ILEK

Summary Report

Adaptive Room Acoustics and Acoustical Conditioning in the Building Sector (ARAKO)

Adaptation of the acoustically effective parameters of textile and membrane systems for improving building acoustical measures, as well as for increasing and adapting the room acoustics and room sound quality

This research project was funded by the Federal Institute for Research on Building, Urban Affairs and Spatial Development as part of the research initiative „Zukunft Bau".

Dipl.-Ing. Fabian Schmid

Dipl.-Ing. Eva Veres

Dr.-Ing. Walter Haase

Prof. Dr.-Ing. Schew-Ram Mehra

Prof. Dr.-Ing. Dr.-Ing. E.h. Dr. h.c. Werner Sobek

Prof. Dr.-Ing. Klaus Sedlbauer

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Fabian Schmid, Eva Veres, Walter Haase, Schew-Ram Mehra, Werner Sobek, Klaus Sedelbauer

1 Abridgement

This research project aims at the verification of the acoustic characteristics of relevant materials and systems for textile architecture, the optimization of multi-layered passive systems and the advancement towards active facades and interior wall systems. Throughout the project, the technological and functional possibilities of sound absorption, insulation and reflection were evaluated and merged with adaptive methods based on multi-layered textile building envelopes to a variable room acoustic. Aside from verifying the appropriate materials, material combinations and adaptive systems, the project focused on the development of solutions and prototypes for optimal sound insulation and adaptable room acoustics. The project expands the research at the institute in the field of multi-layered adaptive textile building envelopes by adding another relevant structural-physical aspect.

Evaluating the acoustic effects of materials and structural systems is becoming increasingly important due to the increasing impact of noise pollution. Users and designers both focus more and more on auditive perception. Loud background noise and acoustic faults often emphasize a lack in understanding and lead to a loss in the quality of life as well as to a decrease in spatial quality. Adjusting the building and room acoustics to the respective use directly reduces not only the background noise and the acoustic level but improves the intelligibility and the sound quality depending on the application. Adaptive spatial acoustics adjusts to each use, reacts to unexpected events or enhances stage performances.

At the onset of the project, an extensive literature and internet research to the physical basics of technical acoustics, the potential materials for textile architecture, the existing system solutions within different disciplines and the required measuring and evaluation procedures in the field of building and room acoustics was conducted.

Earlier research projects dealt with ultra-lightweight, high-efficiency textile building envelopes and the "Zukunft Bau"-research projects "Adaptive multi-layered textile building envelopes" and "Development of fibre-reinforced lightweight profiles and structural elements for textile building envelopes and window technology" resulted in the development of elements for modular building envelopes and wall structures. The resulting knowledge of the design, the structures and the structural physics was considered as given and was used as the basis for the integration of innovative potential technologies and systems.

The results of the extensive research and the knowledge from the earlier projects helped to determine the materials and the layer-design to be investigated. The multitude of products and the resulting possible combinations demanded classification and analysis in order to be able to define the requirements and the key aspects of the research project. Thus the material combinations and systems traditionally used in textile architecture were predominant. This includes pre-stressed Polyviniychlorid (PVC) coated polyester textile layers as well as Polytetrafluorethylen (PTFE) coated glass-fibre textiles. These materials were used as exterior membrane for weatherproofing and to ensure the load-bearing capacity. The textiles for the prototype were supplied by Verseidag-Indutex.

In the course of the project, serial tests and the characterization of materials, material combinations and acoustically effective solutions were conducted. The existing impedance tube for measuring the degree of sound absorption and reflection was further extended and MATLAB, a numerical program to analyse the solution and depiction of mathematical relations, was used to optimize the evaluation algorithms. Calibration and comparative measurements were conducted. A series of evaluations was started and the results were entered in the existing product- and material databases.

Next, a passive system was developed, consisting of a multi-shell combination of Polyvinychlorid (PVC) coated polyester textile layers and polyester-composite non-wovens. The acoustical and structural aspects of the non-woven were optimized and the product was applied as an interlayer and functional layer. A textile top layer, which uses a high material density, was connected to an open-pored non-woven layer, which is well suited for cavity damping. Throughout the project, this non-woven combination was further developed and produced by Groz-Beckert KG. This was the subject of a bachelor-thesis with the focus on textile-technological development, conducted at the technical college in Reutlingen. Thus the non-woven composite could be produced for the prototype superstructures, the preliminary tests and for the tests to determine the degree of sound insulation.

The results derived from the developed passive systems allowed the assumption that their effectiveness could be transferred to an active system. Therefore it was decided to conduct the tests of the degree of sound insulation for both the passive and active systems at the door test laboratory of the Fraunhofer Institute for Building Physics. The door test laboratory is mainly used to characterize doors but may also be used to test façade elements with the advantage that the test specimens may be smaller compared to specimens used in a façade test bed.

The configuration of an acoustically active system could be developed in collaboration with Global Safety Textiles GmbH (GST GmbH). It is possible to increase the surface mass of a layer within the system temporally by adding fluid to a double-layered textile element. The first varieties of the resulting fluid-filled tube fabric could be produced and tested. The collaboration proved to be successful also with respect to the further development and the production for the door test laboratory.

After all relevant structural elements were produced, seven different layer configurations, which included passive acting system designs as well as active ones, were tested. Then the evaluation of the results followed and the most promising solutions for a planned implementation in an exemplary façade demonstrator was determined.

Finally, additional parameters defining the structural physics were determined for the chosen solutions to appraise the efficiency in a façade-application. The tests were further examined with regard to light, temperature and moisture as well as fire protection. A methodical system design process was realized simultaneously to the research project, encompassing functional integration as an indicator for the development process.

The project was concluded with the construction of three façade elements with different systems to demonstrate the functions and the efficiency of the sound insulation of the developed designs.

2 Summary

2.1 Introduction and objective

Multi-layered textile building envelopes are structures consisting of flexible high-performance materials forming the exterior of a building while adhering to all structural requirements, structural physics and requirements set by the user. This façade design is to strictly adhere to the reduction of the resources used, to the interchangeability of all system components and to the user-specific adjustment of all components. The research projects conducted earlier at the Institute for Lightweight Structures and Conceptual Design developed the structural, temperature and moisture related principles. Prototypes focusing on air-, moisture- and temperature-control were constructed and verified.

The different façade requirements will be met by the use of materials with appropriate characteristics in combination with carefully designed frames. The main objective of the design is to produce elements from materials positioned within the structure with sufficient effect to meet the relevant physical, structural and aesthetical requirements. The challenge emerging with the development of textile building envelopes is the necessity of solving the rival requirements placed to the design. This inevitably leads to contrary goals and interactions for and between the different system elements. Only a continuous iterative design process will achieve a sufficient balance between interactions and resolving conflicts.

Major factors to be investigated in detail were the requirements on sound insulation and room acoustics as well as the ensuing effects and solutions. Sound insulation measures in an urban environment are achieved mainly by reducing the noise level, by erecting noise barriers, which predominantly reflect the noise, and finally by strengthening the existing structures i.e. adding sound insulation glass. The improvement of room acoustics is achieved by passive sound absorbing ceilings and walls.

The focus for acoustically absorbing measures in an urban environment is therefore placed on solutions, which use materials with an optimal acoustic flow resistance, and are weatherproof as well as aesthetically highly sophisticated. The comprehensive methodical, conceptual, structural and physical results of previous research projects involving adaptive multi-layered textile building envelopes are a profound precondition at the institute.

Due to their material characteristics and the wide range of applicability, textiles are predestined to meet the requirements of acoustic adaptability and changeability. In addition, they are singularly able to allow the development of material- and resource-efficient solutions. Thus they contribute largely to material efficient, ecological and sustainable structures and emphasize the importance of auditive architecture when evaluating the room quality and the quality of life.

The problems of sound insulation are part of the complex processes involving the designers, the clients and the users each of whom define their own individual requirements and criteria. The so-called sustainable development of buildings, structural elements, infrastructure and respective procedures and processes evolves as the aspect of overriding importance in the future.

Solutions for different requirements are included even in integrated methods. In addition, the goals and achievements attained by the disciplines involved are evaluated from different points of view.

One major aspect of the design process is the expedient accumulation and coordination of the ideas, plans and activities to arrive at comprehensive answers through the process of designing, developing and detailing. Up to now this has only been achieved partially. In the case of lightweight structures, such as the material and resource-efficient design concept of textile building envelopes, the combined implementation of the most expedient measures and the inclusion of various disciplines are of major importance.

The attempt was made to sensitize the partners in research and industry for the greater context by planning the individual work phases for the research project and by simultaneously reappraising the development process. Quite some time was spent on the basic principles to avoid a premature decision for an exemplary solution and to include early-on the existing knowledge of building physics effects as well as the knowledge of production and manufacturing possibilities to the design process.

With the combined consideration of both topics, the additional value with respect to function and aesthetics of urban sound insulation measures become viable and the implementation of adaptive multi-layered textile building envelopes will be further developed.

2.2 Work phases and results

In order to achieve the set goals four work phases were defined:

WP1: Basics

WP2: Characterization of the system superstructure
WP3: Optimization of the system solution
WP4: Documentation

The first work phase included an extensive search covering the subjects of building and room acoustics, electro acoustics as well as manufacturing and production procedures, and also taking into account results from the automotive industry or aerospace engineering. The search was documented in detail using ZOTERO databases.

Descriptions of the function and use of materials, systems and adaption methods were established based on the knowledge gained from previous research projects, the discussions with the Department of Building Physics at the University of Stuttgart (LBP) and the existing preliminary investigations. These were the basis for establishing an evaluation matrix for system approaches and the layer configuration to be developed later-on.

Based on this search the measurements with the impedance tube were confirmed as appropriate for the test series of the materials. A series of tests was conducted with the textiles and the results entered in the Institute's database. The results of the search were also included in documents describing the characterization of material properties and the characterization of potential system solutions. The data entry forms may be used to verify the respective property and may be applied for significant comparison using the weighted evaluation matrix.

When developing the system based on the physical, material-related and structural aspects previous research projects determined the multi-layered structure as an appropriate configuration.

These assessments and expert opinions determined the materials to be used.

Next, the basic design of the core layers had to be defined. Based on the study of the options, the most efficient solution proved to be layers resembling a sheet, Helmholtz or broadband resonator.

Based on early designs, studies of the options and the assessments regarding the manufacture a double-layer, needled product was developed, which was to demonstrate the acoustic efficiency (sound insulation) of a purely textile design and to find various uses in a twin-layer system design.

The developed layer design can serve as a starting or intermediate product for various acoustically passive systems, making it universally applicable. For the intended application, a multi-shell design is interesting, which consists of two mirrored layers with air- and moisture-tight surfaces, as well as a multi-shell structure of two mirrored layers with weight loaded surfaces.

After developing the first passive concepts, initial designs for the implementation of material adaptability could be tested and realized as prototypes in cooperation with GST GmbH.

The system solutions were characterized within the second work phase. In addition to serial tests in the impedance tube the basic system solutions were validated with regard to sound insulation in the door test laboratory. The sound insulation of seven options was measured.

In summary: The sound insulation values of all systems investigated within the project showed neither a typical single-layer curve nor a typical twin-layer curve. It is quite distinctive that up to 800 Hz the sound insulation curve resembles the behaviour of a single-layer element equivalent in weight. Regarding the acoustics the air cushion respective the cavity filling between the two layers seems to behave rather like a flexible sheet and not like a spring thus creating a stiff connection between the layers.

After concluding the test series in the door test laboratory and after evaluating the results three different solutions regarding the requirements for façades were investigated within the third work phase. Thus permitting an overall assessment for the principle functions of a façade (transparent, translucent and opaque) of the effectiveness of these adaptable designs that save material and resources. During the tests effects of temperature and moisture as well as with light exposure and fire protection were simulated. Basic solutions could be developed especially for the aspect of fire protection. Metrological tests could not be conducted within the scope of the research project. Such tests should be conducted since this research project provided interesting material-related and technological solutions. These approaches further develop the integration of functions and the active influence on varying conditions and requirements into an overall design. After the promising solutions were classified, a façade prototype was constructed.
Work phase four included the documentation of the results. In addition, during the project several papers for journals and conferences were published and the results were displayed in exhibitions and made available for the interested public.

2.3 Conclusion

The tests conducted in the course of the research project produced possibilities for the construction of sensible multi-layered textile building envelopes with a sophisticated air conditioning technology and a functioning sound insulation. This was especially demonstrated by the wide range of evaluations of the structural physics regarding the behaviour under temperature and moisture, building and spatial acoustics as well as fire protection and light exposure conducted in the course of this research project.

A major factor contributing to these statements were the detailed examinations of the building and spatial acoustics of ultra-lightweight layer designs. The evaluation procedure proved the pertinence of the correct material choice, the correct layer arrangement and the productive material distribution within the layered structure. Another important aspect were the results concerning the adaptable and adjustable material distribution in such lightweight designs in order to create structures that adapt to different uses and thus develop an optimal, effective and efficient solution.

As a result three essential elements for ultra-lightweight façades were developed: a composite non-woven, a spacer filled with aerogel and a tube fabric filled with fluid. These elements should be further optimized and developed to reach market maturity.

The tests were conducted using scientific procedures and methods to productively and rapidly reach a solution.

Follow-up projects should deal with methodically reaching a solution as well as with developing additional functional elements for ultra-lightweight façades. The resulting knowledge would allow for the development of products and façades within a limited time-frame.

3 References

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