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Adaptive Multilayer Textile Building Envelopes

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1 Introduction

This brief report summarizes the work and achievements of the research project entitled “Adaptive Multilayer Textile Building Envelopes”.

The objective of the project was to develop a modular, multilayer, textile facade system with adaptive properties. This system would take the form of pre-stressed membrane assemblies designed to replace traditional wall and roof assemblies in building construction.

This new form of envelope should be able to adapt with a minimum of energy input to changing environmental conditions and specific user demands. This functionality would be achieved through the use of new materials, coatings, and the development of functional layer combinations. To realize this future-oriented building envelope system, it was essential to design, build, and test functional prototypes featuring different combinations of promising materials.

The first task, designated Work Package 1, was a research phase to determine the state of the art in textile construction, as well as identify promising materials with suitable properties for the proposed systems. The desired performance targets and functional characteristics for the new facade systems were then defined.

The initial research into materials and design objectives established a foundation for the second phase, Work Package 2, in which system concepts for multilayer textile facade assemblies were conceived. An important aspect of this phase was the development of a software simulation program to assess the complex thermal and moisture transfer behaviour of the proposed concepts. It was also necessary to characterize the spectral properties of the materials which would be employed, to obtain the required input data for the simulation program.

In Work Package 3, the concepts developed in the second phase were to be implemented in the form of small-scale prototype facade assemblies, whose thermal transfer characteristics were tested experimentally. The experimental results were then to be used to optimize the prototype concepts.

The final phase, Work Package 4, involved the complete documentation of the project. The experimental and simulation results were compared and discussed, and recommendations were provided for effective textile layer configurations.

Over the course of the project, it became clear that significantly more time and effort were needed for the programming of the simulation software than had been originally foreseen. This was due to the very fundamental approach necessary for its development, based on basic physical principles. It was also apparent during the material and product research phase that many of the input data (spectral and other properties) required for the thermal and moisture-transfer simulation were simply not available, and would have to be experimentally determined.

Both of these observations led to an agreement with the project sponsor and the project advisors to shift the focus of the research to the establishment of fundamentals – the collection of material and product data, the creation of a database to store these properties, the development of the simulation program, the optimization of the experimental test apparatus, and the development of facade assembly concepts.

2 Research Summary

2.1 Establishment of Objectives

Specific objectives were defined in the fields of building physics, structural behaviour, sustainability, and aesthetics in order to develop a functional textile building envelope.

The building physics properties of the envelope should enable it to act as an interface between the building interior and exterior. It should be able to adapt to changes in temperature and incident radiation intensity, regulate air flow and moisture exchange through the facade, and ensure sufficient heat and sound insulation, all while providing a degree of natural daylighting through the building envelope.

In terms of structural function, the facade must be able to withstand the applied forces (primarily wind and snow loads) and transfer them to the primary structure. The possible use of sensor-actuator systems in the envelope was also to be investigated.

The issue of sustainable design was also central to the concept of textile facade systems – in addition to using extremely lightweight materials, modular construction would allow for the separation of these materials for recycling at end-of-life, and would furthermore offer the possibility of introducing functional layers to improve efficiency or to generate renewable energy.

The aesthetic appearance of textile envelopes is also critical to their acceptance, and each concept was therefore developed not only with technical, but also with architectural requirements in mind.

2.2 Structure of Work

To achieve the objectives established above, four Work Packages (WP) were defined:

WP1: Requirements and Research

WP2: Design

WP3: Production, Testing, and Optimization

WP4: Documentation

The first work package focused on research into existing multilayer textile structures as well as the establishment of functional and building physics-related performance requirements. The results of this background research, including descriptions of existing structures, are documented in reference [1]. A key finding of the research was that nearly all existing multilayer textile structures were constructed using membrane materials combined with traditional types of insulation products, which combined with a lack of appropriate detailing often resulted in moisture penetration of the insulation, leading to reduced insulating performance, mould build-up, and other performance and serviceability problems.

In order to organize and store the data collected in Work Package 1, a database was created to allow convenient management of and access to the information. The database includes product information from manufacturers as well as experimental data collected over the course of the project on membranes, films, and functional materials. The database allows individual materials to be filtered and selected based on specific properties, and proved to be a useful tool during the development of the building envelope concepts.

A major aspect of the second work package was to develop a simulation tool to precisely analyze the thermal and moisture transport behaviours of different material assemblies. Once operational, the program made it possible to develop a variety of building envelope concepts by systematically analyzing, comparing, and optimizing different multilayer configurations.

In the third work package, a number of facade assembly prototypes were constructed and experimentally tested using a guarded hot box apparatus, which was also designed and constructed as part of the project. The different assemblies were assessed and evaluated on the basis of both the experimental and simulated results, and optimized accordingly.

The fourth work package focused on the complete documentation of the project in the form of a comprehensive research report [2].

2.3 Research Findings

The experimental and investigative research carried out at the ILEK over the course of the project demonstrated the fundamental potential of modular, multilayer textile facade systems within the framework of the established objectives. This potential was demonstrated especially through the experimental work conducted in the guarded hot box test apparatus, which was designed, built, and verified specifically for the measurement of the thermal transfer characteristics of multilayer textile systems.

During the validation process undertaken to compare the measured and simulated behaviour of the prototype assemblies, it became clear that the thermal transfer mechanism was extremely sensitivity to changes in boundary conditions and material properties. The importance of accurately determining the spectral characteristics of the material layers (transmission, reflection and absorption) in the visible and infrared ranges of the spectrum therefore cannot be underestimated. Product and material data of this nature are rarely available and therefore need to be researched and if necessary experimentally determined on a project-specific basis. Similarly critical is the lack of data on the moisture transfer properties of most membrane and film materials. The scarcity of these data is a major obstacle for planners and consultants responsible for the building physics of textile-clad structures.

The database established within the framework of the project offers an opportunity to improve this situation, if it is systematically expanded and maintained.

An additional major emphasis of the project was on the development of adaptive capabilities to allow a facade system to alter its thermal, moisture, and air exchange characteristics.

Several adaptive prototypes were conceived, designed, and built for public exhibition at the BAU 2009 trade fair in Munich. These included concepts for adaptive openings, adaptive insulation, thermal storage, and the incorporation of lighting and electricity generation in textile materials.

It is intended to pursue follow-up research to investigate the potential of such adaptive systems in greater breadth and depth, and work toward practical solutions to the many intriguing problems.

3 Conclusion

The research work carried out over the course of the project showed that the implementation of multilayer textile systems as effective, efficient, and adaptive building envelopes is a highly complex, but also highly promising objective. The project equipped the institute with the necessary equipment, skills, and experience to pursue further and more advanced research in the complex field of textile facade systems, and follow-up projects are already in planning and in progress at the ILEK in order to continue the investigative work. Two of these further projects are described in Section 4, to underline the importance of the project results to the pursuit of ongoing research efforts.

4 Ongoing Research

4.1 PROFAKU

The design problem of integrating several layers of textiles and functional materials into a modular and practical facade framing system is being investigated in an ongoing project entitled “PROFAKU” (also supported by the “Zukunft Bau” initiative, Reference Number Z 6 - 10.08.18.7-08.29). In this project a system of fibreglass framing profiles is being developed to provide the secondary structure to support multilayer textile assemblies, and to enable the modular configuration of different layer and material combinations. These “PROFAKU” profiles will be able to provide local prestressing of the textile layers, and will transfer external loads from the textile modules to the primary structural system.

4.2 Acoustic Conditioning of Textile Building Envelopes

A further research project is focused on investigating the acoustic modes of action and the acoustic conditioning of walls, ceilings, and interior partition systems based on textile materials and multilayer textile assemblies. The acoustic evaluation of different materials and systems is becoming increasingly important as the negative effects of noise pollution and the effects of sound on the perception of space are being increasingly understood. Distracting background noise and poor acoustic design lead to poor communication and productivity, and have a significant impact on the quality of our built surroundings.

Through the use of adaptive acoustic systems, noise levels can be reduced in a targeted manner, and the intelligibility of speech and the overall acoustic quality of a room can be improved. An adaptive acoustic space can react to unexpected situations, or provided ideal conditions for specific situations such as presentations or performances.

The acoustic conditioning of textile building systems builds upon and expands the ongoing research initiative into adaptive multilayer textile building envelopes to include a further important aspect of building physics. The potential of multilayer textile systems to alter their characteristics, through compressibility, geometric variability, or technical material optimization allows their adaptivity to extend into the realm of acoustic conditioning and optimization.

The objective of the project is to establish the specific acoustic properties of potential materials, to optimize existing multilayer concepts to improve acoustic performance, and to develop functional adaptive technologies which would allow textile systems to alter their acoustic behaviour based on changing circumstances and requirements. The project application is currently in the evaluation phase at the funding agency.

5 References

[1] Haase, W. et al.: „Adaptive Multilayer Textile Building Envelopes“, Research Report for Project Report, Institute for Lightweight Structures and Conceptual Design (ILEK), University of Stuttgart, June 2011.

[2] Haase, W. et al.: „Adaptive Multilayer Textile Building Envelopes“, Project Report, Institute for Lightweight Structures and Conceptual Design (ILEK), University of Stuttgart, April 2011.