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Practitioners' View on the Implementation Potential of Adaptive Façades with focus on The Netherlands

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The adaptivity of façades is increasingly recognized as an important functional feature to be integrated with the state-of–the-art building technology. The aim is thereby to control its reversible system states in real-time to adapt to current indoor and outdoor conditions. Concepts reported elsewhere integrate two or more functions related to structural integrity, ventilation, heating and cooling, solar protection, as well as energy generation and storage. Although advantages are perceived obvious, the number of realized case studies remains limited. Triggered by this observation, the authors of this contribution report research findings from a literature study and interviews with stakeholders in the field, including contractors, building consultants and architects. The three key-findings suggest that (1) the functions daylighting and energy generation/storage are most commonly integrated into façades or façade components characterized as being adaptive, (2) interviewees are divided on the implementation potential of most of the designs/concepts and (3) the aesthetics of the design, (investment) costs, durability and required maintenance are critical for a widespread market uptake. Herewith, this paper contributes new knowledge to the discussion related to finding the right level of system integration in building technology.

Keywords: adaptive façades, practitioners view, building integration, market uptake, façade functions

1. Introduction

Whilst conventional, static façades do not have the ability to respond to varying meteorological conditions and comfort wishes, climate adaptive façades can utilize this variability to reduce the energy demand and improve indoor air quality and comfort (Loonen, Trčka, Cóstola, & Hensen, 2013). The climate adaptive façade concept may take a wide variety of physical forms (Loonen, Hensen, Trčka, & Cóstola, 2010; Loonen et al., 2013), with each adaptive façade or component thereof having its own characteristics. Concepts reported elsewhere (Loonen et al., 2010) integrate two or more functions related to structural integrity, ventilation, heating and cooling, solar protection, as well as energy generation and storage. These functions correspond with the six ideal functions of an adaptive façade as identified by Struck et al. (2015).

Despite the diversity in the manifestation of adaptive façades and the many available options, it has been noted that the concept has yet to mature (Loonen et al., 2010); thus far, the number of realized case studies remains limited (e.g. Prieto, Klein, Knaack, & Auer, 2017). In the literature, a number of barriers have been identified that underlie this observation. Haase, Andresen, & Dokka (2009) mention issues with integration into the building, such as aesthetics, functionality, economy and flexibility. Prieto et al. (2017) also mention physical integration as an issue, but found that the development process is more critical; coordination among different disciplines and stakeholders is problematic.

In the present study, the authors aim to investigate the practitioners' view on the implementation potential of climate adaptive façades to increase comfort and reduce energy demand. Three research questions are formulated accordingly:

a) Which functions are most commonly integrated into façades or façade components characterized as being adaptive?

b) How do stakeholders assess the advantages and disadvantages of a number of specific façade concepts?

c) Where do the addressed stakeholders see the obstacles hindering a widespread market uptake?

2. Research methods

To answer these research questions, a literature study is undertaken and interviews are conducted. The inventory of climate adaptive building shells from Loonen et al. (2010) is used as a starting point. To answer the first research question (a), the hundred climate adaptive buildings shells are analyzed and categorized.

From the hundred climate adaptive building shells, the eight most promising designs or concepts are selected by conducting a multi criteria analysis (MCA), using technology readiness, complexity and the potential to be integrated with the buildings' energy generation and distribution system, as criteria.

To answer the second (b) and third (c) research questions, semi-structured interviews are conducted with relevant stakeholders in the field. In these interviews, the previously selected eight specific climate adaptive façades or façade elements are discussed. The interviewees include architects (2), building consultants (3), contractors (2) and a representative of a maintenance company (1). Table 1 contains background information on the interviewees. Although the study is geographically limited to the Netherlands, several interviewees indicated their company has projects abroad.

Table 1: Eight concepts/designs with highest MCA scores

Interviewees	# years experience	Background	Project locations
Architect 1	10 - 15	Architecture	Netherlands
Architect 2	> 25	Architecture	Netherlands, Germany
Building consultant 1	15 - 20	Structural engineering	Globally (e.g. Netherlands, China, Poland)
Building consultant 2	20 - 25	(Structural) engineering, drafting, building physics	Netherlands
Building consultant 3	0 - 5	Structural engineering, building physics	Globally (e.g. Netherlands, China, UAE, Germany)
Contractor 1	> 25	Sales	Netherlands
Contractor 2	> 25	Aluminum/steel engineering	Netherlands
Maintenance	> 25	Building services engineering	Netherlands, Germany

Each interviewee's assessment of each of the eight designs and concepts is rated on a five point Likert scale (-2 to +2). Consequently, the mean of every stakeholder group is calculated using these numeric values.

3. Introduction to adaptive façade designs and concepts

Fig. 1 shows a categorization of the hundred climate adaptive building shells from Loonen et al. (2010) according to eight functions, in accordance with Struck et al. (2015). The functions daylighting and energy generation/storage are most commonly integrated. (Note that climate adaptive building shells may have multiple functions.)

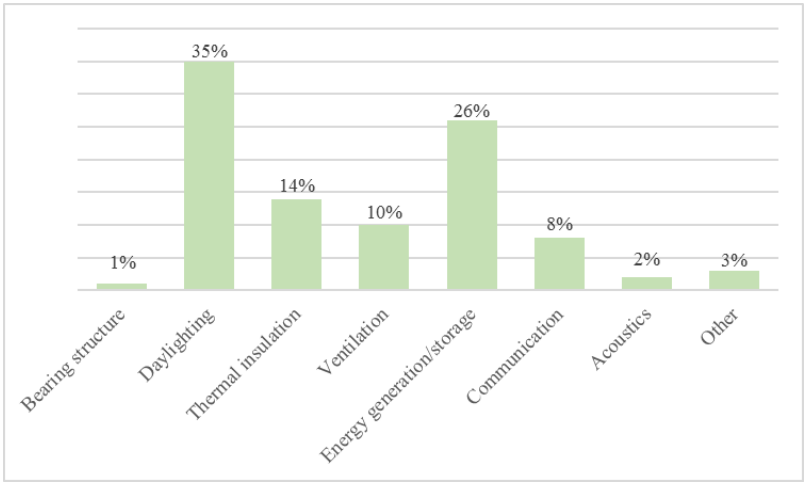

Fig.1: Functional categorization of adaptive façades

Using technology readiness, complexity and the potential to be integrated with the buildings' energy generation and distribution system as criteria, a multi criteria analysis (MCA) is conducted on the hundred aforementioned concepts/designs. The eight concepts with the highest scores are selected for further analyses. See Table 2.

Table 2: Eight concepts/designs with highest MCA scores

Concept/Design	Technology readiness (1-3)	Complexity (1-3)	Energy (1-3)	Total (sum)
GlassX Crystal	3	3	3	9
Blight	3	2	3	8
EWE Arena	3	2	3	8
Smart Energy Glass	3	3	1	7
Climate Adaptive Skin	3	1	3	7
Beadwall	3	2	2	7
Bloomframe Balcony	3	3	1	7
Kameleon Concept	2	2	3	7

The eight concepts from Table 2 are described briefly below. For more extensive descriptions, see Loonen et al. (2010).

GlassX Crystal is a transparent façade part which contains a phase change material (PCM) that stores heat during the day and releases heat at night. The functions daylighting, thermal insulation and energy generation/storage apply to this design. See Fig. 2.

Fig. 2: GlassX Crystal

The *blight* design comprises blinds which are equipped with photovoltaic cells. The electricity that is generated during the day is stored in a battery. At night, this electricity is used to illuminate the interior via electroluminescent foil.

The *EWE Arena* refers to a concept in which a kinetic second skin of photovoltaic panels is placed around a building. Besides generating electricity, this systems also provides shading to rooms that are – at a certain time of day – exposed to direct sunlight.

The *Smart Energy Glass* allows occupants to switch its optical properties. The energy needed is generated by photovoltaic cells at the edges of the window. The functions daylighting and energy generation/storage apply to this design.

Fig. 3: Beadwall

The *Climate Adaptive Skin* refers to a concept in which all functions for heating, cooling, solar protection, energy generation/storage and ventilation are integrated into a single skin. Also see Hasselaar & Looman (2007).

The *Beadwall* comprises a design in which moveable insulation material can – on demand – be blown into the space between two window panes to provide shading and insulate the window. See Fig. 3.

The *Bloomframe Balcony* is a window frame that can be transformed into a balcony. Besides adding daylighting and ventilation, the floor area of a building is – temporarily – increased with this system.

The *Kameleon concept* consists of an aluminum box with replaceable coffers that can perform different functions, such as energy genearation/storage, air purification, advertising (communication in Fig. 1) and rainwater drainage.

4. Stakeholders' assessment of adaptive façade designs and concepts

The stakeholders' assessment of the eight adaptive façades concepts/designs is summarized in Table 2, and discussed below. The results are presented using a five point Likert scale. The extreme positive and negative responses are associated with the +2 and -2 accordingly. The results allow to identify differences in the perception of adaptive façade concepts by four different stakeholder groups. See Fig. 4.

The assessment of the concepts/designs are more differentiated. Fig. 5 shows that six out of eight concepts/designs are assessed slightly positive whilst two concepts, Beadwall and Kameloen concept, are assessed moderately negative. A more detailed summary of the feedback per concept/design is provided below.

Table 3: Results of interviews

	Architect 1	Architect 2	Building consultant 1	Building consultant 2	Building consultant 3	Contractor 1	Contractor 2	Maintenance
GlassX Crystal	-1	-1		1	-1	2	1	1
Blight	0	1		-1	-1	1	1	-1
EWE Arena	-1	1	-1	-1	2	1	0	1
Smart Energy Glass	-1	0		0	-1	1	1	1
Climate Adaptive Skin	-2			-1	1	2	1	1
Beadwall	0			-2	-2	-1	-1	-2
Bloomframe Balcony	2	-2	-1	1	1	0		
Kameleon Concept	0	-1		-2	-2	-2	0	-1

Legend		
	2	Positive
	1	Moderately positive
	0	Neutral
	-1	Moderately negative
	-2	Negative
		No answer

GlassX Crystal: Architect 1 highlighted the aesthetical aspect and noted that, even if certain materials are considered aesthetically pleasing at one point, these may grow out of fashion. The advantage that this system combines light-weight construction with comfortable indoor climates was noted by building consultant 2 and the contractors. Building consultant 3 finds it more obvious to apply phase change materials (PCMs) in floors than in windows. The limited durability of PCMs is a concern of both contractor 2 and the maintenance company.

Blight: Multiple interviewees noted the fact that blinds are more effective when these are placed on the exterior, though this requires more intensive maintenance. Many interviewees also noted that occupants are generally not content with automated systems like these, in particular when these obstruct the view. Contractor 1 mentioned the advantage that this system can be sold as a component, and building consultant 3 mentioned its applicability for renovation purposes. Architect 1 noted the importance of having choice in dimensions and colors for a widespread market uptake.

EWE Arena: Both architects, as well as building consultant 3, positively assessed this design. These interviewees expressed their enthusiasm on the idea of a building following the sun path. Building consultants 1 and 2 mentioned the high costs of the system as being large obstacles for a widespread market uptake, whilst the contractors wondered how this concept might work on a rectangular building.

Smart Energy Glass: Both the contractors and the architects consider the high costs of the system relative to simple solutions (such as curtains) disadvantageous, though architect 2 noted the interesting aesthetic effect that could be accomplished upon application in e.g. hotels. Building consultant 3 mentioned that the desired visual comfort conflicts with the wish to reduce the solar heat gain.

Climate Adaptive Skin: The interviewees were highly divided on the (dis)advantages of the Climate Adaptive Skin concept. Contractor 1 positively assessed the fact that this could be a modular system. Architect 1, however, felt this concept restricts design freedom. Whereas building consultant 3 noted this concept could imply savings on distribution pipes and channels, the costs of the system were of concern to building consultant 2. With regard to maintenance, the importance of accessibility to individual systems was stressed.

Beadwall: This concept is not assessed positively. Architect 1 and Contractor 2 were negative about the aesthetics. Building consultant 2 anticipates practical and technical problems, whilst building consultant 3 and the maintenance company did not see the advantage of this system over currently available highly insulating glazing.

Bloomframe Balcony: Architect 2, as well as building consultant 1, did not see the advantage of this design over a traditional balcony. This is in line with the statements of contractor 1 and building consultant 3, who called it a 'nice gadget' without much added value. Building consultant 2 and architect 1, on the other hand, were positive as they felt this system can enhance the experience of an indoor space by connecting it to the outdoors.

Kameleon Concept: None of the interviewees were positive on this concept. Architect 2, contractor 1 and building consultant 3 found it illogical to integrate these functions in a façade. The representative of the maintenance company mentioned the required extensive maintenance on filters and moving parts as disadvantageous.

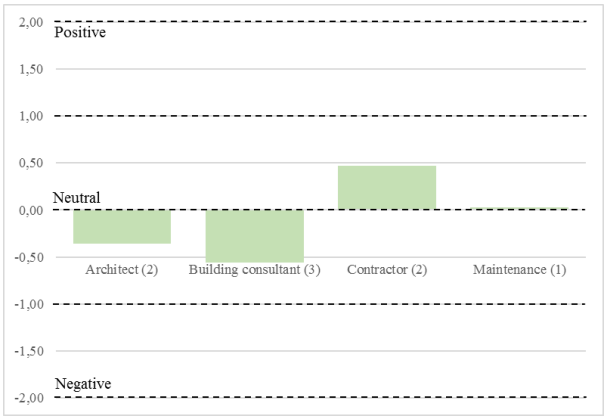

Fig. 4: Average scores by stakeholder group

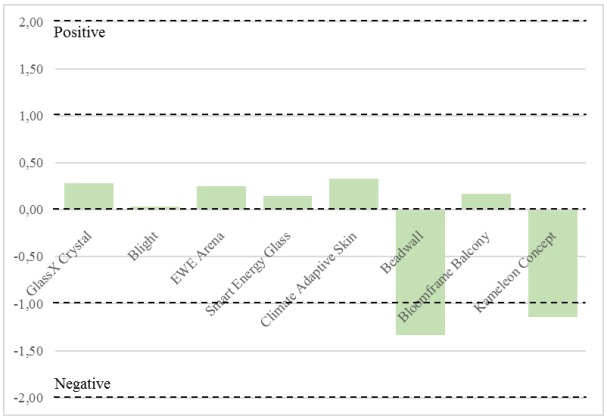

Fig. 5: Average scores by concept/design

5. Discussion

Although the number of stakeholders interviewed does not allow to provide statistically significant results, the data does allow some indicative conclusions. The results show that, within stakeholder groups (e.g. architects), the assessments of certain concepts/designs varies strongly.

The individual scores in

Table 3 show a great diversity of scores from -2 relating to a negative perception to +2, indicating a positive perception. It can also be noticed that stakeholders did not give an opinion on all concepts. There are two possible reasons to for this. The interviewee did assess himself, at the time being, not knowledgeable enough to give an educated assessment or as observed in a different case the interviewer was not able to discuss the concept/design within the time available for the interview.

Fig. 4 indicates that, from the pool of interviewed stakeholders, the building consultants response to the eight chosen adaptive façade concepts/designs was the most critical with an average score of -0.56. The most positive score came from the contractors with an average score of +0.47. The response from the façade maintenance professional was overall neutral. None of the scores were extremely positive or negative.

From Section 4, a number of parameters can be extracted which were found to be of interest to the stakeholders. The aesthetics of the design, (investment) costs, durability and required maintenance were identified as critical for a widespread market uptake. This is in line with the findings of Haase et al. (2009).

6. Conclusions

In this paper, the authors qualitatively investigated the practitioners' view on the potential of climate adaptive façades to increase comfort and reduce energy demand.

It has been investigated which functions are most commonly integrated into façades or façade components characterized as being adaptive. To that end, the hundred climate adaptive building shells from Loonen et al. (2010) were categorized in eight functions. The functions daylighting (35%) and energy generation/storage (26%) are most commonly integrated. Few concepts/designs have a bearing (1%) or acoustic (2%) function.

It was furthermore investigated how stakeholders assess the advantages and disadvantages of eight specific façade concepts and where these stakeholders see obstacles hindering a widespread market uptake. To that end, eight promising designs/concepts were used as input for the interviews with eight professionals, which included architects, building consultants, contractors and a representative of a maintenance company.

It has been found that the interviewees are highly divided on the implementation potential of most of the designs/concepts. Remarkably, it is found that – on the whole – the two interviewed contractors were most positive, whilst the building consultant stakeholder group was found to be most negative on the implementation potential of the eight designs/concepts.

Aesthetics, (investment) costs, durability and required maintenance have been identified as critical parameters for a widespread market uptake

7. Acknowledgements

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