Short Term Scientific Mission (STSM) Report for COST ACTION TU1403: Adaptive Facade Network

TOPIC: Kick-off for investigation and publication on functional and architectural characteristics of adaptive facades targeting at the term "intelligence"

Submission date:	16/01/05
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STSM Period:	15/11/26 – 15/12/05
Host:	Dr. Uta Pottgiesser, Jens Böke (Hochschule Ostwestfalen-Lippe)

1. Summary

This report describes the activities carried out by Susanne Gosztonyi, researcher at Lund University, during her Short Term Scientific Mission (STSM) stay at Hochschule Ostwestfalen-Lippe, Detmolder Schule für Architektur und Innenarchitektur, ConstructionLab (HS-OWL), hosted by Dr. Uta Pottgiesser and Jens Böke. The STSM activity is affiliated to the work group 1 (WG1) in the COST Action TU1403 Adaptive Façade Network, with specific focus on the definition of criteria for adaptive facades. The STSM focused on the initiation of a joint investigation in regards to "intelligent" measures and architectural criteria for adaptive facades, which shall result in contributions to the WG1 database and a scientific publication. A manuscript focusing on architectural criteria for adaptive facades has preliminary been elaborated for the STSM and presented at the international conference facade2015 at Detmold. The results of the STSM are key search criteria to identify case studies and concepts for the specific research focus in various fields (ICT, biomimetics, architectural design and engineering), and a draft of the "extended architectural criteria" as a first version.

2. Purpose of the STSM

The activities carried out in this STSM are affiliated to work group 1 (WG1) in the COST Action TU1403, particularly to the task of developing a database that displays technological solutions and applications for adaptive facades. To collect this data, key criteria that describe the adaptive functionality in facades must be identified and systematically arranged. Since there is no definition yet existing on "adaptive facades", the initial step of WG1 was to define key characteristics for adaptive facades and develop a matrix. The STSM intended to contribute to this ongoing task.

Since both, the beneficiary and the host are currently elaborating key characteristics for adaptive facades in their Ph.D works, based on different knowledge domains (Biomimetics, ICT) and research questions (thermal adaptation, smart devices), the intention was to further develop this towards an **joint investigation on the terminus "intelligence" in the adaptation function of facades from the perspective of architectural design and system engineering**. The investigation targets at a **common view of criteria** and an **meaningful description of the function "intelligence" and "adaptive facades"** that considers different needs from architectural engineering, system engineering and, as

most often neglected, the architectural design. In this process, a taxonomy shall be developed that contributes to the development of the database in WG1. The STSM served as a kick-off for this elaboration, which shall result in a scientific publication.

The objective for the STSM period was to screen literature, case studies, and research work from both institutions, as well as available publications from the WG1, and discuss "adaptive" and "intelligent" façade measures to define tasks needed for the elaboration of the investigation. The STSM was also dedicated to a knowledge exchange about methodological approaches (ontologies, parametric systems) in the two domains "computational design" and "biomimetics". The participation at the international conference facade2015 in Detmold at the beginning of the STSM was therefore a great opportunity. Finally, the development of a work plan for a joint publication dealing with the topic described above was intended. The publication shall add to the existing publications done already on the WG1.

3. *Description of work carried out during the STSM*

For the STSM, following activities have been carried out:

   a. Manuscript elaboration (preliminary work) for "architectural design criteria of adaptive facades" and presentation at the international conference "facade2015 - Computational Optimisation" on 27th November 2016 in Detmold, Germany
   As a preliminary work to the STSM, the beneficiary developed a concept draft for an integrated design approach to functional and formal requirements for adaptation of facades, merging technological (functional) and architectural (formal) measures [1]. The concept targets at the incorporation of architectural criteria in the discussion about "adaptive facades", which seems to be neglected in the current discussions. The concept has been presented at the conference facade2015 in Detmold at the beginning of the STSM. It also served as the basis for feedback discussions at the conference and later, and for the literature survey.

   b. Mapping case studies, technological and architectural concepts of facades indicating "intelligence" and "adaptation" in the various fields to identify a common basis
   The identification of key words for a meta-search has been done in various work sessions. This served to identify publications about façade solutions that incorporate the criteria "adaptation", "architectural quality" and "intelligence" in the field of architecture, façade engineering, biomimetics and ICT. Due to the short period, the literature search, especially in non-related fields, such as in the communication or natural sciences will continue after the STSM. The goal is to establish use cases based on collected concepts, technological examples, and cases studies. The use cases shall describe, in an abstracted form, "intelligent" approaches to adaptation measures of facades and link these to architectural design tasks. A literature list will be provided to the WG1.

   c. Kick-off for joint scientific publication
   The results of the interdisciplinary investigation shall be elaborated in a scientific publication. Hence, the STSM also served for the definition of an outline of the needed work for the publication.

4. *Description of results obtained*

The results of STSM are (a) an established joint research basis, (b) a first listing of key criteria for term 'intelligence' in connection with adaptive facades in order to formulate a taxonomy, (c) reviewed

descriptions and examples for (b) in the fields architectural engineering, computational sciences and biomimetics, and (d) a drafted concept of extended architectural criteria for adaptive facades.

— ad (b): Discussing and mapping existing and possible key criteria for 'intelligent' measures that can be deployed in adaptive façades, collecting data from interviews at the conference and literature review

Descriptions of adaptive façades that incorporate criteria targeting at "adaptation", "architectural quality" and "intelligence" are rarely found. It is more likely to find separate descriptions: Most frequently, "adaptation" and "intelligence" are addressed in the system engineering field (use of sensors, actuators and processors for activation). Another identified approach is the description of kinetic structures, without details about the activation concept. However, a clear definition that combines both is still open for development: Questions to identify key criteria have been identified, such as: What is an intelligent control in the architectural context? Digital vs analogue solutions? Which key criteria are needed to describe controlled central intelligence concepts (e.g. human mobility skills) and local intuitive intelligence concepts (e.g. skin hair)? Can they be abstracted to allow more solutions, combined solutions? Which are the system boundary criteria that must be considered (functionality, production, etc)?

For the mapping of key criteria, existing collections of case studies and concepts have been reviewed and will be further elaborated. The current collection is available online on Pinterest [1, p.4] and as a literature collection (Mind map). It shall be added to the collection of the WG1.

— ad (c): Collecting examples and concepts for the definition of intelligent adaptive facades in the context of architectural design criteria

The term 'intelligence' is applied in architecture with varying intentions and meanings. This can lead to misunderstanding, particularly when used as criterion for defining adaptive functions. 'Intelligence' from the perspective of the system engineering is most likely linked to the integration of computing and sensor technology. Herein, static physical components and/or material properties are turned into dynamic responsive systems by adding automated controls to the system. This approach has been investigated in publications by the WG1 and also in the conference paper that is linked to this STSM [1].

'Intelligence' is also used in context with sustainable building design to describe integral design methodologies or passive design concepts. Herein, intelligent measures refer to the application of processing knowledge of designer(s) tools and methods than to technologic solutions. The host institution has a main focus in the digital design and manufacturing processes, which contributed largely to the selection of possible key search criteria for intelligent measures, from the perspective of system engineering but also from digital design developments.

In nature, 'intelligence' is an embedded function of the composition of an organism. Intelligence is herein not necessarily an actively controlling feature, but can also respond e.g. via complex material compositions on various levels and scales of its structural system, which makes it capable to react "passively" on dynamic performance needs. An incorporation of this knowledge to the identification of possible search criteria is provided by the beneficiary who is conducting research in the biomimetic field.

— ad (d) a criteria concept of "extended architectural criteria" for adaptive facades

Some of the identified criteria in biology have been used for the development of a simple criteria list (draft version) displaying "extended architectural criteria" for adaptive façades [1, p. 6]. This list has been developed for discussion in the STSM and later on in WG1 of COST TU1403. "Extended architectural criteria" shall combine adaptive functionalities, which are mainly targeting technical domains, with architectural aspects including spatial, formal and visual criteria for some states of the adaptation.

— ad (a): Provide an outline for the development of a joint scientific publication

The planned publication targets at a taxonomy for "intelligent measures for adaptive facades considering architectural criteria" (working title). For the taxonomy, ontologies and the theory of technical systems design as well as the application of system engineering in ICT and digital processes are considered. The possible application of these methods needs further discussion in WG1 to define a contribution to the taxonomy of the database.

5. *Future collaboration and contributions to COST TUD1403*

As the STSM was planned as a kick-off for a joint investigation and later publication, a further collaboration with the host institution and also with the members of WG1 in COST TU1403 is intended. The brainstorming on the differing use of the terminus "intelligence" in various knowledge domains revealed the need for an in-depth literature survey and further discussion on the topic. This is currently ongoing. It is planned to discuss this in a WG1 meeting. All results shall be contributed to the development of the database.

6. *Foreseen publications/articles resulting from the STSM*

A scientific article in the fields of biomimetics or computational engineering/building automation is in planning: elaboration in 2016 and submission late 2016/2017. The elaboration of the publication shall be closely linked to the activities in WG1, particularly in regards to the database structure.

7. *Confirmation by the host institution of the successful execution of the STSM*

Please refer to the attached letter.

8. *Additonal documents / references*

[1]   Gosztonyi, S., "Adaptive Façade – which design criteria are needed?", facade2015, conference paper, Conference Façade 2015 – computational optimisation, 27.11.2015.

Adaptive Façade – which design criteria are needed?

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Abstract

Adaptability of facades is often conceived as a performative objective, and less as a formal objective. Hence, so-called 'adaptive' façade systems are highly engineered solutions that autonomously control the energy flow via highly-efficient materials, integrated technical devices and intelligent automation systems. As the design complexity and operation challenges of such façade systems are substantially increasing, the role of integrated design becomes a fundamental question. What sort of adaptation of facades is needed and what is needed to successfully implement it?

A meaningful approach to adaptive functions in facades must be discussed within the integrated design context to enable reliable and accepted solutions. Respective functionality must be combined with formal, aesthetic and social needs that equally have to adapt and/or react. And it must be embedded in the constructive goals for the façade structure and choice of materials to become a cooperating element and not an additive matter. Modern digital design tools and production techniques enable new potentials for embedded adaptiveness that can sophisticatedly respond to the energy and comfort requirements through designed attributes of the construction itself. However, whatever approach is employed for the realization, the needs must be clarified. Hereby, architectural criteria are often missing and must be re-integrated in the objectives. This paper suggests a first sketch for an integrated design approach to functional and formal requirements for adaptation from the perspective of architectural design. The objectives are to start a critical discussion on needed criteria for an adaptive capability of the facade and to open the discussion about the meaningfulness of adaptive facades.

Keywords *(max10 words)*

Adaptive facades, architectural criteria, responsive building elements, integrated design approach, façade design

1. Introduction

Modern energy-efficient buildings are designed to use as little energy as possible for a maximum efficiency in operation and for provision of high comfort levels. For plus-energy building concepts, this target is extended to an integrated production of energy from local renewable sources. One of the most important success factors to achieve these goals is the ability of the building to respond dynamically on demand and on climatic changing conditions and user needs. The responsive performance behaviour of the building and of its critical components is a core focus of developments in the field of intelligent buildings and building technologies. In this context, the building envelope, being the interface between two climatic environments, became a highly engineered system designated to actively control the energy flow, whilst more or less successfully dealing with a wide range of formal, functional and constructive criteria. Modern, so-called 'adaptive' façade systems provoke hereby a paradigm shift of facades by being transformed from passive enclosures and energy consumers into intelligent communicators and interfaces, sometimes referred to as

"living shells". However, the realization of such solutions reveals that architectural aspects and user needs are often pushed to the background in favour to generate a high performing machine.

1.1. The new built-in 'intelligence' of facades

A major characteristic of adaptive façade systems lies in the responsiveness of its components. They are mainly designed to influence the energetic performance and/or thermal, visual or hygienic indoor comfort. Existing products, which are linked to this ability, are called "*Responsive Building Elements*" (RBEs) according to the IEA Annex 44 that has studied intelligent elements in the building envelope [9]. RBEs represent the latest generation of e.g. smart technical systems (e.g. shading and/or daylight systems, air exchange units, decentral micro heating/cooling units) and smart materials (materials with changeable selective, transmitting, redirecting or storing properties). RBEs enable a change in e.g. daylight and/or thermal energy transmission, air exchange, storage capacity or energy generation as needed by changing climatic conditions. This adaptation capability is initiated either autonomously (embedded functionality) or via an automated control system (intelligent functionality) to meet desired target set points. The change steered by the building's automated control system. The operation of such systems is usually maintained by an intelligent building management system, which runs the building and makes sure that the stringent comfort values and energy performance level will be achieved [10].

The majority of realized adaptive façade solutions can be divided into solutions with (mechanically) moveable elements in the façade, that are connected to e.g. integrated daylight and/or temperature sensors and use decentralized motors and extrinsic intelligent automation systems for the operation. Most often these elements are shading elements and thus, contribute to the visual and thermal control of the incident solar radiation. Their architectural appearance is mainly expressed by a morphological change of the surface geometry or change of the surface pattern on various scales, as shown by the examples of Figure 1. Besides the energy-related automation goal, the elements are less often but sometimes used as media performance installations (cp. media facades).
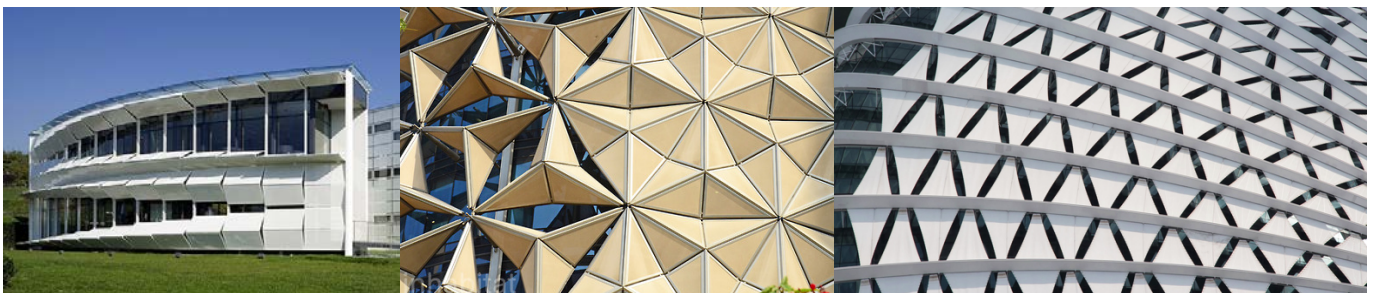

Figure 1: Various examples for adaptive shading systems in facades (from left to right): Showroom Kiefer technic, Bad Gleichenberg, AT, by Giselbrecht + Partner ZT GmbH (shutters made of perforated aluminium panels, form is based on origami patterns) (Source: [1]); Al Bahar Towers, Abu Dhabi, AE, by Aedas (fabric mesh screens, form is based on parametric design to define the geometry) (Source: [2]); Gardens by the Bay, Singapore, SG, by Wilkinson Eyre Architects (shading textiles Soltis 92, form is based on the structure of the glazed roof (Source: [3])

Smart materials in facades are more likely to be found in prototypes and in research context, with some exceptions in regards to the established high-tech glazing technologies. The adaptability is provided by inherent, self-responsive properties of the material that responds to temperature, humidity or other ambient triggers. Hence, the actuators are often intrinsic attributes of the material (e.g. thermo-reactive properties of shape alloy materials), but can also be externally activated by automated controls, such as electrochromic glazing technologies demonstrate.

Figure 2: Various examples for self-responsive, smart materials in facades (from left to right): Centre Professionnel, Fribourg, CH, thermos-adaptive glazing by GlassX (phase change insulation, embedded in glazing system, that reacts autonomous on thermal changes) (Source: [4]); Installation "Bloom", Los Angeles, USA, by Doris Kim Sung (laminated metal sheets with a thermo-bimetal behaviour that is activated by temperature differences) (Source: [5]); HygroSkin, permanent collection, FRAC Centre Orléans, FR, by ICD Uni Stuttgart (maple veneer composites that are shape-adaptive according to moisture content in air) (Source: [8]).

While most of these solutions generally contribute to the energy and comfort optimization, examples for adaptation with completely different intentions are also found. Well-known examples hereby are the wide range of media facades that target at aesthetic expressions, art or commercial media performance, most often not incorporating energy use aspects (see Figure 3). Thus, "adaptation" of façade seen from the perspective of architecture is not necessarily linked with performance optimization. However, newer developments of media façades show more often the employment of renewable energy for its operation or even consider its elements as multi-functional components that contribute to the energy concept.

Figure 3: Examples for media facades with adaptive functionality. Media façade do not necessarily consider building performance aspects. The media façade is then an isolated, added layer to the building envelope (from left to right): Allianz Arena, Munich, DE, by XX (Source: [9]); Green Pix Zero Energy Media Wall uses photovoltaics for the needed energy, Bejing, China, by S. Giostra & Partners (Source: [10]); Children's museum, Pittsburgh,USA, by KEA + Ned Kahn (Source: [11]).
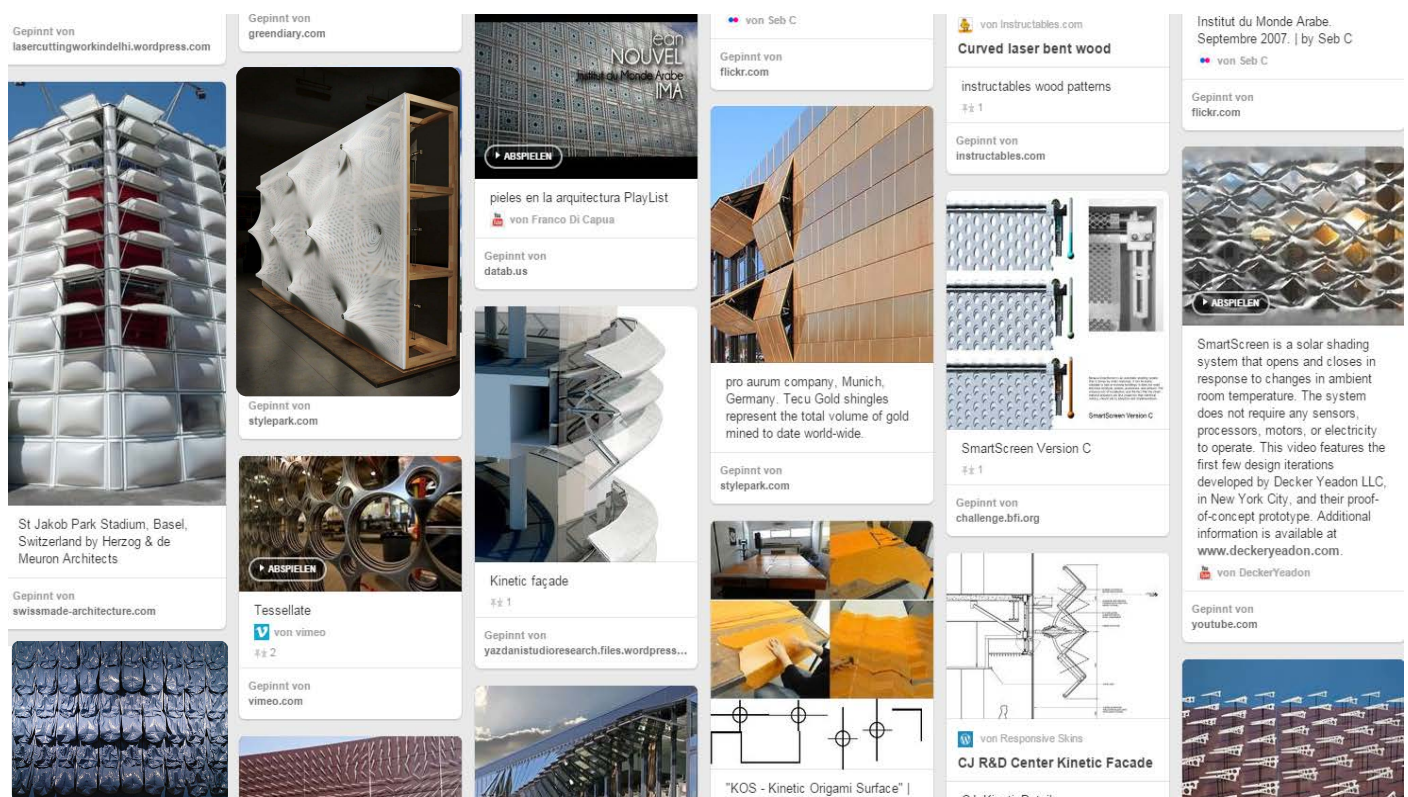
Since the respective functionalities of adaptive facades are mainly developed by technical domains, architectural aspects are confined to the provision of a physical carrier and/or the design of visual patterns for some states of the adaptation. The need to unite architectural and functional aspects for the whole adaptation process would be beneficial to generate a generation of facades that functions as an sustainable and reasonable interface. The investigation of these needs is the objective of this paper.

2. Background

The paper is linked to two research activities: The first is the Ph.D. work of the author, in which biomimetic principles for thermo-adaptive facades are investigated [12]. The objective herein is to identify biological role models, or respectively their functional principles that reveal potentials to optimize or develop novel solutions for thermally adaptive facades. The second is linked to the COST Action TU 1403 "Adaptive Façade Network" [12] that targets at technical knowledge exchange and developments of concepts and evaluation methods for adaptive facades on European level to foster harmonized and interdisciplinary collaborations. Within this framework, the discussion on "How to describe adaptive façades and its criteria?" emerged.

The following presents first aspects on this question, although much of it still needs to be further investigated and validated in detail. Hence, the suggestions shall be considered as a draft that contributes to the need for defining design approaches of "adaptive façade systems".

2.1.   The objective and approach

Adaptive façades are not clearly defined yet, although most of the reviewed sources associate adaptive functionality with performance aspects and/or intelligent measures. To incorporate architectural criteria and to explore the various manifestations of 'intelligent adaptation' in facades, the characterization of functionalities and the development of extended criteria for architectural aspects are suggested. For this, a) existing adaptive façade solutions have been studied in order to b) identify critical criteria and various approaches for the integration of architectural measures.

Based on identified façade examples with the attribute "*adaptive*", found in scientific publications, architectural magazine and respective online sources, a loose collection of potentials has been generated (see Figure 4). This collection serves as a starter set for the investigation and comparison study of architectural-related characteristics for "adaptive facades".

The identification of critical criteria is an ongoing process that shall contribute to the development of a systematic database for adaptive façades, which is foreseen in the COST Action TU 1430.

Figure 4: Collection of adaptive façade solutions, "responsive facades", Pinterest collection by S. Gosztonyi (Status: 15.10.2015)

3. What is SMART / ADAPTIVE in the façade?

Adaptation is, for example, often confused with "intelligence", which can lead to misunderstandings, when used as a single criterion. 'Intelligence' in the engineering field is most likely linked to the integration of automation and sensor technology. Therein, static physical components and/or material properties are turned into adaptive systems by added automated controls. 'Intelligence' is also used in context with sustainable building design to describe integral design methodologies or passive design concepts. Herein, intelligent measures refer to the potentials of passive measures that can induce adaptive behaviour of the building due to their constructive or material properties. In nature, 'intelligence' is an embedded attribute of the composition of an organism itself. Intelligence is herein referred to the autonomous responsiveness of "*materialstructures*" [14] of the organism. *Materialstructures* can be briefly described as hierarchical composed structures made of one single material on various scale and levels to accomplish the desired functionality with the highest efficiency of material and energy use. Thus, the structure is prone to its environment, robust and capable to react on dynamic performance needs without wasting energy.

3.1. First attempts of definition

Various approaches to define adaptive façade functions, such as provided by Loonen et al. [7] or Kirkegard and Foged [8], suggest a systematic approach that comprises the field of actions: The materialization of the system (material and/or mechanical system), the information system that "*decide the feed-in of the dynamic information*" [8] (sensor technologies), and the processing of the information through artificial intelligence systems. Taking this definition as a rough framework, adaptive façade functions could be further subdivided into a (a) <u>operational or functional model</u> describing the performance behavior, and the b) <u>magnitude and order of adaptation measures</u> influencing the design.

As for a), adaptive facades shall provide a physical and/or physiological alteration capability that instantaneously influences the transmission, exchange, conversion of energy, to name a few energetic target functions, or the modification of the spatial and/or visual appearance of facades. Physiological alteration processes of material properties are initiated either by environmental (climatic stimuli) or given commands (automated controls) that induce a reversible change in the chemical properties within a certain time period. Morphological alteration processes are tackled mainly by mechanical (kinetic) abilities of certain façade components, whose position, size or volume can be modified (e.g. shading devices) with the effect of changing their appearance.

As for b), the magnitude and order of the adaptation measure that impacts the design spans from macro scale (e.g. integrated technical devices) to micro scale (material) measures, from intrinsic controls (embedded and self-controlling behaviour of smart materials) to extrinsic controls (sensor and automation systems). These measures request different spatial and constructive considerations in the design and need to be known already in the early design phase. Being merged with the above mentioned fields of actions, they can be presented in a simple matrix for possible adaptation measures, as shown in Figure 5. The intention for such matrix is to provide a visualization of the related design approaches that have to be decided in the early design phase. For example, an inflatable surface needs specific material and air pressure technology placed close to the system, both need enough space to operate and get integrated.
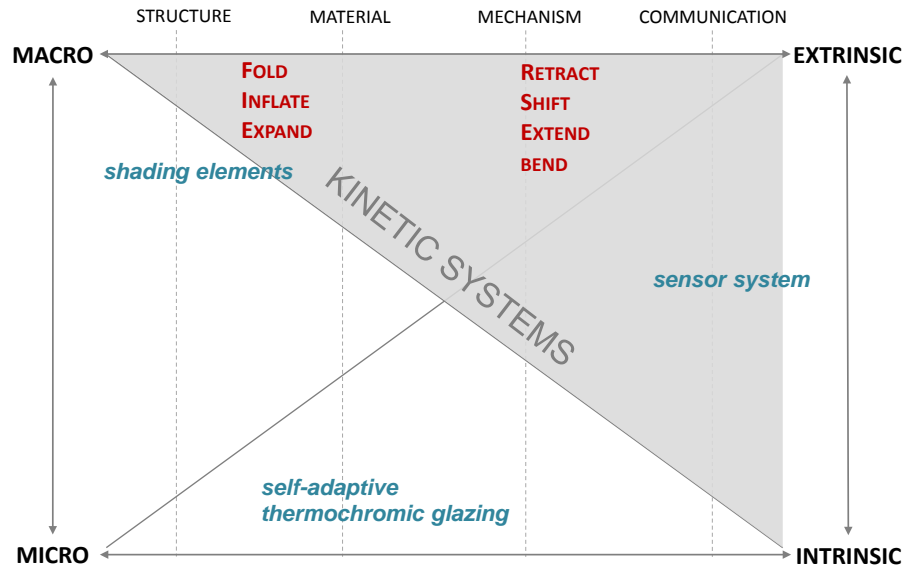
Figure 5: Draft of an simplified design action matrix for adaptive systems that illustrates various impact levels (scale of impact, control type, component type) on the design and possible measures that need to be considered in the design (e.g. folding, inflating) and choice of products(e.g. textiles, glazing, etc.) (S. Gosztonyi)

3.2.   Extended architectural criteria

Related design tasks for adaptation, such as folding, inflating, expanding, etc., or specific building product selections, such as shading elements or glazing technologies, are mainly discussed within a functional context that targets at their performance needs. To link this with formal design characteristic, further criteria, that incorporate architectural and constructive aspects, are suggested. Adaptation functionalities in facades also change e.g. the versatility of the surface, its robustness or colour. Figure 6 demonstrates a possible approach for the description of these extended criteria.
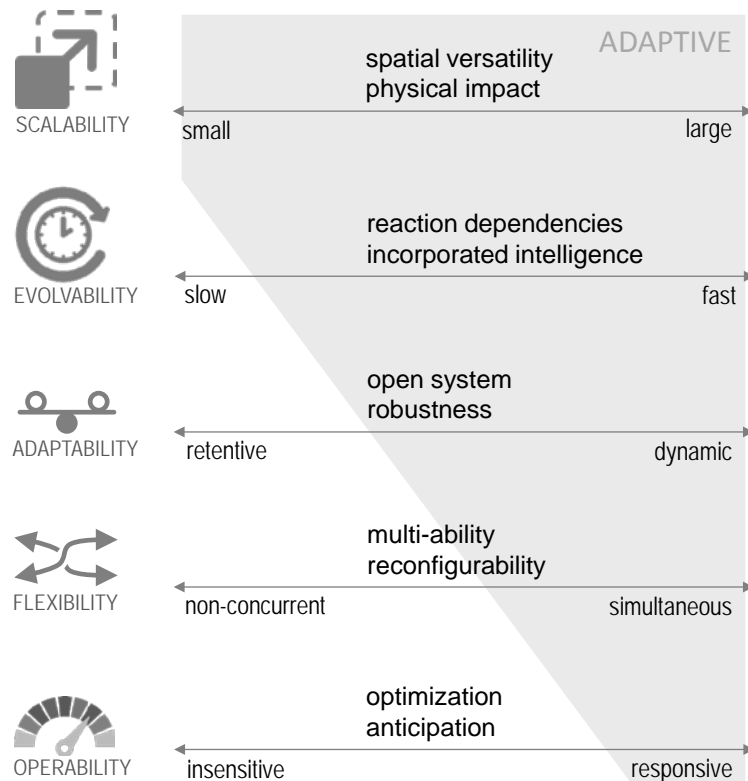

Figure 6: Draft concept focusing on extended architectural criteria to evaluate adaptability in facades (S. Gosztonyi)

The suggested criteria in Figure 6 tackle following considerations:

- <u>Scalability</u> (alteration of size, position, etc. of adaptive component(s) linked to the physical appearance and geometrical morphology of the building envelope):

    - 'Spatial versatility' targets at the choice for various positions, sizes and its effect on the adaptive function at the same time, as well as at the ratio of the unit to total system.

    - 'Physical impact' focuses on the morphological impact of the measure (e.g. integrated or embedded adaptability that causes spatial and/or visual changes).

- <u>Evolvability</u> (dynamics of the measure):

    - 'Reaction dependencies' focuses on the wished reaction time for adaptation and on the inherent reaction time of selected components/material: e.g. the needed time for a certain adaptation (sec/min/hour/diurnal/seasonal/etc.) aligns with the reaction attribute of the element (e.g. thermal inertia of wall construction, thermo-bimetal behaviour). Thus, unnecessary additional measures might be avoidable (downsizing of complexity).

    - 'Incorporated intelligence' looks into the time-depending characteristics more in depth by considering also actuators/sensor behaviour and their self-learning ability. Analogies can be found in nature (cp. fitness ability of biological "systems", such as acclimatisation vs. evolution).

- <u>Adaptability</u> (functional concept flexibility):

    - The criterion "open systems" vs. closed systems (e.g. as for thermos-reacting systems) targets at the non-simultaneous performance, functional transition over time due to meet new circumstances and its retentive properties, as well as the modification options that are dynamic and reversible. This criterion is covering the functional aspects as discussed earlier.

    - 'smart robustness' focuses on the redundancy and scalability in regards to cost-efficiency user interaction and maintenance. Smart robustness shall reduce negative consequences and increase the acceptance, but does not eliminate necessarily the causes of them. Hence, smart robustness criteria focus on the environment, utilization of available resources and downscale to an economic and user-friendly need.

- <u>Flexibility</u> (applicability concept):

    - The 'multi-ability' of an adaptive system targets at its capability to act as a multi-functional element, which not only provides multiple configurations but also non-concurrent characteristics. The use of the system shall address multiple objectives simultaneously or/and consecutively.

    - The 're-configuration' of an adaptive system comprises its adaptation ability in terms of major adjustments due to new circumstances and conditions with major changes of the facade. In this context, the recyclability and/or re-use of the elements are considered.

- <u>Operability</u> (performance aspects):

    - 'Anticipation' is linked with a critical aspect of adaptiveness, the user interaction. The communication and interoperability of the measures with the user's needs, the system response and perception by the users are considered.

- Last but not least, the actual 'optimisation of the performance, which is partly already tackled in the adaptability, is addressed by the evaluation of its responsiveness grade. Adaptive facades performance and/or comfort targets are closely linked to the operability.

4. Conclusion

Understanding how "adaptation" could be incorporated in design has a significant impact not only on the architectural design quality of respective building components and use of components, but also on the functional performance and application optimization. The effectiveness of adaptive measure in the operation phase relies also on criteria which are beyond the function performance tasks. This draft is based on first investigations for these criteria. As it is assumed that a successful integration of adaptation measures in façades leads to higher user satisfaction and better performance (higher energy savings and better use of material), these assumptions must be investigated more in detail.

4.1. Next steps

A next step will be to extend the case studies collection and investigate further their benefits and challenges in regards to adaptation, to discuss the identified characteristics with experts from interdisciplinary fields and to formulate an updated, more sophisticated criteria list. The demonstrated criteria and matrix are both still on a very basic level. To be able to understand equally the needs and the possibilities, also by considering digital production and design techniques, the employment of an interdisciplinary research approach as used in biomimetics will be considered.

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