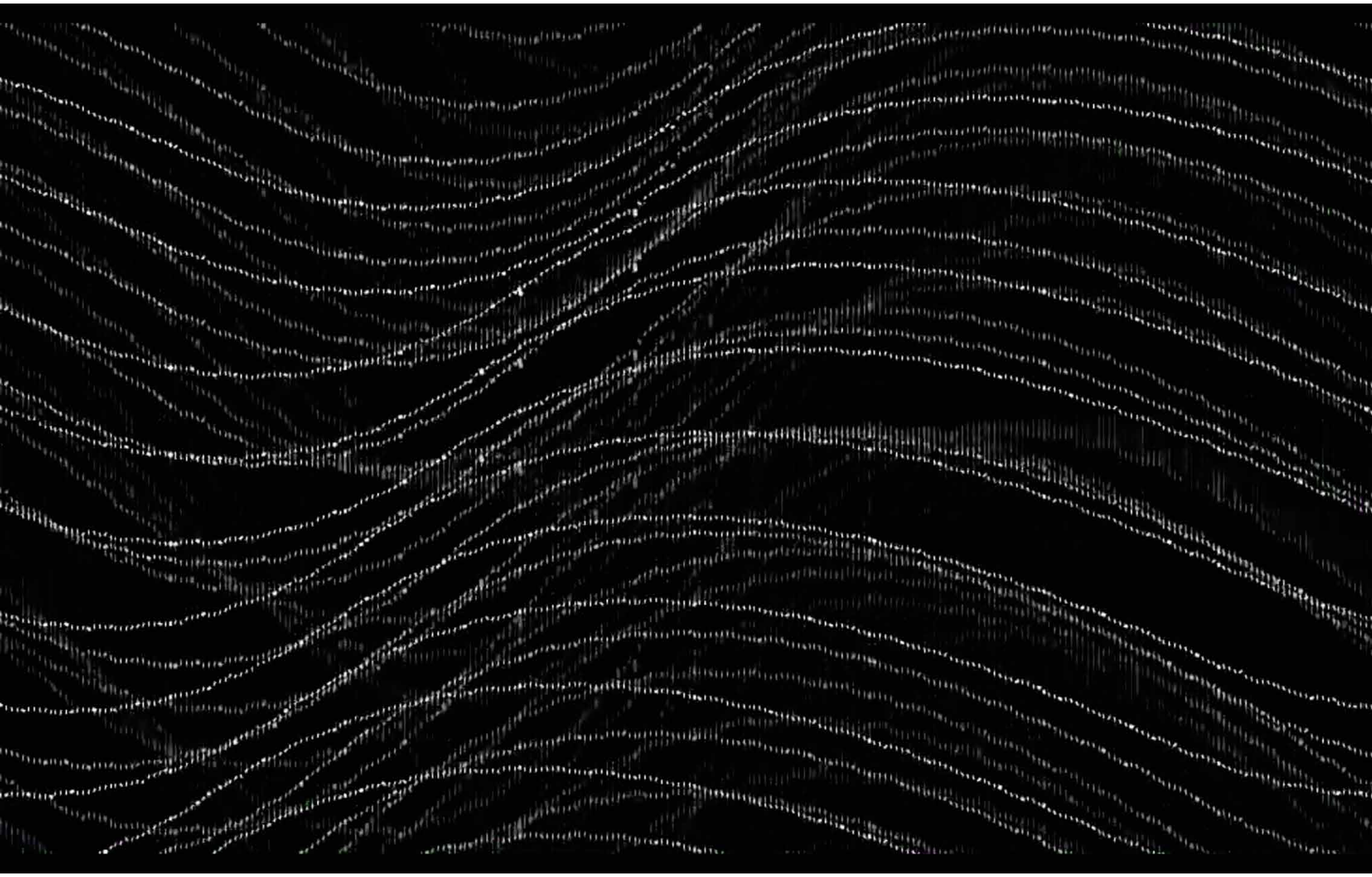
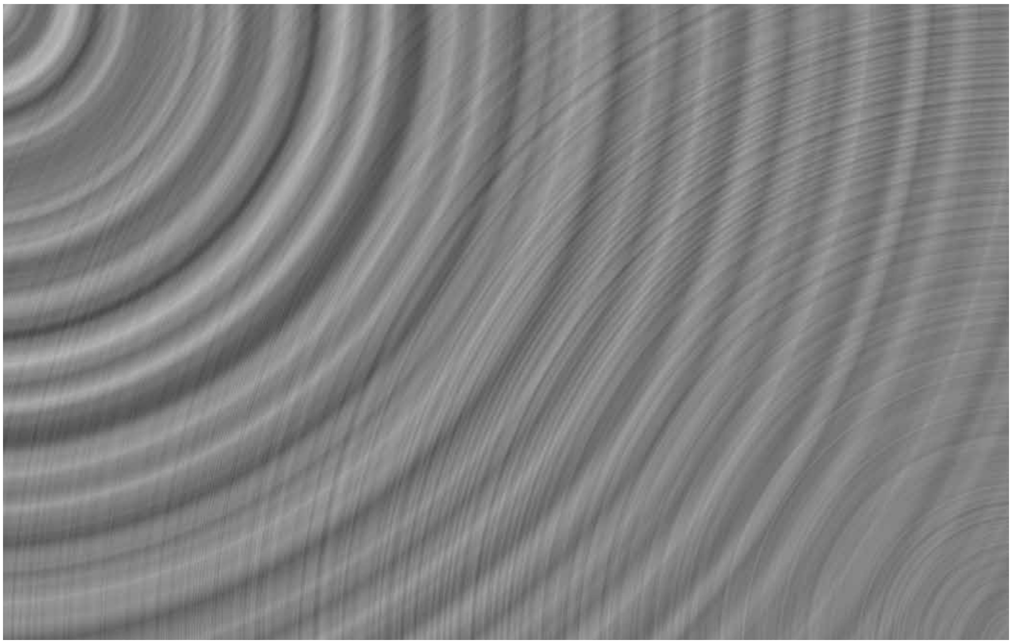
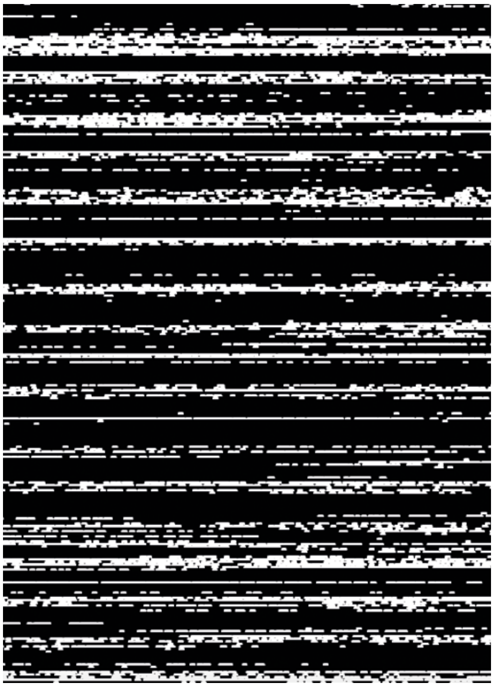


Fig. 4.20 Waves created with loons singing.
Fig. 4.21 Playing with synthesizer.





Interference

- visual idea – how would it look like if two songs were played simultaneously?

Interference program draws the wave shape as outward propagating rings, of which the brightness is determined by the value of the sound signal at the time instant. The center of the ring shape is the beginning of the audio from where it grows. In this example two different songs are rendered on the opposite sides of the screen and blended together. The program creates one image of the interference pattern. (Jouko Saastamoinen 21.6.2016.) Due to the homogeneous look of the visual, I ended up doing only one sketch with this program.

- created – one woven jacquard pattern

Noise

- visual idea – how would sounds look like if they were just points and lines?

Noise programs visualize the volume of played audio as different length horizontal lines. The louder the volume is, the longer lines the program renders. If the volume is low enough, then there is only an empty space. Otherwise these programs have the same operating principle than the wave programs. (Jouko Saastamoinen 21.6.2016.) I did a few different sketches with both audio noise (white and pink noise) and natural sounds.

- created – three woven jacquard patterns

Fig. 4.22 Interference pattern created with two songs: The Weight of Gold by Forest Swords and Transmisiones Ferox by Boards of Canada.
Fig. 4.23 Noise sketch created with the sound of walking on snow.
Fig. 4.24 Noise sketch from listening pink noise.

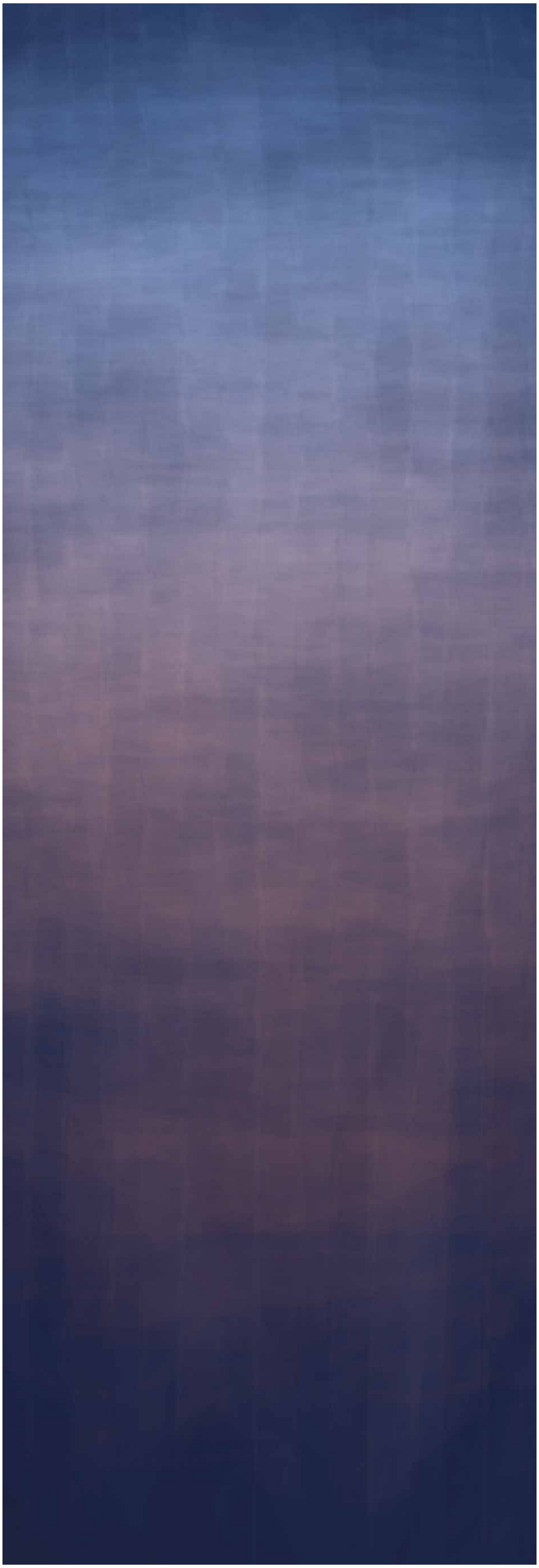
Color Gradient

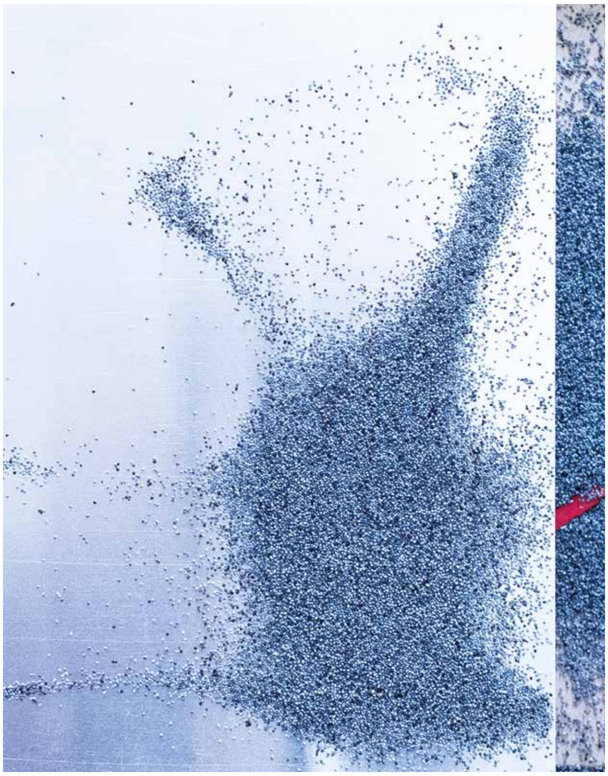
- visual idea – how would a song look like if it were just colors?

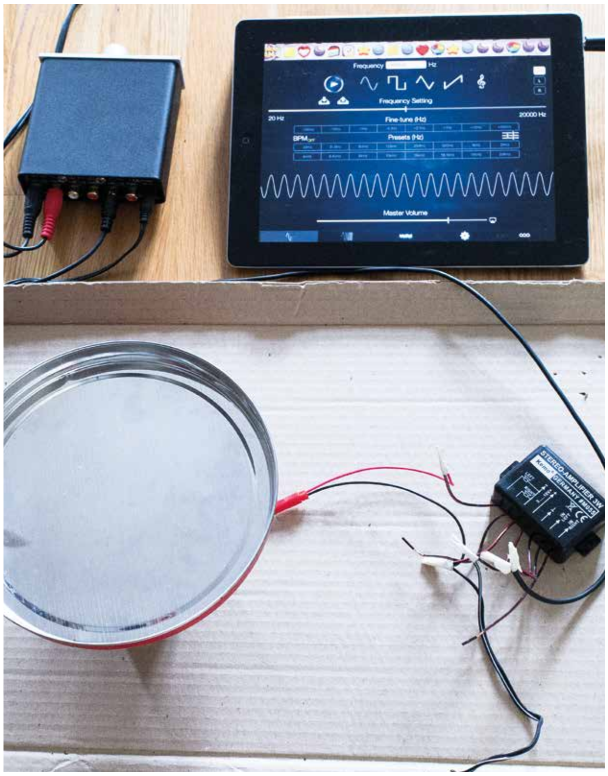
Color gradient programs are the most complex of all the audiovisual sketching programs, and they could be referred to abstract paintings. There are several variables that generate the final image that is created with several hundreds of different polygon shapes in different colors, that blend together creating a gradient. The shapes, colors and positions of each polygon are determined differently. Colors of each polygon are determined by the dominant frequencies of the audio, meaning that the low frequencies are appearing mostly as one of the assigned basic colors, and the high frequencies are appearing as the other assigned color. The code consists of also a background color that mixes with the two basic colors, and that appears in places where only few polygons are rendered. The positions and shapes of each polygon are calculated from other characteristics of the audio, such as differences of the left and right channels in stereo sound. (Jouko Saastamoinen 21.6.2016.) Within these programs I was able to create several tryouts with different sounds and different variables. It was also possible to control the positions of the polygons more precisely and to create vertical columns that appear almost like the pipes of an organ.

- created – two digital print patterns

Fig. 4.25 Color Gradient sketch from The Weight of Gold by Forest Swords.
Fig. 4.26 Vertical columns sketch from piano music.



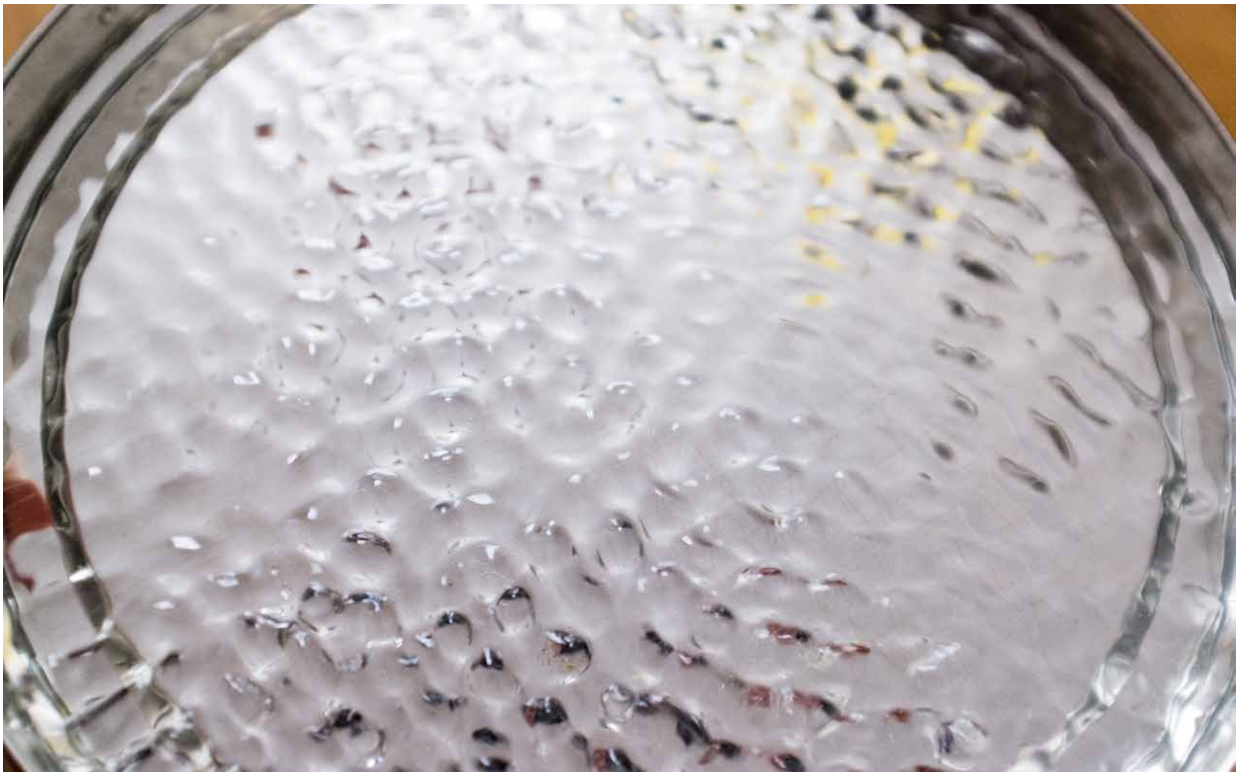





Material Sound Sketching

Along with the digital sketching I also wanted to incorporate material sketching somehow with the sound concept. I started reading about the topic of cymatics and discovered it to be an interesting tool, that could be utilized in visual sketching. Since cymatics is basically about vibrating materials with sound, I needed to build a machine for it. Together with Jouko we built a small cymatics system with a speaker, an amplifier and a preamplifier. Low frequency sine waves generate the most suitable vibration for home experimentation, so those were used in the tryouts. I experimented with different vibrating mediums, such as poppy seeds, water and oobleck. All the tryouts were documented either as videos or still images.

Fig. 4.27 First tryout with poppy seeds.
Fig. 4.28 Material sound sketching setup.
Fig. 4.29 Vibrating water.



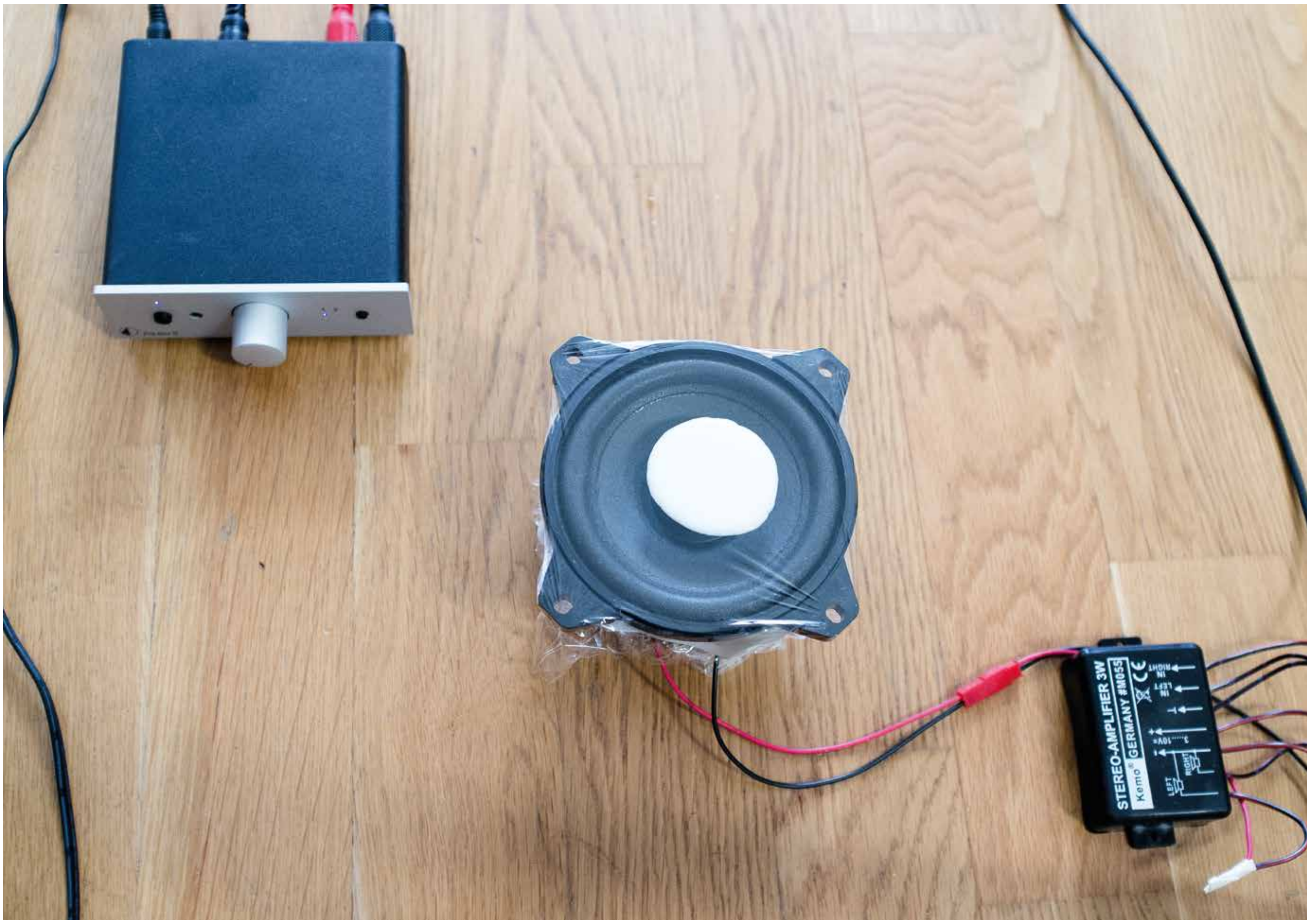
Vibrating Water

- visual idea – will there be structural patterns if water is vibrated?

I started experimenting with vibrating poppy seeds but quickly changed to water, since liquid proved to be easier medium for creating structural patterns.The appearing three-dimensional patterns are dependent on the played amplitudes, meaning both the frequency and the volume of the sound (Cymatic Music 2010). I placed a metal dish on top of a speaker, poured water on it, and vibrated the system with low frequency sine waves. Different structural patterns appeared on water that resembled cell and honeycomb structures.

- created – two woven jacquard patterns



Oobleck Marble

- visual idea – could sound paint an abstract figure?

Oobleck is an intriguing material, since it is a non-Newtonian fluid that has both liquid and solid nature. It is a mixture of 1 part water and 1.5 or 2 parts of cornstarch. If enough force is directed to oobleck, it will instantly thicken. Therefore it is possible to even quickly walk on it. If the force is not strong enough, the material will become liquid. When oobleck is put on top of a speaker of a subwoofer, the low frequencies played at high volume cause the material to thicken, and to start forming vertical moving figures in response to the played frequencies. (Lifescience 2012.) I did some experimentation with mixing oobleck with paints, and realized that when a drop of ink was placed on top of oobleck, it started mixing itself creating a marble pattern.

- created – one digital print pattern

Fig. 4.30 –4.33 Oobleck marble figures used in the digital print pattern.
Fig. 4.34 & 4.35 Oobleck sketching setup.

STEP 4 – PRODUCT DEVELOPMENT CYCLE NO.2

The second development cycle started once I returned to the weaving mill in Italy after my internship. I created a set of over 30 novel designs over five weeks, and I also executed the tentative testing to some of the prototype fabrics during this phase. My initial plan was to do several test rounds, and to develop prototypes further based on the results. Though I was not able to proceed that way, since many of the designs had to be woven simultaneously one after the other. That was due to the used Lurex film yarn, that acquires a special part in the weaving machine for holding the yarn cone. All of the produced prototype fabrics were tested by me later, and a selection of prototype fabrics were also tested at Müller-BBM for the flow resistance test. Test results were then analyzed. The second cycle is without the developing phase at the end, since this thesis work does not include any later development cycles. Though because of the client interest, the prototypes are to be developed further in the future.

Prototyping

During the intensive prototyping phase I created a list of design solutions I wanted to try out. I aimed at more experimental work rather than merely analytical. That decision was necessary for allowing myself to stay in a relaxed workflow. Even though some of the prototype fabrics may look more like shower curtains than soft and drapable interior curtain fabrics, it was important during the process to try also some quirky designs for finding the most fitted solutions.

The same experimental mindset was linked in the visual design process. The two interested clients were looking for plain structures, and in addition to those I wanted to offer also patterned designs. Since Lodetex is known for their several jacquard looms, I wanted to emphasize the possibilities of creating patterned acoustic curtain fabrics at the side of the simple designs. Almost all the designed prototype fabrics have a sound story behind the visual appearance. I kept a sound diary for the audio that I was listening to and that was used as a structural and emotional inspiration for the design work (see Appendix 6).

Altogether I designed and produced 26 novel woven prototype fabrics and 5 digital print patterns, that were printed in 4 different print grounds (see Appendix 2). Eight of the novel designs were done without the use of Lurex film yarn (PES) for figuring out best solutions to replace the plastic look and feel, that the film yarn creates in the fabrics. Two of those fabrics were also designed as hard-set fabrics for blinds and panels. For the most parts I decided to use the thicker Trevira CS warp Linda due to its good results in the first cycle, though I used also other looms for creating a more versatile outcome.

Fig. 4.36 Design 23379 being woven at Lodetex.
Fig. 4.37 Cycle no. 2 prototypes.

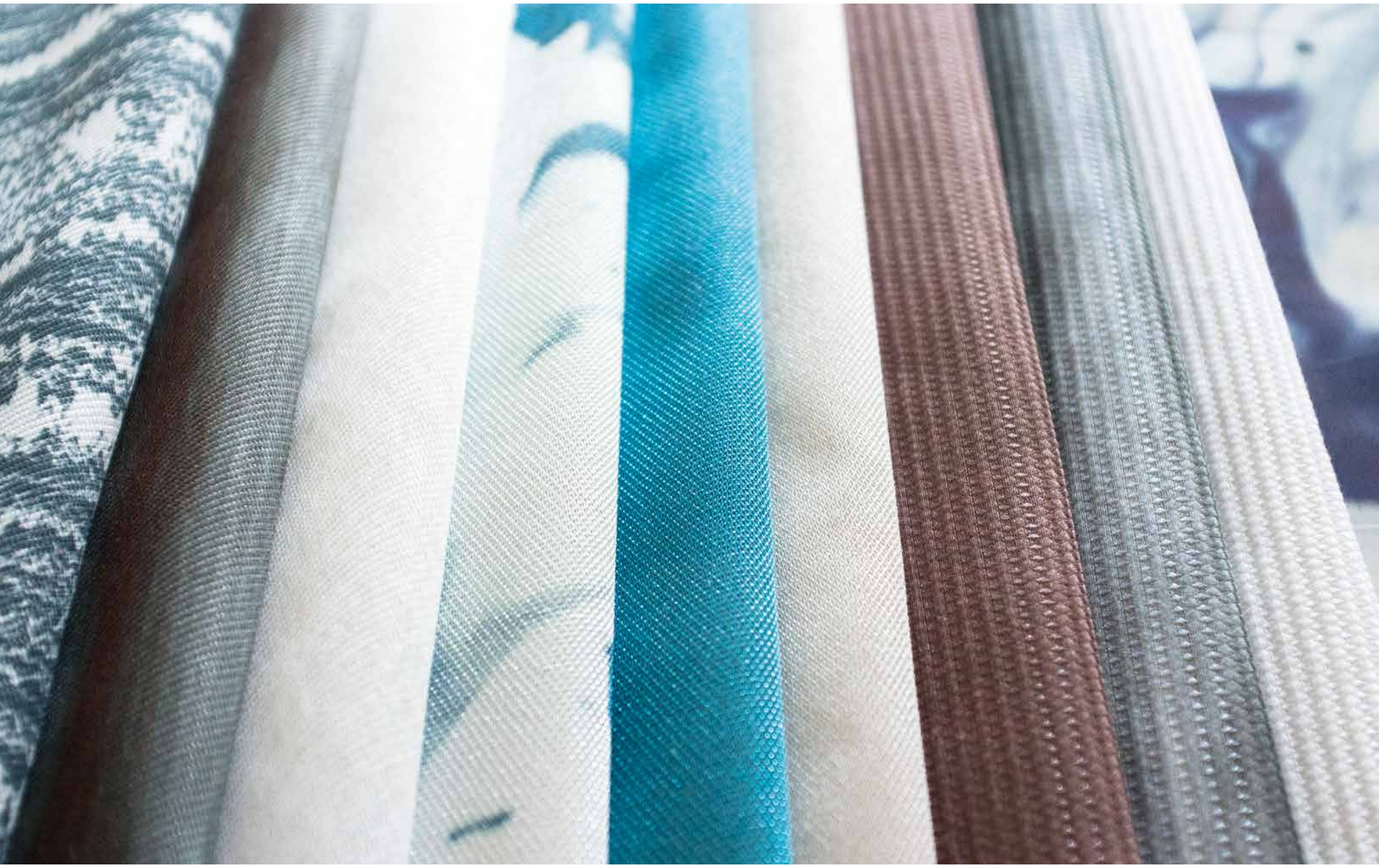


Fig. 4.38 Digitally printed prototypes and the print grounds.
Fig. 4.39 Two designed hard-set fabrics without the Lurex film yarn.

Testing

I executed the first tentative test in the weaving mill premises during the prototyping phase. The test environment was not ideal, because the space was big and empty, and the recorded sound was difficult to isolate without excessive echoes. But still I managed to test 11 new prototypes with the first cycle prototypes, and to place them in a rank order from best to worst. The test showed that 10 out of 11 new fabrics should have better acoustic performance than any of the first prototype fabrics with an R_s value less than 230, and that three of the new prototype fabrics (23355, 23358 & 23368) should have an R_s value of over 400. The later airflow resistance test proved that design 23355 has a value of R_s 531, design 23358 has a value of R_s 494, and design 23368 although was not tested for R_s, should have an R_s value close to 370. The tentative test proved that the results were getting better, and that the development cycle had been successful.

Once I received all prototype fabric samples in small sample size, I was able to conduct two additional tentative tests at home. From those tests I created a final list of all prototype fabrics produced for the project ranking them from best to worst. Based on those results the CEO of Lodetex Shahrokh Farhanghi chose 13 prototype fabrics from the second cycle for the flow resistance test conducted at Müller-BBM (see Appendix 3).

The results from Müller-BBM showed that four of the tested fabrics (23362, 23348, 23372 and 23345) have an ideal flow resistance value for sound absorption. The next five fabrics (23371, 23364, 23361, 23358 and 23355) have slightly lower airflow resistance values, but they should still have at least an average sound absorbing performance. In Müller-BBM's opinion the weights of all the tested fabrics are relatively low for acoustic use, since the weight standards for suitable sound absorbers should be more than 200–300 g/m^2 according to them. That does not correlate in any way with the weights that the lightweight acoustic curtains are targeted to. So in this case all the results are showing weaker in Müller-BBM's evaluation due to the low fabric weight.

Fig. 4.40 Tentative test done at Lodetex's promises in Italy.
Fig. 4.41 Prototype fabrics from best to worst based on the flow resistance results.

Results from Müller-BBM (from best to worst):

- 23362 – 137 g/m², R_s 1106, medium high
- 23348 – 126 g/m², R_s 976, medium high
- 23372 – 219 g/m², R_s 804, medium high
- 23345 – 184 g/m², R_s 729, medium high
- 23355 – 141 g/m², R_s 531, medium
- 23358 – 158 g/m², R_s 494, medium
- 23361 – 111 g/m², R_s 370, medium
- 23364 – 122 g/m², R_s 365, medium
- 23371 – 124 g/m², R_s 363, medium
- 23366 – 124 g/m², R_s 337, low
- 23381 – 95,3 g/m², R_s 321, low
- 23347 – 70,1 g/m², R_s 309, low
- 23360 – 148 g/m², R_s 303, low

Analyzing

Based on the test results I categorized all the first and second development cycle prototype fabrics into 10 groups from best to worst (see Appendix 7). According to my tentative test, the acoustic performance should be quite similar inside each group, so even though the R_s value was not tested from all of the fabrics, grouping should reveal the approximate R_s value range.

According to the tentative test around 20 fabrics from the second cycle should have an R_s value of over 200. All cycle n.2 fabrics were rated better than cycle no.1 fabrics with an R_s 149 or lower, meaning that the second cycle has been successful, and all the developments from the first cycle have improved. Even though the optimum R_s value would be 600–1000, all the acoustic fabrics of Création Baumann for example have v values of 163–229. The result does not directly indicate, that the majority of the prototype fabrics produced would have better sound absorption performance than Création Baumann's curtains, since the R_s values only give an estimate of the suitability as acoustic fabrics, but some hints can be seen that the development process is going to the right direction. In order for receiving comparable results, the prototype fabrics should be tested for the sound absorption coefficient values.

Design 14957, that is used as a general print ground at Lodetex, and that is woven with Lurex film yarn as the only weft yarn, had an R_s value 556 in the first Müller-BBM test, but within my tentative test it rated only to group 9. That is the only tested fabric with a deviant air flow resistance result compared to tentative test result order. I do not know exactly what caused the deviation, but maybe something went wrong during either my testing or the air flow resistance test. Or perhaps the fabric reflects more sound than it absorbs, and that causes the difference within the tests.

Fabrics without the Lurex film yarn were categorized in all groups except 1, 2 and 10. The result proves that it is possible to design acoustic curtain fabrics without the use of Lurex film yarn, though using that yarn seems to improve the sound absorbing ability, especially when it forms a dense background to the fabric. Transparent film yarn enhances the translucent effect of the fabric, though then it also adds the shine to the surface. Lurex film yarn also decreases the drapability of the fabrics, so the desired draping of a specific fabric should be considered before choosing the weft yarns. Since I focused on the high acoustic performance of the prototype fabrics, many of them are not that drapable, but those fabrics can be improved later on. Similarly the translucent look did not succeed in several fabrics due to the focus on acoustic performance, though that can also be improved later on with minor structural and material changes.

Digitally printed fabrics performed slightly weaker than the same fabrics without the digital print, however the differences are minimal. It might be that printing closes the fibre structures a bit causing the microscopic air cavities to decrease. Even so I would say that digital printing does not have that significant effect on the acoustic performance, that it should not be done in the future. With digital printing it is relatively quick and inexpensive to create different visual looks to interiors, so the benefits of digitally printed acoustic curtain fabrics could actually be greater than of patterned woven acoustic curtain fabrics.

With the comparison of the client inquiry requirements of Kvadrat and Silent Gliss (see Appendix 5), designs 23362 and 23347 ranked as the best ones, and design 23358 ranked as third best. Design 23362 clearly has the best R_s value (R_s 1106), and that design got picked up for further development by Kvadrat due to the prototype's good respond to Kvadrat's requirements. Even though design 23347 do not possess that high R_s value, it is able to compete with other prototypes because of it's really sheer and soft feel.

Fig. 4.42 All prototype fabrics without the Lurex film yarn.
Fig. 4.43 Designs 23362, 23347 and 23358, that were most suited with the client inquiry requirements.

STEP 5 – WOVEN SOUNDS / THE IDEA COLLECTION

The fabrics produced within this project are still prototype fabrics, and together they create a collection of structural and visual ideas. The set of prototype designs include curtain fabrics for several uses; sheers for bringing light and airiness to the space, heavier curtain fabrics to give more privacy and protection from direct sunlight, and stiff fabrics to be used as panels or roller blind curtains. All the designs are based on sounds, and therefore the idea collection is categorized into three different sound themes: Organic Nature, Electronic, and Everyday Abstract. The presented designs possess either a great potential as functional acoustic curtain fabrics, or interesting structural and visual ideas for later improvements.

Organic Nature
streams running. grass whistling. lakeside birds calling. whales singing. total silence.

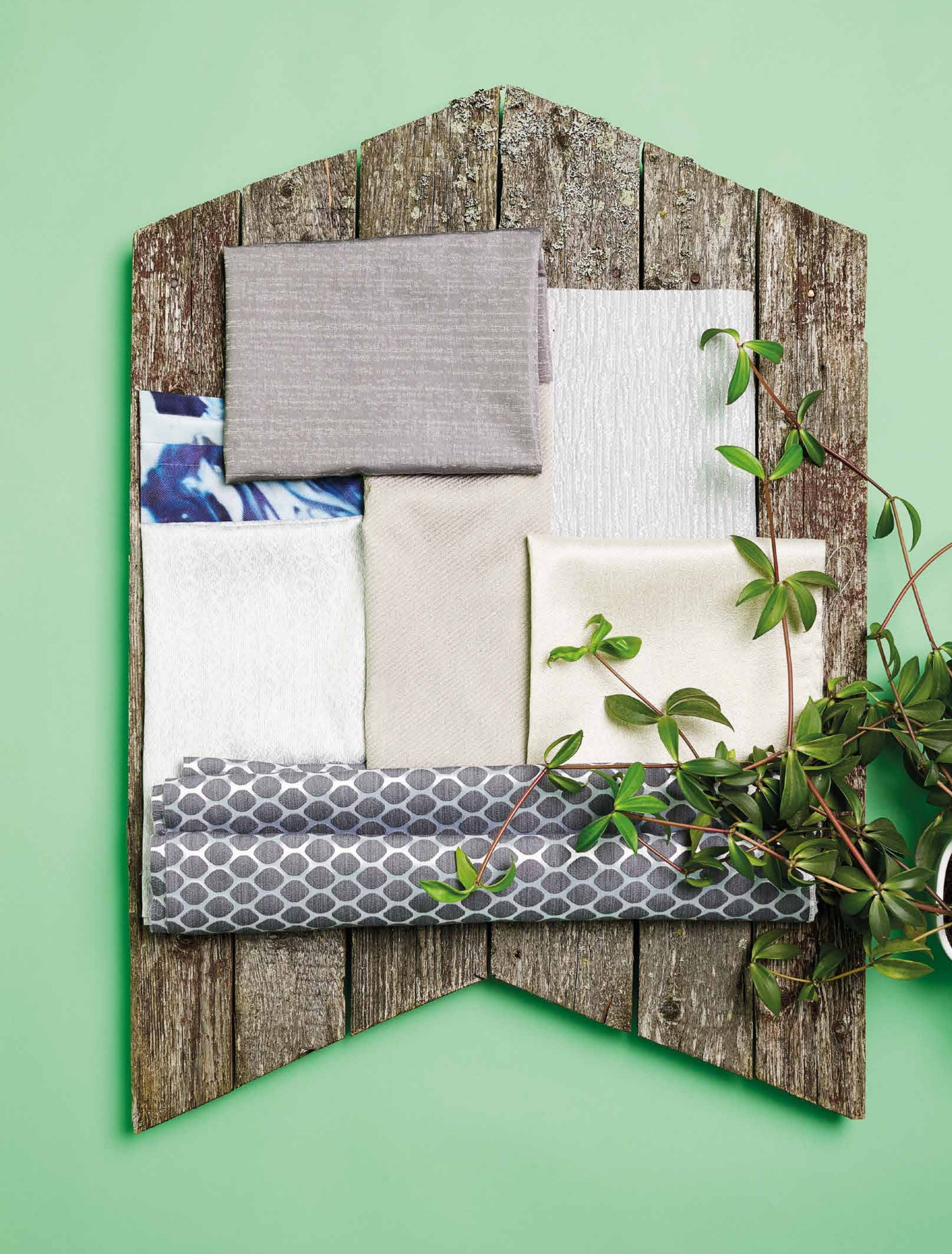
Electronic
electronic. techno. ambient.

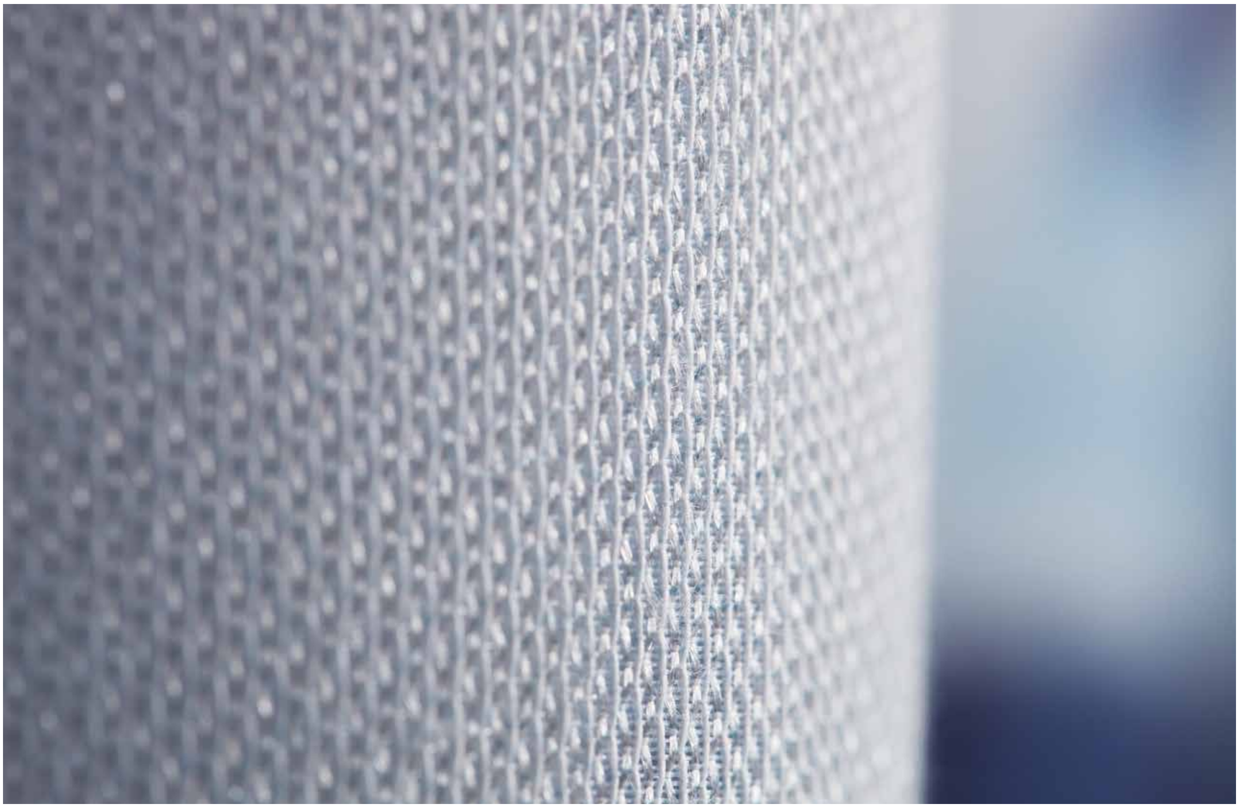
Everyday Abstract
office noises. classical music. walking. piano. Christmas.

ORGANIC NATURE

streams running. grass whistling. lakeside birds calling. whales singing. total silence.

Fig. 4.44 Organic Nature collection.





23132 DP 41025 / SINE WAVE MARBLE

sine waves are humming and buzzing while oobleck is dancing around the ink

design created with material sketching – Oobleck Marble
R_s 417 (print ground)
weight 101 g/m² (print ground)
tentative test group 4 (2–6 dB attenuation from 700Hz and up)
materials PES + Lurex film yarn (PES)

Fig. 4.45 & 4.46 Sine Wave Marble curtain.

23364 / LOONS

kuui-ko-kuui-ko-kuui-ko

design created with digital sketching – Waves
R_s 365
weight 122 g/m²
tentative test group 5 (1–5 dB attenuation from 700Hz and up)
materials TCS

23386 / WALKING ON SNOW

what a funny crunchy squeaking sound snow makes when you walk on it

design created with digital sketching – Noise
(R_s 150–200 based on the test group)
tentative test group 8 (0–3 dB attenuation from 700Hz and up)
materials PES + Lurex film yarn (PES)

23362 / WIND IN GRASS

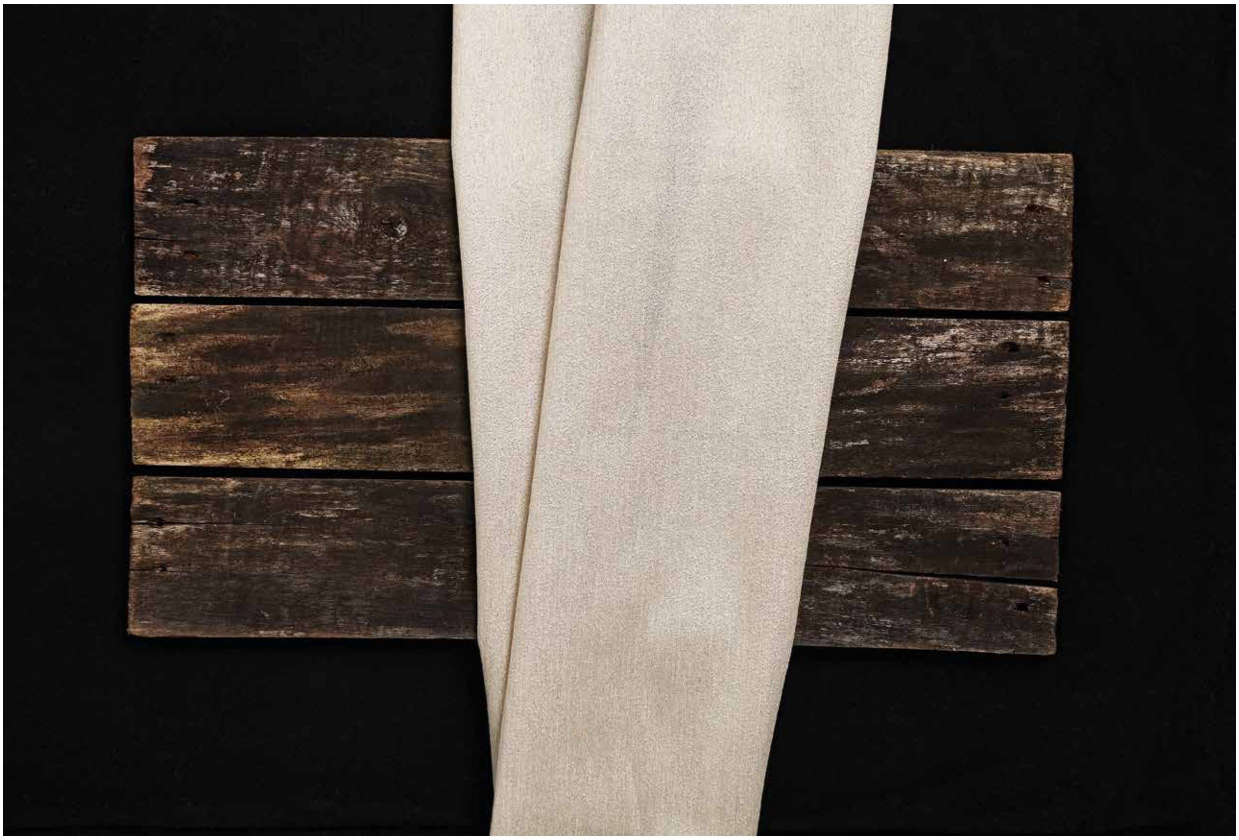
wushhshshsshhhss

design created with sound inspiration – wind in the grass
R_s 1106
weight 137 g/m²
tentative test group 5 (1–5 dB attenuation from 700Hz and up)
materials TCS + Lurex film yarn (PES)

23363 / MUTE

design created with sound inspiration – complete silence
(R_s 150–200 based on the test group)
tentative test group 8 (0–3 dB attenuation from 700Hz and up)
materials CV / WO + Lurex film yarn (PES)

Fig. 4.47–4.49 Close-ups of the designs.



23379 / CELLULAR WATER

how come humming sine waves can create such cellular structure to water surface?

design created with material sketching – Vibrating Water
(R_s approx. 300 based on the test group)
tentative test group 7 (0–3 dB attenuation from 700Hz and up)
materials WO / CV / TCS / PES

23376 / OCEAN AND WHALES

ancient ocean sounds wild, but under the surface whales are singing

design created with digital sketching – Waves
(R_s approx. 150 based on the test group)
tentative test group 9 (1–2 dB attenuation from 700Hz and up)
materials PES

Fig. 4.50 Cellular Water curtain.
Fig. 4.51 Design 23376 / Ocean and Whales.

ELECTRONIC

electronic. techno. ambient.

Fig. 4.52 Electronic collection.

23345 DP 41029 / ELECTRONIC GRADIENT

lows and highs of The Weight of Gold by Forest Swords

print design created with digital sketching – Color Gradient
R_s 729 (print ground)
weight 184 g/m² (print ground)
tentative test group 2 (4–7 dB attenuation from 700Hz and up)
materials TCS + Lurex film yarn (PES)

23347 DP 41027 / TECHNOSCAPE

techno DJ Joel Mull's wave landscape

print design created with digital sketching – Waves
R_s 309 (print ground)
weight 70 g/m² (print ground)
tentative test group 7 (1–3 dB attenuation from 700Hz and up)
materials TCS + Lurex film yarn (PES)

23381 / TECHNO STRUCTURE

still listening to Joel Mull

design created with sound inspiration – Joel Mull's techno playlist
R_s 321
weight 95 g/m²
tentative test group 5 (1–5 dB attenuation from 700Hz and up)
materials TCS + Lurex film yarn (PES)

Fig. 4.53 Electronic Gradient curtain.
Fig. 4.54 Design 23347 DP 41027 on the front, design 23381 on the back.

23348 / SIMPLE NOISE

pink noise – a continuous wash

design inspired by digital sketching – Noise
R_s 976
weight 126 g/m²
tentative test group 2 (4–7 dB attenuation from 700Hz and up)
materials TCS + Lurex film yarn (PES)

14957 DP 41029 / PLEATED GRADIENT

lows and highs (and the wrinkles) of The Weight of Gold by Forest Swords

print design created with digital sketching – Color Gradient
R_s not tested
tentative test group not tested
materials Lurex film yarn (PES)

23358 / DARK ENERGY WAVES

experimenting with Doepfer Dark Energy II synthesizer

design created with digital sketching – Waves
R_s 494
weight 158 g/m²
tentative test group 3 (3–6 dB attenuation from 700Hz and up)
materials TCS

Fig. 4.55 White design 23348 / Simple Noise and blue design 23358 / Dark Energy Waves.
Fig. 4.56 Design 14957 DP 41029 / Pleated Gradient.

23355 / INTERFERENCE

two songs playing cacophonously: The Weight of Gold by Forest Swords and Transmisiones Ferox by Boards of Canada

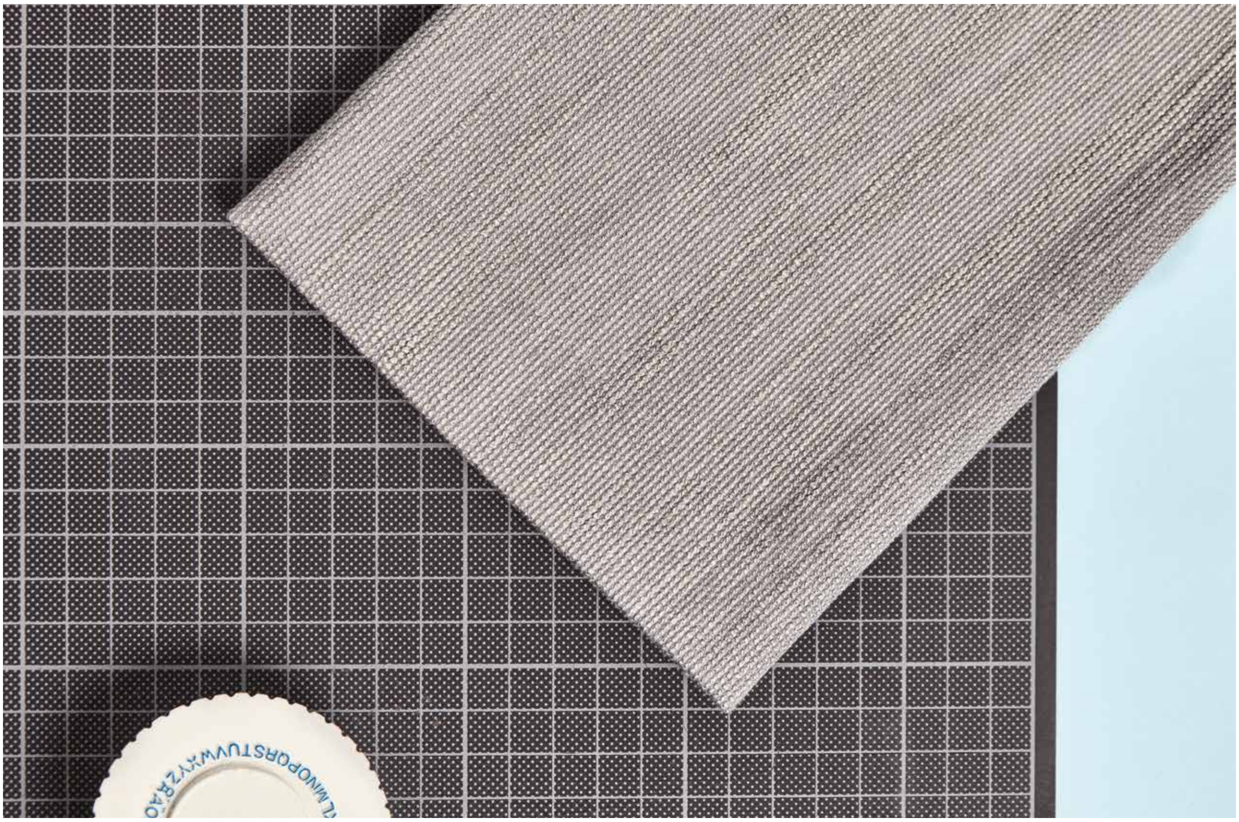
design created with digital sketching – Interference
R_s 531
weight 141 g/m²
tentative test group 2 (4–7 dB attenuation from 700Hz and up)
materials PES + Lurex film yarn (PES)

Fig. 4.57 & 4.58 Interference curtain.

EVERYDAY ABSTRACT

office noises. classical music. folk songs. jazz. Christmas.

Fig. 4.59 Everyday Abstract collection.



23361 / SOPRANO

soprano’s singing, don’t understand what

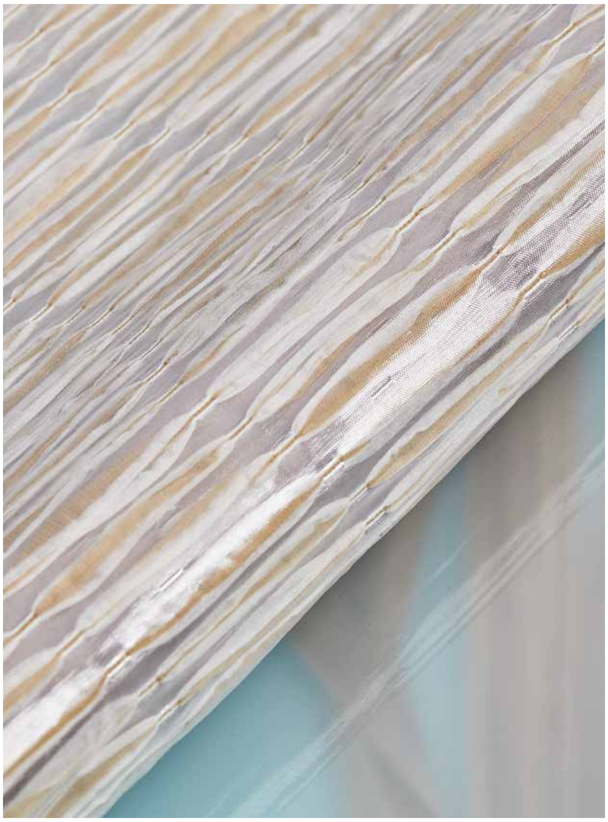
design created with sound inspiration – Giacomo Puccini’s opera classics
R_S 370
weight 111 g/m²
tentative test group 4 (2–6 dB attenuation from 700Hz and up)
materials TCS / PES + Lurex film yarn (PES)

23372 / OFFICE

click-click-click-click

design created with sound inspiration – office noises
R_S 804
weight 219 g/m²
tentative test group 1 (4–8 dB attenuation from 700Hz and up)
materials CV / LI / PES + Lurex film yarn (PES)

Fig. 4.60 Design 23361 / Soprano.
Fig. 4.61 Design 23372 / Office.



23368 / JAZZ

saxophones, piano, and a one-of-a-kind voice

design created with sound inspiration – Billie Holiday
(R_s 321–365 based on the test group)
tentative test group 5 (1–5 dB attenuation from 700Hz and up)
materials PES + Lurex film yarn (PES)

23371 / FOLKSY CAROL

have yourself a merry little Christmas

design created with sound inspiration – folksy Christmas carols
R_s 363
weight 294 g/m²
tentative test group 3 (3–6 dB attenuation from 700Hz and up)
materials TCS

23369 / FOLK HERITAGE

on suuri sun rantas autius, sitä sentään ikävöin: miten villisorsan valitus soi kaislikossa öin

design created with sound inspiration – Finnish folk song
(R_s 321–365 based on the test group)
tentative test group 5 (1–5 dB attenuation from 700Hz and up)
materials TCS

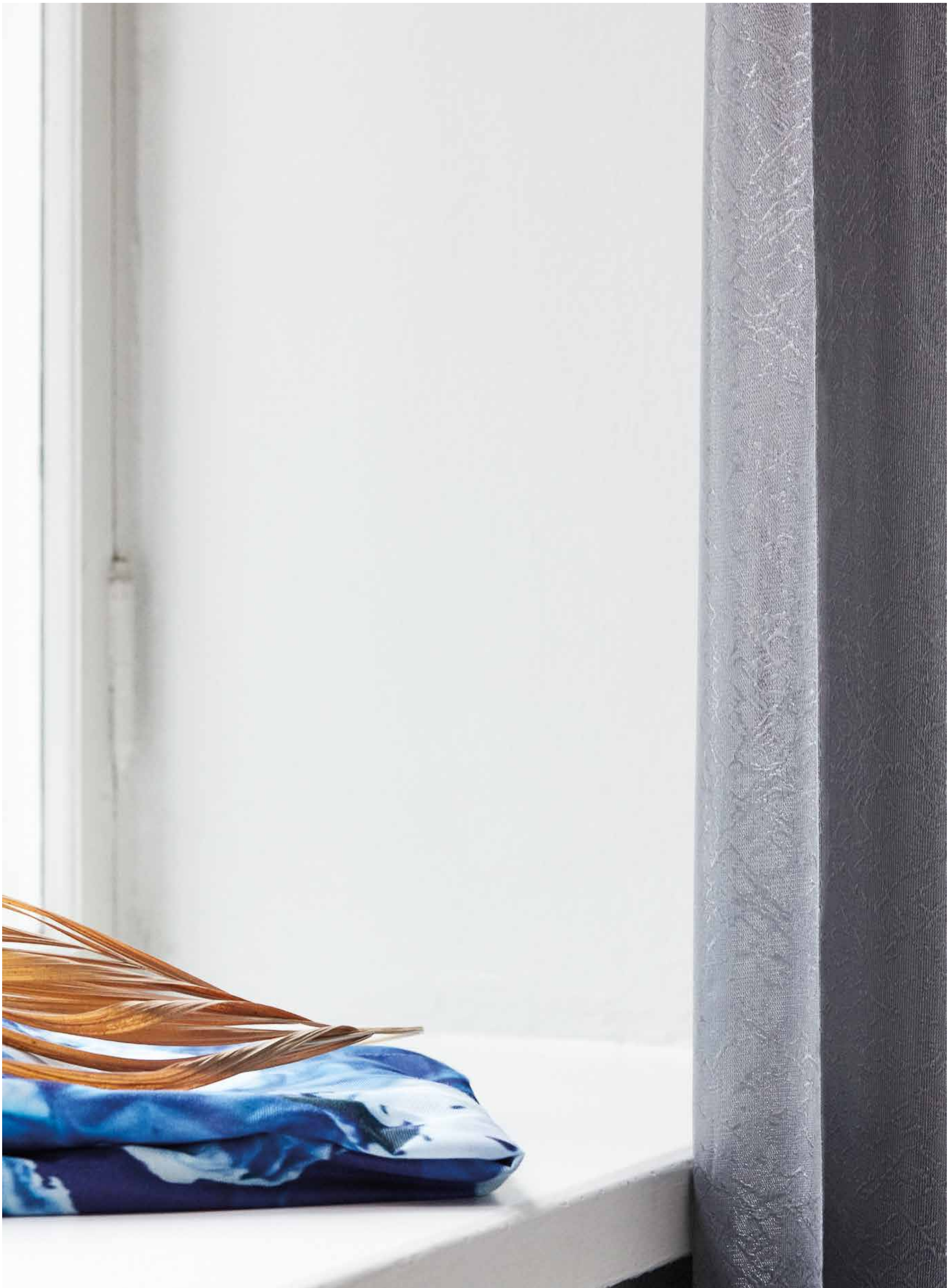
Fig. 4.62–4.64 Close-ups of the designs.

23373 / CLASSICAL

how would Mozart's Requiem in D Minor look like as a wavescape?

design created with digital sketching – Waves
(R_s 150–200 based on the test group)
tentative test group 8 (0–3 dB attenuation from 700Hz and up)
materials TCS + Lurex film yarn (PES)

Fig. 4.65 & 4.66 Classical curtain.



STEP 6 – FROM PROTOTYPES TO POSSIBLE MARKET

When it comes to marketing and selling the products, manufacturing companies are different from other textile companies. Since Lodetex is a manufacturer of woven fabrics, their clients are not consumers but medium-high level companies in the field of textiles, such as editors, agents or wholesalers. As Maarit Salolainen (15.6.2016) explained, editors work under their own brand with their own collections. Fabrics produced for their collections can come from several manufacturers, and in addition editors can also have their own weaving mills. Wholesalers buy stock fabrics from manufacturers, and they sell them forward to retailers and editors. Converters buy greige (unfinished) fabrics from manufacturers, convert them into finished fabrics and then, similarly to wholesalers, they sell them forward. (Salolainen 15.6.2016.)

While the creative team in a manufacturing company works a lot with the design tasks coming directly from clients, designers can also work freely with the company's own idea collections that are presented to several clients. As Maarit (15.6.2016) explained, the sales representatives of the manufacturing companies edit custom collections for each of their client meetings according to the clients' style and wishes. When the manufacturing companies present their work in the annual textile fairs, such as Heimtextil in Germany or Proposte in Italy, it is usual for the creative team of the weaving mill to design an idea collection with their latest innovations and best selling qualities. (Salolainen 15.6.2016.)

The designs can be sold to clients either as they are or with modifications assigned by the clients. The design team from the client company asks for particular colorways from the chosen qualities. The initial fabric testing input should come from the manufacturer, and the clients might want to do some additional tests by themselves. Testings are essential especially with woven upholstery fabrics, where also all different colorways have to be tested, since yarn dyeing might affect for example the abrasion resistance. (Salolainen 15.6.2016.) Testing conventional curtain fabrics is usually less essential with an exception of functional curtain fabrics.

During this project I have had meetings with many company representatives and agents, mainly for collecting the benchmarking data, but also for presenting this design work. Clients with the most interest on the project at the moment are Danish textile company Kvadrat and Finnish design company Innofusor. Kvadrat has been following this project from the beginning with answering to the initial inquiry, testing a few developed fabrics, and finally organizing an acoustic workshop, where I was also invited to join. Innofusor, which is specialized in acoustic products, came along only at the end after a meeting I had with one of the founders of the company. These two clients showcase an interesting comparison of most likely continuation of the project, since even though they are very different, they both share a passion for creating something new to the acoustic curtain market.

Kvadrat's Plain Aesthetics

The Danish textile company Kvadrat produce woven textiles for both public and private interiors with their focus on simple and timeless structures, good quality materials, and really wide color schemes (Kvadrat 2016). They also do a lot of innovative collaborations with leading artists, designers and architects, which I think is an outstanding characteristics of the company. I had been in contact already before with their textile engineer Johanna Apelgren, since she answered to the initial inquiry I sent to Kvadrat during the first development cycle. Kvadrat also had acoustic tests done at Müller-BBM of four of their chosen fabrics from the cycle no.1 prototypes.

I was invited to join in an acoustic workshop held in Kvadrat's headquarter in Ebeltoft Denmark with their product development team. Textile engineer Johanna Apelgren had planned an experimental acoustic test for different sound environments and fabric volumes. Seven tested curtain fabrics were varied in weight and structures; two fabrics were designed as acoustic prototypes and produced in Lodetex (prototype from cycle no.1 Organza 23181 and Kvadrat's own design modified as acoustic Drops acoustic), two fabrics were acoustic curtain fabrics in the current market (Betacoustic by Création Baumann and Absorber light by Annette Douglas), and the last three were Kvadrat's conventional curtain fabrics (Drops, Time and Steel cut trio). The testing took place in an empty showroom with a window-side of the room covered with the tested fabric both as flat and as 100% folded. A speaker played versatile loud sounds, such as laughter, classical and rock music, and a woman singing. The participants wrote notes about their perceptions on the acoustics, and a recorder recorded the actual difference, that the tested fabrics created to the sound environment.

The test result showed that the participants' perceptions of the performance were comparable to the tested alpha values at least with really high and really low performances. It was clearly audible that the fabrics with the highest alpha values (Steel cut trio and Absorber light) changed the sound conditions to a lot more pleasant. Due to the high weight of the fabric, Steel cut trio also managed to take down low frequencies, which improved the acoustics even more. The weakest achieving fabric was Drops, which did not have any difference to the sound conditions of an empty room. The fabrics with the medium alpha value had varied results among the participants, although they all improved the acoustics of the room to the amount that was still audible. The design 23181 from cycle no.1 was one of the weakest, though I knew that it would not stand a chance with the others due to its weaker test results. One really important thing that the test proved, was that the airflow resistance value in itself does not actually relate to acoustic performance of the fabric, especially with the lightweight fabrics. Instead the alpha value correlates directly to the perceptions of the audience.

Tested curtain fabrics from best to worst:

- Steel cut trio – WO/PA, 550 g/m², R_s 787–910, α_w 0.95
- Absorber light – TCS/PES, 149 g/m², R_s 323, α_w 0.80
- Betacoustic – TCS, 125 g/m², R_s 163–188, α_w 0.65
- Drops acoustic – TCS/PES, 108 g/m², R_s 129–138, α_w 0.55
- Organza 23181 – TCS/PES, 68 g/m², R_s 117, α_w 0.45
- Time – TCS, 185 g/m², R_s 66, α_w 0.50
- Drops – TCS, 73 g/m², R_s and α_w not tested

After the workshop I presented the prototypes of the second cycle to the product development team, and they picked two designs for further improvements and acoustic testing. Even though Kvadrat's design team was impressed by the visual sound story of the collection, they chose fabrics that fit into their plain style. The chosen fabrics were 23362 (R_s 1106) and 23372 (R_s 804) with some material modifications. The airflow resistance values should predict that these fabrics have potential to reach high alpha values, and to stand a chance in the acoustic curtain market. However, design 23372 is a heavier fabric and cannot compete with lightweight acoustic curtain fabrics, but still both of the designs work as a really good reference from where to continue the development work if needed.

Kvadrat's participants in the workshop:

- Anne Højgaard Jørgensen – Head of Design
- Anne Elisabeth Kargaard – Project Manager
- Stine Find Osther – Creative manager
- Anna Wilhelmine Ebbesen – Senior Design Coordinator
- Johanna Apelgren – Textile Engineer
- Lea Nordström – Technical Manager

Fig. 4.67 The design 23181 hanged as a flat arrangement.
Fig. 4.68 Close-up of Kvadrat's Steelcut Trio.
Fig. 4.69 Création Baumann´s Betacoustic as 100% folded.

Innofusor's Strong Knowledge on Acoustics

Innofusor is a Finnish design company specialized in acoustic products both for public and private interiors. They have a respect for local design, craftsmanship and ecology. (Innofusor 2016.) They have a wide knowledge on both engineering and design, which is a benefit when it comes to designing a collection of acoustic curtains. One of the founders of the company Toni Oinonen was impressed about the development work done for this project, and about my experimental approach to the whole project. We ended up having a short design meeting with one of Innofusor's designer Krista Kosonen, textile designer Elina Helenius, Toni Oinonen and myself. During the meeting we went through the project and the prototypes done so far. The participants appreciated both the stories behind the patterns and the experimental development work. Some of the visuals received critique about a weird scale or unfinished details, and some of the used colors were not that well fitted into interior textiles. As a result a rough selection of fabrics, that have the most potential for a versatile acoustic curtain collection, was picked out.

Innofusor also executed initial testings at their own premises to five of the prototype fabrics. They wanted to get an idea of the approximate sound absorption performance of those fabrics compared to some of the acoustic fabrics they sell at the moment. The tested fabrics were the same fabrics that were also exhibited at Aalto University's Tekstiili16 exhibition held in Helsinki during May 2016. The tests are still preliminary, since the test conditions were not standardized, but according to the first data received it is possible to see, that the prototype fabrics are performing quite similarly to the acoustic curtain fabrics they tested as reference.

At this moment Innofusor has selected the first six fabrics out of the set of prototypes for their acoustic curtain collection Aava, that is inspired by Finnish arctic hills. The fabrics will be presented in fairs during the near future for receiving feedback from customers, and the fabrics will be then tested according to standards, and developed further if necessary.

Fig. 4.70 Close-up of design 23361 Pallas.
Fig. 4.71 The selected acoustic curtain collection Aava.

Fig. 4.72–4.74 Innofusor's acoustic curtain collection Aava at Habitare Showroom 2016.

DESIGN PRACTICE / SUMMARY

- How to design a functional and visually versatile set of curtain fabrics with a common concept of sound?

This section described how the development work proceeded, and how all the empirical data was collected and analyzed. The design process of acoustic curtain fabrics used in this work was an applied and simplified model of a general interior textile product development process. The core of the process was in a thorough background research, and in a comprehensive ideation and conceptual design work. Based on the collected data and ideas, I executed two separate product development cycles, that included first prototyping, then testing the prototypes, analyzing the results, and developing the prototypes further. The section ended with two client cases, that most likely lead to a commercialization of the acoustic curtain fabrics.

The sound concept appeared in the prototype fabrics both as woven and digitally printed patterns and as structural inspirations. I used two pattern sketching methods for versatile looks: material cymatics sound vibration and audiovisual coding. Both of the methods worked so, that a played sound generated the visuals independently through either a material medium or algorithm capturing the essence of that particular sound. The presented idea collection included both fabrics with high potential of being functional acoustic curtains, and fabrics that may not be that functional yet, but that possess an interesting structural or visual character that could be improved later.

The analyses after each development cycle revealed, that the focus in the structural fabric design should be in a maximized microstructural surface area. That can be achieved both with material choices and weave structures. Also the fabric finishing has an impact to the surface area, and therefore choosing the suitable finishing method is important in the acoustic fabric design. Digital printing may lessen the sound absorption performance slightly, but the difference is so small, that it should not be a reason for excluding the digital printing completely.

The use of flat film yarns, such as the transparent Lurex, improves both the surface density and the translucent effect of the lightweight fabrics, though it then adds shine and stiffness to the fabric. High-performance acoustic fabrics can be designed without the film yarns too, though then the transparent effect is more difficult to achieve. There are a lot of possibilities with layered woven structures and three-dimensional structures, although they also acquire quite dense and stiff surfaces, that are not that suitable for drapable lightweight fabrics.

5 CONCLUSION

The goal of this practice-based study was to understand how and why lightweight acoustic curtain fabrics are produced, and to implement that knowledge to an independent design process of acoustic fabrics. The project was set under the context of sound. Sound was featured in every step of the way as an inspiration, as a technical tool, and eventually as a pen and a brush in the visual design. The work started with a literature research about sound and acoustics, followed by a more detailed review on lightweight acoustic curtains, and finished with a detailed documentation about the experimental development work of woven acoustic curtain fabrics. The outcome of this work was both the presented idea collection and the whole process, since within a practice-based study, the essential information is in the practice and not only in the final artifacts.

Sound absorbing curtain fabrics should be considered as functional interior textiles, and therefore the design work is a combination of art and science. Without a thorough research to the topic, to the restrictions and to the possibilities, it is impossible to achieve the set goals of functional fabric design. And yet following only the most suitable technical solutions without any creativeness and artistic approach, the end result will be dull and unimaginative. The whole ensemble of exploration and experimentation within the theme of sound was the essence of this design work.

The relevance of this work is to provide a new knowledge of functional interior fabric design to the manufacturing company Lodetex and to their clients. The reason for taking this challenging design topic was to add value to the otherwise conventional curtain production. European textile industry needs innovations and strong design statements in order to keep up with the Eastern competition. With their high-class manufacturing equipment and premises, Lodetex is able to compete with other acoustic curtain producers by offering jacquard woven and digitally printed curtain fabrics to the market that is full of only plain and simple solutions. Even though some of the prototype fabrics I designed may seem even too bold for interiors, by designing them I wanted to shake up the commonly seen mindset in the industry of just duplicating what is already in the market.

The most important aspect discovered throughout the process was the unpredictable nature of designing acoustic fabrics. Even though I managed to sum up all the key factors that affect the sound absorption ability, and to follow that list of factors during the development process, the results were never quite how I expected. It seems that the best solutions occurred with a bit of luck and lots of tryouts. I could have carried out a more controlled development work with a well planned structure. Now, as a result of a tight schedule and the lack of proper project management, I ended up with more experimental approach, that also led to a more open-ended outcome. In the end the common consensus of woven acoustic fabrics became more clear, and still it remained a bit of a mystery.

The performance of acoustic curtains is not based only on the designer's technical skills in creating a perfect sound absorbing fabric surface, but a lot of it comes from the application of the curtain fabrics. Those factors, that I listed as external, are a crucial part of the functionality. But how can those external factors be affected by? Since acoustic planning is a complex work, it would be good to leave it to the professionals, who are able to tell what frequency ranges need to be toned down and to what extent. But since curtains are so commonly used as interior textiles, replacing the conventional curtains with acoustic curtains should be an easy solution in spaces where the acoustics do not need to be that well planned. With just some instructions on how to achieve the maximum performance, the consumers could do it by themselves.

The designed and produced fabrics are prototypes and not ready products. Receiving the comparable acoustic test results would have been an essential closure at this stage of the development process for gaining information on how to continue, but due to the excessive investments, those tests were left out in the end. Yet without the proper testings these fabrics are difficult to be marketed as acoustic fabrics. The flow resistance value in itself is not enough to prove anything about the sound absorption performance. The only value that correlates with the audible differences in the sound environment, and that is comparable with other fabrics on the market, is the sound absorption coefficient. Luckily now a couple of interested clients have started their own acoustic testings for some of the prototype fabrics, so hopefully I will gain new data during the near future.

The feedback I received throughout the process was mainly positive. Many textile professionals, to whom I presented the work, showed respect for the way I decided to tackle even the technically challenging parts by myself. Positive feedback was given also for setting up space for experimentation throughout the process. Experimentation was a necessary decision for me in order to achieve a more relaxed workflow. I had to let go of the constraints of trying to gain everything at once, and decided to let myself do even some quirky fabrics for finding the optimal solutions. The visuals derived from sounds were also a part of the free experimentation. Some of the visuals might be too bold to be used in curtains, but I wanted to be unconventional with the visuals as well in order to discover the most suitable solutions. As the fabrics are still prototypes according to their functional qualities, I feel that is the same with the visuals.

One part of the work that proved to be difficult to achieve, was answering to all the needs and requirements that Kvadrat and Silent Gliss listed in the initial inquiry answers. They were looking for fabrics that reach high acoustic performance, overall contract textile requirements with flame retardancy and colorfastness, good drape, translucency, matt effect, and simple structures. Also my goal at the beginning of the project was to come up with a collection of high-performance acoustic sheer fabrics, but I realized during the development work, that in order for reaching such high standards in the future, I would first need to come up with several more accessible solutions. As a continuation of this project, I would develop the fabrics more to the needs and requirements of the clients. Additionally, material research could provide some interesting new solutions, since for example micro-fibers have proven to have effective sound absorption qualities (Soltani & Zarrebini 2012, 875).

An important issue that was left out during this stage was the sustainable aspect, and that should be a vital part of the continuation of the process. I believe that the textile industry cannot run for long without incorporating both functionality and sustainability in their products, and that is the long term goal for me as well. An ideal situation would be to include yarn production as a part of the functional design process. The environmentally conscious material development is growing constantly, so it should not be that difficult to discover materials that are both sustainable and effective at sound absorption. Also implementing other functions to curtain fabrics, such as heat and glare protection during warm periods, and heat loss protection during cold seasons, would have an effect on the energy consumption (Willbanks et al. 2014, 272). All those things should be taken into consideration once the technical solutions for sound absorption are solved.

During this project I gained a new way of design thinking. Not only does a designer in a manufacturing company has to own a vision of what she wants to achieve aesthetically, but in addition the designer has to possess the technical knowledge of the actual production work. It is essential to understand the possibilities and the boundaries especially when it comes to a whole new product development process. I was fortunate to be working in Lodetex first as an intern in order to gain knowledge about the industry from professionals working around me. Looking at this project now when time has passed, there are many things that could have been done differently for a more efficient outcome, but I truly believe that indulging in experimentation and learning from flaws are efficient ways to gain a deeper design knowledge.

REFERENCES

Acoustic Glossary. [online]. Available: http://www.acoustic-glossary.co.uk/ [3 Mar 2016]

Annette Douglas Textiles. Acoustic Collection. [online]. Available: http://www.douglas-textiles.ch/index.php?id=184&L=1 [23 Sept 2015].

Borenius, J., Jauhiainen, T., Lampio, E., Nuotio, J., Pesonen, K. & Pyykkö, I. 1985. Akustiikan perusteet. Finland: Insinööritieto Oy.

Brecheis, C. 2013. Challenging textiles – A study of self-supporting and translucent upholstery in the field of contract textiles. Helsinki: Aalto University School of Arts, Design and Architecture.

Büsgen, A. 2012. New product development in interior textiles. In: Horne, L. ed. New product development in textiles: Innovation and production. Cambridge, UK: Woodhead Publishing Limited, pp. 132–155.

Candy, L. 2006. Practice Based Research: A Guide. CCS Report: 2006-V1.0 November.

Casati, R. & Dokic, J. 2010. Sounds. Stanford Encyclopedia of Philosophy. [online]. Available: http://plato.stanford.edu/entries/sounds/ [16 June 2016].

Correia, N.N. 2013. Interactive Audiovisual Objects. Helsinki, Finland: Aalto University School of Arts, Design and Architecture.

Création Baumann 2015a. Acoustics. [online]. Available: https://www.creationbaumann.com/sortiment_funktion_akustik_en.html [23 Sept 2015].

Création Baumann. 2015b. Basics of Acoustics. [online]. Available: https://www.creationbaumann.com/sortiment_funktion_akustik_en.html [23 Sept 2015].

Création Baumann 2016. Product Finder. [online]. Available: https://www.creationbaumann.com/en/Products-3081,693269.html?filter_modus=1&filter_zusatzfunktionen%5B305%5D%5B4%5D=1&list_layout=grid [16 June 2016].

Cymatic Music 2010. Water Experiments. [online]. Available: http://www.cymaticmusic.co.uk/water-experiments.htm [22 June 2016].

Fislage, V. 2012. Textiles in Transit. An Investigation of Contract Textiles in Airport Terminals. Helsinki: Aalto University School of Arts, Design and Architecture.

Flex Acoustics. Products. [online]. Available: http://flexac.com/en/products/ [2 Mar 2016].

Grant, E. 2009. Making sound visible through cymatics, video file in TEDGlobal 2009. [online]. Available: http://www.ted.com/talks/evan_grant_cymatics#t-36020 [3 Feb 2016].

Grueneisen, P. 2003. Soundspace, Architecture for Sound And Vision. Basel, Switzerland: Birkhäuser.

Herbert, M. 2011. Infinity's Borders: Ryoji Ikeda. In: Kelly, C. ed. Sound//Documents of Contemporary Art. London: Whitechapel Gallery, pp. 162–165.

Ikeda, Ryoji. test pattern. [online]. Available: http://www.ryojiikeda.com/project/testpattern/ [2 Mar 2016].

Innofusor 2016. [online]. Available: http://www.innofusor.com/ [23 June 2016].

Jackman, D., Dixon, M. & Condra, J. 2003. The Guide to Textiles for Interiors, 3rd edition. Winnipeg: Portage & Main Press.

Kvadrat 2016. About. [online]. Available: http://kvadrat.dk/about [23 June 2016].

Lifescience 2012. How to Make Oobleck. [online]. Available: http://www.livescience.com/21536-oobleck-recipe.html [22 June 2016].

Lodetex, 2012. Company. [online]. Available: http://www.lodetex.com/company.htm [31 Oct 2015]

Müller-BBM. 2015a. Determining of airflow resistance according to EN 29053. Test Report No. M100827/99.

Müller-BBM. 2015b. Measurement of sound absorption in a reverberation room according to EN ISO 354. Test Report No. M100827/98.

Müller-BBM. 2016a. Flow Resistance. [online]. Available: http://www.muellerbbm.com/test-facilities/measurement-tasks/flow-resistance/ [4 Mar 2016].

Müller-BBM.2016b. Sound absorption. [online]. Available: http://www.muellerbbm.com/test-facilities/measurement-tasks/sound-absorption/ [4 Mar 2016].

Nielson, K. J. 2007. Interior Textiles: Fabrics, Applications & Historical styles. New Jersey: John Wiley & Sons, Inc.

Paavilainen, T. 2015. Floating & Clipping. Woven Textiles with Weft Floats and Finishings by Clipping. Helsinki: Aalto University School of Arts, Design and Architecture.

Pieren, R. 2012. Sound absorption modeling of thin woven fabrics backed by an air cavity. Textile Research Journal, 82(9), pp. 864–874.

Pieren, R. & Heutschi, K. 2015. Predicting sound absorption coefficients of lightweight multilayer curtains using the equivalent circuit method. Applied Acoustics 92 (2015), pp. 27–41.

Processing. Overview. [online]. Available: https://processing.org/overview/ [22 June 2016].

Reas, C. & McWilliams, C. 2010. Form + Code in Design, Art And Architecture. New York: Princeton Architectural Press.

RIL 243-1-2007. Rakennusten akustinen suunnittelu. Akustiikan perusteet. Helsinki, Finland: Suomen Rakennusinsinöörien Liitto RIL ry.

Rossing, T. D., Moore, F. R. & Wheeler, P. A. 2002. The Science of Sound, 3rd edition. San Francisco, USA: Addison Wesley.

Schafer, R. M. 1994. The Soundscape: Our Sonic Environment And the Tuning of the World. Rochester, USA: Destiny Books.

Seddeq, H.S. 2009. Factors Influencing Acoustic Performance of Sound Absorptive Materials. Australian Journal of Basic and Applied Sciences, 3(4), pp. 4610–4617.

Selinger, M. & Hahn, Y. 2015. Thesis Design. Research Meets Practice in Art and Design Master's Theses. Helsinki: Aalto University School of Arts, Design and Architecture.

Silent Gliss 2013. Silent Gliss The Collection. [online]. Available: http://www.silentgliss.fi/go/Kankaat [15 June 2016].

Silent Gliss 2015. The Collection. Overview. [online]. Available: http://www.silentgliss.fi/go/Kankaat [15 June 2016].

Sinclair, R. 2015. Textiles and Fashion: Materials, Design and Technology. Cambridge, UK: Woodhead Publishing Limited.

Soltani, P. & Zarrebini, M. 2012. The analysis of acoustical characteristics and sound absorption coefficient of woven fabrics. Textile Research Journal, 82(9), pp. 875–882.

Soltani, P. & Zarrebini, M. 2013. Acoustic performance of woven fabrics in relation to structural parameters and air permeability. Journal of The Textile Institute, 104:9, pp. 1011–1016.

Somaini, A. 2011. Catching the Waves: Carsten Nicolai's Klangfiguren. In: Kelly, C. ed. Sound// Documents of Contemporary Art. London: Whitechapel Gallery, pp. 211–216.

Tani, N. 2015. Enhancing the Spatial Experience. Interweaving Textile, Human and Architecture. Helsinki: Aalto University School of Arts, Design and Architecture.

Vescom 2012. new! transparent, acoustic curtain fabrics. [online]. Available: https://www.eurowalls.com.au/assets/Uploads/VES007-55-Productflyer-Acoustics-ENGLR-3.pdf [23 Sept 2015].

Vescom 2013. Translucent, acoustic curtain fabrics. [online]. Available: http://www.vescom.com/translucent-acoustic-curtain-fabrics#/604-2-1-90-0 [23 Sept 2015].

Vescom 2016. curtain 01. [online]. Available: http://www.vescom.com/translucent-acoustic-curtain-fabrics#/curtain_EN-1-52-1-0 [16 June 2016].

Watkins, S. M. & Dunne, L. E. 2015. Functional Clothing Design. From Sportswear to Spacesuits. New York: Fairchild Books.

Willbanks, A., Oxford, N. & Miller, D. 2014. Textiles for Residential and Commercial Interiors. 4th edition. New York: Fairchild Books.

Yoshizawa, A. 2014. Restrictions as inspiration – An exploration of the design process in the contract textile industry. Helsinki: Aalto University School of Arts, Design and Architecture.

Personal discussions:
Iso-Kuortti, Piia. Personal discussion, 27.10.2015.
Jacobsén, Anne. Personal discussion, 23.3.2016.
Lokki, Tapio. Personal discussion, 12.11.2015.
Saastamoinen, Jouko. Personal discussion, 21.6.2016.
Salolainen, Maarit. Personal discussion, 15.6.2016.

Pictures:
Cover photo, close-up of design 23132 DP 4105 / Sine Wave Marble by Ilkka Saastamoinen.
Fig. 0.1 Photo from Tekstiili16 exhibition by Petra Haikonen.
Fig. 1.0 Audiovisual illustration of loons singing by Petra Haikonen.
Fig.1.1&1.2 Photos by Petra Haikonen.
Fig. 1.3 Illustration by Petra Haikonen.
Fig. 2.0 Audiovisual illustration of loons singing by Petra Haikonen.
Fig. 2.1 Digital illustration by Petra Haikonen.
Fig. 2.2 Illustration by Petra Haikonen.
Fig 2.3 aQflex sound absorbers, FlexAcoustics. [online]. Available from: http://flexac.com/en/products/aqflex/ [13 Nov 2015].
Fig 2.4 Woven three-dimensional acoustic textile by Trevira. [online]. Available from: http://www.trevira.com/en/about-us/news/sound-absorbing-and-digitally-printable-interior-sun-protection-textiles-in-trevira-cs.html [23 July 2016].
Fig. 2.5 Wassily Kandinsky's woodcut White Sound, 1913. [online]. Available from: http://www.moma.org/collection/artists/2981?=undefined&page=2&direction=fwd [31 Aug 2016].
Fig. 2.6 Carsten Nicolai's cymatics photograph series Milch, 2000. [online]. Available from: http://artist.christies.com/Carsten-Nicolai-58451-bio.aspx# [31 Aug 2016].
Fig. 2.7 Carsten Nicolai's cymatics installation Wellenwanne, 2001. [online]. Available from: https://vimeo.com/48446412 [31 Aug 2016].
Fig. 2.8 Chladni figure created with sand. [online]. Available from: http://www.electronicshadow.org/nm/?page_id=1082 [31 Aug 2016].
Fig. 2.9 Chladni figures drawings by Ernst Chladni, 1802. [online]. Available from: http://doorofperception.com/2013/11/cymatics/ [31 Aug 2016].
Fig. 2.10 Photo by Petra Haikonen.
Fig. 2.11 Audiovisual performance at MUTEK festival Montréal, 2015. [online]. Available from: http://www.creativeapplications.net/can-events/in-theory-and-in-practice-audiovisual-performance-at-mutek-2015/ [31 Aug 2016].
Fig. 2.12 KNBC by Casey Reas, 2015. Audiovisual installation made of distorted television signals. [online]. Available from: http://reas.com/knbc/ [31 Aug 2016].
Fig. 2.13 supercodex (live set). Audiovisual performance by Ryoji Ikeda, 2013. [online]. Available from: http://allevents.in/turin/ryoji-ikeda-supercodex-live-set-todays-festival-torino/1639727039574481 [31 Aug 2016].
Fig. 2.14 Ryoji Ikeda's Data.Tron [8K enhanced version]. Audiovisual installation, 2010. [online]. Available from: https://en.wikipedia.org/wiki/Ryoji_Ikeda [31 Aug 2016].
Fig. 2.15 Ryoji ikeda's test pattern (enhanced version). Audiovisual installation, 2011 at Park Avenue Armory, New York. [online]. Available from: https://midnightsciencefictionfeature.wordpress.com/2013/12/18/ryoji-ikeda-exploring-boundaries-of-cinema-and-music/ [31 Aug 2016].
Fig. 2.16 test pattern no. 5, audiovisual installation by Ryoji Ikeda, 2013. [online]. Available from: http://www.limelightmagazine.com.au/Gallery/346738,ryoji-ikeda-test-pattern-no-5-at-carriageworks.aspx [31 Aug 2016].
Fig. 3.0 Audiovisual illustration of loons singing by Petra Haikonen.
Fig. 3.1 Création Baumann's acoustic curtains used in a private home in St Gallen, Switzerland. Photo by Anna-Tina Eberhard. [online]. Available from: https://www.creationbaumann.com/en/Range-function-acoustics-4128.html [23 Sept 2015].
Fig. 3.2 & 3.3 Photos by Petra Haikonen.

Fig. 3.4 Vescom’s acoustic curtain Marmara. [online]. Available from: http://www.stylepark.com/en/vescom/marmara [16 June 2016].
Fig. 3.5 Streamer classic col. 100. [online]. Available from: http://www.kr-schweiz.ch/raumakustik/akustikelemente-3/akustikvorhaenge/ [16 June 2016].
Fig. 3.6 Silent Space Collection. [online]. Available from: http://www.douglas-textiles.ch/en/silent-space-collection.html [16 June 2016].
Fig. 3.7 Vescom’s acoustic curtain Carmen. [online]. Available from: http://www.vescom.com/translucent-acoustic-curtain-fabrics#/curtain_EN-1-52-1-0-223 [16 June 2016].
Fig. 3.8 Photo by Petra Haikonen.
Fig. 3.9 Zetacoustic. [online]. Available from: https://www.creationbaumann.com/en/Product-1029,,771509.html [16 June 2016].
Fig. 3.10 Reflectacoustic. [online]. Available from: https://www.creationbaumann.com/produkte_detail_en,631371,978566,detail.html?filter_freitext=REFLECTACOUSTIC&filter_modus=1&sprache_kuerzel=en [16 June 2016].
Fig. 3.11–3.13 Photos by Petra Haikonen.
Fig. 3.14 Close-up photo of the development cycle no.2 prototypes by Petra Haikonen.
Fig. 4.0 Audiovisual illustration of loons singing by Petra Haikonen.
Fig. 4.1–4.15 Photos by Petra Haikonen.
Fig. 4.16 Screenshot by Petra Haikonen.
Fig. 4.17–4.26 Audiovisual illustrations by Petra Haikonen.
Fig. 4.27–4.38 Photos by Petra Haikonen.
Fig. 4.39 Photo by Ilkka Saastamoinen.
Fig. 4.40–4.43 Photos by Petra Haikonen.
Fig. 4.44–4.66 Photos by Ilkka Saastamoinen.
Fig. 4.67–4.69 Photos by Petra Haikonen.
Fig. 4.70–4.71 Photos by Ilkka Saastamoinen.
Fig. 4.72–4.74 Photos by Petra Haikonen.
Fig. 4.75 Photo of design 23379 / Cellular Water by Petra Haikonen.
Pictures in appendices by Petra Haikonen.

APPENDIX 1

Client Inquiry Answers

Answers from Kvadrat by textile engineer Johanna Apelgren

What kind of requirements you have for acoustic fabrics? e.g. used materials and compositions (TCS, PES, naturals, mixed materials etc.), other features than acoustic (fire resistance, light blocking etc.), NRC or other acoustic test values (noise reduction coefficient, reverberation time, surface mass density, airflow resistance etc.)
Kvadrat:
First of all the acoustic fabric has to fulfill the overall performance specification for Kvadrat curtain fabrics:
Light fastness – ISO 105 B02, Min. 5-6 (1-8)
Shrinking – Laundry 40ºC / 60ºC, Max. 1%
Fire (depending on material) – EN 13 773, class 1 & BS 5867, part 2, type B, Pass
DIN 4102, B1
NPF P 92 507, M1
UNI 9177, Classe Uno
As long as these specifications are in place we are open to different materials

When it comes to the acoustical performance we are really interested in a transparent curtain with an alpha w value over 0,6 (the higher the better). If the alpha w value is in place the airflow resistance usually is around 600-1000 R_s, which is the optimal Rs for sound absorption.

As the market mostly focuses on the alpha w value, that's what we have been focusing on. For communication we are interested of getting example values on how much a fabric is reducing the reverberation time in a given space. We are looking into the possibilities of making some trials regarding this. Is that something you would like to participate in?

Which feature would you appreciate more in acoustic fabrics? Sound reflection (blocking outside noise from entering the space) or sound absorption (absorbing already existing noise in the space)
Kvadrat:
As mentioned in my previous answer, we are mostly interested in sound absorption, as the market are focusing a lot on that.

What kind of qualities and end-uses are you looking for in acoustic fabrics? e.g. soft or stiff hand, transparent, medium weight or heavy weight fabrics, fabrics for curtains (draped curtains, panel curtains, roller blinds etc.) or for wall/ceiling/space divider covers etc.
Kvadrat:
Transparency- as sheer as possible so you could have the curtains covering the windows all day but still be able to look out the windows eg. A sound absorbing textile that you can cover a lot of space with but that doesn't cover up too much.
Soft hand- drape nicely as a curtain.

What type of visuals and colors you would wish to see in the collection of acoustic fabrics? e.g. simple structures vs. bold patterns, natural tones vs. bright colors
Kvadrat:
Simple structures in sheer colors like white, light grey and light beige (see my regarding transparency).

Would you have some other aspects to add to the topic of acoustic fabrics? e.g. your experience with technical limitations in acoustic fabrics or soft cells
Kvadrat:
Transparent tape yarns are widely used in acoustic curtains. The backside of that is that it gives the curtain a stiffness which makes it less drapeable than other curtains. We are interested in finding a way to use these tape yarns but still maintain a soft textile feeling. These tape yarns also makes the fabric really shiny which takes away the overall textile feeling. This is also something that we would like to find a solution for. Some construction that allows the use of tape yarns but excludes the stiffness and the quite plastic shine.

Answers from Silent Gliss by project manager Markus Brugger

What kind of requirements you have for acoustic fabrics? e.g. used materials and compositions (TCS, PES, naturals, mixed materials etc.), other features than acoustic (fire resistance, light blocking etc.), NRC or other acoustic test values (noise reduction coefficient, reverberation time, surface mass density, airflow resistance etc.)
Silent Gliss:
normally it is Polyester but as long as it is fire retardant, other materials are also ok.

fire resistant, good light- and energy values, available in soft and stiff version, good hanging behavior, big width,

NRC and airflow resistance are not so important - having the measurements like enclosed are important.

Which feature would you appreciate more in acoustic fabrics? Sound reflection (blocking outside noise from entering the space) or sound absorption (absorbing already existing noise in the space)
Silent Gliss:
Blocking noise from outside or from inside is not so important because this is more or less building acoustic. We are speaking about room acoustic so we like to have influence to the reverberation time.

What kind of qualities and end-uses are you looking for in acoustic fabrics? e.g. soft or stiff hand, transparent, medium weight or heavy weight fabrics, fabrics for curtains (draped curtains, panel curtains, roller blinds etc.) or for wall/ceiling/space divider covers etc.
Silent Gliss:
Customers do not like to hang a “carpet” in front of the widow so the goal from a acoustic fabric is to have good acoustic values bear relation to the transparency.

What type of visuals and colors you would wish to see in the collection of acoustic fabrics? e.g. simple structures vs. bold patterns, natural tones vs. bright colors
Silent Gliss:
We prefer basic fabric without any pattern. Colours are white, off white beige grey and black.

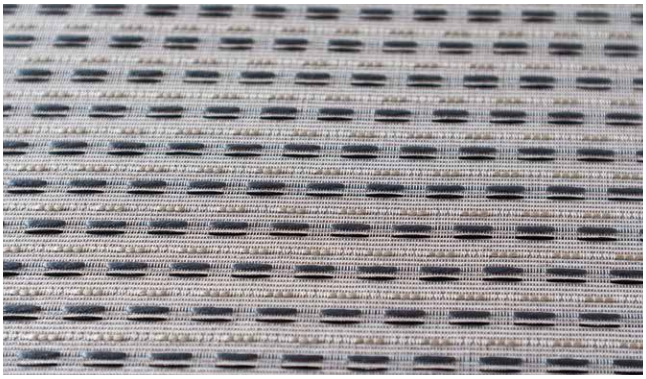
Would you have some other aspects to add to the topic of acoustic fabrics? e.g. your experience with technical limitations in acoustic fabrics or soft cells
Silent Gliss:
Because of the fact, that we are working with flat yarns which are only available in shiny version, we are looking for other fabrics which are not shiny.

APPENDIX 2

All Prototype Fabrics – Information

23109 v201

R_s	268, tentative test group 6
weight	209 g/m²
materials	TCS / LI + Lurex film yarn (PES)
loom	Starlight 40 yarns/cm
density	2 weft system 36 yarns/cm
finishing	hard-set

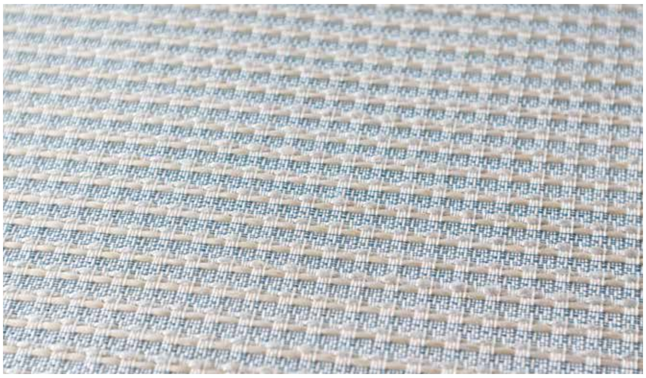


23111 v101

R_s	869, tentative test group 1
weight	143 g/m²
materials	TCS / FR + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 24 yarns/cm
finishing	hard-set

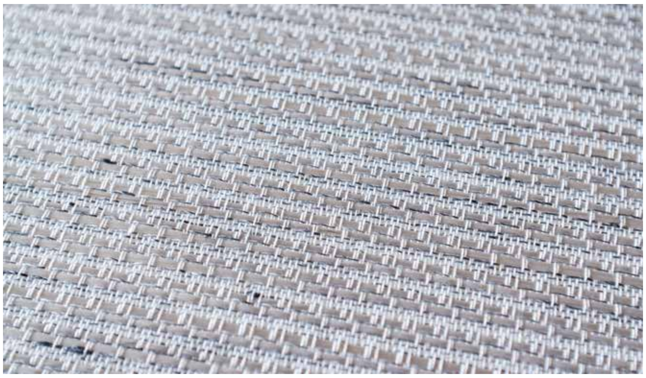
23112 v101

R_s	93, tentative test group 10 / α_w 0.40, class D
weight	87,6 g/m²
materials	TCS + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 24 yarns/cm
finishing	hard-set



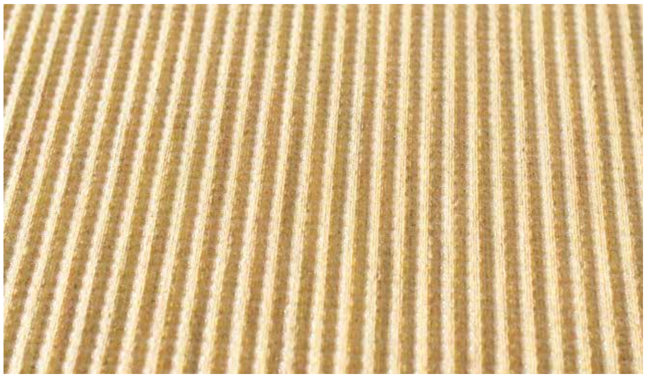
23115 v101

R_s	(363–494), tentative test group 3
weight	
materials	TCS / PES / CV / LI + Lurex film yarn (PES)
loom	30/2 15 yarns/cm
density	2 weft system 18 yarns/cm
finishing	hard-set



23120 v101

R_s	32, tentative test group 10
weight	198 g/m²
materials	LI / PES + Lurex film yarn (PES)
loom	30/2 15 yarns/cm
density	2 weft system 18 yarns/cm
finishing	hard-set



23131 v101

R_s	828, tentative test group 1
weight	177 g/m²
materials	CV / WO + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 22 yarns/cm
finishing	air blow & ironing

23132 v101

R_s	417, tentative test group 4
weight	101 g/m²
materials	PES + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 22 yarns/cm
finishing	air blow & ironing

23132 v102 DP 41025

R_s	417 (print ground), tentative test group 4
weight	101 g/m² (print ground)
materials	PES + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 22 yarns/cm
finishing	digital print + air blow & ironing

23132 v102 DP 41029 v3

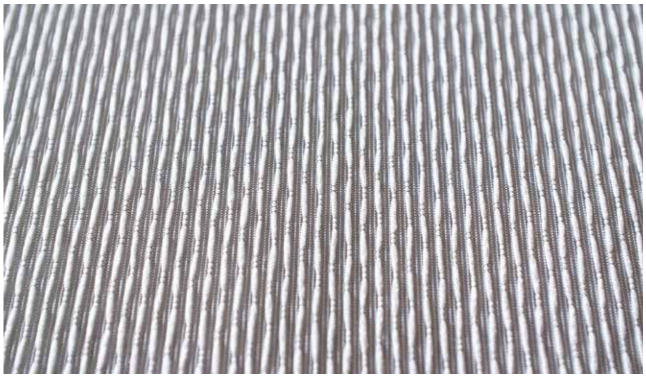
R_s	417 (print ground), tentative test group 4
weight	101 g/m² (print ground)
materials	PES + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 22 yarns/cm
finishing	digital print + air blow & ironing

23138 v201

R_s	58, tentative test group 10
weight	158 g/m²
materials	CV / WO + Lurex film yarn (PES)
loom	Sara 80 yarns/cm
density	1 weft system 44 yarns/cm
finishing	air blow & ironing

23174 v201

R_s 37, tentative test group 10
weight 73,9 g/m²
materials TCS / PES + Lurex film yarn (PES)
loom Starlight 40 yarns/cm
density 2 weft system 30 yarns/cm
finishing shrinking

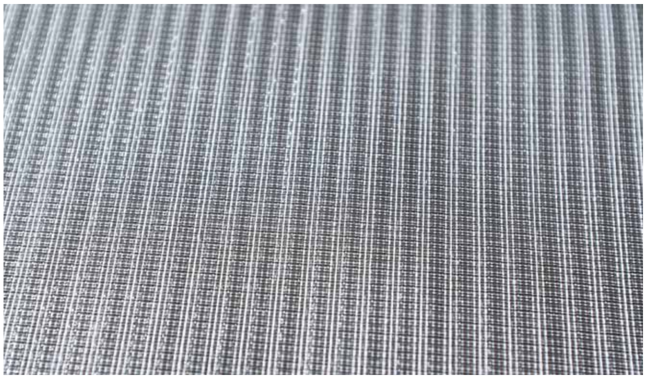


23175 v201

R_s 35, tentative test group 10 / α_w 0.25, class E
weight 89,6 g/m²
materials FR / PES + Lurex film yarn (PES)
loom Starlight 40 yarns/cm
density 2 weft system 22 yarns/cm
finishing ironing

23178 v201

R_s 43, tentative test group 10 / α_w 0.30, class D
weight 55 g/m²
materials PES + Lurex film yarn (PES)
loom Sara 80 yarns/cm
density 1 weft system 46 yarns/cm
finishing ironing



23179 v201

R_s 115, tentative test group 10
weight 69,2 g/m²
materials PES + Lurex film yarn (PES)
loom Sara 80 yarns/cm
density 2 weft system 22 yarns/cm
finishing ironing

23180 v1

R_s 60, tentative test group 10
weight 69,9 g/m²
materials LI / PES + Lurex film yarn (PES)
loom Organza 40 yarns/cm
density 2 weft system 26 yarns/cm
finishing ironing with steam

23181 v1

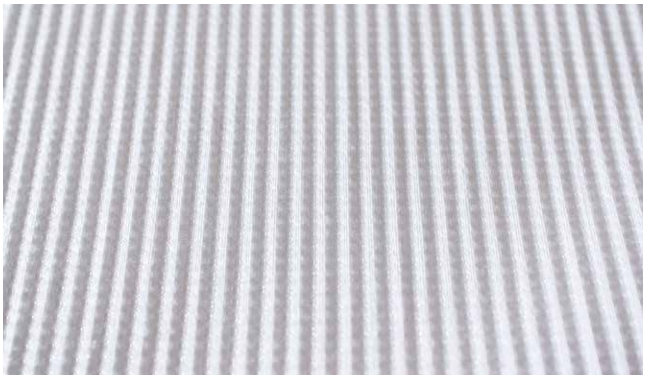
R_s 149, tentative test group 9 / α_w 0.45, class D
weight 69,2 g/m²
materials TCS / PES + Lurex film yarn (PES)
loom Organza 40 yarns/cm
density 2 weft system 26 yarns/cm
finishing ironing with steam

23182 v101

R_s	177, tentative test group 8
weight	138 g/m²
materials	TCS / CV / LI
loom	Linda 40 yarns/cm
density	2 weft system 28 yarns/cm
finishing	ironing

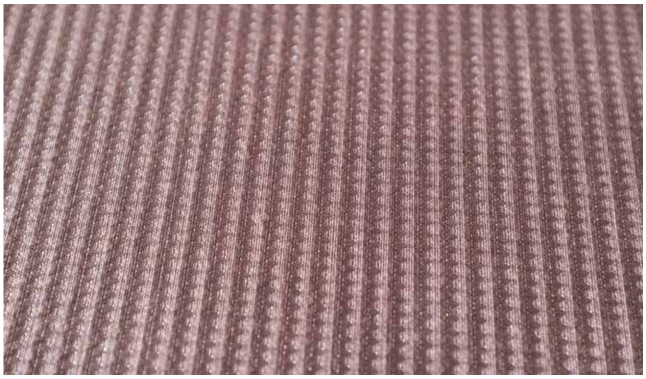
23183 v101

R_s	236, tentative test group 6
weight	211 g/m²
materials	TCS
loom	Linda 40 yarns/cm
density	2 weft system 28 yarns/cm
finishing	ironing



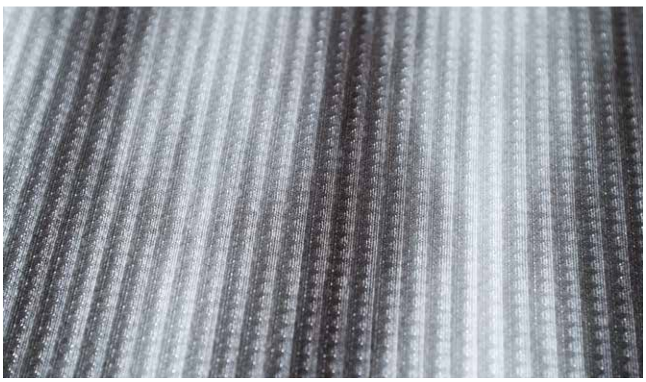
23345 v101

R_s	729, tentative test group 2
weight	184 g/m²
materials	TCS + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 22 yarns/cm
finishing	air blow & ironing



23345 v101 DP 41029 v2

R_s	729 (print ground), tentative test group 2
weight	184 g/m² (print ground)
materials	TCS + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 22 yarns/cm
finishing	digital print + air blow & ironing

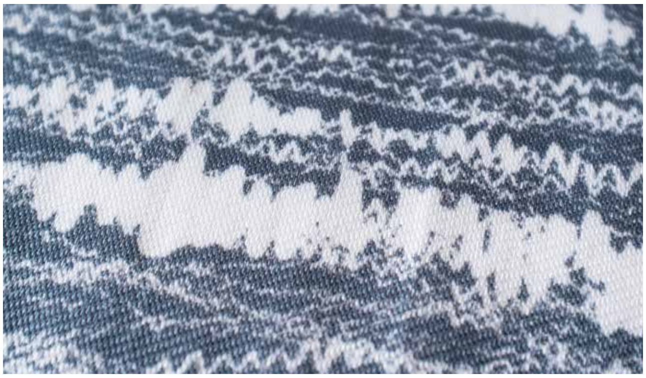


23345 v101 DP 41030 v3

R_s	729 (print ground), tentative test group 2
weight	184 g/m² (print ground)
materials	TCS + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 22 yarns/cm
finishing	digital print + air blow & ironing

23347 v1

R_s	309, tentative test group 7
weight	70 g/m²
materials	TCS + Lurex film yarn (PES)
loom	Organza 40 yarns/cm
density	2 weft system 24 yarns/cm
finishing	ironing with steam



23347 v1 DP 41027 v2

R_s	309 (print ground), tentative test group 7
weight	70 g/m² (print ground)
materials	TCS + Lurex film yarn (PES)
loom	Organza 40 yarns/cm
density	2 weft system 24 yarns/cm
finishing	digital print + ironing with steam

23347 v1 DP 41030 v1

R_s	309 (print ground), tentative test group 7
weight	70 g/m² (print ground)
materials	TCS + Lurex film yarn (PES)
loom	Organza 40 yarns/cm
density	2 weft system 24 yarns/cm
finishing	digital print + ironing with steam

23348 v102

R_s	976, tentative test group 2
weight	126 g/m²
materials	TCS + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 26 yarns/cm
finishing	ironing

23349 v102

R_s	(236–303), tentative test group 6
weight	
materials	TCS + Lurex film yarn (PES)
loom	Sara 80 yarns/cm
density	1 weft system 52 yarns/cm
finishing	air blow & ironing

23350 v2

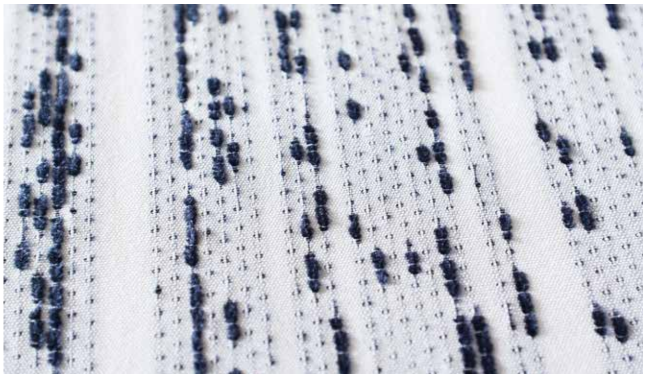
R_s	(150–200), tentative test group 8
weight	
materials	LI + Lurex film yarn (PES)
loom	Organza 40 yarns/cm
density	2 weft system 24 yarns/cm
finishing	ironing with steam

23355 v102

R_s	531, tentative test group 2
weight	141 g/m²
materials	PES + Lurex film yarn (PES)
loom	Starlight 40 yarns/cm
density	3 weft system 26 yarns/cm
finishing	ironing

23358 v201

R_s	494, tentative test group 3
weight	158 g/m²
materials	TCS
loom	Starlight 40 yarns/cm
density	2 weft system 32 yarns/cm
finishing	ironing



23360 v104

R_s	303, tentative test group 6
weight	148 g/m²
materials	TCS
loom	Linda 40 yarns/cm
density	2 weft system 28 yarns/cm
finishing	air blow & ironing

23361 v201

R_s	370, tentative test group 4
weight	111 g/m²
materials	TCS / PES + Lurex film yarn (PES)
loom	Starlight 40 yarns/cm
density	1 weft system 24 yarns/cm
finishing	shrinking

23362 v101

R_s	1106, tentative test group 1
weight	137 g/m²
materials	TCS + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 24 yarns/cm
finishing	air blow & ironing

23363 v101

R_s	(150–200), tentative test group 8
weight	
materials	CV / WO + Lurex film yarn (PES)
loom	Sara 80 yarns/cm
density	1 weft system 48 yarns/cm
finishing	air blow & ironing

23364 v101

R_s	365, tentative test group 5
weight	122 g/m²
materials	TCS
loom	Starlight 40 yarns/cm
density	2 weft system 24 yarns/cm
finishing	shrinking

23366 v202

R_s	337, tentative test group 5
weight	124 g/m²
materials	FR / PES + Lurex film yarn (PES)
loom	Starlight 40 yarns/cm
density	2 weft system 24 yarns/cm
finishing	ironing

23367 v203

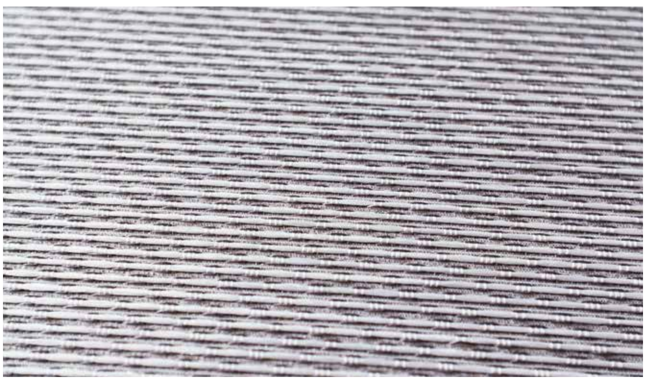
R_s	(150–200), tentative test group 8
weight	
materials	TCS + Lurex film yarn (PES)
loom	Starlight 40 yarns/cm
density	2 weft system 24 yarns/cm
finishing	shrinking

23368 v102

R_s	(321–365), tentative test group 5
weight	
materials	PES + Lurex film yarn (PES)
loom	Sara 80 yarns/cm
density	2 weft system 52 yarns/cm
finishing	ironing

23369 v101

R_s	(approx. 300), tentative test group 7
weight	
materials	TCS
loom	Linda 40 yarns/cm
density	2 weft system 18 yarns/cm
finishing	hard-set



23371 v102

R_s	363, tentative test group 3
weight	294 g/m²
materials	TCS
loom	Linda 40 yarns/cm
density	2 weft system 20 yarns/cm
finishing	hard-set

23372 v101

R_s	804, tentative test group 1
weight	219 g/m²
materials	CV / LI / PES + Lurex film yarn (PES)
loom	Linda 40 yarns/cm
density	2 weft system 24 yarns/cm
finishing	air blow & ironing

23373 v203

R_s (150–200), tentative test group 8
weight
materials TCS + Lurex film yarn (PES)
loom Starlight 40 yarns/cm
density 2 weft system 24 yarns/cm
finishing shrinking

23374 v201

R_s (150–200), tentative test group 8
weight
materials TCS + Lurex film yarn (PES)
loom Starlight 40 yarns/cm
density 2 weft system 24 yarns/cm
finishing ironing

23376 v1

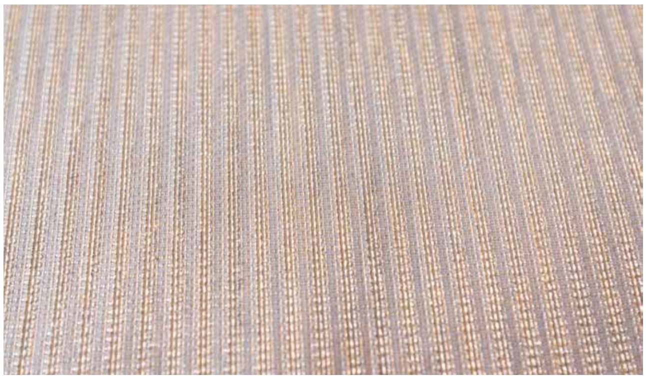
R_s (approx. 150), tentative test group 9
weight
materials PES
loom Organza 40 yarns/cm
density 2 weft system 26 yarns/cm
finishing air blow & ironing

23379 v102

R_s (approx. 300), tentative test group 7
weight
materials WO / CV / TCS / PES
loom Starlight 40 yarns/cm
density 2 weft system 30 yarns/cm
finishing shrinking

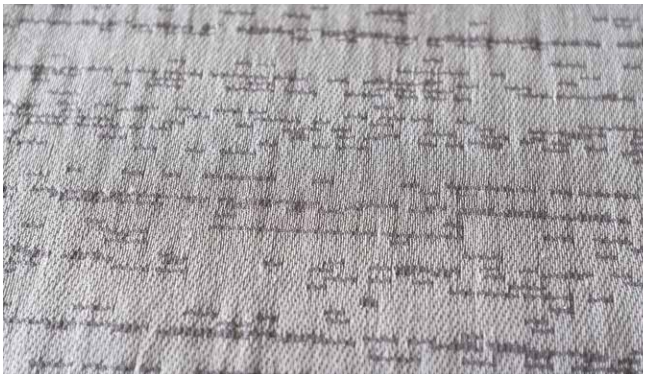
23380 v102

R_s (approx. 300), tentative test group 7
weight
materials TCS + Lurex film yarn (PES)
loom Sara 80 yarns/cm
density 2 weft system 24 yarns/cm
finishing air blow & soft ironing



23381 v101

R_s 321, tentative test group 5
weight 95 g/m²
materials TCS + Lurex film yarn (PES)
loom Sara 80 yarns/cm
density 2 weft system 24 yarns/cm
finishing ironing



23386 v201

R_s	(150–200), tentative test group 8
weight	
materials	PES + Lurex film yarn (PES)
loom	Starlight 40 yarns/cm
density	3 weft system 24 yarns/cm
finishing	ironing

23389 v201

R_s	(236–303), tentative test group 6
weight	
materials	TCS
loom	Sara 80 yarns/cm
density	1 weft system 52 yarns/cm
finishing	air blow & ironing

14957 v2 DP 41025 v1

R_s	556 (print ground), tentative test group 9
weight	37 g/m² (print ground)
materials	Lurex film yarn (PES)
loom	Starlight 40 yarns/cm
density	1 weft system 26 yarns/cm
finishing	digital print + ironing

14957 v2 DP 41029 v2 plissé

R_s	556 (print ground)
weight	
materials	Lurex film yarn (PES)
loom	Starlight 40 yarns/cm
density	1 weft system 26 yarns/cm
finishing	digital print + plissé corteccia + ironing

APPENDIX 3

Flow Resistance Test Results from Müller-BBM

Results of all development cycle no. 1 prorotypes

MÜLLER-BBM

Tabella 3. Risultati delle misurazioni.

Codice articolo	Nome prodotto	Peso g/m²	Resistenza al flusso specifica R_s / Pa s/m	Potere fonoassorbente atteso
23131 st	**Linda acustic stiro**	**172**	**702**	**Medio-alto**
23132 st.	Linda acustic stiro	99,8	367	medio
23131 ai+st	**Linda acustic airo+stiro**	**177**	**828**	**Medio-alto**
23181	Organza white acustic	69,2	149	basso
23182	Linda	138	177	basso
23183	Linda acustic	211	236	basso
23178	Sara black acustic	55	43	Molto basso
23180	Organza white acustic	69,9	60	Molto basso
23179	Sara black acustic	69,2	115	basso
23120	Hard – set acustic	235	90	Molto basso
23120	Hard – set 30/2	198	32	Molto basso
23112	Hard – set acustic	87,6	93	Molto basso
23132 ai+st	Linda acustic airo+stiro	101	417	medio
23111	**Hard – set acustic**	**143**	**869**	**Medio-alto**
23175	Star light black acustic	89,6	35	Molto basso
23109	Hard – set star lig.b. acustic	209	268	basso
23174	Star light black acustic	73,9	37	Molto basso
23138 st	Sara b. acustic stiro	161	50	Molto basso
23186	Star light black cinz	72,3	12760	Molto basso
23138ai+st	Sara b. acustic airo+stiro	158	58	Molto basso
23249	Star light white	105	129	basso
22610	Hard – set linda	154	215	basso
15224	Star light white	66,8	179	basso
14957	Star light white print	36,5	556	medio

Results of selected development cycle no. 2 prorotypes

MÜLLER-BBM

Tabella 3. Risultati delle misurazioni (01.04.2016)

Codice articolo	Nome prodotto	Peso g/m²	Resistenza al flusso specifica R_s / Pa s/m	Potere fonoassorbente atteso
23360	Linda	148	303	Basso
23347	Organza White acustic	70,1	309	Basso
23381	Sara white acustic	95,3	321	Basso
23366	Star light black acustic	124	337	Basso
23371	Hard-set linda acustic	294	363	Medio
23364	Star light white acustic	122	365	Medio
23361	Star light black acustic	111	370	Medio
23358	Star light black acustic	158	494	Medio
23355	Starlight white acustic	141	531	Medio
23345	Linda acustic	184	729	Medio-alto
23372	Linda acustic	219	804	Medio-alto
23348	Linda acustic	126	976	Medio-alto
23362	Linda acustic	137	1106	Medio alto

6 Valutazione dei risultati ottenuti

In Tabella 3 abbiamo indicato qualitativamente il potere fonoassorbente atteso dei materiali esaminati.

Le stoffe 23345, 23372, 23348, 23362 sono interessanti per applicazioni acustiche. Esse hanno una resistenza al flusso ideale per l'assorbimento acustico. Il loro peso relativamente basso ne riduce probabilmente un po' il potere fonoisolante. Per queste stoffe sarebbe utile eseguire una misura secondo la ISO 354 [2] per determinare esattamente il potere fonoassorbente, che è la grandezza che interessa nella scelta dei materiali per applicazioni acustiche.

Le stoffe 23371, 23364, 23361, 23358, 23355 hanno una resistenza al flusso leggermente inferiore al range ideale e pertanto ci si attende un potere fonoassorbente medio. Anche in questo caso si tratta di stoffe molte leggere – questo ha un effetto negativo sul potere fonoisolante atteso. Anche per queste stoffe potrebbe essere interessante eseguire un test secondo la norma ISO 354 [2].

Le rimanenti stoffe hanno una resistenza al flusso troppo bassa per fornire un assorbimento acustico significativo.

Simone Conta M.Sc.

APPENDIX 4

Sound Absorption Test Results Commissioned by Kvadrat

Results of design 23112 as 100% folded arrangements

Sound absorption coefficient ISO 354

Measurement of sound absorption in reverberation rooms

Client: Kvadrat A/S
DK-8400 Ebeltoft

Test specimen: Fabric "Hard-set Acoustic" Kvadrat A/S,
Folded arrangement (100 % fabric addition), 100 mm distance to reflective wall

Material details

- manufacturer Kvadrat A/S
- fabric type Hard-set Acoustic
- material 100 % polyester FR
- area specific mass app. m'' = 87 g/m²
- air flow resistance R_S = 70 Pa s/m
- thickness t = 0.28 mm

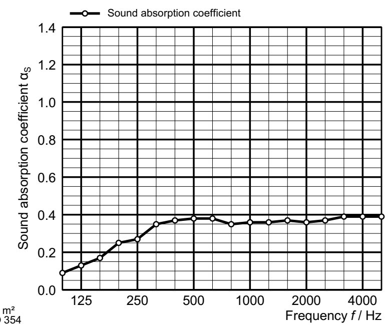
Test arrangement

- test set-up made of 3 curtains: 2 curtains 3.00 m x 3.00 m, 1 curtain 1.00 m x 3.00 m
- arranged folded with 100 % fabric addition and 20 mm overlap at curtain splices
- hanging on a metal rail at the ceiling of the reverberation room in front of a reflective wall, 100 mm clear distance to the wall, arranged without enclosing frame
- total dimensions of the test surface: width x height = 3.48 m x 2.95 m

Room: E
Volume: 199.60 m³
Size: 10.27 m²
Date of test: 2015-12-08

	θ [°C]	r. h. [%]	*B* [kPa]
without specimen	20.5	34.0	96.9
with specimen	20.3	35.0	96.5

Frequency [Hz]	α_S 1/3 octave	α_p octave
100	∘ 0.09	
125	0.13	0.15
160	0.17	
200	0.25	
250	0.27	0.30
315	0.35	
400	0.37	
500	0.38	0.40
630	0.38	
800	0.35	
1000	0.36	0.35
1250	0.36	
1600	0.37	
2000	0.36	0.35
2500	0.37	
3150	0.39	
4000	0.39	0.40
5000	0.39	



∘ Equivalent sound absorption area less than 1.0 m²
α_S Sound absorption coefficient according to ISO 354
α_p Practical sound absorption coefficient according to ISO 11654

Rating according to ISO 11654:	Rating according to ASTM C423:
Weighted sound absorption coefficient α_w = 0.40	**Noise Reduction Coefficient *NRC* = 0.35**
Sound absorption class: D	**Sound Absorption Average *SAA* = 0.35**

MÜLLER-BBM Planegg, 2015-12-15
No. of test report M100827/94
Appendix A
Page 2

Results of design 23175 as 100% folded arrangements

Sound absorption coefficient ISO 354

Measurement of sound absorption in reverberation rooms

Client: Kvadrat A/S
DK-8400 Ebeltoft

Test specimen: Fabric "Star Light Black" Kvadrat A/S,
Folded arrangement (100 % fabric addition), 100 mm distance to reflective wall

Material details

- manufacturer Kvadrat A/S
- fabric type Star Light Black
- material 100 % polyester FR
- area specific mass app. m'' = 100 g/m²
- air flow resistance R_S = 34 Pa s/m
- thickness t = 0.42 mm

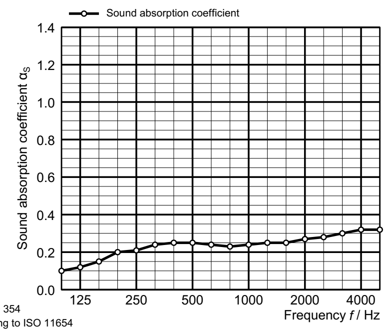
Test arrangement

- test set-up made of 3 curtains: 2 curtains 3.00 m x 3.00 m, 1 curtain 1.00 m x 3.00 m
- arranged folded with 100 % fabric addition and 20 mm overlap at curtain splices
- hanging on a metal rail at the ceiling of the reverberation room in front of a reflective wall, 100 mm clear distance to the wall, arranged without enclosing frame
- total dimensions of the test surface: width x height = 3.48 m x 2.95 m

Room: E
Volume: 199.60 m³
Size: 10.27 m²
Date of test: 2015-12-08

	θ [°C]	r. h. [%]	*B* [kPa]
without specimen	20.5	34.0	96.9
with specimen	20.2	32.7	96.6

Frequency [Hz]	α_S 1/3 octave	α_p octave
100	0.10	
125	0.12	0.10
160	0.15	
200	0.20	
250	0.21	0.20
315	0.24	
400	0.25	
500	0.25	0.25
630	0.24	
800	0.23	
1000	0.24	0.25
1250	0.25	
1600	0.25	
2000	0.27	0.25
2500	0.28	
3150	0.30	
4000	0.32	0.30
5000	0.32	



α_S Sound absorption coefficient according to ISO 354
α_p Practical sound absorption coefficient according to ISO 11654

Rating according to ISO 11654:	Rating according to ASTM C423:
Weighted sound absorption coefficient α_w = 0.25	**Noise Reduction Coefficient *NRC* = 0.25**
Sound absorption class: E	**Sound Absorption Average *SAA* = 0.24**

MÜLLER-BBM Planegg, 2015-12-15
No. of test report M100827/90
Appendix A
Page 2

Results of design 23178 as 100% folded arrangements

Sound absorption coefficient ISO 354

Measurement of sound absorption in reverberation rooms

Client: Kvadrat A/S
DK-8400 Ebeltoft

Test specimen: Fabric "Sara Black" Kvadrat A/S,
Folded arrangement (100 % fabric addition), 100 mm distance to reflective wall

Material details

- manufacturer Kvadrat A/S
- fabric type Sara Black
- material 100 % polyester FR
- area specific mass app. m'' = 66 g/m²
- air flow resistance R_S = 48 Pa s/m
- thickness t = 0.21 mm

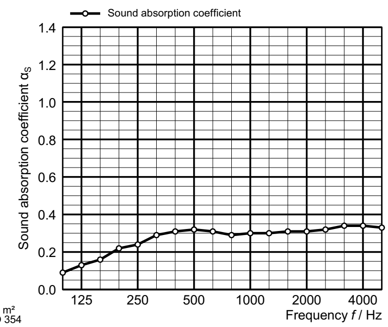
Test arrangement

- test set-up made of 3 curtains: 2 curtains 3.00 m x 3.00 m, 1 curtain 1.00 m x 3.00 m
- arranged folded with 100 % fabric addition and 20 mm overlap at curtain splices
- hanging on a metal rail at the ceiling of the reverberation room in front of a reflective wall, 100 mm clear distance to the wall, arranged without enclosing frame
- total dimensions of the test surface: width x height = 3.48 m x 2.95 m

Room: E
Volume: 199.60 m³
Size: 10.27 m²
Date of test: 2015-12-08

	θ [°C]	r. h. [%]	*B* [kPa]
without specimen	20.5	34.0	96.9
with specimen	20.4	35.8	96.5

Frequency [Hz]	α_S 1/3 octave	α_p octave
100	∘ 0.09	
125	0.13	0.15
160	0.16	
200	0.22	
250	0.24	0.25
315	0.29	
400	0.31	
500	0.32	0.30
630	0.31	
800	0.29	
1000	0.30	0.30
1250	0.30	
1600	0.31	
2000	0.31	0.30
2500	0.32	
3150	0.34	
4000	0.34	0.35
5000	0.33	



∘ Equivalent sound absorption area less than 1.0 m²
α_S Sound absorption coefficient according to ISO 354
α_p Practical sound absorption coefficient according to ISO 11654

Rating according to ISO 11654:	Rating according to ASTM C423:
Weighted sound absorption coefficient α_w = 0.30	**Noise Reduction Coefficient *NRC* = 0.30**
Sound absorption class: D	**Sound Absorption Average *SAA* = 0.29**

MÜLLER-BBM Planegg, 2015-12-15 No. of test report M100827/96 Appendix A Page 2

Results of design 23181 as 100% folded arrangements

Sound absorption coefficient ISO 354

Measurement of sound absorption in reverberation rooms

Client: Kvadrat A/S
DK-8400 Ebeltoft

Test specimen: Fabric "Organza White" Kvadrat A/S,
Folded arrangement (100 % fabric addition), 100 mm distance to reflective wall

Material details

- manufacturer Kvadrat A/S
- fabric type Organza White
- material 100 % polyester FR
- area specific mass app. m'' = 68 g/m²
- air flow resistance R_S = 117 Pa s/m
- thickness t = 0.20 mm

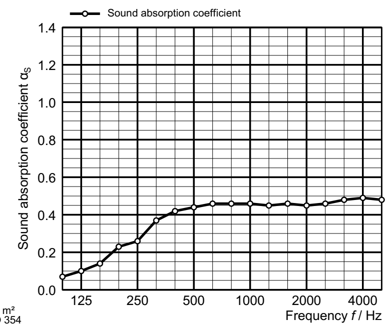
Test arrangement

- test set-up made of 3 curtains: 2 curtains 3.00 m x 3.00 m, 1 curtain 1.00 m x 3.00 m
- arranged folded with 100 % fabric addition and 20 mm overlap at curtain splices
- hanging on a metal rail at the ceiling of the reverberation room in front of a reflective wall, 100 mm clear distance to the wall, arranged without enclosing frame
- total dimensions of the test surface: width x height = 3.48 m x 2.95 m

Room: E
Volume: 199.60 m³
Size: 10.27 m²
Date of test: 2015-12-08

	θ [°C]	r. h. [%]	*B* [kPa]
without specimen	20.5	34.0	96.9
with specimen	20.4	35.6	96.5

Frequency [Hz]	α_S 1/3 octave	α_p octave
100	∘ 0.07	
125	0.10	0.10
160	0.14	
200	0.23	
250	0.26	0.30
315	0.37	
400	0.42	
500	0.44	0.45
630	0.46	
800	0.46	
1000	0.46	0.45
1250	0.45	
1600	0.46	
2000	0.45	0.45
2500	0.46	
3150	0.48	
4000	0.49	0.50
5000	0.48	



∘ Equivalent sound absorption area less than 1.0 m²
α_S Sound absorption coefficient according to ISO 354
α_p Practical sound absorption coefficient according to ISO 11654

Rating according to ISO 11654:	Rating according to ASTM C423:
Weighted sound absorption coefficient α_w = 0.45	**Noise Reduction Coefficient *NRC* = 0.40**
Sound absorption class: D	**Sound Absorption Average *SAA* = 0.41**

MÜLLER-BBM Planegg, 2015-12-15 No. of test report M100827/98 Appendix A Page 2

APPENDIX 5

Client Inquiry Requirements Analysis

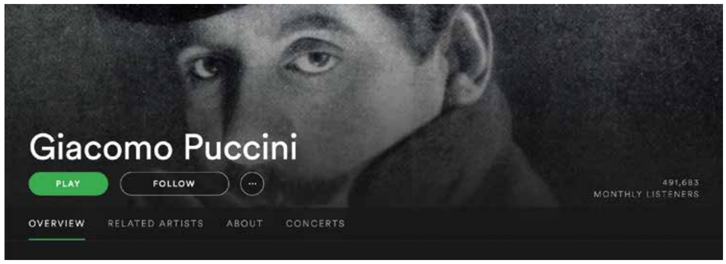
each design is evaluated by the most important factors given by Kvadrat and Silent Gliss
flame retardancy – 1 = 100% Trevira/PES FR fabric, 0.5 = easily modifiable as 100% Trevira/PES FR fabric
high R_s value – 1 = >500, 0.5 = 300–500
other factors – 1 = fully accomplished, 0.5 = partly accomplished

cycle no.1	flame retardant	high R_s value	good drape	translucent	matte effect	overall score
23109						0
23111	1	1			0.5	2.5
23112	1		0.5	0.5	0.5	2.5
23115		0.5		0.5		1
23120						0
23131		1			0.5	1.5
23132	0.5	0.5	1	0.5	0.5	**3**
23138					0.5	0.5
23174	0.5		1	1		2.5
23175	0.5		1	1		2.5
23178	0.5		1	1		1.5
23179	0.5			1		1.5
23180				1		1
23181	0.5		1	1	0.5	**3**
23182			1		1	2
23183	1				1	2

cycle no.2	flame retardant	high R_s value	good drape	translucent	matte effect	overall score
14957 DP		0.5	1	1		2.5
14957 DP+plissé		0.5		0.5		1
23345	1	1	0.5			2.5
23347	1		1	1	1	**4**
23348	1	1		0.5	0.5	3
23349	1					1
23350				1		1
23355	0.5	1	0.5		0.5	2.5
23358	1	0.5	1		1	**3.5**
23360	1		1		1	3
23361	0.5	0.5	0.5	1	0.5	3
23362	1	1	0.5	0.5	1	**4**
23363					0.5	0.5
23364	1	0.5	1		0.5	3
23366	0.5	0.5		1		2
23367	1		1	1		3
23368		0.5		0.5		1
23369	1				0.5	1.5
23371	1	0.5				1.5
23372		1	0.5	0.5	1	3
23373	1		0.5	1	0.5	3
23374	1		0.5		0.5	2
23376			0.5		0.5	1
23379			0.5		0.5	1
23380	1			0.5	1	2.5
23381	1	0.5		1		2.5
23386	0.5		1	1	0.5	3
23389	1		0.5		1	2.5

APPENDIX 6

Sound Diary



Wed 18.11.
stream and natural sounds
Thu 19.11.
bird songs
loons
Fri 20.11.
pink noise
whale songs
Mozart
Bon Iver
Mon 24.11.
Wolfgang Amadeus Mozart
Tue 24.11
Erika Haase, Ligeti: Works for piano and cembalo
Dustin O'Halloran: Lumiere
Wed 25.11.
string quartet, Mozart
Fleet Foxes: Fleet Foxes
Thu 26.11.
Spotify: Calm Before the Storm
Spotify: Focus Now (classical)
The Nutcracker
Opera Classics, Giacomo Puccini
Fri 27.11.
Nature Rhythms: Loons
Wind in the grass
Mon 30.11.
Spotify – Peaceful Piano
Tue 1.12.
ballet – Nutcracker, Swan Lake
Spotify – Women of Jazz
Wed 2.12.
Finnish Folk Songs – Suomalaisia Kansanlauluja, Martti Talvela
Spotify – Folksy Christmas
Thu 3.12.
Spotify – Folksy Christmas
Fri 4.12.
Spotify – Intense Studying
Tue 8.12.
Sibelius
Soundcloud – Invite's Choice Podcast 198 – Joel Mull
Basso Radio – Deep Space Helsinki
Wed 9.12.
Soundcloud – Invite's Choice Podcast 198 – Joel Mull
Fri 11.12.
Spotify – Atmospheric Calm

APPENDIX 7

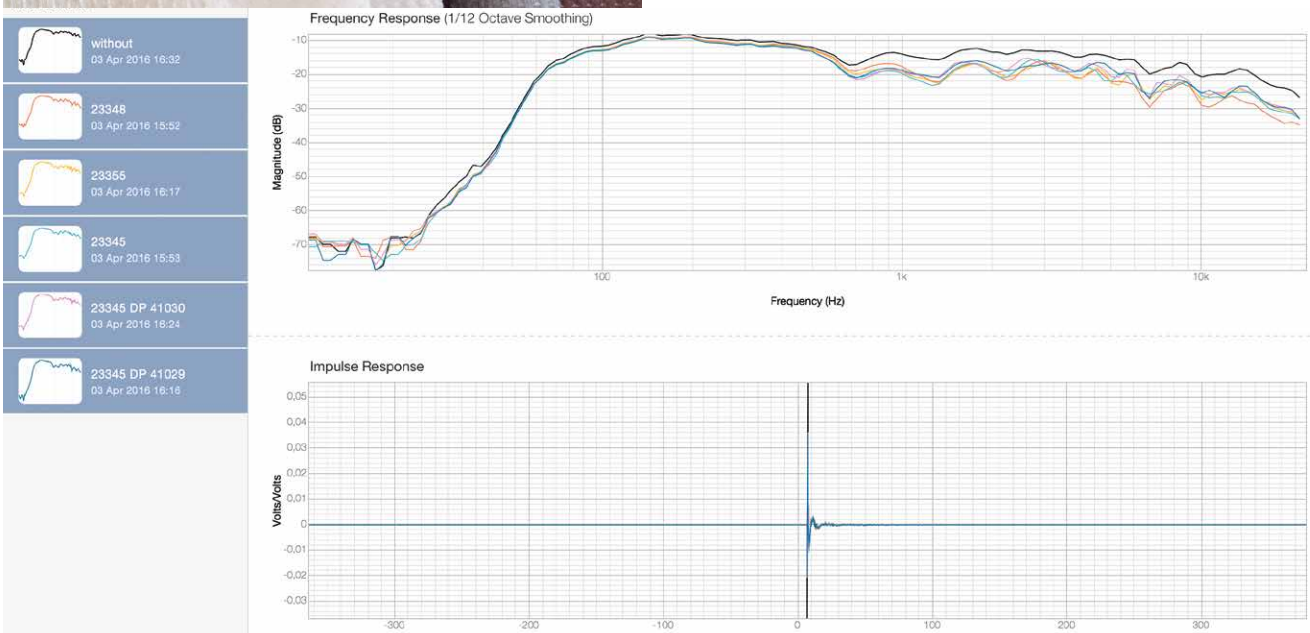
Tentative Test Groups

Group 1 (R_s 804–1106)

attenuates sound passing through the fabric 4–8 dB from 700Hz and up

Group 2 (R_s 531–976)

attenuates sound passing through the fabric 4–7 dB from 700Hz and up



Group 3 (R_s 363–494)

attenuates sound passing through the fabric 3–6 dB from 700Hz and up

Group 4 (R_s 370–417)

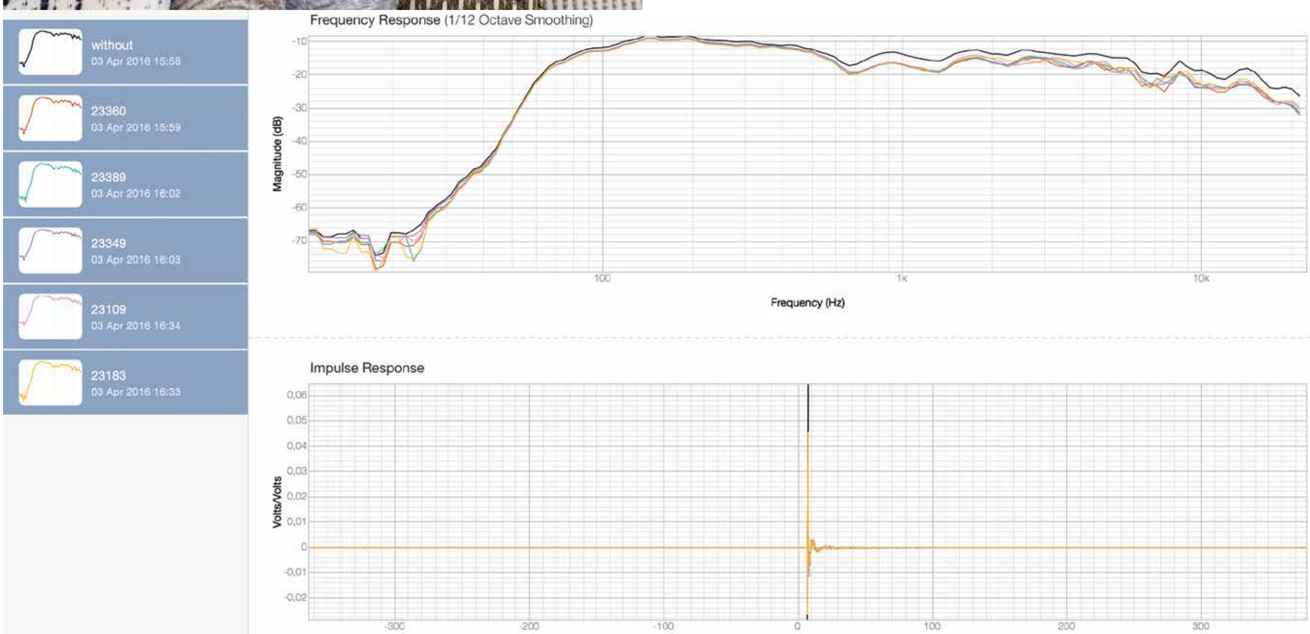
attenuates sound passing through the fabric 2–6 dB from 700Hz and up

Group 5 (R_s 321–365)

attenuates sound passing through the fabric 1–5 dB from 700Hz and up

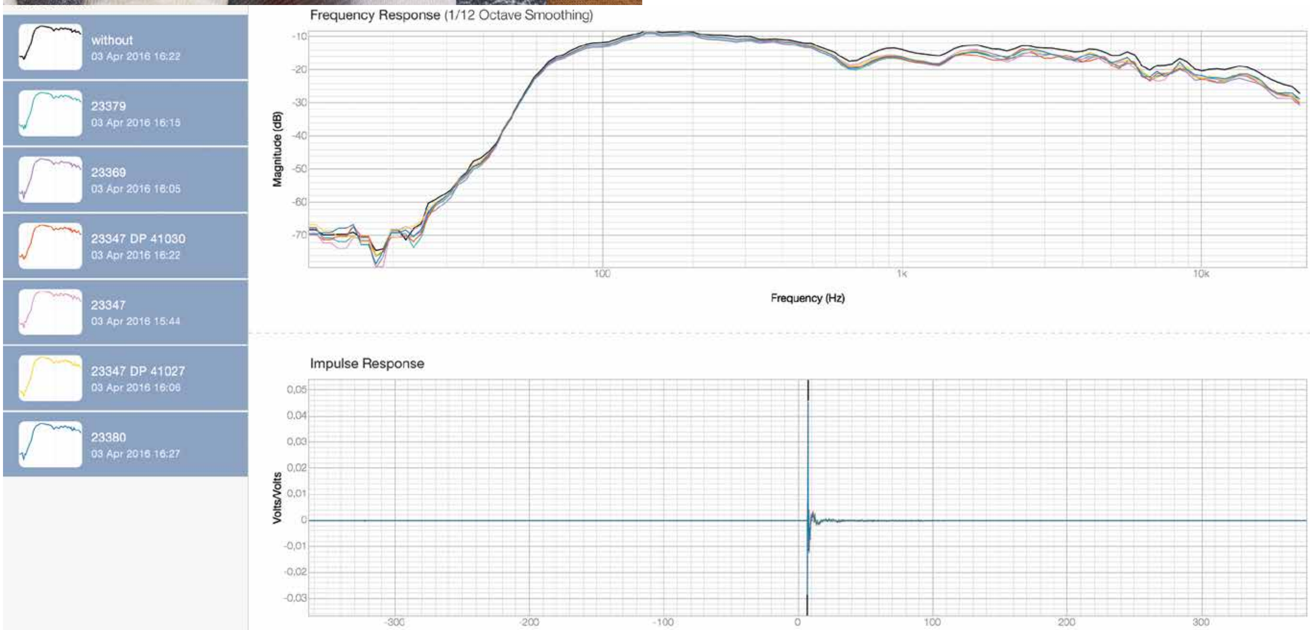
Group 6 (R_s 236–303)

attenuates sound passing through the fabric 1–4 dB from 700Hz and up



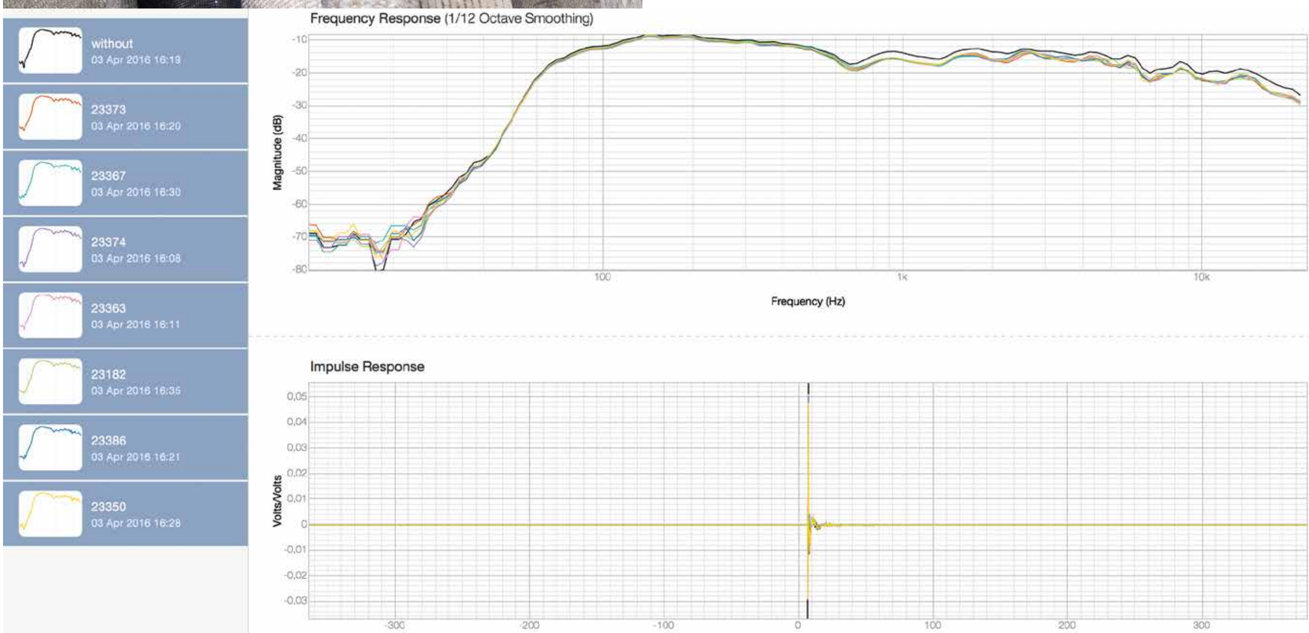
Group 7 (R_s approx. 300)

attenuates sound passing through the fabric 1–3 dB from 700Hz and up



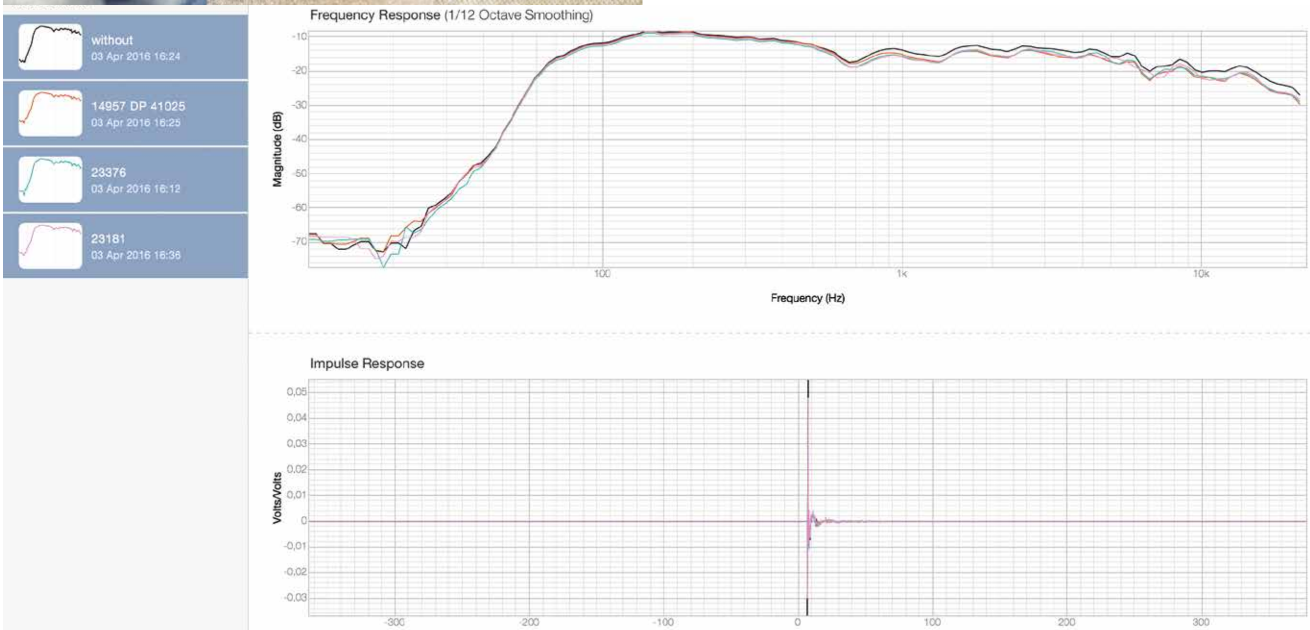
Group 8 (R_s 150–200)

attenuates sound passing through the fabric 0–3 dB from 700Hz and up



Group 9 (R_s approx. 150)

attenuates sound passing through the fabric 1–2 dB from 700Hz and up



Group 10 (R_s 30–115)

attenuates sound passing through the fabric 0–2 dB from 700Hz and up