COST Action TU1403 – Adaptive Facades Network

Short Term Scientific Mission – Final Report
TU Delft, September 11th – December 11th 2017

1. STSM Information

Action number: COST TU1403
Title: The state-of-the-art of adaptive and multifunctional materials
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2. Purpose of the visit and overview of the scientific mission

This STSM was framed into the on-going PhD project "Design and assessment method for Adaptive Opaque Facade Systems". During the early development of this research I found interesting literature and information on the COST TU1403 database (Task 1.1 WG1 Definition of state-of the-art materials for responsive and adaptive facades). Nevertheless, most of that information was about building examples and adaptive façade systems. I realized that the state-of-the-art about adaptive façade materials could be further analyzed. There was also a dissemination gap in reviewed literature and it was not easy to detect potential materials for building industry, neither having appropriated information about their technical features and performance in façade applications.

The aim of this STSM was to fill the gap in the state-of-the-art of adaptive and/or multifunctional materials information, so that the D.1.1 (Task 1.1 WG1) could be successfully completed. The objective was to collect the critical information about promising materials to design Adaptive Opaque Façade systems, in order to help designers and technicians to develop new innovative systems and to help them in design decision-making process. It was necessary to provide shipshape information about adaptive/multifunctional materials from a Building Science approach to enable their new applications and to scope future researches. Potential performance in façades needed to be highlighted and threats and weakness in the building environment to be detected. An approach to the availability in the current market was done, so that the technical feasibility was sighted.

On the other hand, this STSM aimed to contribute in the deliverable task "D3.1 Report on progress made in new adaptive technologies over the course of the Action", focused on smart and multifunctional materials (SM/MM).

This STSM in TU Delft was not only productive but also really enriching because of the networking. I met many young researchers working in the same field and their different backgrounds showed me interesting approaches for the same target. The environment was really inspiring and my PhD project received enriching feedback from peers and experts.

3. Description of work carried out during the STSM

The following table shows the objectives of this STSM and the level of achievement of them according to the activities that have been carried out.

Table 1 *Level of achievement of activities carried out within the STSM.*

OBJECTIVE	ACTIVITY	COMPLETED DURING STMS?	COMMENTS
1. Identifying potential Smart and multifunctional materials to enhance the existing database providing more examples about materials **(D.1.1)**.	1.1 Literature Review	YES	Scientific papers, Open Access Advanced Material Databases and market product information (technical sheets provided by manufactures at their website and asked by email).

	1.2 Contact people from different background researching advanced materials and their manufacture.	YES	I met a lot of people involved in façade and climate design research. I also met people studying additive manufacture for façade application. I could attend to different workshops in the TU DELFT related to these topics. However, it was a pity that I could not contact so many people involved in the study of SM/MM.
	1.3 Complete existing database **(D.1.1)**.	YES	Up to 30 SM/MM were detected and submitted to complete existing database. However, it was not always possible to find all the information and further research is needed to ensure their possible façade application.
2. Classification of detected materials from a Building Science and Façade engineering approach to broaden the existing database **(D.1.1)**.	2.1 Making graphical documentation and tables about the possible application of SM/MM in an Adaptive Façade element and its role.	YES	Attached in this report *(4. Description of the main results obtained)*
	2.2 Organizing information in tables about the dynamic operation of materials.	YES	The results are partially available in the database. Further information will be published in a journal paper. In this report, methodology and main conclusions are outlined (*4. Description of the main results obtained)*
	2.3 Organizing information in tables about the appearance of SM/MM to specify their design potential and application.	YES	
	2.4 Organizing information in tables about the meaningful physical properties of the materials for their façade application.	PARTIALLY	
	2.5 Completing the information of the existing database, focused on the SM/MM **(D.1.1)**.	YES	3 existing data-sheets were completed with extra information.
3. Contribution on the report on progress made in new adaptive technologies over the course of the Cost Action. **(D.1.3)**.	3.1 Detect potential smart and multifunctional materials. Analysis of their properties and proposal of a methodology to study their potential and limitations to apply them as façade materials.	YES	The results exposed in this report aim to be useful to write the final report.

4. Description of the main results obtained

Detected smart and multifunctional materials have been submitted in the *WG1. Database of Adaptive Façade* following the survey:
https://www.encuestafacil.com/RespWeb/Cuestionarios.aspx?EID=2128813&PGND=1&MSJ=NO#Inicio
The aim of this database is to detect as many adaptive façade systems, components, elements and materials as possible, so the properties that are asked in the survey are general in order to be suitable for all of them. Nevertheless, the objective of this STSM was to provide shipshape information about adaptive/multifunctional materials from a Building Science approach to enable their new applications, so more properties were searched. Fig. 1 shows the information that was uploaded to the database for each material (when found). The green color indicates a match between the survey question and the tables that were develop to study SM/MM, the yellow color means that a similar property is asked in the database and in red the aspects that the database cannot consider are shown, even if they would be meaningful when considering façade materials.

Fig. 1 *Provided general information in the WG1. Database of Adaptive Facade VS needed information to understand Smart Materials (SM) and Multifunctional Materials (MM)*

Possible Adaptive Facade Component	Role	Autorreactive facade element	Smart Material	Reference
Missing	DATABASE function, goal	Missing	DATABASE keyword	DATABASE

Chart 2. Dynamic Operation of the Material

Technology	Material type	Material	Mechanism	Reaction	Range	Scale of adaptivity	Speed	Control	Operational Scenario	Reference
DATABASE effect	DATABASE = type of system	DATABASE title	DATABASE = operation principle	DATABASE – actuator (output)	Missing DETAIL (database is general)	DATABASE – degree of adaptivity	DATABASE = response time	DATABASE = trigger (input)	Missing DETAIL (database is general)	DATABASE

Chart 3. Appearance of the MMs and SMs. Design potential and limitations

Technology	Material type	Material	Photo	Avaiable colors	Geometry	Thickness	Width	Length	Assembly Methods	Manufacturing process	Specific property required by ISO	Reference
DATABASE effect	DATABASE = type of system	DATABASE title	DATABASE	Missing DETAIL (database is general)	Missing	Missing	DATABASE Area		Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	DATABASE

Chart 4. Physical properties. Construction potential and limitation

Technology	Material type	Material	Material family	Density	Porosity	Yield Strength	Tensile Strength	Breaking strength	Compressive strength	Elongation	Hardness
DATABASE effect	DATABASE = type of system	DATABASE title	Missing DETAIL (database is general)	DATABASE weight	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)

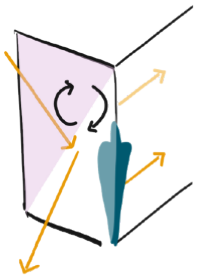
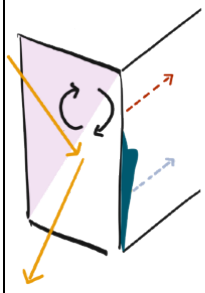
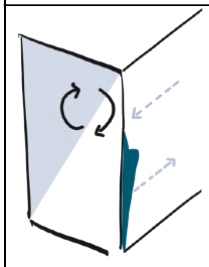
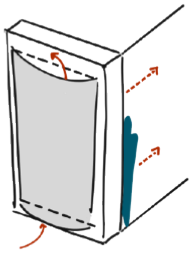
Young modulus	Flexural strength	Flexural modulus	Compressive modulus	Thermal conductivity	Thermal expansion	Work performed	Fire resistance	Water absorption	Specific property required by ISO	Reference
Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	Missing DETAIL (database is general)	DATABASE

Further results than the ones kept on the database were obtained, as it is summarized in the following lines.

On the one hand, in order to analyze future applications of SM/MM in adaptive façade, their possible role in façade components was scoped (see Fig.2). Besides, the dynamic operation of the material was evaluated, so mechanism, reaction, adaptation range, scale of adaptability, adaptation speed, control and operational scenario was studied. Smart and multifunctional materials with different reactions were detected. Main adaptive reactions were related with the modification of the visible light transmission, surface temperature change, reversible color change, volume change, mechanical displacement, reversible contraction or expansion with possible bending, and with self-regulation of humidity. Main triggers were electrical current and temperature change. Operational scenarios and scales of adaptability were not always suitable for adaptive facades, so those ones were not included in the database. Besides, it should be considered that usually these materials react differently, in a nonlinear manner, at different scales. As most of the literature reviewed was not related to the façade application, more experimental research is needed to define the adaptation range of these materials in the built environment.

On the other hand, it was not always possible to detect design potential and limitations. Possible geometries, thickness, width, length, assembly method and manufacturing process was analyzed. Such information was found for Electrochromics, Thermochromics, Photochromics, Shape Memory Alloys, Electroactive Polymers and Hydrogels, as there are commercialized products made by these materials and manufactures provide some useful information for design considerations.

***Fig. 2** Possible application of SM/ MM in an adaptive facade element and its role.*

Possible Adaptive Facade Component		Role	Autorreactive facade element	Smart Material
Smart window		Self Shading	A. film B. special chemical composition/ nanotechnology	Electrochromics
			A. film B. ink/pigments C. Dyes	Thermochromic
			A. film B. special chemical composition/ nanotechnology	Photochromic
				Thermotropic
		Heating effect	A. film	Thermoelectrical
Opaque Adaptive Facade Component		Temperature change (color switch)	A. film B. ink/pigments C. Powder D. Plastic pellets E. Dyes	Thermochromic
		Solar reflectance change (opacity switch)	A. film	Electrochromic
				Photochromic
		Integrated climate control	A. device	Thermoelectrical
			A. Interior surface	Natural porous materials
			A. device B. surface	Hydrogels
Movable double skin		(1) Enhance / block thermal dissipation (2) Auto-reactive air dampers (3) Automatic shading devices	A. surface B. actuator	Electroactive polymers
			A. surface B. actuator C. joint	Thermobimetals
				Shape Memory Alloy
				Heat sensitive plastics
				Light responsive polymer
				Shape Memory Polymers
				Shape memory Hybrids
		(1) Enhance / block thermal dissipation (2) Auto-reactive air dampers	A. surface B. actuator C. joint	Natural Hygromorphs
				Hygromorph bi-layer composites
				Hygromorph Bio-composites
			A. actuator B. joint	Synthetic Composites
				Hydrogels
		Auto-reactive air dampers	A. actuator B. joint	CO2 Responsive Polymers

Some similar characteristics were found according to the product family, specially regarding the possible geometries. Thermochromics and Electrochromics come mainly as rectangular rolls and sheets, whereas self-shaping materials are most of the time manufactured as strips, wires, beams and sheets.

Physical properties were also analyzed, but it was really hard to find suitable technical information. It was only possible to learn more about some Shape Memory Polymers, Thermobimetals, Electroactive Polymers and Hydrothermally solidified soil bodies. Most of the quantitative data that was provided was regarding the density of the material, the structural properties and performance and with the performed kinetic work. Nevertheless, the lack of information was probably due to an inappropriate methodology of analysis, as it was not made any differentiation regarding the materials families or their possible façade role. This research looked for the young modulus, flexural strength, flexural modulus, compressive modulus, thermal conductivity, thermal expansion, performed work, fire resistance and water absorption. Future researches on the topic should consider to search the physical information of these materials using as an example a static material that could be part of a similar façade element, to understand properly the physical properties that play a role in the fulfillment of technical requirements.

5. Foreseen publications resulting from the STSM

This STSM aims to enhance the dissemination of knowledge about Smart and Multifunctional Materials between architects and building engineers. The results obtained during this STSM is in process of submitting in the Journal of Facade Design and Engineering (JFDE) in order to have the biggest impact possible. It is also considered an effective way of sharing knowledge, as it is an Open Access journal.