SOFT TONES – BETWEEN THREE LANGUAGES NEW SPACE IS DISCOVERED

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Abstract: The everyday environment (outdoor and indoor) is exposed to noise from cars, factories, loudspeakers, and noise in restaurants, and reflections by walls and building facades. The research question was how the viewpoints from architecture, acoustics, and art can be combined to find ways to add extra layers of quality to standard materials through smart geometric design and at the same time to improve the acoustic properties of the material. This paper presents results from an interdisciplinary project which were exhibited at the Museum of Perception in Graz, Austria. The collection contains works by students and researchers of architecture and audio engineering. Selected designs demonstrate sophisticated patterns, acoustic efficiency and artistic creation as a link between architectural design, acoustic functionality, and applied art. This exhibition also shows the benefits of working in the interdisciplinary field between architecture, acoustics and art and raises awareness of our surroundings and the possibilities to shape our daily environment. Resulting designs were characterised by acoustic properties leading to a multidimensional classification of the panels (geometric design, acoustic properties and art object) which can be used in different contexts and should provide ideas for future applications, such as absorbing facades, acoustic panels, noise barriers and serve as art objects at the same time. An emphasis is put on how the research questions can be addressed in interdisciplinary lectures at universities and how students can benefit from different viewpoints and scientific approaches.

Key words: architectural geometry, acoustics, folding, bending, kerfing, laser cutter, cutting plotter

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INTRODUCTION

We perceive the world with our senses: sight, touch, hearing, smell, and taste. Neuroscience has been researching for a long time the fact that the senses do not evolve in isolation from each other, but work together.[2] Hence, multisensory information must be put together in our brain to form a coherent image of the environment, enabling us to act in a goal-oriented way. Many researchers also see an interconnection between multisensory perception – seeing, hearing, feeling – and sensorimotor action – walking, grasping, throwing, etc. and are convinced that perception can adapt to a changing environment.[3] When visual and auditory information is presented at the same time, it can have a profound effect on the perception. An example for an audiovisual illusion was shown in the McGurk-effect.[4] Participants were exposed to a video with a speaker saying the word "baba" but seeing the lip movements from the word "gaga". The majority of the participants reported hearing the word "dada", which was neither present in the visual nor in the auditory part of the stimulus.

When we perceive our surroundings with all senses, we realise that our living environment is overloaded with various types of noises such as traffic noise, machinery, leisure noise, or even high noise levels at the daily workplace. This noise has a negative impact on our quality of life[5] and working productivity. Such sound pollution is additionally increased by the reflection of the noise on the building skins, especially in compact urban spaces with street canyons (streets flanked on both sides by buildings)[6] and in the spaces where we are living and working. Contemporary building materials are flat and smooth with highly reflecting properties (like glass, metal or stone) that present low diffusion values.[7] Architectural design has great potential for the improvement and enhancement of acoustic comfort if considered in the early design stage. This improvement can range from the building skin to the surfaces inside the spaces where we live. However, many aspects of the complex interaction between the geometry, their materiality and the acoustic potential have not been properly addressed in current architectural and geometrical research. Hence, it is necessary to study the potential of new materials, and find a useful link between the acoustic potential and the geometry of architectural elements.

This paper deals with three research questions, which are closely linked to each other and aim for a holistic view of the presented topic: (1) How can we find efficient and innovative ways to develop geometries for architectural function and design systems with sound absorbing and diffusing properties?, (2) How can the complex interaction between acoustics, geometry, and architecture be addressed from a multi-modal viewpoint including other human senses, hence linking the auditory

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2 M. Teichert and J. Bolz, "How Senses Work Together: Cross-Modal Interactions between Primary Sensory Cortices", *Neural Plasticity*, 2018, 538–921.

3 K. L Campi , K. L Bales, R. Grunewald and L. Krubitzer, "Connections of auditory and visual cortex in the prairie vole (Microtus ochrogaster): evidence for multisensory processing in primary sensory areas", *Cereb Cortex* 20(1), 2010, 89–108.

4 H. McGurk and J. MacDonald, "Hearing lips and seeing voices, *Nature* 264, 1976, 746–748.

5 European Union, *Decision No 1386/2013/EU of the european parliament and of the council of 20 november 2013 on a general union environment action programme to 2020 "living well, within the limits of our planet,* Off. J. Eur. Union, 2013, 171–200.

6 J. Picaut, et al., "Experimental study of sound propagation in a street", *Applied Acoustic* 66, 2005, 149–173.

7 M. Ismail and D. Oldham, "A scale model investigation of sound reflection from building façades", *Applied Acoustic* 66, 2005, 123–147.

dimension to the visual perception?, and (3) How can the results be disseminated to the public so that everyone involved can benefit from it? When addressing the research questions, the interconnection to other disciplines (next to architecture and acoustics) was discovered, namely the relationship to the theory of perception and art. Finding a common language and building on the fundamentals of each discipline has led to the analysis of the topic from a holistic viewpoint. Research questions 1 and 2 were addressed in the context of interdisciplinary teaching and research collaborations at Graz University of Technology (TUG), including project work with students from architecture and audio engineering. The third question was addressed by a collaboration between TUG and the Museum of Perception in Graz (MUWA), where the results were displayed in the context of an exhibition, thus linking the field of science and engineering to art.

In order to ensure a holistic view of the interdisciplinary field between architecture, acoustics, and art, a multi-modal approach of perception has to be applied. Conveying the fundamentals of perception has been incorporated in the education program of MUWA for many years and is regularly developed further based on the actual state of scientific knowledge. This process of creating continuously new self-experienced knowledge helps to acknowledge that the creation of a common reality we are living in is in a constant state of change. We are currently experiencing this change particularly in the context of the Corona pandemic.

We see the world through the filter of our perception and give what we perceive an individual meaning – so we perceive the world in many different ways. In communication we share our world with the other person – we find similarities and differences – and language is always related to a socially determined action. Siegfried J. Schmid, a literary scholar, states that "Reality is therefore a realm of descriptions/representations, not an ensemble of objective objects. Every description, however, necessarily includes an observer: only for him does something that he can describe become an object that he can distinguish from others. The observer is the last possible reference point for every description."[8] The constructedness of our environment becomes clear when we observe how we observe, act and communicate. Heinz von Foerster, a representant of radical constructivism declared that "an observing organism is itself a part, a partner of, and a participant in its observational world"[9], so he denied objectivism which would require the separation of the observer and the observed.

Perception is essentially dependent on the cognitive system (sensomotoric system, knowledge, emotions, memory), on language and communication, on social structure and culture. Constructed reality is therefore a social reality. The Museum of Perception tries to encourage people to become aware of individual and collective active processes of perception based on their own experiences and in exchange with other people. "Recognition is not about objects, because recognition is effective action and by recognising how we recognise, we bring ourselves forth."[10]

According to the *hands on* motto, perception becomes an experiment without an objectifiable result. Under these conditions MUWAs educational program tries

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8 S. Schmid. *Vom Text zum Literatursystem. Skizze einer konstruktivistischen Literaturwissenschaft, in Einführung in den Konstruktivismus*, Piper Verlag, München, 2003, 152.

9 H. von Foerster. *Entdecken oder Erfinden. Wie lässt sich Verstehen verstehen? in Einführung in den Konstruktivismus,* Hg. Heinz Gumin und Heinrich Maier, Piper Verlag, München, 2003, 43.

10 M. Varela. *Der Baum der Erkenntnis. Die biologischen Wurzeln menschlichen Erkennens*, Goldmann, München, 1996, 262.

to combine all senses within different exercises and invites participants to reflect on their own experiences as well as in exchange with others and their experiences. Martin Grunwald, a researcher on haptics, who held a lecture at MUWA, explains why we cannot live without the sense of touch. He researches on the sense of touch from the embryo in the womb to the end of life, on touch disorders as well as on vital needs for physical contact, up to and including collaboration in the product design segment. With regard to inanimate objects, four properties are particularly effective: temperature of the object, weight, hardness and surface roughness.[11] In this field it is interesting to pay attention to the language: The German word *begreifen* means *to comprehend* something; the literal sense of touching something is connected to the figurative sense of comprehending something.

Actually, the basic experiences of the workshops at the Museum of Perception can be classified into the following fields:

1. Psychological and social aspects of the process of perception; experimenting with perception installations or optical illusions.
2. Experiencing sensory-motoric-craft experiences with practical processes; experimenting with craft techniques.
3. Understanding processual relationships between motif, form and colour; collecting, arranging and exhibiting.
4. Recognising and understanding basic mathematical and geometrical orders; becoming aware of the connections between rational and aesthetic orders; rules in artistic activity.
5. Elaborating and developing further reflexive competencies; promoting the ability to interpret in the above-mentioned areas.

The workshops and the fundamental approach of MUWA inspired the present work in the following way: linking the field of architecture and acoustics and looking at it from the viewpoint of perception as a comprehensive theory that addresses all senses. We designed the research questions as topics that could be addressed in students' projects at university level (seminars and hands-on workshops at Bachelor and Master level), where the participants from the field of architecture and audio engineering could cooperate, exchange their expertise on equal terms and enhance each other's way of thinking.

METHODS

Our approach is embedded between architectural, acoustic and artistic aspects and their mutual influence in the context of research and teaching in an interdisciplinary field. While scientific research in engineering operates with numbers, measured values and their analysis, our aim is to sensitize engineering students and the broad public to the influence of artistic creation as a driving factor for research and/or creative thought processes – based on a centuries-old tradition of linking art and science. Especially in areas dominated by high-tech processes, such as computer-controlled architectural planning and acoustic simulation techniques, haptic fabrication enables students to gain a specific material awareness for architectural-acoustic spatial concepts that can be perceived with all their senses.

In the first phase, the students learned the basic principles of room acoustics and geometric design techniques. Secondly, they applied their knowledge to design and

11 M. Grunwald. *Homo Hapticus – Warum wir ohne den Tastsinn nicht leben können*, Droemer & Knaur, 2017, 165.

fabricate panels in regard to linking architectural design and acoustic functionality. At last, the final results were exhibited at two conferences and in an exhibition in the Museum of Perception in Graz. The aim of the exhibition was to show the benefits of working in the interdisciplinary field between architecture, acoustics, and art and to raise the awareness of our surroundings and the possibilities to shape our daily environment.

Our methodology is characterized by research through experimentation and design. We introduce 1) geometrical topics like folding, bending, patterning and ornamentation as a design inspiration for experimentation; 2) acoustic measurement methods – quantifying each design with acoustic parameters; 3) improvement of design based on acoustic results; 4) preparation of design for digital fabrication, 5) CNC fabrication and 6) assembly methods. With this methodology, we emphasize an interdisciplinary and holistic approach illustrating how research can be implemented in teaching from the very first semester to more experienced students.

A very important task in our approach is to connect teaching with fundamental and applied research. For example, we introduced the topic of folding to the students and young researchers using different kinds of material but the same geometric principles and transformation techniques. In this way, we encourage students' activities that present a wide array of information and viewpoints in the sense of serendipity as an unplanned fortunate discovery.

The next paragraph presents the fundamentals of architectural geometry and architectural acoustics, which were taught to the students. By adapting the topic of acoustics for students of architecture, the goal was to sensitize the students to a field that is important but often neglected. The challenge for them was to combine the fundamentals of both fields and use the knowledge to create novel designs with a certain function, namely a panel that can change the acoustic behaviour of the room and serve as a design object and an essential measure to increase the wellbeing.

ARCHITECTURAL GEOMETRY

Digital technologies and new media have brought about revolutionary changes in the field of architecture, which among other things also concern the discipline of geometry. In the field of applied geometry, a new research discipline called architectural geometry has emerged.

Architectural geometry is an answer to the technical challenges posed by contemporary architecture, especially through its frequent use of free form geometries. It deals with the development of new approaches to the digital representation and manipulation of such forms, including the process of turning them into physical objects. The latter requires the ability to translate these forms into the language of computer-controlled machines in order to enable tailor-made manufacturing processes. So-called parametric design methods and their possibilities to efficiently produce bespoke objects often play an important role in practical applications of architectural geometry. This paper shows how applied architectural geometry can be an inspiration for the design and how digital design and digital fabrication can be implemented in everyday design topics in the work with students.

From a range of geometrical topics for the work with acoustic panels we chose four methods for processing the pieces: (1) two-dimensional tessellation, (2) linear & curved folding, (3) kirigami, and (4) kerfing.

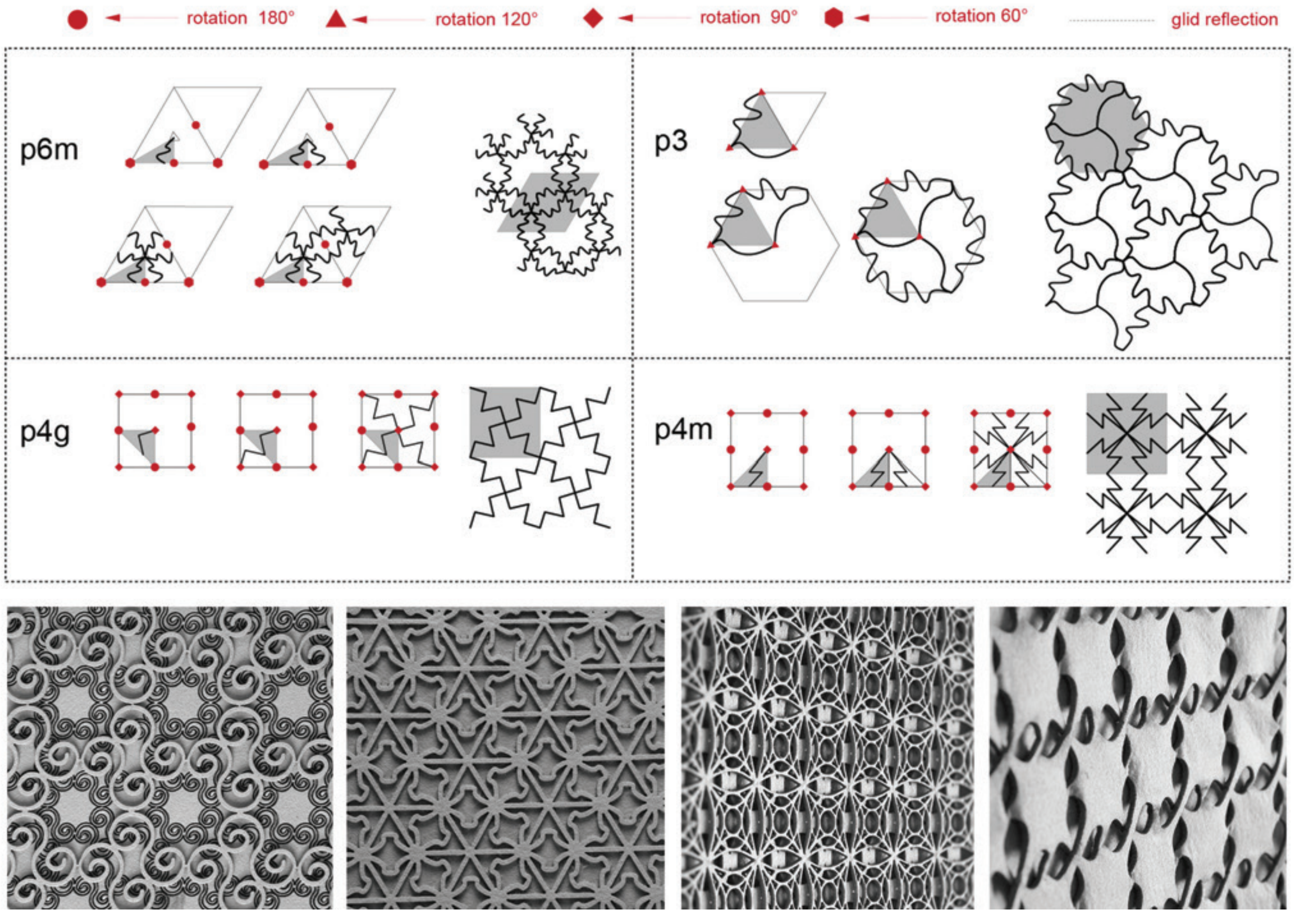

Fig. 1

TWO-DIMENSIONAL TESSELLATION

Two-dimensional tessellation or tiling is the method of covering a plane using one or more geometric shapes, called tiles, with no overlaps and no gaps. Our starting point was the mathematical classification of a two-dimensional repetitive pattern, based on the symmetries in the only one pattern – called wallpaper group. There are 17 different groups of such patterns that are based on only four geometrical transformations: translation, rotation, reflection and glide reflection (Fig. 1, top). One pattern can be interpreted as an amount of 2D shapes, overlaid 2D shapes or a shape that can be developed in a 3D object (Fig. 1, bottom).

LINEAR AND CURVED FOLDING

In folding techniques, a single planar material is folded without stretching, tearing or cutting. We can distinguish between two folding types – linear and curved folding (see Fig 2, top). An Example for a linear folding structure that is developed by folding a plane material along (straight) edges is shown in the first and second image of Fig. 2 on the bottom. This type consists usually of triangles and quadrangles. A curved folding structure is built by folding a plane material along curves (see Fig 2 bottom, third and fourth image). It consists of single curved surfaces, such as cylinders, cones and general developable surfaces.

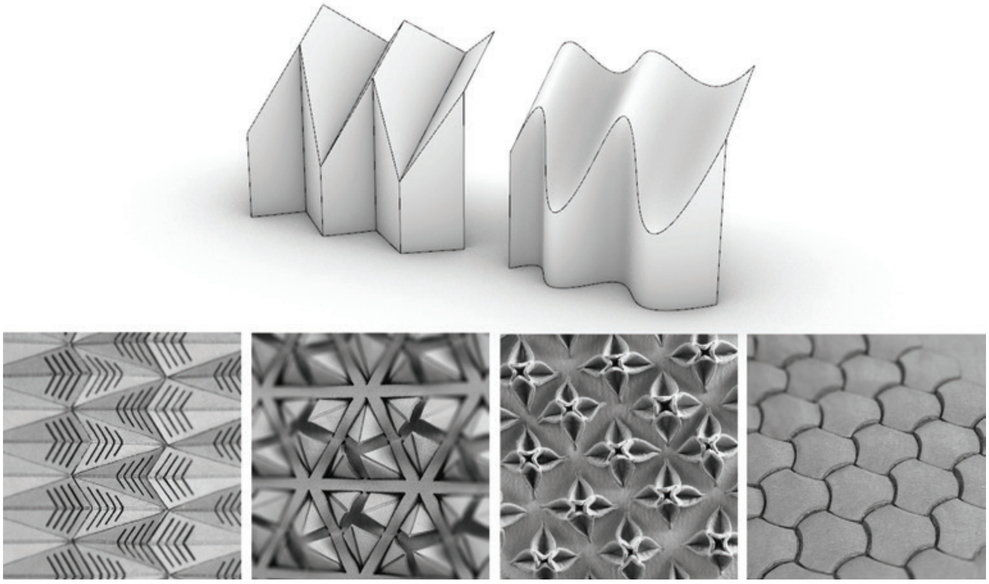

Fig. 2

KIRIGAMI

Kirigami is the Japanese art of paper cutting, whose name is composed of the words “kiru” (cutting) and “kami” (paper). In Fig. 3 (top) an example for the kirigami design is given. If we use this technique with the rigid and thick material, we are facing a new design that can be connected with the original kirigami technique. In such a way, exploring cutting techniques with short and long lines or simple curved, or spiral elements open up broad design possibilities. Using the same technique with different materials, rigidity and material properties surprised with the new appearance and new inspirations (Fig. 3, bottom).

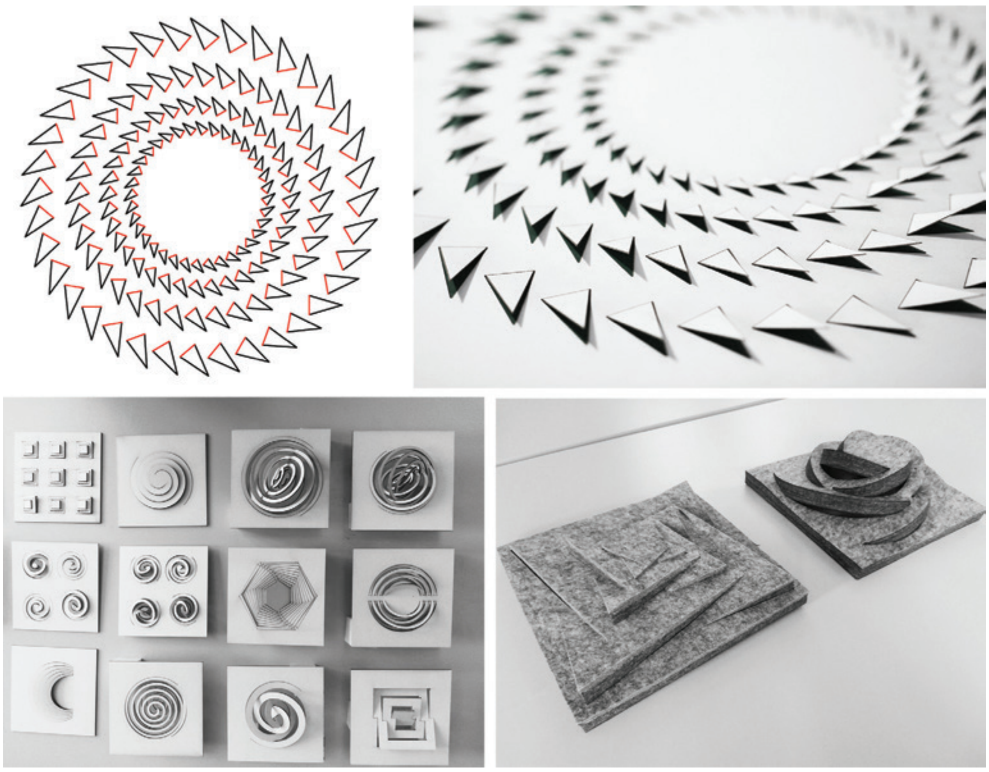

Fig. 3

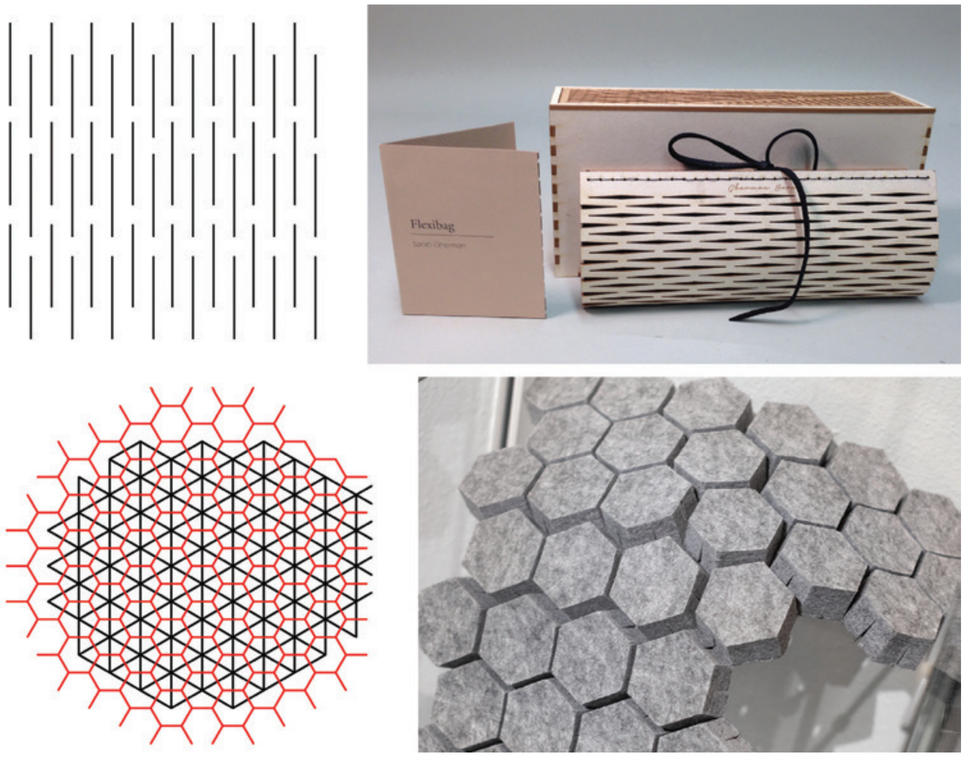

Fig. 4

KERFING

Kerfing or kerf bending is the process of cutting a number of slots into a piece of material that allows it to bend. By kerfing the thick part, the material becomes thinner so it can be flexed to follow a curve. This method is used in the wood industry in order to bend material in one or two directions. This way, a very rigid material becomes soft and depending on the depth and direction of the slots, the material can be bent in one or two directions (see Fig. 4).

ARCHITECTURAL ACOUSTICS AND ACOUSTIC CLASSIFICATION

The field of architectural acoustics can be connected to architectural geometry very easily due to the fact that sound propagation in rooms (reflection and absorption) can be described with simple mechanisms which follow geometric rules. The rules depend on the relation between the dimension of a structure and the frequency range taken into account. If the wavelength λ is smaller than the structure of the surface, the reflection angle equals the incident angle on the surface of the structure ($\gamma_1=\gamma_2$), called a specular reflection (see Fig. 5a). When the wavelength λ is in the same order of magnitude, the structure will cause a diffuse reflection and the sound rays are scattered in different directions (see Fig. 5b). If the wavelength λ is larger than the structure, the sound rays ignore the structure and the plane will cause a specular reflection (see Fig. 5c).

Sound is either reflected or absorbed by a surface. The absorption coefficient α is a central parameter in architectural acoustics. It is a quantity between 0 and 1 and describes how much sound is absorbed by a certain area or surface. For example, an absorption coefficient of 0,6 means that 60 % of the incident sound is absorbed by the surface and 40 % is reflected according to geometric rules described above. The absorption principle of porous absorbers like felt and polyester are based on friction

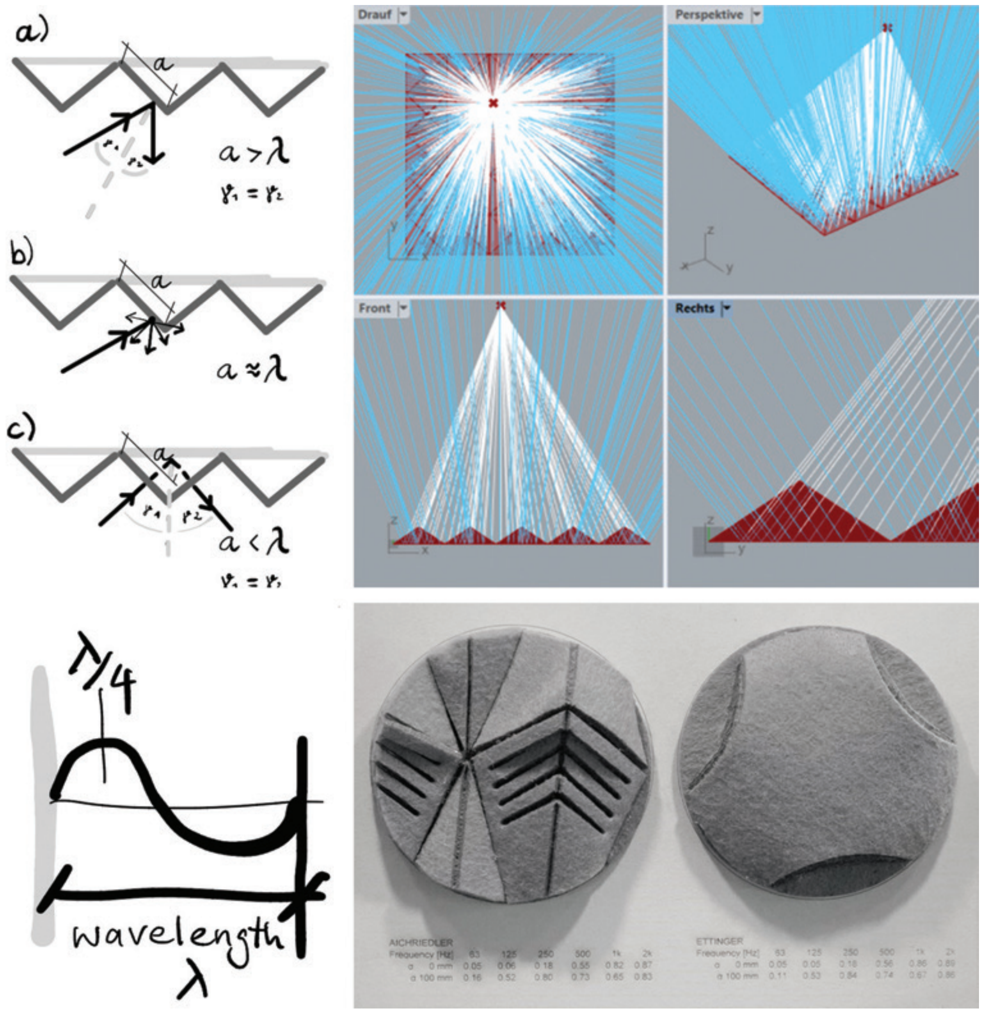

Fig. 5

and are most efficient when placed in the maximum velocity (this equals λ/4 of the sound wave, see Fig. 5). The absorption coefficient with 0 mm air gap and 100 mm air gap behind the structure of the two designs in Fig. 5 are shown in Table 1. The absorption coefficient at low frequencies is increased when the air gap is extended. Furthermore, the design influences the acoustic efficiency and can be used to modify the absorptive and reflective properties for specific geometries and frequencies.

Table 1: Absorption coefficient α for normal sound incidence of two designs from Fig. 5, with 0 mm and 100 mm air gap behind the structure measured in an impedance tube.

	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz
$\alpha_{0\,mm,1}$	0.05	0.06	0.18	0.55	0.82	0.87
$\alpha_{100\,mm,1}$	0.16	0.52	0.80	0.73	0.65	0.83
$\alpha_{0\,mm,2}$	0.05	0.05	0.18	0.56	0.86	0.89
$\alpha_{100\,mm,2}$	0.11	0.53	0.84	0.74	0.67	0.86

To quantify the impact of acoustic measures in a room, the parameter *reverberation time RT*, is used. It is defined as the time in which the sound level drops 60 dB (which relates to the dynamic range that humans can perceive within a short time frame). It can be measured with a loudspeaker and a microphone and it represents

Fig. 6

a central parameter in architectural acoustics. It is denoted as $RT = 0.161*(V/A)$, where V is the room volume and A is the equivalent absorption area of the room. The equivalent absorption area is defined as $A = \alpha * S$, where α is the absorption coefficient of the surface and S is the surface area. When the reverberation time is too high for a given purpose (music, speech, or communication), the noise level will increase and the speech intelligibility will decrease. In order to modify the room surfaces or add extra layers of material for the purpose of increasing the acoustics of a space, one can apply the above mentioned principles and equations to estimate the impact of a measure.

EXHIBITION

The students used the knowledge and theoretical fundamentals from all disciplines and created designs according to the principles of architectural geometry and acoustics. The combined viewpoints led to the fabrication of novel panels,[12] which could be used to increase the acoustic condition of a space or which could be exhibited in a museum due to the artistic character. The exhibition *Soft tones* consciously focuses on the aesthetics of the material and the students' work and in a further step provides information on the research results achieved in the courses (see Fig. 6). The presentation of designs and works already plays an important role at the beginning of architectural studies. In the context of an exhibition for the public, students can be made even more aware of the importance of presentations through a mindful curation of their results.

In Fig. 7 samples of absorbing material are placed in the vitrine, demonstrating the potential of the elements that can be turned into a piece of art by processing it with a cutting plotter and creating a 3D structure. The exhibition shows a balanced range of initial form-finding processes in cardboard that are still detached from the function of improving the acoustics of a room to selected works that, when used in multiples, can provide clear results of improved room acoustics. The exhibits were deliberately not labelled in an educational way, as the visitors' aesthetic experiences are primarily to be achieved by looking at the objects, and explanatory information is only provided in a further step on a flyer or in the catalogues available for viewing. This form of presentation focuses on the viewers and their perceived impressions, referring to a playful, experimental and visionary approach. The progressive

12 M. Stavric and J. Balint, *Architectural Acoustics extended. between two languages new space is discovered*, Verlag der Technischen Universität Graz, 2019.

Fig. 7

character of the exhibition is not imposed on the visitors, but rather automatically incorporated in the way of how the pieces are presented. Some of the samples in the vitrine are labelled with their acoustic properties in an artistic way and the importance of materiality is indicated by comparing rigid to soft panels. Compared to the art exhibitions on the main floor, the focus is on posing questions rather than offering solutions, even though certain materials in the exhibition have been in use for some time. This form of presentation also aims to make scientific research comprehensible as a process where ideas are developed, changed and perhaps rejected, comparable to a procedure experienced by many artists in their work.

ART MEETS FUNCTION

The exhibits were created as pieces of art with multiple functions: to improve the acoustic condition of a space by addressing the auditory dimension and to improve the aesthetic quality of a space by addressing the visual dimension. When entering real spaces, all senses are working together to create a holistic impression of the surrounding. With the following three examples we show how the designs were adapted and further developed to improve the acoustic and aesthetic conditions on site. The first two examples depict a poster session of two scientific conferences (Fig. 8, top). The aim was to improve the experience of poster sessions (both listening and talking) due to the high noise level caused by the participants presenting the poster and asking questions. Especially at places where a high speech intelligibility and privacy are very important, the noise level in the space can be reduced by proper acoustic treatment of the surfaces. At the same time the poster boards serve as art objects and improve the aesthetic quality of the space. From an acoustic point of view, the improvement can be quantified by measuring the reverberation time of the spaces measured before and after integrating the panels. Results indicate that

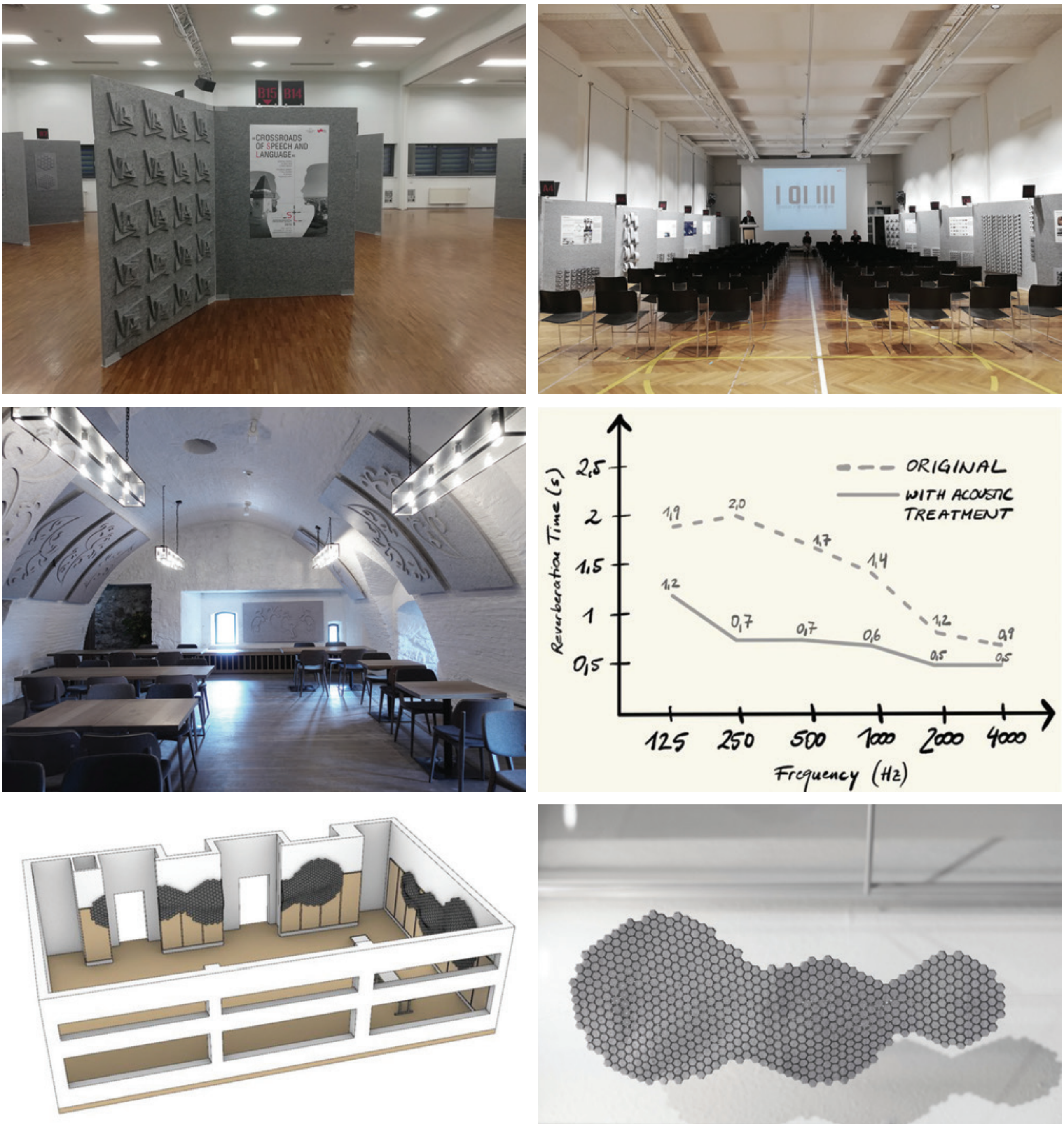

Fig. 8

the reverberation time could be halved, leading to an improved speech intelligibility and a pleasant speech level for the participants.

A third example is shown in Fig. 8, bottom: the acoustic treatment of a vault in an old castle (Burg Forchtenstein, Austria). The space is used as a dining hall in a restaurant, due to the reflecting surfaces (historic stone walls and wooden floor); the high reverberation time caused an increased noise level when guests were talking at the tables. Through the application of 22 m² of acoustic panels (specially designed and built by students of Graz University of Technology), the reverberation time was reduced from 1.7 s to 0.7 s at 500 Hz. By measuring the reverberation time, the benefit of the room treatment can be shown very clearly and the students can see (and hear) the impact of their work.

The last example shows a sketch of a lecture hall at Graz University of Technology. The task was to improve the acoustic situation in the hall in order to decrease the reverberation time and increase the speech intelligibility. In this project students from audio engineering measured the reverberation time in the lecture hall and calculated how much absorbing material is needed to increase the acoustic situation. The results were provided as a basis for the students of architecture to design extraordinary elements for the treatment of the walls. If conventional methods were used to treat the acoustics, usually a perforated gypsum board with a layer of rock wool would be mounted on the ceiling. This way the acoustic design of a room is very unobtrusive and does not add an additional layer of aesthetic quality to the space. However, students from architecture looked at the challenge from a different viewpoint and turned the hall into a gallery by applying acoustic measures in an unconventional way.

DISCUSSION AND CONCLUSION

The attempt of combining three disciplines to benefit from each other's viewpoints was undertaken:

1. *Architectural geometry* served as the basis for novel designs in the field of architectural acoustics.
2. *Architectural acoustics* inspired the design of the elements, which were intended to improve the acoustics of a space.
3. *Art exhibition:* Through exhibiting the acoustic elements as design objects in the Museum of Perception, both the students and the broad public could benefit from novel ideas and gain insight into the auditory and aesthetic dimension when designing our surroundings.

The gain of combining the three disciplines served as the foundation for applications in real situations:

1. Poster presentations at scientific conferences were structured in a new way, where the acoustic poster boards served as absorbing panels to decrease the noise levels in big halls and at the same time turned the space into a large exhibition area for novel designs.
2. The acoustic treatment of a historic dining space in a challenging vaulted hall could be achieved by specially processing a rigid panel and adding a new dimension to the panel.
3. Ideas to design the immediate surroundings of students, namely devising acoustic measures to increase speech intelligibility in a lecture hall by combining the work of students from audio engineering and architecture.

The quantification of measures is highly important in the field of engineering, and an attempt was undertaken to incorporate the world of numbers and measured values into the world of artistic creation. At first, students' designs were classified from an architectural viewpoint by grouping the processing techniques of the materials. The acoustic classification was carried out by measuring the absorption coefficient of each design. When the designs were integrated into real rooms, the reverberation time was measured before and after the objects were placed in the space. Hence, the impact of the design or art objects could be quantified with measured values. This way, the field of architecture and art was combined with the field of acoustics and engineering, and at the same time the objects became pieces of art with a dedicated function when exhibited at a museum. While students of architecture would not take into consideration the aspect of acoustics, students of audio engineering would not consider the importance of aesthetics and visual impressions. The interplay between architectural and acoustic research and teaching was addressed from multiple viewpoints and put into an interdisciplinary context, including perception and art. This comprehensive approach includes the implementation of students' work in exhibitions, which increases motivation and expresses appreciation for the results achieved by the students. At the same time, we offer knowledge transfer to the public and information about the content of university research and teaching.

FUTURE WORK

Within the framework of connecting the disciplines of art, perception, architecture, acoustics and technology paired with a playful approach, it becomes clear that a respectful interaction at equal level benefits the processual work when dealing with research questions. It opens new ways of interaction and raises further questions, for example, which approaches are possible and can be combined in new ways? Which developmental steps raise new questions and in turn lead to new considerations in every discipline involved? The methods of experimentation and the associated reflection and exchange with others will remain important both for the programme in the museum and when researching and teaching at university level. In the future, a strong focus on the multisensory approach in the educational program will be set, which enables experiments and research involving multiple senses. In addition to MUWA's exhibition on visual illusions, the work in the field of acoustics can lead to the integration of auditory illusions. All senses function according to similar principles;converting physical stimuli into neuronal activity, sight and hearing are the best-studied senses, although our survival and well-being also depend on the other senses.

Regarding the materiality of the presented panels, future research in the field of architecture and acoustics should shift from synthetic, plastic-based, recycled materials towards environmentally friendly, biodegradable materials like wool or alginate; following the necessary shift towards sustainable building materials in residential architecture, which have an overall impact on the people living and/or working in them. In this search for new materials, a playful and creative approach is always required and beneficial, as shown in this work. Fundamental research on sustainable materials necessitates the exploration of new qualities of these compounds in terms of architecture, acoustics and aesthetics.

ACKNOWLEDGEMENTS

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ILLUSTRATIONS

1: top) 4 of 17 wallpaper groups with appropriate transformations within one cell with the possible design of a cell and whole pattern design; bottom) a different interpretation of the wallpaper groups in a functional acoustic element made of 3 mm thick fleece: a) single pattern of p6m group b) cut pattern and engrave pattern of p3; c) overlaid pattern of p4m d) 3d interlocking pattern of p4g.
Горе) 4 од 17 група тапета са одговарајућим трансформацијама унутар ћелије са могућим дизајном ћелије и целог узорка; доле) другачија интерпретација група тапета у функционалном акустичком елементу од филца дебљине 3 мм: а) појединачна шара p6m групе б) резана шара и урезана шара p3; ц) преклопљени узорак p4m д) 3д преплетени узорак p4g.
2: top) Two main folding types: linear (left) and curved folding (right); bottom) four variations that offer rigid and curved folding methods.
Горе) Два главна типа савијања: равно (лево) и заобљено савијање (десно); доле) четири варијације које се добијају равном и заобљеном методом савијања.
3: top) Cutting pattern for a kirigami structure, black lines are cut lines and red lines are folding lines; right) fabricated paper kirigami form; bottom) kirigami technique applied on (left) the 3 mm cardboard; (right) the 25 mm thick pressed polyester panels.
Горе) Шема сечења киригамија, црне линије су линије резања, а црвене линије су линије преклапања; десно) форма киригамија од индустријског папира; доле) техника киригами примењена на (лево) картон од 3 мм; (десно) пресоване полиестерске плоче дебљине 25 мм.
4: top) A kerfing-slots pattern and a possible design made of a rigid wooden plate; bottom) lines in the red colour present the slots on the upper side of the material, black on the backside of the material; (right) Slots in the material generate flexibility of the material.
Горе) Шема урезивања прореза и могућност обликовања круте дрвене плоче; доле) црвене линије представљају прорезе на горњој страни материјала, црне на полеђини материјала; (десно) Прорези у материјалу обезбеђују његову флексибилност.
5: top-left) Geometric principles of sound reflection; top-right) geometric reflection on a surface implemented in Grasshopper ; bottom) A porous absorber works best when placed λ/4 from the wall. The gap between the wall and the surface can be constructed by folding.
Горе-лево) Геометријски принципи рефлексије звука; горе десно) геометријски одраз на површини имплементиран у програму Grasshopper; доле) Порозни апсорбер најбоље функционише када је постављен на удаљености λ/4 од зида. Размак између зида и површине може се направити преклапањем.
6: The exhibition "Soft tones" at the Museum of Perception in Graz, Austria.
Изложба „Меки тонови" у Музеју перцепције у Грацу, Аустрија.
7: top) samples of an absorbing material, (right) the same material that has been processed by a cutting creating a 3D structure; bottom) exhibition pieces: the same technique has been used with two different materials, (left) absorbing polyester board and (right) cardboard.
Горе) узорци апсорпционог материјала, (десно) исти материјал који је обрађен сечењем стварајући 3Д структуру; доле) изложени радови: иста техника је коришћена са два различита материјала, (лево) апсорпциона полиестерска плоча и (десно) картон.
8: Acoustic panels used as poster boards and to improve the acoustic situation at the conference (left: Interspeech 2019, Graz; right: Digital Practice Conference 2019, Graz); middle) acoustic panels used as a treatment in a restaurant and the resulting reverberation time before and after the application; bottom) visualization of a lecture hall at Graz University of Technology with a sound-absorbing panel mounted on the wall – the mock-up has been exhibited at the Museum of Perception within the exhibition "Soft tones".
Акустични панели који се користе као постер табле и за побољшање акустике на конференцији (лево: Interspeech 2019, Грац; десно: Digital Practice Conference 2019, Грац); у средини) акустични панели који су постављени у ресторану и резултирајуће време реверберације пре и после примене; доле) визуелизација учионице Технолошког универзитета у Грацу са панелом који апсорбује звук на зиду – макета је изложена у Музеју перцепције у оквиру изложбе „Меки тонови".

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ТИХИ ТОНОВИ – ДЕФИНИСАЊЕ НОВОГ ПРОСТОРА СИНЕРГИЈОМ ТРИ РАЗЛИЧИТА ПРИСТУПА

Резиме: Урбани простор у коме живимо (спољашњи и унутрашњи) свакодневно је изложен буци аутомобила, фабрика, музичких уређаја, угоститељских објеката и рефлексији звука по зидовима и фасадама зграда. Истраживачко питање је било како се могу комбиновати гледишта из архитектуре, акустике и уметности у циљу проналажења начина да се стандардним материјалима додају додатни слојеви квалитета применом паметног геометријског дизајна, а да се у исто време побољшају и акустична својства материјала. Овај рад представља резултате интердисциплинарног пројекта који су били изложени у Музеју перцепције у Грацу (Museum of Perception in Graz), Аустрија. Збирка садржи радове студената и истраживача архитектуре и аудиотехнике. Одабрани радови демонстрирају софистицирани геометријски дизајн, акустичку ефикасност и уметничко стваралаштво као везу између архитектонског дизајна, акустичне функционалности и примењене уметности. Изложба такође истиче квалитет рада у интердисциплинарном пољу између архитектуре, акустике и уметности и подиже свест о нашем окружењу и могућностима да обликујемо наше свакодневно окружење. Остварени радови одликују се акустичним својствима која су довела до вишедимензионалне класификације панела (геометријски дизајн, акустичка својства и уметнички објекат), а могу се користити у различитим контекстима и дају идеје за будуће примене, као што су апсорбујуће фасаде, акустичне плоче, звучне баријере, а истовремено служе и као уметнички предмети. Нагласак је стављен на то како се једно истраживање може реализовати на интердисциплинарним академским студијским програмима и какве користи студенти могу имати од различитих гледишта и научних приступа.
Комбиноване су три различите дисциплине са намером да се оствари жељени циљ: 1) Архитектонска геометрија је послужила као основа за нове дизајне у области архитектонске акустике; 2) Архитектонска акустика је инспирисала дизајн елемената који су имали за циљ да унапреде акустику простора; 3) Уметничка изложба акустичких елемената као дизајнерских објеката у Музеју перцепције омогућила је да се посетиоци (студенти и шира јавност) упознају са новим идејама и стекну увид о синергији звучних и естетских карактеристика приликом пројектовања просторних елемената нашег окружења.
Резултати комбиновања три дисциплине послужили су као основа за многе примене у стварним ситуацијама: 1) Простор за реализацију постер презентација на научним конференцијама је структурисан на нов начин, тако што су акустичне постер табле трансформисане у апсорбујући панеле за смањење нивоа буке, а у исто време оне претварају третиране површине у велики изложбени простор за нове дизајне. 2) Акустични третман изграђеног историјског простора, засвођене трпезаријске сале, спроведен је посебном обрадом крутог панела и додавањем нових карактеристика самом панелу. 3) Идеје везане за пројектовање непосредног окружења, односно за осмишљавање акустичких мера у циљу повећања разумљивости говора у сали за предавања, реализоване су у сарадњи студената аудиотехнике и архитектуре.
Кључне речи: архитектонска геометрија, акустика, преклапање, савијање, сечење, ласерски резач, плотер за сечење, уметнички дизајн.