



Adaptive Facades performance assessment

Interviews with Facade Experts

by **Shady Attia**

photo courtesy: Terry Boake

Report Information

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Foreword

There are two other types of barriers that hinder the successful market adoption of buildings with adaptive facades:

- The first barrier relates to difficulties in performance quantification and evaluation of buildings with adaptive facades. There is a lack of holistic performance criteria based on testing, assessment and monitoring. Although there is an ample number of standards and criteria to assess façades at the material or component level, there are hardly any standards for complete façade assemblies. In addition, there are no prospective studies or best practices assessing and documenting the performance of adaptive facades systems. This knowledge gap is significant and requires being addressed by the scientific community in order to simplify the evaluation of adaptive facades based on solid science.
- The second barrier concerns the delivery process of high-performance facades, which consists of multiple stages, including the design-assist stage (e.g. durability testing, visual mockups, onsite panel mounting and weather stripping), construction verification stage, commissioning stage, soft-landing stage and operation stage. Design and construction of buildings with adaptive facades tend to transcend multiple engineering disciplines, expecting a high degree of coordination among all the actors involved. This leads to a number of process-related challenges, which take place in a professional environment with procurement mechanisms that in many cases are not streamlined to efficiently accomplish these tasks.

As a contribution to addressing the mentioned barriers, the purpose of this report is to identify the gaps related to adaptive facades systems' evaluation requirements and processes, and to provide insights into current trends and future trends in this domain. More importantly, the report groups excellent experts in the field of facades engineering. The report allows understanding deeper and gaining more extra knowledge and insights to explore in depth the experts point of view, experiences, feelings, and perspectives. The report creates a fragmented snapshot pictures for best practices in European countries regarding adaptive facades performance, to bridge the knowledge gap and to eventually increase the adaptive facades market uptake.

Executive Summary

Adaptive facades can ensure step-change progresses in the energy efficiency and the use of renewable energy while improving the comfort of the occupants. Therefore, the purpose of this structured interview is to assess advantages, disadvantages and future expectations considering the adaptive facades. This work is a part of actions of The COST Action TU1403 Adaptive Façade Network. The objective of this report is to gain an understanding of how experts currently define adaptive façade systems, which simulation tools they use, the major strengths, weaknesses, opportunities and treats of adaptive façade systems, key performance indicators they use and their vision for the future of adaptive facades. With this information gathered, it is anticipated that adaptive façade professionals will carry on assessment of adaptive facades. A qualitative study design was employed, using semi-structured interviews. Twenty-seven interviewees working in academia, practice and industry were selected. The interviewees represented the range of possible adaptive façade professionals, from researchers and designers considered optimization in the assessment of adaptive facades. Also, every interviewed expert was asked to approve their responses and add any additional comment to their answers.

Methodology

For this report, we opted for in-depth interviews as a qualitative research technique which is used to conduct intensive individual interviews where numbers of façade industry experts are focused on adaptive façade technologies. The advantage of in-depth interviews was to allow us to understand deeper with the participant and gain more extra knowledge and insight than focus group discussions or literature content analysis. In-depth interviews allowed us to explore in depth the experts point of view, experiences, feelings, and perspectives. More importantly, it allowed us to establish a personal contact with those experts and expand our network.

This study started in 2016 and lasted until 2019. The three years allowed us to meet twenty-seven experts and refine the research questionnaire in relation to the report title: Adaptive Facades Performance Assessment, interviews with facade experts. We opted for semi-structured in-depth interviews, because this allowed us to refine the interviews questionnaire over a three years period based on experts' feedback. In 2015, and prior to starting our interviews rounds we launched a pilot study to test our questionnaire. The pilot questionnaire was on a checklist of topic areas or questions around the SWOT model. The intention was to get the test-interviewees talk in their own terms, hence questions tend not to be too specific allowing for a range of possible responses to refine our interview questions and adjust to the one-hour maximum interview time policy. Doing the pilot runs helped to get a high-quality feedback.

For expert's selection we used purposive sampling in which we relied on own judgment when choosing members of the façade industry population to participate in the study. Purposive sampling is a non-probability sampling method and it occurs when "elements selected for the sample are chosen by the judgment of the researcher. We believe that we could obtain a representative sample by using a sound judgment. Purposive sampling was the most appropriate method available in the context of limited number of primary data sources on adaptive facades. Also, we made sure to assure the homogeneity of the sample by interviewing scientist, consultancy professional, contractors, manufactures and facility managers. Working Group 3 of the COST Action TU1403 validated the choice of experts and assured the homogeneity of the sampling. We continued expanding our sampling until we reached saturation and interviewed experts from the four major adaptive façade technologies categories (dynamic shading, chromogenic glazing, solar active and insulative facades).

All interviews were recorded and manually transcribed. We shared with each expert the original transcribed version and asked for permission and approval to edit the interview transcripts. Repetitions, interjections and stutters were removed, and additional references were added to enhance and support the content. In this report, we did not interpret the results. In a future publication, we will analyze and interpret the interviews outcomes.

Interview with Philippe Samyn, Samyn Partners

Name: Philippe Samyn

Date: 08.12.2015

Place: Brussels, Belgium

E-mail: sai@samynandpartners.be



Questionnaire:

A. Background Information:

1. What is your core specialization?

The team's client services include Planning and Programming, Urban Planning, Landscaping and Architectural Design, Interior Design, Building Physics, MEP and Structural Engineering, Project and Construction Management.

2. What kind of projects have you been involved in?

A wide range of projects: industrial buildings, offices, interiors & sculptures, commercial activities, public services, health & social care, hotels & restaurants, auditoriums & theatres, schools & universities, research centers and housing projects...

3. How would you describe your main roles in the company? How long have you been in this field?

Philippe Samyn begins his consultant activity as an architect and engineer in 1972 and founds "Philippe Samyn and Partners" in 1977, incorporated in 1980. He is "*the*" designer of the office.

B. Interviewee Definition of an Adaptive Façade:

4. How do you define an adaptive façade? What is the purpose of adaptive façade?

The definition isn't complete. Somehow, every building on the planet requests some adaptivity to be useful. For example, you have a curtain in your sleeping room to adapt it to the sun coming in, and you have a window in your house to let the air in. Adaptive façade is therefore a misleading concept, because a façade should always be adaptive.

C. Advantages of Adaptive Façade:

Definition: Adaptive façades are building envelopes able to adapt to changing climatic conditions on daily, seasonally or yearly basis. By *adaptive*, we mean the ability to respond to, or benefit from, external climatic conditions, in order to meet efficiently and, above all, effectively the occupant's comfort and well-being requirements.

5. What kind of projects did you participate in that fall under this definition?

For all my projects, the principle of architecture is designing emptiness (space). After all, the architect is defining a void. To make that void a reality, you need construction. The adaptiveness of a façade is a fact of construction but it qualifies the architecture. A good example of non-adaptive façade is what has been built in the last fifty years, those reflective office boxes with tinted glass.

6. What are the adaptive characteristics in those projects (active transparent façades, switchable glazing, phase change materials, automated louvres) and

what was their main added value (reason) (comfort, energy, real state value, image etc...)?

Firstly: The ability of the building not to get dirty. That implies an obsession for low maintenance cost.

Secondly: respect of the 5 senses (quality of light, light transmittance, insulation value, acoustics, etc.).

Thirdly: the order of the magnitude, the quality of touching, smell and the noise and music of architecture (the way the building space and façade interact with sound).

7. What key performance indicator(s) were used to evaluate those characteristics?

What you need as a designer is a bright client with a vision and a goal. The projects absolutely need to be humanistic. The way the brief of a competition is written tells you everything about its morality.

You have to take the time to appropriate the site (quality of earth, wind direction, trees) with the big dream of the client. This is the way to fuel your inspiration. My real motto when going through a project is: discover, invent and create.

8. When and how did you intervene in this project (AGC Building)?

The competition was launched by AGC. They were looking for a design & build team, so they called for manifestation of interest. MATRIciel helped AGC write the design brief. We made two projects: a brave one and a serious one.

The brave project was made of bricks and aluminum, to respect the urban planning rules. I proposed after that to Emmanuel hazard (who represented AGC) about the same project, but with a fully white glass façade: a building covered with clear vision glass (guaranteeing natural light and a clear sight), that would have a g factor equivalent to solid aluminum.

The louvres are my invention. I sold it to AGC who, with the help of their R&D team, were able to realize it.

All this was in the concept development. When you came with this idea, were you not afraid because it was not validated yet?

I am permanently calculating.

9. Who were the team members of such a project?

The consortium was composed of: SAMYN and PARTNERS sprl, architects & engineers with BEAI sa, Van Roey (general contractor), Daidaluz Peutz assisted us for the energy and building physics issues.

10. What modeling tools, that you consider good tools, helped in design?

None. Even in this time of many possibilities offered by computer simulations, we continue to see models as an important articulation in the development of projects. Models provide an additional security in the testing of what is intended to be built.

(Source: <http://samynandpartners.be/design-approach>)

11. What features would you like to find in the future in an adaptive façade?

The white stripes could be replaced by white photovoltaic.

12. How did you test the façade offsite and onsite (fire, blower door)? Which standard did you refer to for testing?

The calculations were made by AGC's R&D center, **Daidalos** did the simulation work and then **Peutz** in Netherlands made the physical testing. Energy measurements were taken in a black room twice (once in the development with **Peutz** facilities, and then with the mock-up of the real façade on site.

13. How did you do the commissioning process? What standards did you comply with and which tests did you conduct?

Table 1: Thermal Comfort Performance value

	Description	Standard	Category	Performance value
1	PMV-PPD indices	thermal comfort index NBN EN ISO 7730:2006 NBN EN ISO 1525:2007	B (Normal Level)	No more than 3% of the building occupancy period
2	U Value	The thermal transmittance measures the thermal performance of a building component NBN B 62-002:2008 NBN EN ISO 6946:2008	-	2.5 W/m ² K (overall value for the curtain wall)
3	K Level	Global level of thermal insulation of a building NBN B 62-301:2008	Average quality	K36
4	E _w Level	Annual primary energy use under standard operating conditions NBN EN ISO 13790:2008	Higher than high quality	E _w = 42
5	The Temperature factor	Is a measure of the risk of surface condensation Belgium's BBRI	-	Higher than 0.7

Table 2: Air quality Performance value

	Description	Standard	Category	Performance value
1	Air Change Rate (Envelope) n ₅₀	Number of air changes per hour at 50 Pa. NBN EN 13829	-	n ₅₀ = 0.77
2	Humidification	NBN EN 15251:2007 Article 57, General Regulations for work protection	Level B, Normal Quality	40%

Table 3: Indoor light quality values

	Description	Standard	Category	Performance value
1	Daylight Factor	is the ratio of internal light level to external light level NBN EN 15251:2007 NBN EN 15193:2008	Level B Strong Penetration Daylight	3% FLJ ≥ 3%
3	Light Reflectance	Measure of visible light that is reflected from a surface when illuminated by a light source		41%
4	Light Transmittance	The fraction of incident light passing through the glazing		11%
5	G-Value	To measure the solar energy transmittance of		0.17

glass

14. When you were close to the commissioning, Colt was the company responsible for the automation. Would it have made a difference, had this company been early on the design team?

No, even the actuators were not selected by Colt, but by one of my partners. We had full control over engineering and drawings here, and we designed every little bolt.

a. Is it possible to convince clients to pay more for an adaptive façade?

Yes. Most of my clients accept to pay more as an investment, to get the return within a couple of years.

With the break of internet, there is a huge risk with computer-driven buildings. In the case of the AGC building, we have a weather station and an automated louvre, but there is no internet connection. It is a closed cycle.

b. Do you think that adaptive façade technology is mature to penetrate the market? Why?

You do not need technology for an adaptive façade. Technology is not associated with adaptive façades.

c. Did you consider the life expectancy and maintenance of adaptive façades a challenge? Why?

I have no idea of its life expectancy, but I can reasonably say that it will be higher than a normal office building. It will work perfectly as long as it is properly maintained. Buildings components have to be low-tech even if they seem high-tech. What I mean by low-tech, is that every component should be easily produced, assembled and maintained.

D. The Future of Adaptive Facades:

15. What is your opinion regarding the specific nature of adaptive facades (coming from component and elements in the factory and getting assembled on a system level in the building)? Is the process smooth enough? What is the most critical phase and why?

Education.

16. What needs to be done for a better adaptive façades process and performance quality? Do we need to invent new performance indicators? And new standards?

No, we do not need new performance indicators.

17. What happens if POE and monitoring become obligatory?

Nonsense. It is a constrain limiting the freedom of thinking. We can reduce the energy consumption just by a good human behavior (turning light on/off...).

18. What is the holy grail of adaptive façades in the future?

Keep it simple.

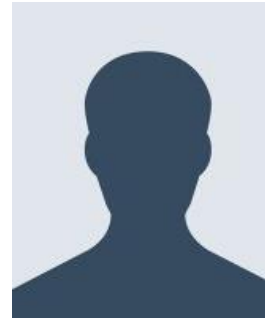
Interview with Kurt Booms, Colt

Name: Kurt Booms

Date: 08.11.2015

Place: Mechelen, Belgium

E-mail : kurt.booms@be.coltgroup.com



Questionnaire:

A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

We are experts in moveable external solar shading systems, we also have fixed systems but we are really specialized in moveable systems: horizontal, vertical, all types of ideas that started from the architect.

Mostly, we are involved in public buildings like office buildings, hospitals sometimes but mostly bigger scale projects.

2. How would you describe your main roles in the company? How long have you been in this field?

Based in Belgium, I have been fifteen years working in this field and I am responsible for Belgium, Luxemburg, Holland and France. My role is visiting architects and engineers, talking about possibilities and looking at energetic and cost aspects from the first starting point of the project. My aim is to study the possibilities, what are the advantages and on the site of cost, is it feasible to go this way or not?

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of adaptive façade?

An adaptive façade is a moveable façade that can give an added value to the energetic point of view of the building, not only regarding solar shading but also in the means of natural daylight entering the building. The reason that it has to be moveable: when you have fixed system, it is nice in summer but when it is a darker day, more artificial light will be needed, then we have to look a little bit more on the cost and the heating of the building, not only on the cooling side but also the heating requirements of the building.

4. Who and what drives the idea (raison d'être) of adaptive facades in most of your projects?

Energy is our main drive; we are trying to reduce the primary energy needed in the building. Very often the aesthetical aspect in the building for some architects is very important. Nowadays, there are new requirements for building like Zero-Energy and from that point of view, we as **Colt** try to give some interest for that.

C. Advantages of Adaptive Façade:

Definition: Adaptive facades are building envelopes that are able to adapt to changing climatic conditions on daily, seasonally or yearly basis. By adaptive we mean the ability to respond or benefit from external climatic conditions to meet efficiently and more important effectively occupant comfort and well-being requirements.

5. What kind of projects did you participate in that fall under this definition?

The Berlaymont, the headquarters of the European Commission, SBB Railway Headquarters, bio-reactive façade in Hamburg and the BMW headquarter in Munchen and South-Africa.

6. What are the adaptive characteristic in those projects? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

The solar shading and their steering (controls).

7. What were the components of this adaptive façade? And what key performance indicator(s) were used to evaluate those characteristics? (Orientation, Snow, Solar radiation?)

- Everything that form the second façade is mostly carried by us.
- **For physical components:** the vertical and horizontal beams, the motorization and then the louvers themselves taking into account the thermal bridging.
- **For soft components:** the software of the steering, the weather station, the central control panel and everything that need to come together there like HVAC context and fire alarm context from there you go to a secondary panel connected to the motors (11:00).
- Our main indicator is **static calculation** for the structure (wind loads, etc.) to determine in first case what structure do we need in a static point of view that goes stand together with a motor. When this is done you know the force you need with a motor and then you go to the controls. The more force you need, the bigger your component for steering will be.
- It is also important here the individual need of the customer depending on which type of building: for example, in schools they want louvres to be closed for presentations so they want to have darker rooms (manual motorization/override for the individual uses).
- We are looking mainly to secure and guarantee the stability and robustness of the second façade and that it will function, will take the loads and operate from a structural calculation point of view.

Performance Indicator's Matrix for the structure:

- **Newton/m²** wind load, we also take into account snow and ice.
- CP (coefficient of pressure), CF (coefficient of form) (internal and external). Taking into account the form, dimension and the position of the building.
- Type of material, thermal expansion, color, shape.
- Safety rails so people can not fall down especially in high buildings.
- **Indicator Matrix for energy:**
 - Light intensity (kilo lux). We don't do a simulation for the whole building, we mainly 1) simulate the light on the façade for the whole year for the whole year, 2) determine the position and intensity of the sun, then we calculate the **g and e value** and then we give the advice of the total **g value** for the glazing.
 - **G value** is determined by the architect and we can deliver a varieties of **g value**. Therefore, our first question to the architect is: which **g value** you want to achieve then we do our calculations and we advise the client for the most suitable solution. We always give this remark: with

solar shading system especially **glass louvers**, there is no solution for glare, mostly an internal solar shading has to be used.

- Our static calculations are done with in-house and commercial software's (ANSYS Fluent)
- Solar heat gain (watt/m², per day).
- **Manual overriding/occupant control:** we listen to the occupant, they tell us how they want to run it and we impregnate the operational options into the controlling system. Parameters can be changed for every group of the shading system on different floors. When someone is using the manual overriding: the affected group is programmed to return to its original state after a certain time (ex: one hour).
- **Static performance indicators that architects/clients would look at:**
 - Louvres Direction (horizontal or vertical).
 - Type of Material and its capabilities (shape, type, color, texture)

8. When and how did you intervene in this project and who were the team members?

Most of the time, at the beginning of the project with the architect. The procedure can be defined through four main process:

- Before contract: We have a meeting to talk about the possibilities with the architect and the client, they already have the initial drawings, the project concept and description. A second meeting is arranged to give our advice with principle drawings and cost estimation.
- After contract: A mock-up is done to see if everything goes well and after that we deliver the detailed drawings and explanations.
- Approval drawings (signed by the architect): static calculations, dynamic calculations (6-8 weeks).
- Production drawings, then pre-assembly for the moveable parts, components are tested, and then delivered to the site and mounted. We have our own internal commissioning

9. What modelling tools were used during the design?

We have our in-house software based on the European standards for the static and dynamic side.

10. How did you test the façade offsite and onsite (fire resistance, access to fire, blower door)? Which standard did you refer to for testing?

An internal test is done to see if everything goes well. We already have our own test facility, we do wind tunnel, pressure, structure, loads. For the wind tunnel test, we build a louvres' mock-up with 10000 to 20000 cycles that open and close simultaneously. Simulations took up to two or three months)

11. How did you do the commissioning process? What standards did you comply with and which test did you conduct? Did you develop or use a checklist? What was it about?

For static calculation, we use the following European regulations:

- NBN B-03-002-2: Windlasten – Dynamische effecten
- ENV 1999-1-1: Berekenen van aluminium structuren
- EN 1991-1-4: Windlasten

12. How do you perform soft-landing or post occupancy evaluation or monitoring? What did you learn from soft-landing?

- We stay at least 2 months with an engineer on site after delivering the building to check the facades and the regulations.
- We sign a maintenance contract: one visit every year, in which we check the façade and if there is something that is not working we replace it.
- We talk to the facility manager and security to make sure that everything is regulated and function well.

13. What standards did you comply with and which test did you conduct? How did you validate the performance?

The European regulation, but sometimes we set our own maximum deflection of a system which depends mainly on the type of materials: very often 1:200 is the maximum deflection, and 1:50 with glass.

For fire, the fire department ask to have a specific part of the façade that must be able to open separately as an access in case of emergency.

Concerning performance's validation, we don't do it in general unless in some projects, when other special departments (ex: research labs) are involved. Very often in Germany, the **Algea Building**, we were working together with a research institute that did the measurements and monitoring.

D. Disadvantages of Adaptive Façades:

14. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

10 or 15 %, I think cost related.

15. What would be the average cost per square meter for the adaptive façade vs a static façade? And does the cost impede the penetration of the market? What is the influence of customization on cost?

If we compare a fix system with a moveable system: physically, a moveable one will cost 10 to 15% more than a fixed one.

16. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

Yes, we already have a lot of examples and I think it is already proven.

17. What is the life cycle of such an adaptive façade? Did you consider the life expectancy and maintenance of adaptive facades a challenge? And why? (How long is your solution age)

10 years at minimum. We have many buildings with more than 15 years with moveable façade like the **EU Barleymont**. Maintenance is not a challenge and it is part of our services but it has to be done regularly because if we didn't, later on the system will have a lot of problems because of external factors (temperature difference, wind, etc.) and then cost will be much higher.

18. Do you think there is a real need of adaptive facades? And why?

Yes, we try to give solutions that work very well on a statically and energetic level but also building's occupants have to be satisfied.

The user satisfaction of the building is very important. For that reason, we are moving to glass louvres because it is possible to watch outside of the building even if they are completely closed.

Occupants have a bad experience with vertical aluminum louvres, they have the feeling that that are in prison.

E. The Future of Adaptive Facades:

19. What is your opinion regarding the specific nature of adaptive facades (component and elements coming from indoor automation world and getting assembled on a system level in the building to perform outdoor)? Is the process smooth enough? What is the most critical phase and why?

I think that we are already on the right track, we are doing this already for a long time and we are working together always with same producers. **Colt** is an integrated company who try to bridge the machinery (automation) industry into the building industry. Every project has its type of motor depending on the type and material of the louvres.

We are trying to upgrade this kind of automation's solutions to cater more to the building's solutions and here comes the experience when looking at higher accuracy, difference forces, loads, speed, special dynamic loads and quality of materials.

We also have a special module that is measuring the time with certain steps so we do an auto calibration 2 times a week. For example, we measure the time to open and the time to close at night and that's stored in each individual motor module.

Planning and accuracy (working in millimeters) while mounting is the most critical phases.

20. Can we mass customize Adaptive facades or they will remain tailor made solutions? And why?

Nowadays, our steering can do all types of solutions here in **Colt** (standardized system) but this depends on the software and programming operation (it isn't easy to be standardized). At the end, we don't say anymore we have a solar shading system, we say we offer an operating system.

21. What needs to be done for better adaptive facades process and performance quality? Do we need to invent new performance indicators? And new standards?

- From our point of view, I think we have enough experience, we know what we do. If we work in the future on satisfaction indicators, universal and standardized to associate them with the performance of adaptive façade, then we can find more energy indicators.
- Open buildings as case studies allowing researchers and users to report its performance.

22. Do you agree that soft landings, POE and monitoring should become obligatory?

Yes, we already monitor every parameter in some of our steering systems, this will be an added value.

23. What features would you like to find in future in an adaptive facade? What goals should we attain to increase the use of adaptive facades in buildings in the future?

When you set your goals, you achieve them. I would like to find an active adaptive façade like the building in Hamburg: a shading façade that generates microalgae biomass. Additional Cost to integrate something active like Algae is much lower because all the basic requirements (structure, steering) are set.

Interview with Claude Pimpurniaux, SECO

Name: Claude Pimpurniaux

Date: 19.12.2015

Place: Brussels, Belgium

E-mail: c.pimpurniaux@gmail.com



Questionnaire:

A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

SECO acts as a third party in the field of buildings and civil engineering. Regarding the Envelopes and Facades department, our core specialization concerns mainly the windows, the curtain walls systems and the glass roof canopies. In addition, we also control claddings, handrails, internal wall partitions, internal joinery, suspended ceilings... Air and water tightness of the skin of the building envelopes is of our main concerns and some projects have to deal with comfort and energy.

We assist the building team, architects, study offices, developers and owners, during the study of the projects, when buildings are being erected and for the commissioning.

In total, SECO deals with 600-700 projects a year, 450 projects concern the buildings, the other part concerns the civil works. For the engineers of the department, it is around 40 to 60 projects a year with about one third in execution, one third in study and the last third, in development.

Within the department, we try to develop "value engineering": we put our wide and extensive experience at the service of the developers and their teams¹.

2. How would you describe your main roles in the company? How long have you been in this field?

I am responsible for the Envelopes and Façades department. I technically support the engineers of the department, but also engineers from other departments: we work in team and share our experience, but all these valuable advices need to be structured and commented in order to have a common technical opinion. I have an administrative follow up of the projects: this means a cost monitoring of our works and an administrative view.

I also follow up myself some projects in order to keep contact with the reality of our business.

More than years of experience (I have 32 years of experience), I prefer to refer to the number of projects in which I have participated, around 750 at the time.

¹ It is to be noted that the information given were exact at the time of the interview.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of adaptive façade?

From my point of view, we can define an adaptive façade regarding on one hand the stability of the façade and on the other hand, regarding how the envelope will react in its environment.

Regarding the stability, the static schemes, the profiles, the anchors (type, position...) and the fillings (glazing units, panels, operable parts) can be studied in order to adapt or to remove some parts of the façade according to the needs of the occupants. For instance, glazing units could be replaced by operable parts, or by glazing units having a better U-value.

Concerning the way, the envelope reacts with its environment, the facades can be designed in a static or a dynamic manner, taking into account the orientation of the façade (it needs to study the heat solar gains through the façade, for instance) and the natural lighting possibilities (buildings shadowed by others will need more artificial lighting and therefore, this means a higher electrical consumption).

Statically, we can force in, or use, different techniques according to the orientation of façade. For example, in the south façade, we have the opportunity to use controlled glazing solar systems, or to install sun permanent protection, or to place movable sun shading.

Dynamically, regarding the natural light transmission available, we can for instance place the glazing units with a high light transmission factor, and we can couple this option with light sensors and piloting systems in order to make it an adaptive façade.

The purpose is to adapt the façade to the conditions of the environment and doing this, to gain money by saving energy inside the building.

4. Who and what drives the idea (raison d'être) of adaptive facades in most of your projects?

Direct costs play an important role: by direct costs, one should understand the costs of the construction. Indirect costs such as maintenance costs, or energy consumptions costs are more rarely taken into account.

For some real estate developers, the return on investment costs is also a predominant factor.

The developer defines with his architect office a program (offices or residential buildings, budgets and commercial approach of the market...) and according to the program, the architect proposes an architectural design of the projected building. In that kind of relationship, we could say that it is the architect that carries the responsibility to propose an adaptive façade.

C. Advantages of Adaptive Façade:

Definition: Adaptive facades are building envelopes that are able to adapt to changing climatic conditions on daily, seasonally or yearly basis. By adaptive we mean the ability to respond or benefit from external climatic conditions to meet efficiently and more important effectively occupant comfort and well-being requirements.

5. What kind of projects did you participate in that fall under this definition?

For instance, Realex Building (which is the name of the project given by the developer) is a project dealing with adaptive facades.

The architectural design considers different options for the envelope in its whole, and specifically, for the façade, different systems are studied and taking into

account the environment, the proposed systems could be different according to the orientation.

The intended design recommends a double skin façade system that can adapt to outside winter and summer conditions.

6. What are the adaptive characteristic in those projects? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main benefit (reason) (comfort, energy, real state value, image etc...)?

Specifically, for the Realex project, as the design considers a double skin façade system, 2 possibilities can be conceived: a double skin façade acting as a ventilated buffer and a system called Closed Cavity Façade which implies a sealed cavity connected to air pressure compressor.

In the first case, condensation may occur on the glazing units depending on the outside temperature and the temperature of the air in the buffer. In the second case, air moisture is regulated in the sealed cavity and no condensation can happen.

Both systems are more expensive than a single skin façade. In addition, the second system is more expensive than the first one due to machinery.

7. What were the components of this adaptive façade? And what key performance indicator(s) were used to evaluate those characteristics (orientation, snow, solar radiation?)

It depends on the type of façade system. Regarding the system itself, the components can be:

- 1- The profile system itself: a standard system is more adaptive than a tailor-made one;
- 2- Mechanics (motors) that drive the movement: for instance, movable sun shading protections;
- 3- Software that controls and pilots the movement of the mechanics parts depending on the weather conditions. For instance, louvers of the European Headquarter of AGC in Louvain-la-neuve are piloted according to the sun position, but also to the natural lightning available.

Regarding the indicators, we can divide them into 2 categories: basic indicators and additional indicators.

The basic indicators can be:

- 1- Wind resistance, water- and air tightness evaluate the essential performances of the façades²:
 - the effects of the wind on the whole facades, or on parts of the facades such as louvers for instance, have to be calculated in order to achieve the stability performance;
 - facades have to be watertight: water leakage can provoke moisture and promote molds and fungus which have a negative action on the health;
 - air tightness influences the inside comfort of the occupants and the energy consumption.

² **NBN B256002-1 Menuiseries Extérieures – Généralités** deals with the performances of windows, curtain walls and glass roof canopies and define how to classify a facade system regarding its performances.

The additional indicators can be:

- 1- acoustic behavior is a concern of occupants in term of comfort;
- 2- natural and artificial lightning affect the comfort and the energy consumption;
- 3- thermal performances (insulation, inside temperature) affect the comfort of the occupants on one hand and on the other hand, influence the energy consumption of buildings;
- 4- energy behavior of the envelopes.

The fact that a façade, or an envelope, is adaptive is quite a new feature of façade systems.

8. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?

It depends on the point of view.

For the occupants of the building, we may point out that the comfort is the predominant factor (acoustic, lighting and thermal comfort).

For the real estate developer, construction cost, and sometimes maintenance cost, are the factors that are taken into account when deciding to develop or not a project. So, regarding our experience with comfort, I would say that comfort is an important factor. One day or another, owners or developers will be confronted to comfort problems.

9. What was the key milestones of the façade design and construction?

A good cooperation between all the people involved in the project is of the uttermost importance: architects, stability engineers or MEP engineers have to work as a team. Real estate developers, cost and quantity engineers and advisors in the field of environmental regulations are part of the team. It is to be noted that if for most of the projects, a team exists, the team often lacks a strong conductor.

For the envelope, one of the most important key is the choice of the façade contractor. Every contractor works with different systems: standard systems or tailor-made systems. This means different or variable performances and costs. This also means different ways of erecting the facades. Coordination during the study and the execution phases are very crucial. The engineers should be integrated in one team and work together.

10. What modelling tools where used during the design?

First of all, whatever the tools used, we try to get involved as soon as possible in the project. The earlier we come the sooner we can foresee the problems by collaboration, asking questions, and using our experience. Coming late would psychologically affect the team members in a negative way because a hard work has already been done and it is very upsetting to face a problem after all that time of hard work.

We have used some soft wares such as Design Builder (energy simulation of a building), Wufi (vapor transfers), Bisco and Bistra (calculation of U-values, heat transfer and condensation, static or dynamic) regarding the energy performances of envelopes. We have also used stability software such as Robot, Mepla (calculation of glass) and in-house softwares.

11. How did you test the façade offsite and onsite (fire resistance, access to fire, blower door)? Which standard did you refer to for testing?

For common projects, standard and well-known systems are used. Those systems benefit from standardized tests results. If those tests are in accordance with the performances required for the project, no particular tests are realized.

For particular projects, tests in laboratories have to be realized. A program of tests is established in cooperation with the manufacturer and the team. Wind resistance, air and water tightness and thermal tests are done.

If needed, additional tests may be asked: acoustic performances for instance are not always tested in a laboratory.

Fire tests are sometimes realized.

According to the systems or materials proposals, a specific tests program can be realized.

On-site tests may be done, but it needs most of the time, a particular test protocol. It is also quite difficult to test envelopes and facades on site.

We also follow up the works on site on a regular basis. This follow up assesses the conformity of the works with the drawings, calculation notes and materials.

We refer to European standards or European Technical Approvals when no European standards exist. Specifically, for windows, curtain walls and glass roof canopies, the Belgian standard NBN B25-002-1 Menuiseries Extérieures – Généralités gives a summary of all the European standards to be applied to those systems.

12. How did you do the commissioning process? What standards did you comply with and which test did you conduct? Did you develop or use a checklist? What was it about?

What is mainly concerned by the commissioning are the technical equipment, thus, HVAC systems (Heating, Ventilating, Air Conditioning), electrical devices, lightning...

We work on the basis of a performance checklist, on the basis of our comments and remarks done during the execution and with our feeling. Feeling and experience guide us through the commissioning process.

Regarding the envelopes and the facades, an important part of the commissioning has to be done during the execution. For instance, anchors of the windows or of the curtain walls are hidden by finishing works and have to be checked when the placing is on doing.

Some performances can be validated by on-site tests: acoustic tests can be done, but also, air tightness tests according to NBN EN 13829 (Blowerdoor test).

13. How do you perform soft-landing³ or post occupancy evaluation or monitoring? What did you learn from soft-landing?

At the end of the construction, the commissioning report has to state if the required performances are achieved and if not, to propose procedures to correct the noted problems.

³ Soft-landing is the fact that you stay with the client for 6 months or 1 year in order to detect and correct problems in the system.

A coaching or a follow up during the life occupancy can be put in place, in cooperation with the occupant and the maintenance department. Indicators can then be measured (energy consumption, temperature and air moisture...) and evaluated according to the design values.

The way to evaluate the benefit of Adaptive Façade still has to be defined and protocols still have to be established.

D. Disadvantages of Adaptive Facades:

14. The majority of your projects are static, why most of your projects are not adaptive?

In Belgium where real estate developers put a priority on direct costs, Adaptive Façade is rarely an option.

Active façade can be an option when great surfaces of glass are present and when comfort of the occupants can be a problem (cold or hot surface of Insulated Glazing Units).

If Realex project is going on, this will probably be the first façade of this kind in Belgium.

15. What would be the average cost per square meter for the adaptive façade vs a static façade? And does the cost impede the penetration of the market? What is the influence of customization on cost?

Single skin facades, stick systems and only a few operable parts: 450-550 Euros/m².

Active facades, thus double skin facades with a little depth: 600-700 Euros/m².

Double skin facades acting as a buffer, with great depth: 700-900 Euros/m².

Regarding the proposed façade system proposed for Realex, 900 and above Euros/m² is probably the actual cost.

16. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

Developers in Belgium are conservative people and so, their preference goes to "traditional facades". Furthermore, Adaptive Facades need an actual cooperative team which is not really the case in Belgium: different study offices are put together; there is no integrated study office⁴.

17. What is the life cycle of such an adaptive façade? Did you consider the life expectancy and maintenance of adaptive facades a challenge? And why?

Not all companies have the knowledge and experience in adaptive façade. A good study and good specification are needed to make good interpretations. That is why it is risky to implement the adaptive façade.

E. The Future of Adaptive Facades:

18. What is your opinion regarding the specific nature of adaptive facades (component and elements coming from indoor automation world and getting assembled on a system level in the building to perform outdoor)? Is the process smooth enough? What is the most critical phase and why?

As already stated, we miss experience and practice in Adaptive Facades in Belgium, and even, in Europe. So, we probably need to perform more testing. If we

⁴ By integrated study office, we have to understand an study office where architects, stability and MEP engineers, environmental consultants... work together under the guidance of a team manager.

do not have a relevant experience of a system, we should replace experience by tests based on standards, if possible, or on specific protocols. The interpretation and the exploitation of the tests results can be long and difficult. We will probably have to learn from a first experience and improve the process step by step.

For instance, for Close Cavity Facades, tests have been carried out on components of sun shading devices integrated in the cavity in order to select the materials adapted to the change in temperature of such a system⁵.

19. Can we mass customize Adaptive facades or they will remain tailor made solutions? And why?

Even if standard systems can be developed, each project remains a prototype and so, it will be a mix between standard systems and tailor-made solutions.

In fact, we need to close a building with a well-known façade system in order to obtain the required performances. The adaptive parts of the façades will differ from one project to another, depending on the required performances, the cost of the façade system and the architectural vision of the architect.

20. What needs to be done for better adaptive facades process and performance quality? Do we need to invent new performance indicators? And new standards?

Basic and additional factors⁶ are well-known and can be used to define the performances and the quality of Adaptive Facades.

Comfort, in terms of thermal and visual comfort, and energy behavior (consumption, use of renewable energy) certainly need new indicators.

These indicators need to be dynamic. Follow up of the performances of the Adaptive Facades is therefore of the uppermost importance.

⁵ Tests realized by Scheldebouw, a subsidiary of Permasteelisa Group of companies.

⁶ Basic and additional factors are given under paragraph 7.

Interview with Abdulmajid Karanouh, Ramboll

Name: Abdulmajid Karanouh

Date: 30.05.2016

Place: Dubaï, UAE

E-mail : a.karanouh@ramboll.com



Questionnaire:

A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

High School mathematics specialization and received his bachelor of architecture in Beirut. I worked for IT company for 3D printing in Spain.

my specialization is High-Tec facade and I worked in several projects including turning torso in Sweden, and in several other towers building in Abu Dhabi and London with HEDES.

I currently enrolled in Bath University in the master of facade engineering.

2. How would you describe your main roles in the company? How long have you been in this field?

In 2001, I participated for exhibition stand and motion sensors detecting user's activities; with AEDES I work in a stadium project with retractable roof; for AL-Bahr tower, I was the LEED designer and I worked with a team to develop the geometry and supporting the structure.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of adaptive façade?

I define the adaptive facade as an intelligent part of the building that it is performing based on a preset occupant behavior. this include recognizing behavior pattern and enabling artificial intelligent.

we are lost and we don't know what is needed, what is come to facade.

we need to explore the potential of artificial intelligence to help us predict and act to annoying situation. the problems of facade are that they are static; however, the weather pattern, solar path and temperature are varying; therefore, we need artificial intelligence and active facade to better operate building however we need long term building monitoring to identify occupant needs and behavior, test facade and assist the risk associated with adaptive facade.

4. Who and what drives the idea (raison d'être) of adaptive facades in most of your projects?

the main driver behind adaptive facade to better operate buildings.

C. Advantages of Adaptive Façade:

Definition: Adaptive facades are building envelopes that are able to adapt to changing climatic conditions on daily, seasonally or yearly basis. By adaptive we mean the ability to respond or benefit from external climatic conditions to meet efficiently and more important effectively occupant comfort and well-being requirements.

5. What kind of projects did you participate in that fall under this definition?

Dubai Metro, Turning Turso.

6. What are the adaptive characteristic in those projects? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

We are lost to know what is needed from adaptive facades. There are two types of adaptive facades: Ones with artificial intelligence built in and ones acting on a pre-set of behavior. An Al Bahar facade is a Masharabiya mechanical shading system that operates respecting a pre-set behavior.

But we can use artificial intelligence to better operate buildings. We need to explore artificial intelligence to help us predict and act to unknown situations. Buildings are static and are not meant to move, but we can use weather pattern and solar path to better operate buildings.

Beside those characteristics there are: politics, logistics, economics and legal issues. We need also to do life cycle cost analysis to identify building behavior and the risk associated with adaptive facades. Also, adaptive facades require research and testing.

For Al Bahar Façade we had software (Siemens) acting on a pre-set of behaviors and coupled to light intensity, wind speed and water sensor. Controllers actuate actions and motors open or close the dynamic screen.

7. What were the components of this adaptive façade? and what key performance indicator(s) were used to evaluate those characteristics? (Orientation, Snow, Solar radiation?)

The main component of Al Bahar adaptive façade are the shading screens made from steel bars and aluminum frames.

8. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?

Occupant Satisfaction

Work from here up

9. What were the key milestones of the façade design and construction?

The project went through five stages:

- Competition with the dynamic Musharabeya Concept (Abdulmajid)
- Setting Design Team, (AEDAS+Arup)
- Submit the project (July 2007)
- Wining the competition (Nov 2007)
- Assembling a design team (70 architects and 150 engineers (structure, MEP, Fire etc.)) + Design Development and Construction Documentation
- Tendering and Contractor Selection
- Mock-ups
- Benchmark
- Construction
- Occupation
- Commissioning
- Soft Landing

One of the key challenges through the whole process stage is the under estimation of what it takes to design and construct a unique as this dynamic screen facade. People don't have manufacturing and high-tech production background and appreciation.

10. When and how did you intervene in this project and who were the team members?

Owner/Developer: Abu Dhabi Investment Council

Design Architect: Aedas Architects, Ltd.

Associate Architect: Diar Consult

Structural Engineer/MEP Engineer: Arup

Cost Consultant: Davis

Project Manager: Mace International

Main Contractor: Al-Futtaim Carillion

Contractor: Yuanda

Façade Engineers: Yuanda Basel

Façade Contractor: Shenyang Yuanda

Facilities Management: Mace Macro International

11. What modeling tools were used during the design?

A bunch of simulation tool. They are listed by Arup.

12. How did you test the façade offsite and onsite (fire resistance, access to fire, blower door)? Which standard did you refer to for testing?

The referenced dynamic shading system took years of development and testing involving many established organizations from all over the world (US, UK, France, Germany, Switzerland, the middle east, china, and japan among others.

We had a limited budget in relation to the project size. We had to rely on simulation tools and CFD analysis. We did some static mock-ups and the mechanical mock-up was put on hold. It was important to set up a visual and kinematic mock-up. The façade contractor was responsible about three mock-ups:

- a. Onsite mock up for fabric testing
- b. Lab tests in Switzerland (Yuanda Basel) in a special chamber to test the mechanics for 30.000 cycles (humidity 100%, 65 Celsius and sand mixed with salt).
- c. Mock-up in China for lighting (Shenyang Yuanda). Then a benchmark was set up on site.

13. How did you do the commissioning process? What standards did you comply with and which test did you conduct? Did you develop or use a checklist? What was it about?

The system has been designed and tested to operate for many years in the Abu Dhabi environment without experiencing structural failure or systematic/mass functional failure.

We had issues with commissioning the building façade. It was supposed to have a third-party commissioning company but it was done finally by the façade sub-contractor after two years of operating the building. The process was under paid and has mis-representing professionals. In general testing and validation is under appreciated when it comes to adaptive facades. The Institute de Monde Arab building is a show case of continuous-commissioning and facility management problems.

14. How to you perform soft-landing or post occupancy evaluation or monitoring? What did you learn from soft-landing?

We did a late commissioning of the buildings and we just got to do a soft-landing last year (2015), the building constructed in 2011. We needed 24 months to do the soft-landing. The idea is to monitor the building for 12 months then effectuate changes and then measure again the results of our intervention to reach the optimal operation mode. However, we could only do it for 12 months last year. We followed the behavior of building users and identified the deficiencies during the summer and winter cycle. I would recommend in the future doing a 24-month soft-landing.

the system comprises of 2098 mechanical umbrella-like unitized units, each about 4m x 5m in size.

Comprising of a fleet of 2098 cars, it is reasonably expected to have part of the fleet (several cars) parked at a time for periodical inspection and maintenance, which includes replacing parts (worn tires, worn out brakes, dead batteries, burnt out fuses etc.) only when a numerous number of major malfunctions are experienced forcing a systematic/mass replacement of each car with a completely new one prior to the end of their anticipated service life is when the fleet (i.e. the system) is considered.

15. What standards did you comply with and which test did you conduct? How did you validate the performance?

We complied with British and local standards for the main tower performance requirements such as fire resistance, structure, MEP etc... However, for the adaptive facade we used mainly qualitative measures. We focused on reducing air draft, distributing light and avoiding glare, provide thermal comfort. Hundreds of users expressed their satisfaction with diffused lighting levels and significant thermal comfort. However, as I told earlier, we could do a POE or monitoring due to the high security nature of the building.

D. Disadvantages of Adaptive Facades:

16. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

In the automobile, marine or aerospace industries a lot of R&D money is spent for testing and standardization. Huge amounts of money are spent on prototype development and with the mass production of modular units there is midterm return of investment. Also, companies working in those areas are preserving their design in terms of knowledge experience and clients take Toyota as an example. The employment cycle for Toyota employees is relatively long with a high sense of loyalty. On the other side, buildings are rarely replicated. The AEC does not accept the same building more than once. Architects might emulate styles but not the exact design.

17. What would be the average cost per square meter for the adaptive façade vs a static façade? What is the costliest elements of an adaptive façade (soft cost vs hard cost)? And does the cost impede the penetration of the market? What is the influence of customization on cost?

The cost depends on the project size. In this project, we had 2098 unit. So, scale, size and quantity of façade components play a major role in determine the cost. But keep in mind that the larger the project the smaller the share of soft cost in the total cost. In the case of Al Bahar Tower the project façade cost per square meter was 5-10% less than a double layer or double skin façade in Germany. This is mainly due to the large scale of the project and the heavily pre-rationalized design process so we did not need to go for value engineering.

18. Do you think that adaptive façade technology is mature to penetrate the market? And Why? What is the life cycle of such an adaptive façade? What is

the risk associated with adaptive facades? Did you consider the life expectancy and maintenance of adaptive facades a challenge? And why?

Yes, is it a mature technology but we need a higher awareness among building professionals and clients. The AEC industry is conservative and is the last to follow innovation in the automobile, marine or aerospace industries. It is a matter of time that adaptive facades become a mainstream application. Take the example of curtain walls. Curtain walls were only adapted by the AEC industry after inventing rubber gaskets for car wind shield. The combination of glass, aluminum frames and rubber/silicon required how many years to migrate into the building industry. It took very long before becoming a main stream in building facades.

Regarding the risk associated with adapted facades it is mainly not educating users and facility managers about the optimal maintenance and use of those facades.

When it comes to life expectancy I would expect the fiberglass fabric to last 15-20 years, aluminum m profiles 30 years, steel frames, 30-50 years, bearings 10-15 years, the motors (SBNS) by last 2-3 years.

E. The Future of Adaptive Facades:

19. What is your opinion regarding the specific nature of adaptive facades (component and elements coming from indoor automation world and getting assembled on a system level in the building to perform outdoor)? Is the process smooth enough? What is the most critical phase and why?

We have to design those buildings together like designing a car. Customization and prefabrication has to be a common practice with a complementary integrated design process. The most critical phase of this process is to get clients engaged as early as possible to commit to the project. In the case of Al Bahar Tower we were lucky to have committed client from the design and concept phase until the end of the project. I consider communication as very important and integrating the client, design team (architect), facility manager, contractor and engineers as early as possible in one team.

20. Can we mass customize Adaptive facades or they will remain tailor made solutions? And why?

For sure that is what we did in Al Bahar Tower we customized 2098 unit.

21. What needs to be done for better adaptive facades process and performance quality? Do we need to invent new performance indicators? And new standards?

Historically, we have been designing buildings as sculptures that are static and that will stay without change. However, Owners, Engineers and Architects have to change this perspective. We need qualitative and quantitative performance indicators. If we only focus on quantitative performance indicators we will lose the battle. On the other side, if we add the qualitative side including the psychological aspects of well-being, productive and satisfaction. If you compare Al Bahar Tower indoor environmental comfort with any conventional office tower in Dubai you will find it providing better solar control, light distributing, air temperature and distribution.

22. Who should be responsible of façade engineering and operation? Should adaptive facades companies deliver product and assign sub-contractors for construction or should adaptive façade companies deliver product and operate?

It is the design team.

23. Do you agree that soft landings, POE and monitoring should become obligatory?

From my experience, smart buildings are sometimes underperforming conventional buildings. Because it adds on cost, complexity and fails in most cases to achieve a fixed performance target. Therefore, it is very important to identify first what is an adaptive façade and what is the purpose of the monitoring process. I prefer to raise the awareness among the building industry and in particular the façade industry to such topics. We cannot police the façade industry but we should build best practice behaviors and ethics internally with a focus on POE and monitoring.

24. What features would you like to find in future in an adaptive facade? What goals should we attain to increase the use of adaptive facades in buildings in the future?

Adaptive facades should be driven by users instead of having only automatic computerized operating systems. We should allow users to set up the façade preferred position for shading or glare control. Personalized and individualized control is very important increase the uptake of adaptive facades. However, learning and training component must be associated with the use and control of adaptive facades other with we might have counterproductive problem to operate those facades. Adaptive facades are not remotely control gadgets that can be used without education on how to use them.

Interview with Thaleia Konstantinou, TU-Delft

Name: Dr. Thaleia Konstantinou

Date: 24.04.2017

Place: Delft, The Netherlands

E-mail : t.konstantinou@tudelft.nl



Questionnaire:

A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

She is an architect (Dipl.Ing., MSc) and now a researcher at TU Delft. She had PhD on Façade retrofitting, her specialization areas are façade construction, energy upgrade. She involved some other projects like:

- Retrofitting of prefabricated façade modules (integrated ventilation pipes, building systems and PV in second skin project) etc.
- Façade construction, addition manufacturing façade, construction of concrete panels.

2. How would you describe your main roles in the company? How long have you been in this field?

She is on the side of knowledge institution (university) in these projects. She worked as a part of the design team to support decision-making during the design process and she also worked during the façade integration. At the end of the construction or post construction, they had mock up so she also involved in testing and validating the design façade. Now, they are preparing a prototype and it is in the design phase.

She has been working on façade systems for seven years.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of adaptive façade?

Every façade is adaptive; at least most of them are adaptive. Adaptive façade would be any façade that can do react external and internal conditions, improves the occupant comfort. It can be a simple operable window, sophisticated shading system, phase changing material.

The purpose of adaptive façade is firstly comfort, then functionality. Also, an adaptive façade can adapt to help changing the function.

4. Who and what drives the idea (raison d'être) of adaptive facades in most of your projects?

Regardless of her projects, in general, the purposes of designing an adaptive façade are using more advance technology, function and the comfort. In some cases, architect and in some other cases consultant has the ambition of using advance technology to design an adaptive façade. Client will not normally be the one formulating this ambition at the beginning. However, he can seek advice and can potentially be convinced for the added value of adaptive facades on the project.

C. Advantages of Adaptive Façade:

Definition: Adaptive facades are building envelopes that are able to adapt to changing climatic conditions on daily, seasonally or yearly basis. By adaptive we mean the ability to respond or benefit from external climatic conditions to meet efficiently and more important effectively occupant comfort and well-being requirements.

5. What kind of projects did you participate in that fall under this definition?

- Second skin
- 3D Printing the façade module - proof of concept – Spong3D
- Façade Leasing

6. What are the adaptive characteristic in those projects? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

- Second Skin – operable windows and shadings with standard solutions, (trickle ventilation or ventilation openings on the window frame ??) ventilation system
- 3D Printing the façade module – heat storage (starters??) that can be circulated from outside to inside and they observe the energy and release it using water pipes. Using the Petg (plastic mainly). Storing duration is hourly.
- Façade Leasing – there are different systems (central ventilation, PV, different types of shadings, electrochromic, etc.). It is more like idea of disassembling the façade.

7. What were the components of this adaptive façade? and what key performance indicator(s) were used to evaluate those characteristics? (orientation, snow, solar radiation?)

Performance Indicator:

- Second skin - annual energy consumption, energy demand, construction issues (qualitatively measure like fast integration of the materials or fast disassembling on site), user acceptance or perceptions before the construction, cost. There is a publication that proposes this study that published in 2015.
- Spon3d - printing time – reduction of material (optimize material use), energy saving (done by modelling), performance of structure (tension, compression)
- Façade Leasing – business model for coordination of suppliers and materials, performance simulations.

Could you manage to quantify the “integration”?

Requirements at the beginning. It is difficult to quantify the integration at design phase; you can do it in the construction. It depends on the performance.

8. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?

- Cost
- Occupant satisfaction
- Energy

9. What was the key milestones of the façade design and construction?

- Ambition of client and design team
- Concept design

- Tender (costing) and design assist
- Construction
- Post occupancy evaluation

10. When and how did you intervene in this project and who were the team members?

Second skin and spon3d

11. What modelling tools were used during the design?

Energy modelling, BIM, Design Builder, Rhino, Grasshopper, AutoCAD, Sketchup, Visualization.

12. How did you test the façade offsite and onsite (fire resistance, access to fire, blower door)? Which standard did you refer to for testing?

Not in these cases, as they were in the research phase. During the second skin they followed up fire regulations. They are just working on design of the facades, preparing the mock-ups. No performance for safety issues.

13. How did you do the commissioning process? What standards did you comply with and which test did you conduct? Did you develop or use a checklist? What was it about?

She did not participate any commissioning.

14. How to you perform soft-landing or post occupancy evaluation or monitoring? What did you learn from soft-landing?

In Second skin project, she participated in the mock-up experiment, primarily performed by another consortium partner, the Faculty of Industrial Design. TU Delft. The mock-up team set up a room and showed the simulations to the occupants and asked them that what do they think? How do they feel about it? The mock up team also had a mock-up for the balcony. People shared about their ideas about their balcony.

Now a prototype is being prepared by the general contractor and the façade design team. It was a new thing because normally housing associate would do the acceptance processes in Nederland.

Lesson learned for the soft landing:

- The soft landing is a kind of convincing process. They are advising people the used technology by using the model house
- Design team objectives are very different from the user's.

D. Disadvantages of Adaptive Facades:

15. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

Very small fraction around %5-10 for very complex systems, based on general feeling, not exact number. The main reason of this small fraction is cost (of construction, design and maintenance). The second reason is that lack of effective control system. When it becomes too complex and adaptive, it is harder to control it.

16. What would be the average cost per square meter for the adaptive façade vs a static façade? What is the most costly elements of an adaptive façade (soft cost vs hard cost)? And does the cost impede the penetration of the market? What is the influence of customization on cost?

The hard elements are technology and control. Building design can be count as soft element however the design of control system is hard cost element.

You can bring the cost down if you applied in large scale (with massive application). Also, you can reduce cost improving the technology and control because maintenance costs of these small elements cost huge amounts and lack of proven technology.

17. Do you think that adaptive façade technology is mature to penetrate the market? And Why? What is the life cycle of such an adaptive façade? What is the risk associated with adaptive facades? Did you consider the life expectancy and maintenance of adaptive facades a challenge? And why?

Yes, because technology is not so developed and it is still not performing, as you would like to.

Complexity and maintenance are challenges, a very famous example: Institut du monde arabe of Jean Nouvel. It is nightmare because everything is so adaptable but it does not work.

- Maintenance
- Control
- Opposing functions (performance and function conflicts)

E. The Future of Adaptive Facades:

18. What is your opinion regarding the specific nature of adaptive facades (component and elements coming from indoor automation world and getting assembled on a system level in the building to perform outdoor)? Is the process smooth enough? What is the most critical phase and why?

There is a PHD student that is working on this subject. Jens Böeke.

Design phase is very critical for decision-making and execution is very critical.

19. Can we mass customize Adaptive facades or they will remain tailor made solutions? And why?

In terms of construction, components can be mass customize. We have additive processes so a façade panel can be adaptive.

If you have same system and the technology the mass customize is possible. If we mean very complex facades, there is not a standard practice.

The supply chain is important for people who try to reduce cost. So, a business model is needed.

20. What needs to be done for better adaptive facades process and performance quality? Do we need to invent new performance indicators? And new standards?

User is a part of it. Key performance indicator needs to be connected to how users experience to it. Most automatic shadings are blocked by vandalism because people hate and cannot operate.

- Control system can be effective, it can be works in both ways (automatically and manually)
- Conflict of functions
- Performance and function quality should be judged from to the user side
- If we find a way to link KPI with user satisfaction, we can use this for the extra cost of adaptive façade

Occupant comfort - cost – productivity can be linked together for design of adaptive facades.

Interview with Francesco Goia, NTNU

Name: Francesco Goia

Date: 22.06.2017

Place: Trondheim, Norway

E-mail: francesco.goia@ntnu.no



Questionnaire:

A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

Building physics, and teaching building physics but has been connected to building envelope technologies

Architect – Technical – Material science – PhD in energetic

Façade in general, with a focus on glazing systems and technologies. Examples are transparent ventilated façade, dynamic glazing materials/systems, and all-in-one facade modules including BIPV. Research method is a combination of experimental and modelling/numerical analysis.

2. How long have you been in this field?

From 8 years, since 2009

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of adaptive façade?

A system that can change its thermos physical properties because of a stimulus or a system that control the facade. The purpose is to reduce energy use without impairing (or even improving) comfort condition for the users

4. What is the strengths of adaptive facades? (Strength)

You can save energy and improve comfort

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

- Adaptive Transparent Facades:

Difference configurations, though all mechanically ventilated: large, 2-story cavity climate façade; single-story height module, primary experimentally and also comparing possibility to simulate the system with current building performance simulation tools

- PCM glazed system:

Different configuration, with just PCM or additional systems (thermotropic glass)

- Actress Active Transparent:

responsive façade in the form of an all-in-one facade module with ventilated opaque cavity, PCM, BIPV, inter-pane shading system, aerogel window. Originally planned with intelligent and automation, but eventually tested with very basic controls because of project/time constrains

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

I don't think there is a big gap in the big categories. I think "visual performance" and "acoustic performance" could be moved from the category "function" to the category "energy and environmental performance"; "durability" could be in the "function" category (and not in the life cycle).

I think there can be another way to call "user control" and "user experience". I would suggest a different categorization. "User control" could be better called "Integration with the building energy systems/concepts". "User experience" can instead be called "User's experience and control".

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?

Energy – occupation – cost

8. Do you know any standard with dynamic performance values for adaptive façade? How do you think we should validate the adaptive or dynamic performance of adaptive facades?

No.

D. Disadvantages of Adaptive Facades:

9. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

Simple adaptive facades systems (like façade integrating shading) are already standard solutions, but if we talk about more advanced ones, the share is basically nothing.

In my opinion, the reasons why they are not many examples with (advanced) adaptive facades are:

- 1) Requirements set by regulation that are quite simple and do not allow adaptive facades to "express" their performance fully
- 2) It is not easy to prove the better performance (only through advanced simulations), and usually better performance are more sensitive to (small) mistakes in both the realization and the operation phase
- 3) Industry/contractors usually don't like too much to take the risk – why should they go for more complicated solutions if the requirements do not call for them, and it is more complicated to prove their effectiveness?

More advanced facades mean more risk to have complains from the users later (not common practice, too high uncertainty)

10. Does the cost impede the market penetration? What is the influence of mass customization on cost? (Weaknesses)

Yes. Adaptive facades are often tailored-made solutions, with dedicated development for a specific building. It is hard to make them a mass-product. In my recent research project "REINVENT windows" (Responsive, Integrated and VENTilated windows) the focus is placed especially on this point: to develop a product that is the same for all the building, but tunable for each individual case after installed

11. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

Yes, because there are robust technologies already developed, and there exist companies that are selling the systems (meaning that they are reliable)

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

Maintenance become a dominant aspect. E.g. if I have a shading system I need to assure that it works efficiently, and does not stop working because of lack of maintenance.

E. The Future of Adaptive Facades:

13. What needs to be done for better adaptive facades process and performance quality?

I think the way to make it working is that they are mass customized. Mass customized means that you combine the advantages of mass production with the flexibility of tuning each particular solution to the individual requirements of the case. This is one, if not the most important aspect of my most recent research project. There the aim is to develop a system that is just one when comes out from the factory, and can be tuned for each individual building before or even after the installation.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

I think it is the building owner, because from my understanding it's a part of the building, so it is who should be responsible for keeping the building upon running in general, I don't think it's the facade consultant.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

I think should be obligatory to all the buildings not just for those with an adaptive façade.

16. What features would you like to find in future in an adaptive facade?

I have a vision of a system that can decide what to do with 2 environments that are decoupled by the facade, the inside and outside. This is very extreme far idea holistic vision, you have a border between two environments, and the system that separates the two is a completely flexible one. This border is intelligent, reads the boundary conditions, and decides how to change its features according to what is sensed and thought to be the most suitable action not only for that exact moment, but also considering what will happen in the near future.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

First of all is the disruptive innovation that we can see in ICT.

also in this sense, the rapid decrease of costs will have a big impact: cost of small sensor are becoming cheap and cheaper, the same for controller, and for communication devices.

I would say people living in better building, it could be a good push to go for these systems.

Another big opportunity is again innovation in material science and technology. It is now possible do things that are incredibly advanced compared to what was possible

just 5 years ago. If I have to imagine the future in 20 years, I don't see that we will have building with mechanical shading system. I see instead solid-state solutions, active layers that change their properties because of climatic condition processed by a controller.

Interview with Roel Loonen, TU-Eindhoven

Name: Roel Loonen

Date: 22.06.2017

Place: Delft, The Netherlands

E-mail: r.c.g.m.loonen@tue.nl



Questionnaire:

A. Background Information:

- 1. What is your core specialization? And what kind of projects you have been involved in?**

Building physics and building services at the Department of the Built Environment. My specialization is in modeling and simulation of building physics.

- 2. How long have you been in this field?**

Seven years.

B. Interviewee definition of Adaptive Façade:

- 3. How do you define an adaptive façade? What is the purpose of adaptive façade?**

In one of my papers, I proposed the following definition: a building envelope, it can either be a wall or a roof, that is able to change some of its functions, features or properties over time, and it does this with the idea to improve the building's performance and generally in relation to energy saving and energy efficiency or improving comfort. We see also energy production as a part of the adaptive functions of a façade.

- 4. What is the strengths of adaptive facades? (Strength)**

Ability to dynamically react to changing conditions.

C. Advantages of Adaptive Façade:

- 5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?**

- **PeerPlus / Merck liquid crystal window:** Switchable glazing technology based on liquid crystal technology that can change its transparency when a voltage is applied. The project started as spin-off from the university, based on a 5x5 cm prototype and over time has evolved into a full-scale product that is currently in the pre-commercial phase. My role was to give advice from the building physics perspective, for example about desirable g-values, and to quantify the impact on the indoor environment. A main difference with competing technologies such as electrochromic windows is that the window state switches much faster, and that it has a color-neutral appearance.
- **Lumiduct:** A façade-integrated optical sun tracking device. When the modules point to the sun, the direct sunlight is redirected onto PV cells that generate electricity at high efficiency. The diffuse light is not concentrated but transmitted into the room. Lumiduct therefore also functions as a shading device. G value + energy generating and then translated to energy efficiency, heating, cooling, ...

- **Active insulation:** Dynamic insulation system that can be switched on or switched off. It is an opaque system that increases or decreases the thermal resistance of a wall element by controlling the circulation of air inside the element. We work together with a startup company, investigating heat transfer to optimize the building integration of the system.

6. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?

Occupant, then cost then energy, because I think the reason why we build buildings is not to save energy, it's to run a business or to live healthy or happily. I guess energy will not be a problem anymore in the near future, which makes cost more important because all these different adaptive façade technologies that we have actually somehow need to be economically viable.

7. Do you know any standard with dynamic performance values for adaptive façade? How do you think we should validate the adaptive or dynamic performance of adaptive facades?

The national fenestration rating council in the US is working on a system for shading devices or dynamic glazing where instead of one U-value and one g-value, multiple values for the same indicator are given as a way of expressing the dynamic performance range of these adaptive components.

D. Disadvantages of Adaptive Facades:

8. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

Yes, because the price of adaptive facades is more expensive. It is higher than the conventional alternative. Costs play a major role. Adaptive facades can improve comfort and productivity, which can be expressed in a monetary value, but the benefit comes during the operation of project, while many decisions are based on initial investment costs. Something similar can be seen in BIPV projects. The payback time is generally considered as too long., but there are different reasons why people still want to buy it. However, such benefits tend to be difficult to quantify.

9. Does the cost impede the market penetration? What is the influence of mass customization on cost? (Weaknesses)

I currently keep an overview of buildings with adaptive facades on a Pinterest website. All of them are tailor-made solutions. As long as this is the situation, adaptive facades will always be more costly than alternative solutions. From a technological perspective, it is possible to have scalable, affordable solutions. There is also an architectural side to it, which can be positive or negative. Take the Zigzag solar energy harvesting facade as an example. It gives a signature to the building, which makes the solution very unique, and therefore associated as a unique building. I have talked to architects who say that such a building can only be built once, because architects would not like to "copy" it. This can be seen as a threat.

10. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

There is a range of different available technologies.

For example, with clever control of solar shading in combination with natural ventilation, already a lot can be achieved. This is not so much challenging from the hardware side, but it's really the intelligent operation that makes it difficult to achieve high performance.

Many more promising technologies are in the prototype stage. In my role as researcher in the university I actually try to help to improve some of these products in an attempt to bring them closer to the market.

11. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

There is a risk related to the lack of performance guarantees

Many professionals are aware of negative examples (e.g. Institut du monde arabe/ Jean Nouvel). This makes them reluctant to recommend adaptive facades.

In general, it is difficult to provide evidence about the performance benefits of adaptive facades.

E. The Future of Adaptive Facades:

12. What needs to be done for better adaptive facades process and performance quality?

Two things. The first one is to rely on considering what a building really needs, instead of thinking of a theme (e.g. biological analogy) or pre-conceived idea of adaptivity. The key is in finding many solutions and really considering many options in the design stage.

The second aspect relates to the need to have better use of tools to predict the performance of the building and the use of them in a way to play an active role in the design process not just in the end. Many of the building performance simulation tools are not ready for taking into account that dynamic properties of adaptive facades.

13. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

There is a need for new ways of thinking, for example in terms of performance contracts. It is important to consider this on the whole-building level, not just the façade or component level.

Occupants should not get this task. Ideally someone should be rewarded if performance targets keep being met.

14. Do you agree that soft landings, POE and monitoring should become obligatory?

No, because I think if it's obligatory there will always be ways to avoid it or do it in a minimal way. I believe that these things should take place in a bottom up way. Once it is clear that these methods lead to tangible benefits, there will be intrinsic motivation.

15. What features would you like to find in future in an adaptive facade?

Every individual is different and every building occupant is going into interact with the façade in a different way. It is very difficult to predict this in the design stage and the building users can also change over time. So, think that future adaptive facades should take the human being into consideration in a more advanced way. Future adaptive facades should depend on intelligent feedback mechanisms. Ideally, the facade can learn and predict.

16. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

It's a way to address many of the urgent problems we are facing in the built environment. We can use adaptive façades to make buildings more beautiful while also being more sustainable.

More attention should be paid to the beneficial side of indoor environmental quality. Instead of the focus on minimizing the occurrence of discomfort, adaptive facades can actually be used to improve occupant satisfaction and productivity.

Interview with Andreas Luible, Lucerne University of Applied Sciences and Arts

Name: Andreas Luible

Date: 26.02.2018

Place: Lucerne, Switzerland

E-mail: andreas.luible@hslu.ch



A. Background Information:

1. What is your core specialization? What kind of projects have you been involved in?

I'm a Civil engineer who starts in 2004, works for facades companies in Structure calculation, Building physics, Development of facades. I worked for companies: SHMIDLIN, GARDNER, YUANDA and also as a professor for University of applied sciences of Curtain walls and steel glass structures in 2010.

My typical projects are Curtain Wall projects on Highrise building and steel glass structure. In 2010 with YUANDA, I work in the Al Bahar Tower located in Abu Dhabi as responsible of restructure calculation of the façade and the curtain wall: the shading system and development of the mechanic of the shading system.

2. How would you describe your main roles in the company? How long have you been in this field?

He works in the façade since 2004

B. Interviewee Definition of an Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of adaptive façade?

An adaptive façade is a facade which is able to adapt its properties and its behavior to several environment conditions and also to user requirements in the objective of reduce and optimize energy consumption of the building. There is also an adaptivity regarding to esthetics or visual aspects like media facades, but what we generally understand as adaptive facades is more related to energy consumption.

4. What are the strengths of adaptive facades? (Strength)

Ability to adapt its properties, react to dynamic conditions and to dynamic requirements. Adaptive facades reduce the energy and carbon consumption, so the façade is always working at its optimal behavior

It increases the comfort of the building and you have a better indoor environment quality. It results in a better productivity of people working in the building.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

My main project is the adaptive shading system on Al bahar towers. This is a very special geometry (triangles). The objective is to optimize indoor light penetration quality, the client wants an iconic and unique building, and can pay for an expensive one.

The key points were the comfort and energy consumption. After measurements, the outside temperature was very low compare to other buildings in the same region.

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

I'm not sure if we must add additional indicators. For an engineer who is working in design stage this is criteria related to the design stage, which at the end are also arguments for some decisions of how the façade are going to be designed. The table is only about performance but the early stage where you have decision if you choose an adaptive façade or normal façade. Because of the complexity of this facades, you need a holistic approach to design

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?

For a designer the most important is Energy, then occupant satisfaction, then cost. An investor will rather be looking for cost, then Energy and finally occupant satisfaction.

8. Do know any standard with dynamic performance values for adaptive façade? How do you think we should validate the adaptive or dynamic performance of adaptive facades?

We need to modify and change our standards because they can't be applied for adaptive technologies. These standards are made for static values, for constant U-value, for constant G-value, not created for systems with dynamics performance.

The biggest problem when you realize a project is that you have to stick with standards. In my opinion it's not a big necessity to change standards because they cover a lot of things in adaptive facades, but we can improve them.

For example, there is a small lack of Regulation of moveable parts.

D. Disadvantages of Adaptive Facades:

9. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

Adaptive facades represent approximately 10 % of the market. First of all, you have to think who takes the decision whether you go to an adaptive façade or a static façade.

You must discuss very early if you choose an adaptive façade or not, because it has many impact on the other part of the building. This has to be the first decision when you start designing a new building. At this stage of the project, most architect are involved with the client and don't know about adaptive facades, probably too complex for them to understand the advantages and knows the impacts on the building. This is probably one of the main reasons why it's not applied very often. There is a lack of examples and experiences and it's requires a lot of specialists.

The problem is also the cost and lack of competition: for an investor point of view, he wants to be open and choose between many companies, but for a specific product, there are few companies, so you're restricted a lot.

10. Does the cost impede the market penetration? What is the influence of mass customization on cost? (Weaknesses)

Yes of course, it's one of the weaknesses, this is the situation right now. But if you have more projects, case studies, examples the price will certainly decrease and get closer to a standard product.

For example, three year ago, switchable electrochromic glazing was very expensive, now the price is decreasing and in some years, it will be a standard product. If you

are able to create a system like LEGO system, it might reduce the cost of this adaptive facades.

11. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

Yes, we have technologies which are many developed. We just need to integrate them.

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

This depends on the system: if you have a mechanical shading system, his life expectancy and his maintenance is less than an electrochromic glazing system. Components of the façade are standards and already exist (motors, sensors). They are combined in a specific and a TaylorMade adaptive façade.

It's could be a threat if the adaptive façade system is designed in a way in which replacement of parts is very complicated. We must design facades where parts can easily be changed.

For example, the CCF (close cavity facades) can't be open after the façade is constructed: if you have a problem you have to open the facades, cut the joints, glue off the glass and it's very expensive and alters the quality of the façade.

E. The Future of Adaptive Facades:

13. What needs to be done for better adaptive facades process and performance quality?

Our standards have to be adopted. We need performance simulation tools, to be able to prove in the design stage that the facade is working. Characterization tools to show the improvements and benefits to the clients like energy consumption reduction. We need to standardize methods to evaluate the performance.

We can also develop smart materials, or less complex techniques compared to existing ones. We have to train decisions makers, architects, facades engineers and bring it to a wider public.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

In the first stage, the general contractor and the façade designers are responsible that the facade has the expected performance, but then the maintenance must be done by building owner. If you sell a façade to a client, you must give him a very clear document on how he should do the maintenance during the operation of the building.

What could be a chance for a new business model: a company that takes all the responsibility for the client, controls and maintains building and façade during lifetime.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

I think it's very important. Currently is the contractor who is responsible for the functioning of the building. It's the contractor who is responsible if, after the construction of the façade, the real performance does not correspond with simulations results.

16. What features would you like to find in future in an adaptive facade?

One area which is very interesting is the biomimetic systems. This is systems taken from biology and transferred to the building sector. There is a high potential in this sector, we can draw inspiration from everything: materials, functionalities...

We could develop materials that react on moisture, temperature, wind speed or sun radiations, like systems in animals and plants.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

We need more examples like realized projects and case studies. We should show to people that adaptive facades can work. We have to teach the decisions makers, the investors and the engineers, they need to understand the basis. We have to develop new types of standards which allows dynamic behaviors of systems, dynamic properties related to energies consumption of buildings

Interview with Nicolas Nestle, BASF SE

Name: Nicolas Nestle

Date: 04.05.2018

Place: Ludwigshafen, Germany

E-mail: nikolaus.nestle@basf.com



A. Background Information:

1. What is your core specialization? What kind of projects have you been involved in?

I have a background in Physics, I got into the adaptive facade topic by teaching future civil engineers' physics over ten years ago. Seven years ago, my chemical company entrusted him with leadership on adaptive facade projects.

For the projects, the idea was to come up with something that was beyond insulating. I installed phase-change materials on the inside to make use of solar gains on the winter and avoid this solar gain in summer. We found than buildings getting excess heat during the summer, it led us to the idea that we needed to find how can we switch off insulation when heat trapping need to be avoided.

2. How would you describe your main roles in the company? How long have you been in this field?

B. Interviewee Definition of an Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of adaptive façade?

An adaptive façade is a facade which can change his transports properties for all kinds of energies (radiative, thermal...) either as a passive reaction to changing environment conditions or as an active switch controlled by a building control assistant.

The purpose of adaptive facades is creating maximum comfort for occupant with minimum energy consumption.

4. What are the strengths of adaptive facades? (Strength)

In many places it's still a concept and not really implemented beyond solar radiation management which is essentially about shading.

Shading is the only thing that has market penetration at the moment. In my opinion there is several problems that make the industry not yet ready for making a broader use of adaptive façade: The lack of proving systems and the facts that even adaptive facades that do adaptive shading don't really live up with their promises so many people don't trust the technology at the moment. Control solutions are limited to shading control and nothing beyond.

The main challenge for the adaptive façade is to really come up to a holistic control concept for adaptive properties and making the full use of their potential for energy management. In the end adaptivity will only be a mainstream thing if it's economically viable. It will be challenging if the energy cost or the CO2 tax goes up become a bit easier from an energetic point of view, but the façade must really be able to live up to their energetic promise.

The complexity of the technology. Many players in the construction industry are not used to deal with complex solutions. Many architects will essentially use the things they know it's works.

C. Advantages of Adaptive Façade:

- 5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?**

We looked into several features. We work at Phase-change material behind the insulation then we approach switchable control of convection flow. We added translucent functionalities to the elements and a possibility to shape the whole thing in the way that reflective elements in the façade will reduce the G-value and the U-value of the façade.

Bringing in translucence into the elements makes the case much more attractive because light management is a field where you can really realize savings with respect of the energy used. In many buildings a third of the primary energies goes into lighting even with LED devices.

That need a paradigm shift from the binary idea that a façade is either transparent like a window or completely opaque. In the translucent elements you can guide a light in a different way to avoid extreme shading light between an overly bright area next to a window and a too dark area behind which leads to better daylight management.

- 6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)**

The table covers a lot of important aspects. It might be one aspect that is missing is the environmental performances. We should add a point on interaction with other buildings, like for example what are the impact of reflective radiations from your building to the urban heat island.

We also need local energy networks: depending of the time of the day, you have buildings that requires heat and other and that have too much, with this type of network you might be able to equalize this. This brings again another level of complexity but the future of research in adaptive facades should take this into consideration.

- 7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?**

For an investor the most important is the cost of ownership: initial cost, running cost, dismantling or longtime maintenance cost. From a researcher point of view, the most important aspects are energy and occupant satisfaction.

While Regulatory authority looking for reduce the environment footprint, Occupant will rather search comfort, satisfaction and how often do I have to worry about dealing with the building control system

- 8. Do know any standard with dynamic performance values for adaptive façade? How do you think we should validate the adaptive or dynamic performance of adaptive facades?**

I don't really know, and I find that the problem. As long as there is a lack of standards, it's difficult to convince the authorities that you are better than a static solution. In

many cases you have to bring a full-blown building simulation to the decision maker who, most of the time, doesn't understand this simulation

Standards are good for safety of the investment. I think there is a few tests needed for validate an adaptive façade. Validating an adaptive U-value is relatively easy, validating a G-Value is much more complex.

Wanting to test in a test cell is very time consuming because you need to wait until the environmental conditions has given you enough variations to really be able to validate. Simulation protocols are too complex to run them in a routine way. There are only very few people who can simplify solutions in that field, simulation will only work if you don't need a super computer to run it: it's too time consuming to try to get an accuracy in the last few percent.

D. Disadvantages of Adaptive Facades:

9. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

It's limited to different types of shading essentially. Most of projects don't have adaptive facades because of the complexity, the lack of standards, the lack of controls systems.

The percentage depends of many things, I will say it's between 3% and 7%. In order to fulfill the energies goals of the European Union, this percentage needs to goes up drastically in the future.

10. Does the cost impede the market penetration? What is the influence of mass customization on cost? (Weaknesses)

Mass customization will reduce the cost. The solutions need to cover not just the adaptive elements but also the building technical systems, the problem is at the moment those things are offered by different stakeholders.

In my opinion there's a need to be an ecosystem of open standards that is accessible for all the different parts of the building technologies. Big players of the building technologies like ABB or Siemens need to understand that they need to come up a full-package solution that really works, and because of the stickers Siemens or ABB on it this might work even better.

The problem is that all the solutions are rather closed and limited to the home-turf of the suppliers.

11. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

There might be mature adaptive elements, but the market as a whole is not yet mature. It's depends how open are of the culture and the country to this market.

We need to change the way we build: many buildings have a large fraction of solid walls, creating the static of the building. You can't use stuffs like translucidus elements in those parts and the U-Value is determined by this static structure. I'm more limited that I would be if I had a different type of building structure in which you can separate the static functionalities and the building envelope, like a static core and a façade fixed as a building skin. This could change the scratch of the market.

Even with technologies that would be compatible with this then the situation is in many cases just some kinds of glazing systems installed, and people really need to be willing to go beyond glazing.

Introducing translucence into projects is something very appreciated by architects, unfortunately many investors do not see the interest of this technology because they do not know the light redirection functionality that's comes with it.

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

That's a difficult question. Even with a lot of simple shading systems with open lamellae people are often afraid that the system breaks down. People ask: If you protect it as hermetically, how do I fix it? In Finland and Switzerland for example, most houses have this lamella system and it's very rare to see one that doesn't work. There are a lot of devices with moving elements that come mainly from automobile industry. In one hand, it's good because the car industry has many experiences. On the other hand, those systems don't last for that long because there is one difference to a car: In a car the main elements in contact with the outside is closed doors which protect the system from dust and leaves. The system of facades is half of the time open and half of the time closed, so the impurities reach more easily the motor parts. So, it makes sense to do whatever adaptive functionality innovative that is protected from inside and from outside.

E. The Future of Adaptive Facades:

13. What needs to be done for better adaptive facades process and performance quality?

The main story is to make standard control and standard for the adaptive functionality. There must be a control platform that will take care of energy saving and user's satisfaction.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

The utility or the provider of the control platform should be responsible, we really pay those guys for the façade performance. It's going to be either a full package provided by the manufacturer or something that utility find useful because they have an easier job if there is a lot of adaptivity in the system. Everyone is denied the responsibility, and everyone can blame someone else for wrong operation.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

Yes, I think it makes sense to do soft landings. There are models that should be accepted in the market.

16. What features would you like to find in future in an adaptive facade?

Most of them are there. We can modify the flow of solar radiations, we can modify heat transfer properties, ventilation.

Smartness features should be one of the key priorities for the future. It's visible, we have all proofs that is possible however it's not implemented enough. That's what we'll need in the future for the facades to develop their full potential.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

First, that people realize that you get more for less: You have better comfort and less energy bills if you use adaptive facades.

Then, if new players and new business models coming in the construction, it will change fundamentally. The value chain is over fragmented, very slow and hard to bring innovation in the market.

Interview with Tillmann Klein, TU-Delft

Name: Tillmann Klein

Date: 27.09.2018

Place: Delft, The Netherlands

E-mail: T.Klein@tudelft.nl



A. Background Information:

- 1. What is your core specialization? What kind of projects have you been involved in?**

My core specialization is architecture, façade design and product development.

- 2. How would you describe your main roles in the company? How long have you been in this field?**

I'm in this field for 23 years.

B. Interviewee Definition of an Adaptive Façade:

- 3. How do you define an adaptive façade? What is the purpose of adaptive façade?**

Adaptivity, in facades is the ability to adjust in terms of different functions: climate, comfort, architectural design... The adaptation can be on a material level or on the component level. It's a change of functionality to improve certain aspects, it could be energy performance, indoor comfort or also architectural issues. Structural adaptivity can also be possible but I haven't really seen any example of it, except perhaps bomb blast resistant systems.

- 4. What are the strengths of adaptive facades? (Strength)**

It's their potentially better performance. Strengths of adaptive facades are a better energy performance in the building, climatic performance, comfort improvement, or also architectural design.

C. Advantages of Adaptive Façade:

- 5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?**

We are working on a TU Delft project; we build a new façade for the civil engineering building. It is delivering added value in terms of user comfort by using adaptive shading systems...

- 6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)**

Generally, the table is good. For 'energy' and 'environment performance', I think it's correct. For 'embodied energy' I'm not sure because I don't think you going to change embodied energy through adaptive features. We can compare embodied energy of AF with static facades and check what does it deliver over the life time. We need to understand if the investment in term of materials pays off.

Functional performance, I think it's fair. Feel and look, I think it's correct but maybe architectural performance is underestimated. I would add a sixth column just for

architectural performance, because architectural design is one of the main driving forces to implement new techniques. All the famous examples of adaptive façade are mainly architecture driven. You can like it or not, but this is the fact. One example is the FlectoFin in Korea, it's purely architectural driven but is brought attention to adaptive façade. Until now the advantages of adaptive facades, like comfort performance, are well understood by clients, but often main argument for them is the architectural value. They look at every euro when it comes to initial investments but when you have architecturally interesting, features money seems to be less of an issue. It's really hard to measure the impact of architectural design. Media citations can be a way

I like the fact that you include command and control and engagement, adaptivity helps to create a better interaction with the facades, reporting technologies and failure.

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?

I wish I could say cost count least, that is not how it is but that's how it should be. Because the cost of proven adaptive components is low. If you see that in relation to personnel cost of a company, it's really not matching.

So, first or second energy and comfort. Maybe for the building's client, comfort should be first. As mentioned above, energy cost is low compared to personnel cost. To be honest I don't want to rank it really, because I think it's depended on the project himself.

In Germany, external shading systems are really desired by architects, because they know about the importance for the user comfort. In other countries designer rather opt for pure glass façade out of architectural reasons.

8. Do you know any standard with dynamic performance values for adaptive façade? How do you think we should validate the adaptive or dynamic performance of adaptive facades?

I think the adaptivity should be judge on what it does: The effect on the building as a whole system. It needs validation systems that allow for quick assessment during early design stages. Here one can make the biggest impact. Designer must be able to evaluate different design options easily and with minimal effort.

D. Disadvantages of Adaptive Facades:

9. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

In Europe it's at least 80-90% of all office facades because we all have an operable window. Façade with non-operable component are disliked in Europe, it's a different thing in America.

10. Does the cost impede the market penetration? What is the influence of mass customization on cost? (Weaknesses)

Yes, I would say that mass customization will reduce the cost. We can see that with electrical sun shading. 20 years ago, clients still argued for manual systems because they were bit cheaper. Today it's absolute standard and for 100 euros/m² you can get a good electrical sun shading system.

11. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

It's depends on the type of adaptive technologies. On material level, we don't have enough to show but in a component level there are many mature technologies: louver systems, shading system, operable window (automated or manual).

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

I think in principle it's oversee able. Some client might be reluctant because their facility management has to deal with those components themselves. Also, some architects still believe that adaptive systems will create a lot of trouble. The risks are higher if we talk about new systems. I have a good example of one of our projects: A façade with an in-glass sunshade, (double glazing with an integrated louver system inside) broke. In this case it is repairable but these kinds of issues pose serious financial risks to builders.

E. The Future of Adaptive Facades:

13. What needs to be done for better adaptive facades process and performance quality?

It's starts with performance: I think we have to monitor the effects. With a good sun shading system, for example, you have a massive improvement and it's makes a big difference between internal and external sun shades.

Also, a whole life cycle view on facades and buildings must be made. We mustn't judge the project only on the initial investment, we have to include energy savings.

Our fragmented market situation is not helping. We have a system where the minimum quality is specified by the designers, and then it get procured for the lowest price. This always leads to minimum quality for lowest price results. There is no real incentive for some of the building decisions makers to do something better. There is no link to life cycle performance. The whole fragmented market situation is a problem for adaptive facades.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

Responsible should be the ones who is the best suited for it. We need to align incentives. The ones who would benefit from a good performance. For example, in a façade we intend to build in April, the façade builder will be responsible for 15 years of operation. That leads to the decision to see if we can count the operation time of the sun shade and how often it will go up and down. They want to try to learn something about the situation and planned their maintenance much more efficiently. For example, exchanging parts before they break...

15. Do you agree that soft landings, POE and monitoring should become obligatory?

That would be beneficial and needed. Obligations will have a lot of legal consequences. It'll put a whole new challenge and many people are not ready for that. In Germany, a lot of responsibilities are given to the architect, I've seen cases where the general contractor was bankrupt, and the architect took the responsibility. Maybe the building is not efficient in terms of energy, the problem is that we don't know who is responsible, maybe the customer left the window open during the winter. Legally that might be very difficult. However, we need monitoring to learn, improve and optimize the system we have.

16. What features would you like to find in future in an adaptive facade?

Principally better user's interfaces. I think that the adaptivity need to go hand-in-hand with optimal applications. The façade is like one component of a machine, the user is also part, that would be very desirable to have a good communication and optimal control. User don't generally have the understanding the complex functioning of facades.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

I think the product/service idea will be an enabler of more complex system. That's means instead of product delivery as we do it today (buy a façade, put it in the building, pay for it and it's yours) rather be service oriented. because in the service contract, the service provider can make more decisions and has more control over the life cycle. We believe that eventually adaptive facades perform better, and that performance can be translated into money. Builders can make other choices, that tend to favour more adaptive solutions.

Interview with Dave Bush, ES-SO and Hallmark Blinds Ltd.

Name: Dave Bush

Date: 03.10.2018

Place: London, United Kingdom

E-mail: dnbushhallmarkblinds@hotmail.com



A. Background Information:

1. What is your core specialization? What kind of projects have you been involved in?

My core specialization is solar shading. I've been in the shading industry since 1977. I've been engaged with the British Blind & Shutters Association and have chaired our technical committee for almost 20 years. I am a board member of the European Association ES-SO.

2. How would you describe your main roles in the company? How long have you been in this field?

I'm in this field since 1977.

B. Interviewee Definition of an Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of adaptive façade?

The purpose is to maintain the comfort in the building with additional owner maximum energy savings. But it's primarily the occupant comfort that is the most interesting.

4. What are the strengths of adaptive facades? (Strength)

To minimize solar gains in summer, maximize it in winter. To do that any system has to be adaptable to the changing weather conditions, that's the challenge. It's stopping the heat before it's transmitted through the façade.

The experience in the UK is probably different to in many other areas, we have been mostly in the decorative industry, so it will take some time to understand the full benefits the shading could bring to our facades.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

The most effective building is a large commercial building with double skin façade. The shading is within the façade and by using natural ventilation you are removing the heat gains that have been prevented by the shading.

The principal thing is: If you stop the heat before it gets to the glass, you will be reducing solar gains significantly. It's an obvious statement but it isn't generally appreciated enough in the UK. We've had years of cheap energy, we have not developed building modeling which assess the G value, the heat rejection. The experience in the UK is been a challenging one of trying to educate and change the way we do things.

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

The table covers a lot of important aspects. It might be one aspect that is missing is the environmental performances. We should add a point on interaction with other buildings, like for example what are the impact of reflective radiations from your building and of the urban heat island.

We also need local energy networks: depending of the time of the day, you have buildings that requires heat and other and that have too much, with this type of network you might be able to equalize this. This brings again another level of complexity but the future of research in adaptive facades should take this into consideration.

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?

The occupant has to be the key; you have to be designing for the occupant comfort. So, in order of importance: first Occupant, then energy, aesthetics and finally cost.

8. Do know any standard with dynamic performance values for adaptive façade? How do you think we should validate the adaptive or dynamic performance of adaptive facades?

Yes, indeed in our industry we have standards for calculating G-value. My responsibility in the European association was to develop the European shading database which has detailed performance characteristic for shading materials (www.es-so-database.com). You can calculate the G_{tot} values, combining with blinds or the shading devices with glass to get the total amount of energy transmitted through the glass.

We have standards like:

14501 EN: shading performance

13363-1 EN: now ISO-500 22 01 Simple calculation method

13363 EN: (now ISO-500 22 04) More detailed calculation method

ISO-500 22 01

ISO-500 22 04

In the advanced calculation method, it's possible to calculate the daily value.

D. Disadvantages of Adaptive Facades:

9. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

The fraction is probably less than 1 %. Historically, we haven't got a market penetration for external shading, we have had is fixed shading because in a revision of the building regulation 13 years ago, there was a decision by the regulators that they could not recommend moveable shading as occupiers might not use it.

In BREEAM for example you have no easy calculation for the benefits of solar shading, you only get 1 point for glare control. Building modeling is also affected by out of date calculation. As a trader association we try to change it but it's a cultural problem: in general building engineers don't allow for dynamic shading in their calculations.

The result of that is 20 % of the new buildings we created are overheating. Overheating is probably the biggest problem in the construction at the moment. The solution that is considered is to reduce the size of the windows.

10. Does the cost impede the market penetration? What is the influence of mass customization on cost? (Weaknesses)

No, it's a lack of knowledge, we can easily prove the cost benefits of shading. The capital cost of shading compared to mechanical cooling with high specification glazing is recoverable from day one

From an engineer or an architect point of view, if they don't do this calculation of cost savings between the alternatives, the result is that cost of installation is very difficult one to eliminate post-contract.

The fundamental problem is the awareness of the benefits. We focus on a building design for heat retention in the building, you need the thermal mass. Lighter weight constructions are exacerbating the problem that is being creating heating anyway increasing the effect of the problem of solar gain. We try to construct passive houses in the UK without shading systems, it's impossible they don't work, the design isn't attentive.

11. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

Certainly not in the UK and even in Europe. People in southern Europe know they need shading, but they don't really appreciate the benefits of it.

For example, we were called in a project 4 years ago, the first or second double skin façade construction in UK 1982 with blinds in the facade. They were going to remove the shading as they did not realise the benefit then one day 3 years ago the Building Management System failed and by lunch time the temperature in the building had risen to 30°C and the staff were threatening to walk out. The engineers remembered that there was an override switch for the shading. So, they realized that the old shading system that they were going to dispose of had a benefit and needed maintenance.

Of the 345 blinds we only replaced 4. We've got the system running cleaned, and I think the total maintenance cost was equivalent to about 15 minutes of their labour cost if the staff had walked out. They suggest omit it does not add to the point then they argued the cost that we've charge.

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

The life expectancy of materials and Fabrics in 15 years it'll discolor but aluminum slats will last for 20-30 years. Mechanism, lifting tapes, support tape may require replacement but generally the life cycle is slightly underestimated. The running time for motors is very short, it's about 20 seconds so it's not going to be an issue.

E. The Future of adaptive Facades:

13. What needs to be done for better adaptive facades process and performance quality?

Shading has to be considered in an early design stage, too often it's considered to be part of the finishes, consider retrofits. To a holistic approach, shading is not the magic solution it has to be part of ventilation and mechanical cooling, it's a dynamic façade because it reacts to the conditions.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

The problem of our methods is the “value engineering”. The construction system is based on fitting and run away. We need a complete change of attitude in the construction industry.

Responsible is the building developer. They want the cheapest possible building and ought to recognize also that they need a functional building. They need to put a requirement for maintenance in the building contract.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

We're need to force the POE in the UK, that for sure. BREEAM is only an approval of the design, it's not POE. What it need is the Well standard or Nabors (Australian), if you introduce that, you will get a completely different outcome. So, I believe that the POE should become obligatory, but I don't know if that's going to happen.

16. What features would you like to find in future in an adaptive facade?

Simply shading being consider properly

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

For the ES-SO position, the potential increase in the market of shading systems, if it's applied properly, is probably a ten-fold increase, but that will need a lot of work. We have in the UK a foundation on the level of education and training in the industry and because we evolved as a decorative industry, it's shows that it's a lack of understanding in many parts of the industry.

We need education to promote the benefits of solar shading. So, the opportunities are there but we have to work in prepare engineers and architects. This applies not only in the UK, we currently discussing with American's university and they want a Lawrence Bekeley National Laboratory to develop international shading database. The potential is massive and the energy and comfort benefits, if we can achieve it, are real.

For solar shading, the advances are probably more in the control than in the actual product. We have improvements in wind resistance, but fundamentally what increases market penetration is the changes in terms of controls. There is an internal shading benefit of heat retention and glare control, so the perfect solution is two shades for windows, it's sounds expensive but it's actually very cost effective. In internal shading market there are many developments, the actual driver of change is due to problems with internal blind cords, which led to increase the use of motorization. Motorization costs have decreased dramatically, so the change is probably more in motorization and control.

With automation you must consider the user, you can't have a system that does not allow user to override and suit their particular conditions. Reset the control at the end of the day by all means, but don't ignore the user. For example, many years ago, I went to a site where there have been a large quantity of external blinds recently installed. They operated during a presentation by the managing director which ruined the attention on him so he order them to be removed.

Interview with Arno Schlüter, ETH Zurich

Name: Arno Schlüter

Date: 15.10.2018

Place: Zurich, Switzerland

E-mail: schlueter@arch.ethz.ch



A. Background Information:

1. What is your core specialization? What kind of projects have you been involved in?

Originally, I was trained as an architect, and then get further studies in computational design and buildings systems, so I'm someone between architect and engineering. I'm leaning to engineering, I'm especially interested in modeling and simulation.

My biggest project has been an adaptive solar facade in 2012, the aim was to create a light weight interface. It was more an adaptive shading or light guiding system than a facade, that allows to add like a filter to the existing facade. The focus was to develop a new way of actuating those elements. We wanted to achieve these 3 objectives:

1. Positive impact on energy consumption reducing heating and cooling need
2. Allow energy generation on the facade
3. Occupant Comfort

2. How would you describe your main roles in the company? How long have you been in this field?

I started during my PhD in 2006 in a negotiate between architecture and structural building systems, primarily on the simulation side. I've been moved in physical pieces from 2010. We expanded the digital into the fabrication realm having the potential to digitally fabricate pieces that allows us to do this adaptive facade. I started really on small component and then went on research projects larger.

B. Interviewee Definition of an Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of adaptive façade?

I think there is a confusion because a lot of things are being called adaptive, but for me it's clear what adaptive means. There is a lot of kinetics facades and responsive facade, the first one is facades which can move and change, the second one is a facade which can respond to user input. Adaption means learning from a situation improving the behavior, so adaptive facade will be connected to the systems that are able to learn, optimize itself.

For me is there a key distinction and 90% of what we see is either responsive or kinetic and some sort of adaptive. True adaptive facades are connected to some learning process behind, I don't think a lot of facades actually are, that would make up the adaptive. Intelligence is the key feature and it's important when it goes beyond the facade. Intelligence is to consider also the space behind, the facade doesn't make any sense if you're not able to learn from the space behind, from the weather and environment outside.

4. What are the strengths of adaptive facades? (Strength)

We have this epic problem to balance energy consumption and user comfort. The adaptive façade has the best potential to mitigate in the best possible way between human needs inside the building and energy requirement of the entire system.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

We created this cable network that you can position in front of the facade or make it an integral part of it. This network which also hold necessary infrastructures: individuals' modules are placed on the nodes of this network, on the front of an aluminum panel which have a laminated CIGS solar cells.

You can move panels with soft robotic actuators, and each panel has also small electronic units showing the valves and electronic equipment to control the pressure inside the actuator. So, there is 2 key components: the rod network and the modules with actuators and solar panels.

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

That's looks pretty complete. Which would be good is to add cost economic indicators and scaling potential. I don't think it's necessary to add a category on aesthetics because it's difficult to quantify and that wouldn't be a good metric. What could be a good metrics is the potential for design flexibility: if you have façades that always look the same it's hard to be successful and architects always want to have a unique façade.

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?

For my point of view occupant comfort and service will be first, then energy because in the future buildings need to be energy neutral or energy generating but it doesn't help if people doesn't feel comfortable. Finally, I would place the cost in last position.

8. Do know any standard with dynamic performance values for adaptive façade? How do you think we should validate the adaptive or dynamic performance of adaptive facades?

I don't know, I'm not used to work with standards. Standards are slightly moving to allow dynamic simulation. We need to overcome is strict value of building components. Norm and standards should give you a target to achieve like energy consumption goals and the way to achieve it should be more flexible. I would discard definite values, it's the designer who balance it, so standards should be focus on the result to achieve.

D. Disadvantages of Adaptive Facades:

9. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

The fraction is low. I think most of projects don't have adaptive façade because of knowledge of the architects and aesthetics constrains. For cost reason and awareness too. Cost is a main driver for the decision.

10. Does the cost impede the market penetration? What is the influence of mass customization on cost? (Weaknesses)

Yes, definitely the cost impedes the market penetration, if you come up with a cost comparative concept you have better chances. I'm not sure if mass customization will have a strong influence.

In Germany there have been facade makers like in E-square facade project who have tried to do changeable insulation and solar cells, but that didn't fly. Components are still expensive. Given that you're able to bring down the piece cost and still maintain the design flexibility that's allow you to make solutions.

11. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

Of course, I think it's the main constrain, because you have a lot of moving parts that requires maintenance, especially if they are exposed to a harsh environment. So, the maintenance cost can be high. The materials are generally maintenance free, there is a low risk. With mechanical pieces there is a certain risk because there are exposed to a rough environment. The risk is just that you have higher cost for maintenance and operational systems than a standard façade and at the end that's offset all the gain you have with adaptive facades.

E. The Future of Adaptive Facades:

13. What needs to be done for better adaptive facades process and performance quality?

There is a big potential in using digital models and digital fabrication. There is a realistic chance of having more complex component using digital process or digital chains. That work well the entire process except the first stage where the architects were supposed to design and work with this environment. So, we need to make sure this chain is closed from the very beginning to the end with the rise of fabrication.

This work good but architects need to join the chain. Most of the time architect are not the technology savvy and they need to see the design potential.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

I could imagine the responsible could be the building owner or his facility manager, that's the most realistic given that it's a simple system. But it can be a new type of business model where the seller who wants to add adaptive features like solar shadings can take over the cost of installation and maintenance. Most building owner and facility manager doesn't do this focus on occupants due to a lack of knowledge on how to operate their system. Occupants should have the potential to interact with the façade, which must adapt to their needs. For me Maintenance will be really making sure that is functional, it's not for control. The control system should be sophisticated enough to take this into account.

We built a living lab in Singapore the facility management of the owner was totally reluctant and afraid to remove the system installed. Because they don't understand completely the process behind, they tried everything to push that away from them. I have numerous examples where efficiency of the buildings didn't work because of this

lack of understanding, this is why we need something like a new business model, especially for most sophisticated systems.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

That would be necessary to make sure the façade is functional. Soft landing and post occupancy evaluation should be obligatory, monitoring is more relevant for standards and certificate, if you want to prove that you're actually cheap

16. What features would you like to find in future in an adaptive facade?

Basically, the features we are working on today but with a balance of the inflow and outflow of heating and mass transfer on building envelope while respecting to comfort and energy efficiency.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

The rising demand of on-site generation of renewable energy will increase the use of adaptive facades. solutions are not necessary adaptive, but it will open up potential for adaptive facades. So, clearly regulatory in some parts. Couple years ago, I was believing that If you have convincing cost-effective solutions people will take it but learning from the past years that not necessary the case. I think one central aspect is risk: the whole construction industry doesn't want to engage because they are afraid of risk to an extreme amount.

The opportunity would be if you come up with a business model like I said before, for example contracting with different schemes that mitigate the risks on the side of the building owner and the project developer. Efficiency alone will not fastest that too much. A second driver is the rising awareness of comfort. Regulation will be the strongest driver

Interview with Anders Hall, Somfy

Name: Anders Hall

Date: 23.10.2018

Place: Gothenburg, Sweden

E-mail: anders.hall@somfy.com



A. Background Information:

1. **What is your core specialization? What kind of projects have you been involved in?**
2. **How would you describe your main roles in the company? How long have you been in this field?**

B. Interviewee Definition of an Adaptive Façade:

3. **How do you define an adaptive façade? What is the purpose of adaptive façade?**

An adaptive facade is constantly able to change in accordance with the actual climate situation. It should also be responsive to people needs and preferences. The way we think at SOMFY is that if nobody says anything the building will act on its own and set the façade in the more sustainable and energy efficient settings. But if people enter the building and they don't agree with what's going on in the façade, we need to give them the opportunity to override. A simple example is the level of daylight: sometimes you have direct sun or clear sky, the screen goes down in the façade that will dim the light in the building. You have people with different ages and we need different amount of light to be able to read with comfort etc... Also depending on task that we are doing, we might need more light.

The purpose it's to make the building as sustainable and sufficient in term of energy use as possible and also present a working environment for people to be happy, healthy and productive. Tenants want to work in an environment that mirrors the green ambitions of the company. Cost and wellness of the people is becoming more and more in focus, particularly now when we see that overheating is becoming such a huge problem.

4. **What are the strengths of adaptive facades? (Strength)**

The strength of automatic dynamic shading is that. Providing the automation allow control algorithms that are well thought of. There are different levels of automations that catch the possibilities and variations and prove.

C. Advantages of Adaptive Façade:

5. **Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?**

We have one beautiful example here: it was when I was still in the sales management role of control systems project. Back in before 2010 I was contacted by a consultant in a project with the aim was to reach Green Building gold at the time but he turned out to become one of the most energy-efficient office buildings in Sweden and it still is.

They set some very interesting criteria and I was involved extremely early: even before they didn't even start digging the hole in the ground. It never happened before in my life, so I was amazed! They decided on a holistic approach (which is key in my seminars) they brought together all the key components to create sustainability and a good working environment at the very beginning of the project. So, it meant people like myself from solar shading, the manufacturer of the shading products, the facade construction, the glass people and the ventilation HVAC everybody were together very early.

In Gothenburg we don't have any huge skyscrapers or anything and they managed to build an office building for some 200 people with the 65% glazed area, external automated venetian blinds, manual interior roller screens for additional personal glare control in the different office rooms. They made the agreement with me I had to sign that three years after completion, I had to come back if called for twice a year for three years to follow up on the settings and the management of the building in order to follow up and improve the performance of the building.

didn't have to go back six times but I was back at least three and today I know the consultants that are the tenants here and I know that they run the building on 40 kWh per square meter a year, this be 5% glazed area facade area which means that summer time we have like 32 degrees but in February we could have between 15 to -15 to -20 degrees as well.

The name of the project it's called by the abbreviation BD building, it stands for Bengt Dahlgren which is a name of an HVAC consultancy company. Something which is good to know is if you don't have dynamic glazing you have static glazing and dynamic shading but choice of glass is detrimental to the result because 95 percent of the world market on commercial buildings is interior shading not exterior.

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

In general, I don't have any specific comments, it's looks good.

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?

I would put the satisfaction of people if it also embodies the whole concept of a good indoor working conditions, that should be the top one because that's where the most money lies. I would say energy savings number two and the cost number three: Yes, it will cost money for sure but we need to be serious about sustainability, it's not an option anymore.

8. Do know any standard with dynamic performance values for adaptive façade? How do you think we should validate the adaptive or dynamic performance of adaptive facades?

I never so far came across that potentials. At my latest seminar in Hong Kong with the Green Building Council, I said to a hundred and eighty architects: you should talk to the Green Building Council here that next time they update the Hong Kong building regulation they should allow for a dynamic value on light transmittance or TVs and the solar heat gain coefficient and not a fixed value. I'm convinced that the fixed value comes from the long-time running standard of what the glass industry can deliver in terms of performance and it based on that and nothing else. No, I never came across any recognition of dynamic values. It is frustrating because it will be extremely difficult because as I said, the fixed values we have today in the regulations come from a

common practice of the glass industry when it started in the 1960. In the meantime, the solar shading industry with the dynamic component were totally absent and asleep.

Now it's up to us to start the process to create awareness around the dynamic values of the facade. It might take us five to 10 years to get there but we need to start somewhere, so that's why people like myself we are advocating this over and over again at any chance we get. We saw an effort, the tech 10 building regulations in 2010 in Norway did a very smart thing: they said that the G value should stay at 15% but it should always be combined with a certain daylight level factor.

They said at any given time you should you must guarantee 2% of the daylight measured on the outside of the building at this certain point inside the room and combine them with the G value of 15%. I met the guy who wrote that regulation in Norway and I said I'm positively surprised because this proves that behind a regulation you spent time on really understanding the dynamics of a facade. He just smiled back at me and said well that's the reason why I wrote it this way.

Now it turns out in practice that this has been criticized because it does have some drawbacks particularly in a major city like Oslo, Stockholm or London where we do have densely populated areas with very high buildings. With that configuration daylight level is physically impossible to reach, you will never get that daylight level on the lower ground levels if you have high building standing very close to each other in permanent channel for example.

D. Disadvantages of Adaptive Facades:

9. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

I would say well below 1% I mean maybe a quarter of a percent. I think it's it's very much based on first of all lack of knowledge about dynamic solar shading obviously. My explanation to this is with architects' consultants and building owners solar shading is seen as an accessory not a necessity. I use that a lot because you go to any kind of architect office in Europe today you will find in the main library things like cement, windows, roofing materials, construction and then you want to go look for solar shading then you have to go to the additional section which is like carpets, furniture, curtains, plants...

Solar shading predominantly has been managed and treated like an interior kind of curtain not as a technical functionality of the building. So, I advocate that this section solar shading at least the functional section should move over to the necessity part. This is also supported by when we wrote the RIBA guidebook some years ago, we took the initiative to said in the preface that solar dynamics should always be the first consideration in the design of an HVAC system for a building because of its high level of influence on the thermal balance. He touches on the other factors like the costing because we are seen as an additional cost not as part of the big budget because if we will move to the big budget and we right size the HVAC accordingly and we make a more cost-efficient choice of glass these two savings are according to RIBA pays for all solar shading investment. It's about not downsizing HVAC it's about right sizing, if you take for example the RIBA guidebooks number 12, you will find they made three examples and said we need to look at both the CAPEX and the OPEX because on the OPEX the payback time is very often far too long to be accepted for an investor but instead if you move to the CAPEX level and you say I need HVAC factor 100 but if I bring in solar shading here my factor for HVAC goes down to 75. Because

I will have less thermal load to managed through the HVAC system and then I don't need so expensive highly coated glass in this house. So, I can buy a less coated glass or even a clear glass you don't actually need coating on glass it. So cost goes down on HVAC installation and cost can potentially go down on glass as well and that's an awesome cost in a building.

I'm waiting and I will fight and struggle when I get back to Australia next time to have a meeting

Interview with Dirk Van Buggenhout, Helioscreen

Name: Dirk Van Buggenhout

Date: 12.11.2018

Place: Belgium

E-mail: dirk.van.buggenhout@helioscreen.be



A. Background Information:

1. What is your core specialization?

As experts in moveable external and internal sun protections, we offer to our clients a total solar control solution in combination of automation. We are active on the project market, specifically for office buildings, hospitals, residential care facility, public buildings, residential apartment blocks, air ports, etc.

2. What kind of projects have you been involved?

Mostly we are involved with the leading projects based in Belgium and GD Luxembourg. We offer total solutions in combination with existing or new building controls to those projects. We are more and more involved with energetic and cost aspects from the project. We calculate the effect on the energetic balance of our solar control as well as the total G-value of chosen glass in combination with sun blind, as well the light effect inside the room. New references for this year: New headquarter BNP Brussels, office building Mobius Brussels, Infrabel Charleroi, Tweed Brussels, Siemens Huizingen, Vives Kortrijk, Biologic Institute VIB Ugent Ghent, Shape Brussels, CMI GDLux, etc... and a lot of residential care facilities and residential apartments.

We will provide the BeNeLux market this year with about 44.000 external/internal sun protections/blackouts.

3. How would you describe your main roles in the company? How long have you been in this field?

About 33 years ago, I started as a technical and architectural draftsman for Helioscreen, always from the beginning interested in physical and energetic building aspects, I got caught up in more. I was able to gain experience in multiple available functions as service manager, logistic manager, office manager, operation manager. And since three years, with a baggage of experience and knowledge, in a changing and challenging project market, as Sales Manager. Through a large network of architects, builders, investors, contractors and window assemblers, I quickly felt at home in the fascinating and competitive construction market.

B. Interviewee Definition of an Adaptive Façade:

4a. How do you define an adaptive façade? What is the purpose of adaptive façade?

The design of adaptive facades has the opportunity to utilize the dynamics in their environment. This can be created by anticipating and responding to changing outdoor conditions and comfort wishes, the possibility to add extra benefits to the passive building method in an active way.

But application in practice remains limited for the time being, despite the promising concept. Building simulation play an important role in the design process of adaptive

facades. The conclusion is that adaptive facades can contribute to the achievement of ever-sharper energy targets, without having to compromise on comfort perception. This means solar control (sun blinds or sun screens) integrated in the adaptive façade or as an optimization. Monitoring energy efficiency is important, so we can leave 'intuitive buildings' and move to 'holistic buildings' with total energy and comfort control.

4b. Who and what drives the idea (raison d'être) of adaptive facades in most of your projects?

Our intention is to help construct zero-energy buildings with addition of a good solar control system. We developed currently an all-in-one window system (SmartSolution) with a windproof integrated screen directly into the window frame, with optional ventilation and insulation. A solution ready integration, as optimization for adaptive facades. Installation and maintenance from inside of the building, made for tall buildings and for the renovation market. In mean time we realized already the first projects with this system in The Netherlands. If we look to the future of 2050 and further, we believe certainly in the green building approaches, according to ecological ideas as our Belgian Ecologic Architect Vincent Callebaut. On demand of the city government of Paris he made a smart building proposal for each district of Paris. <http://vincent.callebaut.org/page1-img-parissmartcity2050.html>

In mean time he realized already a lot of his projects around the world.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

We have provided solutions to different projects as Aeropolis Brussels, SD Worx Hasselt and SD Worx Kendall Antwerp, and others, with outdoor louvers automated by a building management system. Usually from the beginning under the guidance and collaboration of engineering office Cenergie.

<https://www.cenergie.be/nl/component/advportfolioprop/project/15-energiezuinige-technieken/17-kendall-sd-worx>

Adaptive facade is new and welcome in our leading projects. More and more we have BIM projects, where the adaptive facades will find their entry and place.

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

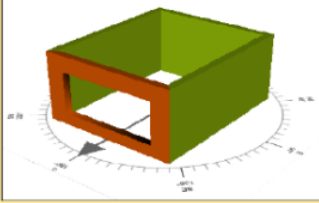
However, advances in adaptive facades are erratic and are characterized by fragmented developments, on the hand, mostly driven by discoveries in the field of material sciences (colored or switchable glass, adjustable thermal storage capacity, variable insulation, etc.), all developments that have not shown any actual results and performance for the time being. That's why we have to look beyond a few attempts, and we must keep the combination of adaptive facades in mind, in combination with building simulation and optimization, such as mobile and dynamic sun blinds in combination with natural night ventilation. The most important aspect is to prevent the building from heating. The energy to cool it down is too expensive and a waste purging. This is also the reason why in future, plants and algae growth will prevent our heat-sensitive buildings from heating-up.

7. Can you rank cost, energy, occupant satisfaction(view) in order of importance for adaptive facades?

What is the contribution of sun protection in combination of an intelligent building management system: Better buildings pay themselves!!! Reduction between 35% and 25% on energy level.

- Reduction of the cooling load and installed cooling capacity
- Gives us free solar energy during the winter
- Saving electricity for lighting, by better use of natural and free daylight
- Better thermal & acoustic comfort for the users of the building (heat & sound management)
- Better visual comfort & working conditions (less artificial light & less air conditioning)
- Improved productivity (active office workers, better school performance, active home residents, ...)

Energy & comfort balance in a standard office with standard window

Kantoorruimte met raamopening Glazing C : Clear 4mm/Argon 16mm/Clear 4mm LowE outwards	 Hunter Douglas Energy and Light tool Rating Kantoor: Ingeloten met ++ excellent buitenwand + goed Breedte: 5m o middelmatig Diepte : 6m - niet geschikt Hoogte : 3m n.r. niet relevant Raam : b 4m x h 1,8m no shading	Passief Koelen	Passief Verwarmen	Verbetering thermische isolatie	Thermisch comfort	Visueel comfort	Contact met de buitenwereld	facade oriëntatie	Windvastheid	Orientaton	Koelings-energie KWu/jaar	% winst op koelingskost	Verwarmings-energie KWu/jaar	% toename op verwarmingskost	Totaal koelings & verwarmings-energie KWu/jaar	% opbrengst	Minimale opbrengst (koeling & verwarming)	Maximale opbrengst (koeling & verwarming)	
																			Zuid
Opbrekbare buitenzonwerping	no shading									Zuid	1494	+	593	=	2087				
	Venetian blinds, automatisch en geïntegreerd	++	++	-	++	o	o	OZW	+	Zuid	713	52%	609	3%	1321	37%	20%	35%	
	Venetian blinds, gemotoriseerd handmatig	+	++	-	+	o	o	OZW	+	Zuid	495	67%	1123	89%	1618	22%	10%	20%	
	Screens, automatisch en geïntegreerd	++	++	o	++	++	+	OZW	o/+	Zuid	764	49%	607	2%	1371	34%	20%	35%	
	Screens, gemotoriseerd handmatig	+	++	o	+	+	+	OZW	o/+	Zuid	561	62%	1060	79%	1621	22%	10%	20%	
	no shading									Oost	1315	+	893	=	2208				
	Venetian blinds, automatisch en geïntegreerd	++	++	-	++	o	o	OZW	+	Oost	719	45%	896	0%	1615	27%	10%	25%	
	Venetian blinds, gemotoriseerd handmatig	+	++	-	+	o	o	OZW	+	Oost	478	64%	1124	26%	1602	27%	10%	25%	
	Screens, automatisch en geïntegreerd	++	++	o	++	++	+	OZW	o/+	Oost	758	42%	896	0%	1654	25%	10%	25%	
	Screens, gemotoriseerd handmatig	+	++	o	+	+	+	OZW	o/+	Oost	533	59%	1099	23%	1633	26%	10%	25%	

8. Do you know any standard with dynamic performance values for adaptive façade?

How do you think we should validate the adaptive or dynamic performance of adaptive facades?

A combination of existing standards to control the expected performances for a comfortable, healthy, clear and sustainable building. As example:

Thermal comfort: Warm enough in winter, not too hot in summer (average temperature 21 ° C to 23 ° C)

Visual Comfort: Enough light (illuminance: $E_m > 500$ lux), few glare (direct glare through luminaires, with glare degree UGR 0.5), optimal colour rendering (colour rendering index of the used light sources: $R_a > 80$), view outside (minimum class 2 - moderate view, prefer class 3 - good)

Acoustic comfort: No noise pollution (< 60 Db) Good air quality

Enough healthy air: ($CO_2 < 900$ mg / m³ or 500 ppm)

D. Disadvantages of Adaptive Facades:

9. In your opinion what will be the fraction of adaptive facades in today's market?

Why most of the projects are not having adaptive facades?

The prices of adaptive facades are too expensive in comparison with conventional facades. Adaptive facades improve comfort and productivity, where the benefit comes during the operation of the project. The contractor decisions are based on initial costs. Integration of construction techniques means the realization of mutual potential synergies. Synthesis reports can be made with building simulations to allow the builder to take targeted decisions. Unfortunately, the profit is recoverable afterwards.

10. Does the cost impede the market penetration? What is the influence of mass customization on cost? (Weaknesses)

Can the existing adaptive facades market guarantee their performances? On this moment adaptive facades with actual glass solutions have not shown any actual results of performance for the being time. A lot of assumptions have been made in applications with coloured glass, causing undesirable effect.

11. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

We need urgently to rearrange our approach at a world level, and focus our attention on a livable world with zeroenergy buildings with nice comfort for people. We need to balance the four natural elements as air (CO emissions), water (basic needs), earth (with respect for nature to build with lighter, stronger and more sustainable building materials), fire (zero-energy) in a natural environment for people. So yes, adaptive facades with sun controls will help a lot at the energy and comfort requirements. For BNP Brussels we integrated our windproof screens directly in the facade construction and created a solar controlled situation.

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

We need for our adaptive facade and solar control smart sensors who can monitoring the current quality level, with interaction for proposals of maintenance. We need to have the opportunity to correct some parameters directly from a distance by internet connection. So we have also feedback of the actual result. For our sun protection we monitoring them already from distance, so we can react directly in case of malfunction, with the aim of optimizing the life cycle.

13. What needs to be done for better adaptive facades process and performance quality?

The adaptive facades will have to consist of newer, lighter, stronger and more sustainable materials. The integration of self-thinking and self-acting, facades combined with solar protection will be able to respond perfectly to the new trends.

14. Who should be responsible of maintaining the adaptive façade performance after construction?

As supplier of our solar control systems, and after two years of installation of the sun blinds, we try to conclude a preventive maintenance contract with the responsible facility manager or current end-user. So we can check installations and adjust were necessary. We can control a lot of automation directly from a distance by internet.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

It would be an added value, but can't become an obligation.

16. What features would you like to find in future in an adaptive facade?

The needed features to realize more green projects in the future. For example, tailored integrated drainage systems for plants in green buildings, with recuperation system of collected water. The already realized green projects gives us insights into the used facades with unfamiliar surroundings, such as plants, bamboo, grasses, etc. An attempt is made to recreate the liveable and fertile environment, in which flowers, insects, birds, animals, etc., find their way back into the green environment of cities. Quality aspects of the adaptive facades are very important, they must also according to European quality standards (norms) to guarantee their performances. Our external sun screens are TUV qualified according the norm EN13561, as also our external sun blinds are TUV qualified according the norm EN13659.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

Improvement and traceability of performance of the adaptive facades. It's important to provide designers, architects, engineering, energy consultants, ...from the right data flow, according to the 'state of the art', about the possibilities of 'adaptive facades' in combination with others functionalities (HVAC & lighting) and 'sun blinds' (Solar control), to achieve the right comfort and energy performance (EPBD & EN 15232). Total solar control (G-value) and light performance (Tv) must be respected to guarantee the performances. As a total solution we advise always a building management system.

Interview with Hannes Gerstmann, Genolux

Name: Hannes Gerstmann

Date: 30.11.2018

Place: Guntramsdorf, Austria

E-mail: gerstmann@geniolux.com



A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

I am a lobbyist for the sun protection industry (adaptive systems) in Austria and run an engineering office for lighting and shading. My project list mainly includes smaller office buildings (facade size 1.000 m²) where the use of daylight or light control and effective shading were essential functions of the facade.

- Hauptgeschäftsstelle der Bayerischer Bauindustrieverband e.V. München Germany / 2002 (renewed in the meantime)
- Tiroler Sparkasse, Innsbruck Austria/2003 (renewed in the meantime)
- Arbeiterkammer, Innsbruck Austria / 2004
- Lichtakademie Bartenbach, Aldrans Austria / 2005
- Gymnasium Kremszeile, Krems Austria / 2015
- HLW-Türnitz (Schule), Türnitz Austria

2. How long have you been in this field?

I have been dealing with adaptive shading since 1991 and since 2001 I have also been working with daylight and glass technology. Since 2007 I run an engineering office for the optimisation of transparent components (windows and facades) beside my activities for the Austrian Sun Protection Association. I observe very closely the developments in the field of facades and try to bring my experience and observations into research projects again and again.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of adaptive façade?

For me, an adaptive façade is adaptive if - from a technical point of view - it functions both with regard to the regulation of solar energy input (i. e. heat gain in winter and heat prevention in summer) and for the use of natural daylight (high daylight autonomy). From the point of view of users, it must be designed in such a way that the view is as natural and unadulterated as possible, if sun protection or glare protection does not have to be given priority for reasons of energy efficiency and health. Adaptive facades, which only open a peephole but limit the free incidence of light due to their construction depth, are not sufficiently adaptive for me.

4. What is the strengths of adaptive facades? (Strength)

Adaptive facades can give the interior a better quality because they transfer the dynamics of the weather into the building. Rooms that change with the course of the day (direction of light, light intensity, light colour, etc.) are rated significantly better by users, increasing their vitality and willingness to perform. Adaptive facades naturally also have strength in terms of energy efficiency, because they minimise the energy

required for heating and cooling and also help to reduce electricity consumption for lighting. In office buildings, energy consumption for lighting can be the biggest energy consumer, and this potential is currently being under-utilised!

C. Advantages of Adaptive Façade:

- 5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?**

The essential characteristics of the adaptive facades I use are:

1) No spectral change of daylight for mainly biological reasons. As a result, I only use glasses with high light transmission and a very good colour rendering index.

2) Fully retractable shades, these can be slats (advantage of light control) or façade awnings (screens, open weave to ensure transparency).

- 6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)**

Visual comfort includes glare protection, privacy protection, visual contact, use of daylight, colour rendering. These functions must be evaluated individually; for example, electrochromic glass only provides glare protection (against direct sunlight) if it is dimmed to 99%, which entails the use of artificial light. In a partially darkened state (glare protection against bright clouds) light spectrum and colour rendering are strongly manipulated.

Daylight should not only be judged according to visual criteria; therefore, I miss the non-visual effect of light in the table, i. e. the occupational health aspect!

- 7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?**

User satisfaction is seldom surveyed, but this is about productivity. But the advantage of better productivity will usually not benefit the building owner or the operator of the building. It would be important to develop a win-win-win model so that high user satisfaction and success also pays off for planners, developers and operators and increases the value of a building.

- 8. Do know any standard with dynamic performance values for adaptive façade? How do you think we should validate the adaptive or dynamic performance of adaptive facades?**

No, because at least in Central Europe there is no standard that uses the energy balance of transparent components as a planning basis and certainly not including lighting!

D. Disadvantages of Adaptive Facades:

- 9. In your opinion what will be the fraction of adaptive façades in today's market? Why most of the projects are not having adaptive facades?**

I don't know! In residential buildings, adaptive facades (or windows) are inevitable, as long as the building standards do not allow mechanical cooling (which will unfortunately change due to climate change). In non-residential buildings, the double façade with intermediate sun protection seems to be less en vogue at present. The further development of glass technology towards switchable glazing will presumably lead to a higher proportion of adjustable facades, provided that the technology works, prices fall to an acceptable level and occupational medicine ignores the effect of

selectively changing daylight on people. Why many projects do not have adaptive solutions is probably due to the cost and aesthetics of "monolithic crystals".

10. Does the cost impede the market penetration? What is the influence of mass customization on cost? (Weaknesses)

Of course, the costs of adaptive facades are higher. If you only see the investment costs, because you don't have to consider the operating and wage costs, static facades are of course a more lucrative investment!

11. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

No, I don't think so, because it requires holistic planning based on life cycle costs and an expectation of added value. If we plan and build using the traditional model (with a focus on construction costs), adaptive facades will not prevail.

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

There is no doubt that adaptive facades are more susceptible to failure, which is why the client demands a longer warranty period than usual. From my own experience I know (when I was still developing products) that our systems were not sufficiently tested for this. The failure rate was significantly higher than expected and the resulting costs were enormously high!

E. The Future of Adaptive Facades:

13. What needs to be done for better adaptive facades process and performance quality?

One should take an example from the car industry. A car is certainly no less complex and challenging than a façade. There are certainly some facade builders who work highly professionally at the highest quality level. But there are also those who only copy paste and that's definitely too little (I got such a case – closed cavity façade - on my table this year).

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

This must either be offered by the facade builder as a service (precautionary maintenance) or awarded to a company specialising in facade maintenance.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

Yes - 100 percent!

16. What features would you like to find in future in an adaptive facade?

Not only protection against the sun but also the best possible (qualitative and quantitative) daylight supply for the rooms. High degree of automation with partial user intervention. The aesthetics of the facade must meet the demands of the architecture, but the architects must become more aware that an adaptive facade is part of the building services to satisfy the needs of users. Therefore, aesthetics must not be placed above the functional benefits of a façade!

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

Office buildings of the last 3 decades have usually consumed significantly more energy than predicted, especially for cooling! I think that a refurbishment market for office buildings could also be developed by retrofitting (or replacing) an inefficient facade with adaptive systems, thus increasing buildings life expectancy, while

increased energy consumption (compared to planning) coupled with rising energy costs would shorten life expectancy for economic reasons. This would be an important step for the sustainability of buildings.

Interview with Thomas Auer, TU-Munich and Transsolar

Name: Thomas Auer

Date: 30.11.2018

Place: Munich, Germany

E-mail: thomas.auer@tum.de



A. Background Information:

1. What is your core specialization? What kind of projects have you been involved in?

I'm the managing director of TRANSSOLAR a company specialized on the development of climate and energy strategies for buildings and districts and since 2014 I'm also professor at the Technical University of Munich. With TRANSSOLAR we develop energy and climate strategies where the facade plays a very important role. We started in the 90s, where glass façade became very popular. We were the part of the development of these highly adaptive facade systems with double facades shading devices integrated trying to integrate natural ventilation as part of the overall system, so having daylight and solar control as well as the control of natural ventilation.

One of the key projects are the Manitoba Hydro, the Prisma building in Frankfurt, the Norddeutsche Landesbank in Hannover, the ministry for Foreign Affairs in Berlin, a library in Hamburg for the law school... So those were a series of buildings with a lot with adaptive facades.

2. How would you describe your main roles in the company? How long have you been in this field?

I have been in the field for 25 years

B. Interviewee Definition of an Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of adaptive façade?

An adaptive facade is adjusting to various boundary conditions. As an engineer we always think in boundary in control zones, so the facade is the boundary of a control zone for the indoor environment and we have varying outdoor and indoor conditions, the façade properties need to adapt to those varying conditions. So far, we always considered a mechanical adaptation, moveable parts in the façade like shading motorized windows or manually operable windows.

However, I just recently reading the definition of adaptivity in Wikipedia that it was self-controlling, which we always considered as something like autoreactive and the self-control system or whether it's small materials which lead to an adjustment of physical properties. But however, I would consider an adaptive facade something that is adjusting its physical properties to changing boundary conditions.

4. What are the strengths of adaptive facades? (Strength)

The purpose is minimizing energy consumption for operation while optimizing environmental quality and that's also the strength of it. So, if it works as designed it has to lead to better environmental quality. The primary purpose It's user satisfaction: can we provide daylight while having direct solar exposure while avoiding glare.

It should also reduce energy consumption for operation, minimizing the burden that has to be covered by mechanical systems, reducing loads and reducing the capacity of downsizing mechanical systems. To the extent that we might be able to avoid certain mechanical systems so therefore the adaptive facades could also lead to a reduction in capital costs for building a building.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

The main feature is daylight and solar control, often in a way so that we have a weather protection for retractable system included. With the specific requirement that daylight control also works as clear control.

The next purpose for us is always providing natural ventilation, whether it's in a hybrid system supported by a mechanical system at certain weather conditions or whether it's a controlled natural ventilation, deals with hygienic air exchange but also deals with climate control for the indoor environment.

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?

Number one is occupant satisfaction then cost and number three is energy consumption. I mean from an ethical standpoint of our profession the main purpose we do buildings is to provide environment that people appreciate, that's the focus of all of our work, the main requirement for our profession.

In terms of costs the main issue is that cost for people in an office environment is about a hundred times bigger than the cost for operating the building and ten times bigger than the cost for the building itself. Of course, every developer thinks of first costs: that's the nature of the business and as designers we have to deal with it. We always had been successful convincing a client of adapted facade systems when the system had been integral part of the architectural design including the mechanical design. I give you an example: The Manitoba Hydro building that we had lots of debates about the double facade with shading integrated and natural ventilation, very uncommon in this very harsh climate. The convincing part was that without the double facade we would never be able to have an excellent shading and the radiant system wouldn't have been sufficient to cool the space in summer, we would have needed to add another mechanical system for providing cooling. With the other system this would have questioned the radiant system, we would have received recirculating air but we wanted no recirculating air for hygienic purposes on this 100% outside air system, we would have questioned the Winter Garden as a kind of the community and so on.

The lesson we have learned in TRANSSOLAR over the past twenty-five years is that we are always successful when it's a fully integrated system and the adaptive facade is one piece of it. It's not the concept it's one piece which is often essential for the overall concept. I hate when in these design meetings clients ask us for a shopping list and say I want to have the adaptive facades, but I don't want to have this or I want to have the radiant system but not the adaptive façade. There is no shopping

list, we have a concept which includes the façade, includes the mechanical system, includes the architecture, includes everything and it comes together and then you can choose between the buildings but no single pieces of the concept.

8. Do you know any standard with dynamic performance values for adaptive façade? How do you think we should validate the adaptive or dynamic performance of adaptive facades?

The only thing I could think of our adaptive comfort standards so as soon as we have natural ventilation and no mechanical cooling. In buildings we can use adaptive comfort standards we know that people do accept a wider temperature humidity range if they are in passively conditioned environment, so this would certainly require a certain adaptivity within in the facade. It's not specifically mentioned you can only use an adaptive comfort standard if you have adaptivity in the façade, but it's kind of implicit.

D. Disadvantages of Adaptive Facades:

9. In your opinion what will be the fraction of adaptive facades in today's market? Why most of the projects are not having adaptive facades?

The question is what level of adaptivity: if we say operable windows and a retractable shading device then I would say in housing it's 100%, then office buildings and commercial buildings is probably fifty percent. Any commercial buildings like shopping malls don't have adaptive facades but most of the office in Europe have adaptivity. We need to admit that many facades we build with adaptive features require a lot of maintenance, require control systems and we have millions of problems with all the control systems. I visited a spa we design with a very adaptive façade were 20-30% percent of all the motors were broken. We have to admit that it requires a certain level of maintenance and caretaking for on all different levels. I understand more and more why people are hesitant I don't want to say it's right or wrong but looking in retrospective on many projects we work done visiting those buildings later a second point is certainly the failure rate we have in control systems which is extremely high. For example at the University I work we do have an external shading device and I still do not understand the logic that have program that is operating the shading device, it's just stupid and it's a very simple requirement: if you exceed a certain solar radiation on a certain facade orientation drive it down and if it gets below a certain threshold drive it up.

Then what we also see is the user satisfaction: I'm still totally convinced that adaptive facade overall can increase user satisfaction, provide much better environmental quality than fixed systems. However very often like if we are coming back to this example of an external retractable shading device, those systems lead to an instantaneous change of conditions. As a user you sit in your office, you like your view and suddenly the shade goes down and you don't like it, so you have to get up you have to override it and then after a certain period of time it comes back down again. Things like this very often leads to complaints, we see user overriding systems, user interacting with the building and we see a huge performance gap between what designers were envision and what we see in reality. Looking at school's buildings 95% of them don't work as designed. That's something we need to be critical about we need to have a critical reflection of our work and rethink the amount of complexity we put into the adaptivity.

10. Does the cost impede the market penetration? What is the influence of mass customization on cost? (Weaknesses)

I very much hope that cost contributes to more acceptance of adaptive systems, it also contributes to the research that happens at the universities in this field. I think part of the research have to be how can we simplify an adaptivity of facade systems. So, I don't know cost has an impact but I very much hope.

To respond to mass customization question, if we can buy an adaptive facade system from a manufacturer which is like off-the-shelf design then it's already boring, architecture is always about reinventing the wheel, it's part of the DNA of the community. So, the regard there is a big potential in mass customization in my mind if you have components that are systemized and they work and they're reliable but I can still assemble it in a way which is new. But the assembly is a piece of parts and all the parts are systemized and manufactured in a way and come with their control system: that's very important to be really sure the controls are working as designed.

11. Do you think that adaptive façade technology is mature to penetrate the market? And Why?

Adaptive facades technologies are used for probably a hundred years or even longer in architecture so of course there are mature enough. I think in this kind of individualization of façade systems and reinventing the wheel every time we have too many problems and getting them to operate as design. That's why the adaptive facades do have a bad reputation and we as designers need to work on this we need to develop more robust systems so that we build up a better reputation. But overall I would say absolutely they are mature enough to have a bigger market penetration

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

The risks are mainly the motors and controls, those are the two weak parts of an adaptive façade system. When we do building design we try to compare always what we do to the automotive industry but as a matter of fact in average I think all the cars are used about an hour per day, a building is used 24 hours a day. So, if we have shading devices that react to Sun position every half an hour these are millions of movements over a couple of years so that's why motors fail after a couple of years and it's a nightmare: we have one maintenance person who does nothing else then changing these motors. So again, we have to be more careful in designing those things that we get a robust and reliable over at least 20 years.

E. The Future of Adaptive Facades:

13. What needs to be done for better adaptive facades process and performance quality?

Starting with the performance quality I think we need to have kind of post occupancy monitoring or designers involved in a phase where the building is occupied to really make sure that we get the feedback from building operation but also as a community have certain learning and improvement throughout the process. That's something that should become more common in building design, we certainly need iterations we need to all have overlaps between the different groups.

Maybe I'm wrong but I think that the rating systems we have so far whether it's in Germany or whatever it is they're always done by the moment the building is occupied. We have no rating system where energy numbers and post occupancy evaluation or whatever need to be reported after a year or two after final competition. I think what's very relevant for all the rating system is people talking to each other, so I think it's very important that maintenance people are already included in the design process and also that there's an overlap between design team and building team.

Communication between teams is important and particularly in North America we had the experience with commissioning teams and also the operators being early in the design process, we get a better result at the end. I think we cannot solve everything by rating system, we cannot solve everything by a BIM system now people need to talk to each other.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

First of all, the building owner. If you buy a car it's your responsibility to make sure the car is maintained when necessary, nobody can take over responsibility from the building owner. It should be in the interest of the designers to make sure the building is working as designed and going beyond the typical product you before final completion of the building. The user should have an interest that building is working as design because it's about environmental quality and last but not least the contractor has a responsibility to deliver a building which works as designed.

So, all of them are actually responsible but it's mainly the responsibility of the owner and he has to insist that the building is working as designed. Post-occupancy evaluation is not required, it's not part of a scope to deliver a building so he has to pay for it but he should have an interest because he wants to provide a building where he gets good user satisfaction.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

The answer is very short and easy: yes. I think the building which requires an educational process for the user is not a good building. A building should be designed to be used intuitively. Once in a building we design, we gave the user an education, we trained them and then we came back to this building 10-15 years later and there was nobody who understood the system and we were recognized they have a lot of change of staff and there was totally different type of people. So, this knowledge is getting lost if we don't design in a way that it's used intuitively then it's going to fail earlier or later. I talked about the user not about the maintenance people and facility managers, of course they have to understand all the logic behind, they have to understand the control system... this requires some educational. But to answer to your initial question, we can't force this obligation.

16. What features would you like to find in future in an adaptive facade?

I think we need to put more focus on this question of natural ventilation, natural ventilation controls. The other features I would like to see is materials which have a more autoreactive adaptability or adapt more autoreactive by some intelligence which is embedded in the material, non-motorized adaptivity. Dealing with noise is first of all a design issue, you can still have naturally ventilated buildings despite the noise level outside. Talking about air pollution, who said that we have an air quality issue? We need to understand and recognize that in Europe air quality since industrialization has never been as good as today, what happened is that we changed the threshold, and everybody believes we have bad environments. As a matter of fact, in Germany over the past 20 years NOx emissions have been reduced by 75%. We have to work on it, of course it must be an obligation to improve air quality, but they at the same time we should not panic, you should not go crazy about it. And the other thing we have to understand is that most of the pollution we talk about particularly NO x is not filtered by additional mechanical systems, that you need to have an active coal filtration, I

don't see a single building using this. Therefore, it's just a belief that mechanically ventilated buildings give you better air quality it's not true. On top of it I would say if there are some people who think we need to go in the direction of having active coal filtration to create this really super healthy environment, it's such a big effort that we would start because of cost reason but then we have indoor pollutions like VOCs then we would live in an environment with no NOx, no hydrocarbon whatever molecules that come from the outside but would up higher concentration that comes from the inside, so I'm not sure if this gives us a better environment.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

I think the biggest opportunity would be if we can make people and clients understand the potential in providing better environment for people. If we design a building for the best categories in accordance to code environmental quality, we create dead environments people hate. People love to have certain change in temperature every once in a while, it a thermal sensation. People love to open the window we know that we have a higher acceptance for buildings with operable windows. But if people understand this potential in providing better environments with the facade systems and if this becomes desired by the user or at least desired by the client, then this would be a breakthrough for getting adaptive façade systems in play. Saving energy will not become the driver.

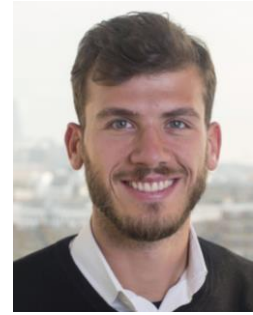
Interview with Fabio Favoino, Polytechnic University of Turin, Italy

Name: Fabio Favoino

Date: 30.11.2018

Place: Torino, Italy

E-mail: fabio.favoino@polito.it



A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

My course specialization is building performance, with a specialty on building envelopes.

I've been working in academia for several years and worked in the industry as a building performance and façade consultant. So, projects are both research project and real project as well.

2. How long would consider yourself in the field of facade?

Since 2011.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of an adaptive façade?

My "preferred" definition is the one that focus on the capability of an adaptive façade to achieve certain performance requirement by changing in a reversible way their properties. So, I would like to stress on the fact that the focus for me over an adaptative façade is not just about the physical way in which these properties are changed, and not how these are controlled but on the reason why we want to do this, which is improving a certain performance objective.

So, when we talk about the reason why we want to have adaptive façade in the building environment, it is about the performance requirements which can be varying, so that you can expect potentially some visual or thermal requirements that can be different from one point of a space to another, or in different time over year. So I think that the best definition for me is the one that focuses on the capability to accommodate these changing requirements according to changing boundary conditions.

You can have different purposes depending on the perspective you are looking, so if you are a client that is interested in renting a building the purpose can be just marketing (or commercial), from my point of view the purpose is to use the resources in a more efficient way while providing a higher level of comfort generally.

4. What are the strengths of adaptive facades? (Strength)

In my opinion, their strength is their same weaknesses as well, it is the fact that intrinsically an adaptative facades is not an intelligent facade. In the sense that the capability that they have, which is adapting their properties, it's something that must be either designed before hand embedding intelligence into a material, or ensured during operation.

In the same way their strength is the capability of being controlled or to be designed to fit a certain purpose. But we don't put sufficient effort in understanding what is the level of intelligence needed and how to ensure this during operations.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

I've been involved in a number of research project, and, I would mentioned mainly 3 of them: ACTRESS, SMART GLASS and development of the control for PVC glazing. The first one is called ACTRESS facades, *Act* for active, *Res* for responsive and *S* for solar, in integrates different technologies, in a plug-and-play façade module splitted equally between a transparent and an opaque area, working synergistically together.

Shady: can u later one adds a reference.... (8:00)

(2016) Favoino F., Goia F., Perino M., Serra V., Experimental analysis of the energy performance of an Active, RESponsive and Solar (ACTRESS) façade module, *Solar Energy* 133, DOI: 10.1016/j.solener.2016.03.044.

(2013) Favoino F., Goia F., Perino M., Serra V., Experimental assessment of the energy performance of an advanced responsive multifunctional façade module, *Energy and Buildings*, Available online 19 September 2013, ISSN 0378-7788, <http://dx.doi.org/10.1016/j.enbuild.2013.08.066>.

The added value of the ACTRESS façade was to have a plug-and-play unitised system embedding renewable energy generation to drive shading, ventilation and latent thermal energy storage, with a relatively lightweight but with a high level of thermal mass.

SMART GLASS project analyzed and characterized potential of different technologies integrated into glazing, from phase change material to thermochromic, thermotropic and electrochromic, and the coupling of them.

The added value of the smartglass prototypes was mainly comfort, both thermal and visual, adopting technologies that could prevent overheating while providing daylight at the same time.

Last one was to develop and evaluate control strategies for PhotoVoltaChromic glazing, a technology that could couple photovoltaic effect to electrochromic, so that to be able to control the glazing either passively, proportionally to solar radiation, or in an active way (while producing electrical energy). Within the project we developed control strategies able to minimize energy use and maximize energy flexibility to the electrical grid from one side, while maximizing visual comfort on the other.

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

So, first on technologies, I would remove or maybe change slightly some of the technologies. I guess the technologies is just a list. So, you, it's not important the rows, but the columns, but just here on the rows there is this insulated "nano technologies 14." I mean strictly speaking, we're not talking about adaptive.

You can see in my book on chapter 2 or 3 quite a good list of facades technologies and they are classified in different groups too. (Please refer to Cost Action final booklet 3.2, Chapter 1 and 2)

In terms of columns, if you talk about energy environmental performances, there is energy consumption generally and then, you divided cooling and heating load. Why do you want to specifically divide heating and cooling load? And why load and not energy? Is there any reason?

So first of all, I would add lighting and ventilation. Generally, if you are talking about cooling and heating what is missing out is lighting and ventilation.

And then, I would make a distinction between energy, because this energy consumption which is called operational energy because then we have embodied energy and embodied carbon.

But then you are talking about energy consumption during the operation but talking about carbon consumption during operation which is a different thing. This is included in the embodied but not in the operational energy. So just maybe you need to clarify those points.

Then regarding loads and energy, it's up to you to decide but, potentially, because it's very important. So apart from the loads the maximum design loads of your building services, so potentially we can assume that adaptive facades, given that they are adapting to the loads that the building has, potentially, can lead to smaller building services. So, you can let's say under damage of your building services might lose less money.

The other thing is about the loads and the kind of adaptability of to the electrical loads and your building to the electrical grids. So, if you are going to smart grids its will be also important. I would call it: Electrical grid flexibility.

Just about user experience and control, it's just a semantic issue but in literature they are mainly referring as occupant not user. I mean it's different thing, it depends on what you call user.

Maybe you should be clearer on the description of the table. For functional performance, there might be two level so if you look at visual performance per meter can be the visual transmittance of calculating and other thing is actually the effect of that change in the internal environment which is you need to achieve regarding lux levels, glare, DGP or whatever. So, this table is not clear to me.

Question about command

This part is very vague, it's hard to understand what to include there. They could be so much in just those two words, maybe, this have to divided in two or three fields. Also, it's the action feedback.

Actual feedback, it might be related to that.

Clarification and action feedback explication

This whole section is not very clear.

TABLE 1

Adaptive Façade Technologies Performance Matrix																											
Adaptive Façade Technologies	Energy & Environmental Performance							Protective Performance					Building Control and Services				Occupant Control and Experience				Maintenance Durability and Circularity						
	Energy Consumption	Embodied Energy	Embodied Carbon	Cooling energy	Heating energy	Ventilation energy	Electrical Grid Flexibility	Structural Performance + bonding/fixation	Visual and Acoustic Performance	Water tightness and air permeability	Thermal and Fire Resistance	Radiation properties	Visual Comfort/ Acoustic comfort	Thermal Comfort/ Aspiration comfort	BMS Interaction	HVAC Interaction	Engagement and command control	Action Feedback	Comfort Aspiration & perception	Failure and dissatisfaction feedback	Product take back & global guarantee	Façade Material Durability / appearance	Façade elements replacement	Façade cleaning	Façade Operation Maintenance		
Movable Shading																											
Switchable Windows																											
Complex fenestration systems																											
Adaptive insulation																											
Opaque PCM																											
Transparent PCM																											
Opaque Ventilated Façade																											
Transparent Ventilated Façade																											
Solar Façades																											
Green Façades																											

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades and justify that?

1. Occupant satisfaction (view including): because it's a bigger cost
2. Energy, even though is also a cost, this is related also to GHG emissions
3. Cost

8. Do know any performance-based standards (not absolute values) for adaptive façade? Do we need new standard for adaptive facades performance assessment and Why?

No, my experience in the practice is that we are going more and more forward in performance based design. So that for building integrating adaptive façade is always necessary to prove the performance with overall performance indicators.

D. Disadvantages of Adaptive Facades:

9. In your opinion, what is the fraction of adaptive facades in today's European market? And why?

Very low, less than 1%.

For lots of reason, one is the technology readiness level or for some technologies that we think that we could use but not (technology maturity level). The other one is the cost, not the technology itself and as well the indirect costs which is the costs that you need in the complexity that you need to face into design, and the complexity you need to face in operation.

10. Does the cost impede/hinder the market penetration? What is the influence of mass customization on cost? (Weaknesses)

When we talk about direct cost (cost of the technology itself), I don't think that necessarily impedes market penetration, it's just slowing it down. While about indirect cost, I think that this is actually impeding it, I mean that there is not enough maturity in the market itself and in the professional around market to be able to reduce these kind of indirect cost as well.

One of the best examples, is what you presented at the COST Action conference, which consisted in basically trying to use electrochromic just to avoid overheating, but completely ignoring additional energy in artificial lighting (reference: project of electrochromic).

11. Do you think that adaptive façade technology (motors/actuators, sensor, products (e.g. louvers) and control strategies) is mature to penetrate the market? And Why?

There has been a lot of push for some technologies like double skin facade, but what happened is that the control of those and the integration of these technologies in the buildings was not done in the proper way a lot of time.

The sense is that, there are different technologies that are quite mature, like double skin facades, like some smart glazing technologies, but the issue is that the market is not ready yet to integrate them. I mean it is not completely mature to integrate these solutions from all points of views. This is an educational and knowledge gap that the market need to fill first, but also the building systems supply chain and operation need to adapt for a proper integration of adaptive technologies. There is a lot of innovation that need to happen in order to get a good penetration of these technologies, it is not just about technologies readiness, but also about project delivery process, supply chain innovation, maintenance and operation innovation.

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

It very much depends on the technology. If you think about liquid crystal or electrochromics, if compared to external blinds, sometimes the cost ensuring durability and performance over the lifetime of the building and its maintenance can easily justify the initial investment in a smart glazing. Moreover some technologies are very mature, and can have the same life expectancy than other product of facades, so for example EC or LC the guarantee of the industry is 10 or 20 years which is the same as coatings in standard glazing. And in term of lifetime, we have standards that are telling you how to do an accelerating testing for ten thousand cycles, but there are other technologies that are not there yet, so it's very technologically related.

E. The Future of Adaptive Facades:

13. What needs to be done for a better adaptive facades project delivery process and better performance quality?

There are many things here: there is the design, there is construction and supply chain and then the operation. And we need innovation on these three fields.

On the design, education is one thing, not only at student level but also at the professional level, and that include having better standards as well.

Then for construction and supply chain, I can see that in other industries concepts related to circular economy are working really well. In facades one manufacturer could think: "I don't sell you the facades, I own the facades and you are just renting the services". So, they are paying for the performances that this façade can give.

There can be also manufacturing process innovation in order to reduce costs of mass producing some of these technologies (i.e. smart glazings).

And then, about performance and quality, to ensure these kinds of facades operates correctly. One aspect is better modelling and forecast of climate conditions, of what happens in the building, and of how the façade action can effect the building and the occupant. Another aspect is about sensing, there is all sorts of low cost sensors that can be embedded into the façade, but how to use these sensors to perform better controls is a field of investigation.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

Well the facades consultant is not responsible to maintain the performance calculated during the operation, finally it depends on the business model for the specific building: it depends whether the entire building is being rented or sold, or if there is a unique building owner, or multiple owners. Finally the building owner(s) should contract a specialized building manager (which in some cases can be or be connected to a specialized or general contractor).

15. Do you agree that soft landings, POE and monitoring should become obligatory?

There are different levels of what is included in these POE and soft-landing, and I think we need a scheme to understand when this is needed, and when different level of soft-landing and POE are needed for different buildings and facades.

So, not generally being obligatory for everything because it is very costly, but we need a better understanding of the level of commissioning and the soft-landing and the POE needed for different kind of buildings depending on the technologies that they have, and depending on how the building is operated.

16. What features would you like to find in the future of adaptive facade?

I would like to see adaptative facades as an extension of the building services, an adaptative façade as a feature that is used to control the environment, not just to separate one environment from the other. But I think one of the best feature to be included in adaptive facades is being able to control the transmitted solar radiation in a building independently in the visible and infrared spectrum.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

I don't think the opportunity will come from the renovation sector because of the costs of these façade solutions. But I think dynamic façade need to prove their performance in new building first, also because the advantages of adopting adaptive façade is more evident where it is possible to implement very energy efficient solutions already (new zero energy buildings).

Then also from the standard point of view, standardisation should stress the attention not just on energy but also on achieving high levels of indoor environmental quality. Achieving both objectives at the same time would only be possible with more dynamic and responsive façade.

Finally the biggest opportunity will come from very powerful industries, which can invest a large amount of money in innovation in supply chain and manufacturing (i.e. glass and coating industry, chemical industry etc.).

Interview with Per Heiselberg, Aalborg University

Name: Per Heiselberg

Date: 30.11.2018

Place: Aalborg, Denmark

E-mail: ph@civil.aau.dk



A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

My course specialization is building physics and could say building related to dynamics. And in relation to facades, I've been involved in a range of project from very simplified window type then to the more complicated double skin facades in office buildings.

And I think in the beginning of my career it was mainly the more complicated stuff, and now, later on my career, typically the more very simple one. That's how it has developed in the last year.

2. How long would consider yourself in the field of façade
30 years.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of an adaptive façade?

I think the purpose of an adaptive facades is to be able to react to the needs of the indoor environment, so it can change its characteristics and functionalities to be able to provide these indoor environments. So, to me the studying point is always the indoor environment and then: How do you react? How should the facades react in order to be able to optimize that or to increase that?

And then the definition of an adaptive facades in principals, more or less, all facades are adaptive as soon as you have a window that can be opened, you have a curtain you can draw curtain, in front of the glazing. Then you have an adaptive facade, then, of course, discuss where do we start because to me, an adaptive facade is also adaptive even if it requires occupant to interact. So, they have to open the window, they have to draw the curtain, they have to activated the solar shading. To me this is still an adaptive facade.

But of course, then you can have different degrees of motorization or control systems and sensors and automatic control and so on. Until you, on the other hand the scale come to a fully automated, you could say, I don't know, it is shortly called intelligent, but at least in a fully automated facades based on sensor you could be able to react automatically to the need of people. So that's a to me there is a very big spend when we talk about adaptive facades, but I guess what you talk about in this cross project is of course mostly these technologies, in the end, when you use sensor and automatic control and so one, to control the façade.

And not in particular but the definition is important because, for example we have a lot of new passive houses or, let's say, nearly zero or net zero energy buildings and the designers think they don't need any more to have any

openings that can be manually control. So, according to your definition adaptive façade should be part of any project, at least if it's a manual, simple window.

Yes, yes, because this also mean that in other aspect of an adaptive facade is of course, that you think these adaptive functionalities into the design of your building. So, this mean you also need to, if it's based on occupancy you need to explain this or describe this to the occupants but this is actually part of the strategy of these buildings, that is should be used. It doesn't mean that you could just design the facades and then don't talk to anybody about it, you need to do that if you assume the occupant is going to operate and I think you need to do it anyway if you have an automatic system.

4. What are the strengths of adaptive facades? (Strength)

In my opinion, most of the facades are adaptive but the reason why we need those facades to be adaptive is because we can achieve a large energy saving and we can improve the indoor environment. Without much you could say if you controlled the characteristics and the function of the facades. So, I think it would have both an energy saving impact and also an improvement of the indoor environment if you can control the facades better.

The advantage of having this automation, to me, it is a way of assisting occupant in reaching what they want and this is because sometimes occupants are not there and we need anyway to control the facades to prepare the building avoid overheating or something like that before people are coming.

People are also usually reacting too slow, so they don't react until it's too late, we have the problem. If you have automation of your facades, you can anticipate what is going to happen and have the façade to react before it becomes a problem so you can take it before it's been a problem. And I think, that's a very important aspect of the control that can assist people in controlling the facades.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

At the one hand on a simple path, we have work with what we called a ventilated window, so this means it's a window with a double pane and then an air gap and another pane, and in these pane you have solar shading and we have the ability to transfer, to open for ventilation also to the space. So, this mean we can have ventilated through the window during the winter for preheating, glazing into the room or it can go to through the place in or out again so you can cool the solar shading during the summer time. So, this is a very simple window unit which can provide ventilation, solar shading to the building according to the needs.

Then, I've also been working in facades for offices where will also integrate shading and natural ventilation and daylight control and the main issue there was not the integration of technology but more the control of technology. How do we make the control? So, we can focus on energy optimization or so you can do the control so you can focus on indoor environment.

And unfortunately, these two are contradictory in a lot of buildings. So we have been looking into things like what compromise do we make in relation to keeping the view to the outside and still have some activation of the solar shading, or should you

activate natural ventilation before the solar shading so you could keep the view out for longer time at period by using natural ventilation for cooling instead of solar shading in order to improve comfort.

So, we have look into different aspect in order to improve occupancy satisfaction with the control facades and what should be the strategies to use.

By now, we also working with technologies to integrated in the facades and some storage in phase change materials. The idea is to have a kind of solar heat exchanger so we capture solar radiation and then we transfer it to the ventilation air and then to the space. And we are looking to how can we use this during daytime for capture solar energy and maybe, we can also use it cooling down during night and then use it for cooling in the daytime but at least kind integrated storage in the facades and then see how can we use such an energy storage locally for improving the energy performance.

(will add reference when verification)

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

The only thing I would say is, you have a headline called user experience control, but actually its does not seems to be part of the point you have, so, this user interaction with the facades. The user integration is not included.

Update about table 1

That sound great.

Nothing about esthetics, should we include esthetics in the performance?

No, you can say... yes... in a way esthetics is a driver for introduce the technology that you can create, you could say, this was the driver for the double skin facades that actually this was the way the architect would get these very plane glazed facades and the engineer could have some functionality to the facades. Esthetics have always been very important in the way we design façade but if it's a performance characteristic or performance metric, I don't see that either.

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades and justify that?

1. Occupant satisfaction: This is the purpose of our building. To create a comfortable environment for people to live and work in, and this is the main purpose of a building. So, that why I put it first.
2. Cost: cost is also quite important too because this one of the biggest challenges we have, when we try to make a little bit more advance technology, that also become very costly and, therefore, this is a big challenge.
3. Energy: Of course is important too for the environment, I think this is not a big ..., everyone want to do that but, let's say, bigger barriers for introduction of the technology than energy.

8. Do know any performance-based standards (not absolute values) for adaptive façade? Do we need new standard for adaptive facades performance assessment and Why?

This is pretty much the same discussion that we had about daylighting, where they are struggling where everybody is using this daylight data and everybody knows that it's not actually reliable representative the quality of the daylight in the building, and then they do have developed different dynamics indicators, like daylight, autonomy or all of parameters which are estimated/based on hourly calculation on hourly basis

and then we develop these indicators. And I think we need to go in the same direction with the performances of adaptive facades. We don't use these data U-Values, solar shading factor and so on but actually evaluate the performance of the facades instead.

So, I fully agree that it would be good to rule that, but, in a way, we can say, I think we do have the standard because if you look at the European standard, there are also standard for, you could say, dynamic calculation and buildings performance. It is not just that in many countries, it is not used as much it has to be.

So also it should be linked or there is already existing dynamic calculation so there should be kind of more review of them and referring of them? or applying them more?

Yes, you can say it's an egg or a hen problem this because the reason that we, you could say, are not having more dynamic performance indicator is because, there is, reluctance to require design or to use dynamic tool especially for simple building that we should be possible to do it by static or monthly calculation.

There is a reluctance to introduce dynamic performance indicator because at the same time it would imply that it would require everybody to do dynamical calculation. So, I think what we should do instead is actually to try to emphasize the need for dynamic calculation to estimate the technology properly and then we could also quite easily develop dynamic indicator that make sense.

I am trying to push this but I haven't been successful and there is a number of industries solar shading, facades and industrials who are also pushing for this because, in order to prove the benefit of these technologies, it can only be done by dynamical simulation. We cannot do it by static tools. So, they are pushing too.

I'm not sure how it is in other countries but we have been able to make in Denmark. There is a requirement that you have to use this monthly tool to prove the performance of the building, in the regulation.

We have a compliance tool which are based on a minimum calculation of the performance of the building and this tool have to be used when you prove the compliance of your building with the regulation. But we have reason to get the possibility that we allow to do dynamic calculation, and then, calculate the input parameter that for the min monthly tool, same result, so it is a little bit backward. But I see this as a starting point. But I think this is actually, this point is very critical because it is a big barrier for the introduction of these technology that you cannot prove its inducted performance in these tools.

D. Disadvantages of Adaptive Facades:

9. In your opinion, what is the fraction of adaptive facades in today's European market? And why?

If we refer to these, you could say, more advanced, with a lot of automation and so on, I think that this is quite low. At least, in what I know, I think it is a little bit different in center Europe, but in north Europe it is quite low.

I think it is mainly because of the cost because people are afraid of the maintenance of the facades. And because, have been a many example of difficulties in controlling them correctly. So, it has been difficult to achieve occupancy satisfaction and actually the energy saving has not been reached and so on. So, there are a lot of bad examples. That is a barrier.

I can, at least see, on the more simple solution, I can see a more develop now because there is a strong development, you could say everybody can buy a sensor

and connect it to some kind of control device or some kind of unit where you can program some kind of control strategies but these are technologies that you can find in the market and you can, well, not easily, but relatively easily you can put things together, so therefore I see now, a lot of small companies coming up, offering different solutions for shading, window, opening and so on. I see it's coming as a kind of grass roots movement where you see, smaller companies offer different services to people or different, calling it, smart home, control or something like that, that can be added to the existing buildings.

So, in one hand there is in a development in this automation, and you could say, in IOT development that is making things more automatic and motorized also even in homes.

You can say, it is a different type of actors coming into the sector which are more focused on services, how can they improve the services for people and their control of the buildings is one of these aspects that include in this package or services they offer to people. So, they develop in this direction, you could say from the low rent of the adaptive facades where you have manual control before, I don't see the same development in the other hand that these technologies are getting, let's say, strong improvement, I don't the same development in that hand.

10. Does the cost impede/hinder the market penetration? What is the influence of mass customization on cost? (Weaknesses)

I think the cost has a big impact and is one of the main barriers for market penetration. I fully agree and I'm not sure that its, yes, you can say mass customization, but, I think it's also have something to do with, you could say, integration, because, if you have a façade there is a lot of things that you also need to do to make it work. So, it's maybe you need to have wiring for sensors and you need to adjust the control and so on. So, there is a lot of things that you need to do when this could be made a little bit more automatic, for example you have to match, there is a huge work in matching all the sensors you have in the buildings with all the right motors and all the right motors actuators and boxes and so on. So, just making all these connection work and be right is actually quite a big work, to do this. And if you could develop some kind of, let's say, more automatic system for that. So, you could say, the façade already identifies the closest room you need and the sensor you, some kind of DPS automation or something like that the weather were and in which zone of the building and so on. So, this could be created automatically, then this would also save a lot of cost.

Because when I look on the cost this façade, this cost is actually quite high and need you could say, the cost that mainly differentiate a more ordinary façade with an adaptive one, because the paint is the same, the construction is the same, shading and so on, a lot of things are the same product, so they don't cost more than the typical façade.

I think so, because now the building you refer to and many other buildings, I would say are unique buildings. There are the one who have very high profile and where the esthetics and presence of the façade is very important for the building. But I think we also have a more ordinary of construction where you need to build thousands of square meter of office buildings for work purposes and so on. So, I think a more typical market and in that market I'm sure that mass customization will have a place and will be important and these are also typical of construction a where you have more limited budget. So, you have to be more aware about the costs. While in these

unique buildings, sometimes have another, let's say, level of budget to work with and actually can afford to develop your own solutions. But you right that if you look at this ordinary office buildings sectors that they are not using adaptive façade and maybe this is the cost is too high and this mean that if you could this mass customization that would be a possibility to increase the market here also to these buildings.

11. Do you think that adaptive façade technology (motors/actuators, sensor, products (e.g louvers) and control strategies) is mature to penetrate the market? And Why?

I think actually, we have a lot of knowledge on what does work and what does not work. So, we do have a lot of knowledge and experience. So, I think it is a mature technology.

It seems that we put more and more functionality into the glazing, so, before, at the beginning, glazing was the weak point in term of insulation, now, they have developed the glazing and the window pane unit so, actually they insulate better than the frame, so this means that it's better to have as much glazing as possible. And what is happening now is, actually, that with the solar shading that we never have being able to find good solutions for solar shading, because are they internally or externally and so on.

And now, it seems to be putting into the glazing so this is a functionality of the glazing so to me it means that more and more things are putting into the glazing and the pane unit. So, they can handle more and more things, more and more functionality and ventilation.

This is what I see in development and I..., probably, it will continue in this direction.

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

This of course all the motors and actuators, and this is because there are a lot of examples of..., yeah, problem with motors that does not have the lifetime that is expected and require more maintenance then expected, so, I think that's the main risk.

The motor does work for a long time but if you have motors and 99% this is working, this is successful for the company, but for the buildings. They focus on the one that does not work. And not on the 99% that is working so I think it's a question of proportion. That from the building perspective you will always looking at the few that are not working and they are pain, but don't think it was actually nice that 99% of them is working.

And then, another thing is of course noise, because this is sometimes, and I don't know if this is because you try to save some money when you pick motor or whatever but I think often noise is a big challenge in this system.

E. The Future of Adaptive Facades:

13. What needs to be done for a better adaptive facades project delivery process and better performance quality?

I think it's better communication and by that I mean that, you could say, today, communication between the façade, contractors and then, you have all the other contractor which are delivering the HVC system to the building or the lighting system to the building and that often, there is a lack of communication between these they don't always work well together and this mean you quickly lose the benefits. So, a better communication between, we could say, all the actors in the façades is necessary to be successful and improve the quality of the performance.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

I think this is a big challenge we have that this is probably also the big challenge why we have so many building we do not perform well, that we don't have..., nobody is actually responsible for making sure the building is working as intended and have the performances that we expect. I don't think this is only a problem for adaptative façade, this is a general problem we have in the building sector. To me, I would say the most probable solution is to have a special service on this, because, I don't..., the contractor actor has no interest in maintaining things in the operation phase and the building owner have a lack of knowledge on 'how to do it' and the occupant have other focus, they should not focus about the maintenance thing, they should do their work or whatever they are doing. So, I think we need a new, you could say, operation contractor, or whatever it is, that had the contract to maintain and operate the building in the most efficient way. So, I would not put any of those in this act but a new actor.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

I think, in the long run, I am sure, it would be obligatory. If I look in the Danish building legislation its more and more emphasis on monitoring and on, control that things are working as intended. And I think the main reason it is maybe not as high level yet I think it's because of the increase of cost because at the moment even though you can build..., you can buy cheap sensor when all the cost is putting them together and then, they communicate to other things and so on. Then, actually, the cost is quite high to do the monitoring, so I think that's a big barrier, but development is going in the right direction. So, I think, as soon as, we have product on the market which can monitor what going on in the building at a reasonable price, then we would also see a requirement to actual performance of buildings and requirements to continuous monitoring.

16. What features would you like to find in the future of adaptive facade?

My dream would be that we move everything to the façade. So, all the services are in the facades. Instead of having the services, in shaft and so on, distributed in the building, I could see that you could move it to the façade instead. This should make it, you could say, more flexible and maybe also easy to maintain. So that was my dream to put everything in the façade, so this means that we have..., so I see we do have some, especially in renovation activities where we tried but we were unfortunately not successful but actually we tried to put all the services in the façade, the motor, the drainage, the heating, the ventilation, everything was in a shaft in the façade. So, it was easily accessible from the outside and then you also organize bathrooms and kitchens, so they have access to this unit in the façade, so you did not need to have distribution high pipe and things in the apartment.

But it turns out to be quite heavy because it is mainly because, the way apartment is organized today is typically, around this central core where you fit all the services. So, this means if you want to realize, if you want to move services to the facades, it means you also need to change the layout of the apartment.

So, you have all the functionalities that require a lot of service like kitchen and bathroom and so on, are close to the façade instead of being would in center part of the room, of the building. So, it proofs to be more difficult to implement in renovation then.

Do you have a reference or a study, publication for that?

For renovation, yes, I have some work in IEA in annex 51, where there are some examples where I put, I think they put the ventilation in the façade that you can see many bases.

(references)

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

I think that would have changes, because I see, if we look at the way we are tightening the demand of a performance of our building, I think some of these goals cannot be achieved without having adaptive façade. You need to have some..., it needs to be adaptive, otherwise you cannot have fulfilled requirements with the static façade, that's not possible, that's man it need a push for adaptive façade, then you could say the development in IOT and you could say, soft glare and so on, are also booming quite fast, and maybe especially in other areas, but as I say before, we see google, apple and amazon are moving into our fields and I also see this as a which can be booming suddenly. And this would also make it more easily available to install adaptive façade because we can couple to technologies that is there and for other many purposes as well. So, this means we can get this control and so on for much lower cost than we have today. So, I think they are, I see quite good opportunity for the future.

Can we call it smartness? is there any opportunity in the smartness?

Yes.

Is there an opportunity when it comes to the wellbeing things or you included also in the smartness? The raise of awareness? Or it cannot be a driver?

I am not sure it would be a big driver because ... no, I don't think it would be a big driver that we can constantly improve the wellbeing or indoor environment ...I don't see that as a big driver.

But more in the control side and knowing when to use it side and operation side.

Yes.

Interview with Dick de Leeuw, De Leeuw Ltd.

Name: Dick de Leeuw

Date: 03.01.2019

Place: Ross-On-Wye, UK

E-mail: dick@deleeuw-ltd.co.uk



A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

Core specialization is determining which type of solar & glare control is best for a particular situation / building considering the occupiers' needs, wishes, orientation of the facades and surrounding buildings.

2. How long would consider yourself in the field of façade?

35 years; since January 1983 with references across the UK, the European Continent, Middle East, Latin Americas and the Far East.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of an adaptive façade?

Adaptive facades can change to the needs of the occupiers as both internal and external environmental conditions change. Solar shading & glare control externally or internally fitted, depending on the latitude of the building, can also change the U-Value of the façade during winter.

4. What are the strengths of adaptive facades?

Main strengths are, providing a well thought out system is in place, improved internal environmental conditions resulting in higher staff productivity, reduced energy costs, therefore reduced CO2 emissions.

B4a – Main weakness: Quite often systems are well designed but poorly executed due to lack of knowledgeable installation personnel / supervision, under-specified materials due to 'value-engineering' during the manufacture stage and / or the occupiers overriding the controls as many do not understand the benefits of the system.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

New Suffolk College; approximately 350m² single cell insulated glazing. Orientation: South. Excessive heat build-up and glare issues made the building unworkable. A/C running at full capacity but not coping. Too much light inside the building for it to function as a building of education with all its 'whiteboards'.

Fully automated roller blind systems were installed, deploying automatically when 330 w/m² is projected onto the glass. Staff do not have the facility to raise the system. Staff can only 'lower' or deploy the system if needed, for example, during winter with low sun angles when the temperature on the glass might not reach 330 w/m² but light

intensity is too high; i.e. To reduce glare. The material used to achieve success was Mermet SNU screen as calculations and measurements by a Building Simulations Company showed this material to have the correct values.

6. **Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)**
7. **Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades and justify that?**

This largely depends on who is doing the ranking:

Developer: No 1 is cost of the system / No 2 is energy (to meet BREEAM).

Occupant satisfaction is not important for the developer.

Architects: No 1 is energy rating to meet BREEAM / No 2 is cost / No 3 is occupant satisfaction.

Occupant Finance Officer: No 1 is cost reduced because lower energy cost / consumption / No 2 is maintenance cost of system / No 3 is occupant (staff) satisfaction.

Occupant (staff): No 1 is occupant satisfaction.

8. **Do you know any performance-based standards (not absolute values) for adaptive façade? Do we need new standard for adaptive facades performance assessment and Why?**

No, not aware of any standard. Standards would almost be impossible to set unless we first have standards / directives dictating the maximum energy that is allowed to penetrate a building, but those would be impossible to set as well as it is dependent on geographical location of the building, time of day etc. etc.

D. Disadvantages of Adaptive Facades:

9. **In your opinion, what is the fraction of adaptive facades in today's European market? And why?**

I estimate the fraction of adaptive facades to be less than 0.1%. Unfortunately, shading, energy and glare control are still very much an 'after-thought' and only given 'lip service' by architects during the design stages. Many architects still think that the 'right glass' will solve all their problems plus developers of bigger buildings count their 'Pounds per square foot' or 'Euros per square meter' development cost, leaving solar shading to the occupiers as an afterthought.

10. **Does the cost impede/hinder the market penetration? What is the influence of mass customization on cost? (Weaknesses)**

See 9. Cost is a major factor during capital outlay considerations. Mass customization, if possible, would certainly give 'economy of scale' but no 2 buildings are the same.

Do you think that adaptive façade technology (motors/actuators, sensor, products (e.g louvers) and control strategies) is mature to penetrate the market?

And Why?

Adaptive façade technology is mature. Further ideas, tweaks to systems, materials can be further developed so it will evolve over time but in principle the technology is here today; it just needs to be accepted as a standard building element like a front or back door, like a roof on top of the building; you can't do without it!

11. **What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)**

It is generally regarded that 'adaptive facades' or let's say, fully automated environmental control systems, are susceptible to high maintenance. Up to a point, this is true, but only if systems are too complicated and / or inferior materials are used. ('Value engineering?'). Electronic control systems are highly reliable these days providing they come from a recognized and well-known source. Hardware systems often 'let the site down' due to cheap materials being used (too many plastics and not enough aluminum and stainless-steel components). The solution for adaptive facades, for both external and internally fitted systems, is to keep it simple, few as possible moving parts.

E. The Future of Adaptive Facades:

12. What needs to be done for a better adaptive facades project delivery process and better performance quality?

For better adaptive facades, we need to educate the buildings' architects / designers, so the structures of adaptive systems can be incorporated in the design, making them less susceptible to the elements. Architects / HVAC engineers, need to be educated on the properties of the different shading materials / systems that are available, having all the advantages / disadvantages of each solution explained to them: i.e. Solar thermal performance; light transmissions and if used internally, improved U values. They need to understand that a beautiful design of a system may break down within 6 months if made cheaply.

13. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

Ultimately, it should be the designer / architect that is responsible for maintenance (i.e. cost). The general contractor can't be held responsible as they only put in what they were asked to put in (Unless they 'value engineered' it and cut costs). General 'annual' maintenance should be funded by owners / occupants and executed by the suppliers / installers of the system. Any serious breakdowns to be funded by the designers within let's say a 5 year period. This will sharpen the designers' minds to design something that is robust.

14. Do you agree that soft landings, POE and monitoring should become obligatory?

Yes, soft landings, post occupancy evaluation (POE) and onsite monitoring should be obligatory but once again it will come down to cost. If this is built into the first main contract, it makes the system more expensive. If not, then a maintenance budget needs to be set aside. So, either the developer or the owner / occupant. Experience tells me that both parties will take their chances for as long as possible and wait until something breaks.

15. What features would you like to find in the future of adaptive facade?

Adaptive facades, or rather the automated systems that make a façade adaptable are uniquely positioned to make use of the very energy they are designed to keep at bay. I am convinced that 10 or 15 years ahead, will see some serious development of photo-voltaic systems integrated with the basic elements of solar and daylight filtering equipment on both the inside and outside of a façade. Not only to drive the systems themselves but also to feed any surplus into the grid or for use in other parts of the building.

16. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

Opportunities present themselves on a daily basis but unless we grip the bull by the horns, it will remain a 'niche solution'. As energy consumption, output of CO2 and cost become bigger headlines every day, the very principle of adaptive facades and its advantages needs to be brought to the attention of the legislators so that buildings over a certain size (to be determined) and projected energy consumption have to have adaptive systems as standard.

Interview with Mauro Overend, University of Cambridge

Name: Mauro Overend

Date: 08.01.2019

Place: Cambridge, UK

E-mail: mo318@cam.ac.uk



A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

My core specialization is on glass facades. The projects that I have been involved in, mostly recently, are on research and development rather than real world buildings.

2. How long have you been in this field?

So, I have been in academic role since 2004 and before that I was working in consulting engineering firm, which included consulting façade engineering so to this design of real-world buildings.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of an adaptive façade?

So, in my opinion, an adaptive façade is a façade that can modify its performances and its immediate environment, in response to environmental stimuli or to occupants' requirements. The objective or the aim of the adaptive façade in doing so is to improve the performance of its immediate environment, could be external, could be mostly likely internal environment and of the occupants or the people that interact with it.

4. What are the strengths of adaptive facades? (Strength)

An ideal adaptive façade would be strong because it can cater for a very broad range of needs and environments. So, it can perform in optimal or very good energy performance at a range of environments rather than at just one particular instant when it's very hot or very cold or some intermediate free-floating kind of period. But it can perform throughout the range of different conditions.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

Mostly, the purposes of projects, with which I had some involvements, are to deal with physical shading devices. More recently within the façade, in some kind of cavity system facades, where there are shading devices: louvers or blinds that respond to the external environment, the internal environment and the occupant requirement, that's one. A similar approach where, instead of having physical shading devices, there is so form of chromogenic or switchable glazing. Nothing else perform in a very similar way in order to moderate the solar radiation and from external to internal environment. And the lights, essentially the control of glare. I have been involved recently in another version of adaptive façade that should be included, within the definition of adaptive; it is the adaptive in the long term, in the sense of adaptive in terms of circular economy. In other words, materials that are

used or components that are used in facades that can be made easier or the system can be designed and manufactured, in a way in which, it will be easier to reuse or recycle some of those components at the end of its life. Or indeed, when the components need to be replaced. So, this would be not short term adaptivity to some diurnal or seasonal environmental change. But this would be the adaptivity in response to a change of use on buildings or when the façade needs to be replaced. To summarize, adaptivity comes in different time scales. So, in short time scale, the sun is out, during operation. In this way, looking at a much longer time scales of adaptation. Adaptation of the buildings meaning that it can be easily upgraded or either replaced. Or maybe change the use of buildings. What if the building changes its use? You have an office that becomes a residence, can the façade respond to that or be easily adapted?

- 6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)**

The main headings, I think, are all there.

- 7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades and justify that?**

It depends how you measure importance, so, occupant satisfaction, energy and cost maybe in that order.

So, I would put cost last because, particularly, if this a commercial building which is not defined but if it is, then the overwhelming majority of the cost comes from the occupant's comfort, productivity and satisfaction. So, I think occupants' satisfaction will be a very good proxy for operational cost which is a large component of the total cost. So this is why I put cost last. It's already within that context, within that definition, its already imbedded within, or most of it is already imbedded in occupant satisfaction. And if satisfaction also means comfort, which I imagine it does.

Energy also has a component of cost but there are other implications in energy, which is particularly the non-renewable nature. So, I would put occupant satisfaction first because its already incorporates quite a bit to some extent of the energy and a lot of the cost in it. And the biggest future potential, I see for adaptive facades, is in improving and being in tune with the occupant satisfaction. I think that's where the big potential is.

- 8. Do know any performance-based standards (not absolute values) for adaptive façade? Do we need new standard for adaptive facades performance assessment and Why?**

Not really no. The only one that potentially, but I am not sure, I haven't looked at it recently, but there was in the buildings regulations in the U.K., a provision, I am not sure it is even still there, that you could asses the energy performance of your building in terms of overall CO₂ equivalent emissions. So, this is a very tenuous link here, but that means is that rather being a prescriptive u-value or g-value what it is, it is what it allows effectively is for the designer or the engineer or whatever, to come up with whatever façade and to show that over a typical meteorological year, that CO₂ target is being hit. Its performance based rather than a prescriptive u-value for example. I can check its status if it is approved or not. But this was never intended explicitly and exclusively for adaptive façades but mainly for buildings. Its intended to allow the flexibility for designers to come up with a strategy without having to stick to some perspective value.

We need new standards, whether they are new standards or whether they are existing standards that are amended. So that they allow the flexibility and they allow us to really make use of the potential of adaptive façade. I am not sure whether it

has to be a new one or if the existing standards are not adequate. I think it's going back to what I was saying; it really is a mean of allowing the designers and the architects and engineers to have flexibility, to come up with a system, in this case adaptive façade, which is transient. It's not a static system, so they really can make use of that of its potential in terms of performance, in terms of occupants' satisfaction, in terms of energy reduction, in terms of all these things. So, as the conditions and requirements are changing, transiently, and the performance or the characteristics of facades are changing and to optimize its performance. So, I can't see how we can do it with a single prescriptive value.

D. Disadvantages of Adaptive Facades:

9. In your opinion, what is the fraction of adaptive facades in today's European market? And why?

It depends what we include as adaptive, so strictly speaking, even if you can draw your curtain or open your window or open a vent in your façade, this is adaptive. But in a way that people, in general, understand what we mean by adaptive is having some level of automation optimization, some intelligence, smartness. I think this is less than 1%. This is not used because of, first, the cost and secondly, complexity, by complexity I mean things that are more difficult to procure, so contractors will be willing to install them, things that go wrong and start to break down. So, not only maintenance, in the sense of things are designed, and they are running as they are intended to, but they break down much more frequently that they were ever intended to break down. So, the problem is quality and robustness of the systems.

10. Does the cost impede/hinder the market penetration? What is the influence of mass customization on cost? (Weaknesses)

Yes, cost impede the market penetration. The influence of mass customization would be to push the cost down. It could potentially work because the only thing that needs to be changed is the control strategy, so, if we have an adaptive range, a switch ratio, it really depends when you are turning this on and off and what you are doing in between. So, you could have something that is broad enough in terms of achieving or being required in different climatic regions but it's being used more often or at certain levels at one region and less often or more often at other settings in another region. It's a matter of control strategy and I think this is why this might work in a similar way... like for example unitized systems where something quite unique and rare only use on signature buildings a few years ago. And now unitized systems are the large proportion of curtain wall façade, so I think it's a matter of technology developing and filtering down into the more everyday kind of applications.

11. Do you think that adaptive façade technology (motors/actuators, sensor, products (e.g louvers) and control strategies) is mature to penetrate the market? And Why?

I think there are motors and products, not very many, but there are few, and a few producers and manufacturers. And I think that those are either mature enough or very close to being mature enough and in fact, there are being used in the signature building as you put it, in adaptive facades. I am not sure that control strategies are so well developed, I mean there are control strategies and they must have work but I don't think they are making the best use of adaptive facades currently. Mostly what they are missing, in my view, I am not so sure in some control strategies, in the sense of how, so I am talking about automated strategies here, that some simple measurements are taken from sensors, sometimes even externally, for example, without really considering what's happening internally. For

example, for shading a building. So, some of those environmental sensors that are used and where they are used and how that data is used to form the control of the adaptive façades. I think that still more needs to be done, a lot more needs to be done there but even more so in the interaction with occupants, I think that's where even more needs to be done with control strategies. Of the three components you mentioned I think the control strategies is the one that may be lags a little bit behind.

But overall do you see it as a mature technology to penetrate the market? Or we are in the midway or we are very early? So it can be used in different ways without problems.

Without problems, yes, I think it can penetrate the market. But I think there are many short comings, so many failures, many problems with the façade not operating as it was intended to or as it was expected to. So, this sounds to me as if it probably is not mature enough. It's being tried and its being in some case successfully but the success rate is not very high. This is all anecdotal, I haven't got statistical bases but I hear about too many, I think, on average facades that have some adaptive features not performing as they were expected to.

So, let's say that one of the areas that needs still development is definitely the controls strategies. And in general we cannot say the water a sealed, water sealed technology it is mature but still it is not in a 100% maturation.

It needs more work on its reliability.

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

The biggest risk in my view is the failing of moving components, the motoric or mechanical components. This is the biggest risk in the current like generation of adaptive facades. So, I think the very moving components of these adaptive facades is what often or the little I've come across it seems to be the root of the problem.

Maybe this take off of the interview because I am trying also to make a drawing of the generation of adaptive façade and I was talking with a German expert and he would say that adaptive façade, for him, would have start when we invented the steel chroma, or steel coating in 90s that were transparent and integrated in the glass sheet to use the solar radiation going through the component. When do you think it started?

That's a good question, so I wouldn't put the coating, the high performance coating whatever they might me: low emissivity coatings, solar control coatings, spectrally selective coatings, I mean they have made huge improvements in that domain of glass, but they are not adaptive, that is static perform in that way, always, light transmission radiation, reflect it in whatever circumstances in constant percentage. So, there is no elements of adaptivity there, so in that sense an openable window is more adaptive than high performance coatings. In fact, high performance coatings are not adaptive at all.

So, this put me in the trouble that if I want to say adaptive façade as a technology, if I want to create a timeline of the evolution, I will go back to the Romans or something.

Absolutely! You have to find the first... So, at the beginning building just had openings right, with nothing in there. So, you have to find the first instance, which I don't know where it is, when somebody put something on the window that would temporarily put on or remove, it could have been a piece of wood or clothes or whatever.

And then, I think the next step was movable, manual shading. That we see in the Mediterranean also.

Yes.

Louvers can be a second kind of evolution.

The louvers, yes.

And then I think we would have a long distance until we come to the technology after world war 2, what do you think would be the first generation after having the movable windows and after having also manually operated devices or installation? What would be the first that we would consider as adaptive.

It's got to be the first mechanized. I don't know which one it is. The first mechanized louvers systems. The first shadings system I would imagine.

And then after that, I guess, we would have electrochromic

Yes, I think the first shading device which has come before is also the ventilation control, right. In double skin façade and things of this sort.

But double skin façade come after the motorized louvers?

I think so, I 'm pretty sure. Do you know, but here were others before, the well-known Jean Novel institute?

Yes, "l'Institut edu Monde Arabe", true, maybe it has to do with iconic building if we trace historic.

But It must have giving forward, there must be ones before that.

Yes, because Jean Novel building was already advanced. It couldn't do such a building without building on previous success.

And what is the meaning for you of "current generation"?

So, the current generation that is used mostly in the few real-world applications, real-world buildings mostly involves shading devices that are, in some way, mechanized. So, traditionally these were shading devices that were used externally on buildings and these were reliability because they used to get, they use to fail, they were exposed to the elements and to large temperature variation and everting else.

E. The Future of Adaptive Facades:

13. What needs to be done for a better adaptive facades project delivery process and better performance quality?

For better performance quality, I think we really need two things. One, testing these adaptive technologies close to reality contexts before we install them in buildings. Because one of the problems I see with adaptive facades is that none of the performance testing requirements of conventional facades are suitable, in the sense that you get water tightness test, the air tightness test, all these mock up type of tests on facades that are intended to assess and verify the performance of facades before it is actually installed in a building. So currently, there is not a range of tests that would be suitable for adaptive facades that would test their cyclic reliability. So, what happens is that these facades that are being designed, some of them are tested for water tightness and air tightness and soft body impact and hard body impact and all these range of tests which all very nice and very well. But what is often not tested is the reliability in terms of the cyclic adaptation and performance of facades. And the façade gets installed in the building, and guess what? It fails in this adaptive feature of it, right? Because it hasn't been tested properly.

So, one of them is testing and the other one is the development of components and the materials and systems that are a little bit more robust, I think whether they involve fewer moving parts, whether they can deal with maybe larger temperature variations or whatever it is that these components are being exposed to. So, those

are the two aspects that will improve performance. They test thing of existing things to make sure that they work and secondly development of new better performing materials and components.

In terms of the adaptive façade project delivery, I am not entirely sure actually, I think with the project delivery process, it would be very nice they will do in which, you could reduce as you say the fragmentation but I am not sure there is an easy answer to this because by... the reason there is so much fragmentation is because there is an intention to spread the risk. So, by definition I think if you are going to lump everything together you are going add up a high risk, for the company that's doing it. So, I am not if there is somebody who is going to be brave enough or confident enough maybe to do so. I don't think there are big enough players in construction industry, it is a reality. There is not a Toyota in the construction world, is there? If you can show that the risk is reduced even more implied to take more on there is not lot of risks but with adaptive facades I think there is a perception that there is a high risk cause its, you know, things are moving, things are adapting, things can go wrong things are quite new. Right? It is not very right, not very tested technology. So I think the answer must be to do more testing and to do more to reduce that risk and that seems to be in their performance. Then, hopefully the delivery process might become a little bit less fragmented and more companies will be willing to take more on and centralized the tasks rather than distribute them. I am not sure this is going to happen.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

So in a proper lawyer's kind of answer, I think it depends on the contract. So, if it depends what has been agreed in the first place. In an ideal world, I think it should be the general stroke façade contractor who must be responsible for maintaining it. But the others need to be involved, in an ideal world, because the building owner needs to be involves in terms of the feedback and the occupant satisfaction and whatever else. The façade consultant should be involved because it could be useful information for them to update their knowledge base or whatever it is, of how these facades are performing for the next project. So, I think all of them should be involved in some way, in terms of executing the work. I think in an ideal world it should be the general contractor stroke façade contractor who should do it. Because the ideal procurement system would be one that does not simply install is not, as you say hit and run, you install the façade and you disappear. But that you install the facades and what the general contractor or the façade contractor is providing is a façade that not even a façade, what they are providing is an environment or an experience. So, what they will be doing is maintaining that environment and experience to a great level of whatever it is over the course of the service life of the façade. So, the procurement becomes not installation and that's it. But a performance base service life agreement. So that's the ideal, but all of them should be involved in the loop right that process of upgrading and assessing its performance over the service life.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

Yes, on the base of what I just answered before. This is a service life performance then, absolutely, all of those are essential. Soft landing is to making sure that everything is right in the first place and its working as expected and operated as it should. And then, the POE and the monitoring should happen throughout the service life and not just in the beginning.

16. What features would you like to find in the future of adaptive facade?

I would like to find most of all is the mass customization of occupant's satisfaction, in other words that the facades can respond actively or passively, but adapt successfully to the requirements of different users in the space. In other words, if I am sitting behind a façade and my colleague is sitting behind the next two panels down or whatever, two units down from me, then that façade is responding according to my current needs, which might be different from the needs of my colleague who is maybe two desks away from me. To personalize the response.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

I just want to tell you that china just published two really interesting papers, I just want to share with you what they published, they said that the European and American construction industry prevented China to penetrate the market for one reason, for having strong standards, so China today construction increase 300 times in the last decade. And this increase was made mainly in Asia and Africa, but they never managed to enter the US and Europe and one of the reason was the strong standards in Europe and US, and in this context I think, what are the opportunities for us here in Europe to increase the use of adaptive facades in the future?

I am not sure what..., so this actually is really interesting what you have just mentioned. I am trying to see the connection between.

The connection is that it is not only about cost because if we want to have low cost we can get Chinese company to come and builds our adaptive façade. There must be something else that we have here in Europe that can be an opportunity for the adaptive façade. So, simply the only thing I'm saying, it is that not we say that only if the cost decrease adaptive façade... There must be other opportunities and qualities that you are seeing.

I think if we are able to somehow quantify or show in the design process how important the ongoing performance of a façade is, during its service life, both to the energy but also and maybe the occupant wellbeing and satisfaction and productivity. I think this would be the game changer as it were for adaptive facades. But it's difficult to do so, because then you have a very important lever and a very important trump card if you like you say okay are you spending ten fifteen twenty percent more in the construction of your adaptive façade but this is going to save you, you know hundreds of millions of whatever it is right? over the service life of a building, in terms of productivity improvements, in terms of wellbeing of occupants, in terms of energy performance. So, I think the more we are able to draw on the service life performance and quantify that, and the more the construction industry and the client and everything else buys into that and understands that, the more the opportunities will be for adaptive facades.

Interview with Philipp Molter, TU-Munich

Name: Philipp Molter

Date: 09.01.2019

Place: Munich, Germany

E-mail: philipp.molter@tum.de



A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

I am an architect working on adaptive facades but also in the field of facades in general. Our research at the Technical University of Munich is focusing on autoreactive facades. Autoreactive facades are able to react to the climate conditions without any sensors and actors. So, the façade responds to the climate conditions within that system itself. We have done some projects together with the façade industry especially with Frener and Reifer, a company specialized on highly sophisticated façade systems.

2. How long have you been in this field?

Now, it's been let's say 10 years.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of an adaptive façade?

According to us in the chair of building envelopes, adaptive facades respond to their environments mainly to climate conditions. We distinguish adaptive façades and auto reactive façade. Adaptive façades is a generically used term meaning that a façade can react to the environments. Facades can specially react in a very direct way where they don't use any further energy except the energy they take directly from their environmental change.

Can we put the reactive façades under the adaptive facades?

Yes, definitely. It's a special field within adaptive facades. An adaptive facade can also be a façade that is manually operable or by motor. However, an auto reactive façade would be openable by temperature changes and use those temperature changes and the energy flows within the façade and their environment.

In your opinion, what is the purpose of auto reactive façades?

Auto reactive facades should mainly simplify the management of the façade. So actually, auto reactive facades should improve the maintenance and the everyday exchange with facades.

4. What is the strengths of adaptive facades? (Strength)

Improving the indoor comfort for users and reduce energy consumption.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

So, one of our biggest project is the Flexcover project. It has a double skin façade, which opens up the cavity auto-reactively due to the temperature change. Then, it cools down the double skin facade and especially the blinds or the suns shading devices by natural ventilation. In winter time, it reduces the heat losses because it is

very close to the cavity, which is not ventilated and improves the buffer zone of the cavity.

Another project we have investigated is the Shade-wing with auto reactive shading devices. The shading devices unfold by temperature raise in order to provide shading, for fully glazed façade. In the condition, when low temperatures levels are present, the sun shading device fold it and much self-shadow is avoided on the full glazed facades.

Persiani, S. G. L., Molter, P. L., Aresta, C., & Klein, T. (2016, September). Mapping of environmental interaction and adaptive materials for the autoreactive potential of building skins. In *Proceedings of the 41st IAHS World Congress Sustainability and Innovation for the Future, Algarve, Portugal* (pp. 13-16).

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

I think now circularity is a big topic and I am not sure its circularity can be part of this. I think, it is part of the embodied energy or the embodied carbon. Of course adaptive facades should be based on simplified components with simple assembly instruction methods but in reality they are technically complicated and too complicated to disassemble. I think that somehow in between embodied carbon and embodied energy, maintenance is a big issue. So the table is missing the maintenance and durability and circularity criteria.

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades and justify that?

Can I add one to them?

Yes.

I think flexibility. Flexibility is number one because if the façade component is not flexible then it will be replaced in a very short period.

What do you mean by flexibility, can you define flexibility?

Then, cost is always sort of related to a certain time period, so investment cost is only for the period of investment, but it has nothing to do with the maintenance of the building. So when we talk about cost, we talk mostly about investment cost and not about maintenance cost. But we know that maintenance cost are mostly more important than investment. Flexibility has to do with this because if a building or a façade is flexible to respond to different uses and to different users and occupants. The investment cost could be higher because the lifetime of the building is supposed to be longer as well, because, after certain period, the façade component could have another use. For instance, office building could later be used as residential buildings or residential buildings could be used as an office building. So the flexibility of the façade and the building itself defines the cost frame of the investment cost. In this sense, I rank first flexibility then occupant satisfaction, then cost and finally energy.

That's very interesting because flexibility allows for an extended life of the façade and a multiple use.

Right, if you take for instance a building in Barcelona or in Paris that it was mainly used and built for residential purposes it can be now used as offices. Those building can work perfectly fine and they might have major investment costs, way more than what we would invest in a residential building. Today because they have higher ceilings and a very good structure they have very long life time.

8. Do you know any performance-based standards (not absolute values) for adaptive façade? Do we need new standard for adaptive facades performance assessment and Why?

Something like the FC value that you put before the g-value because the FC value sort of defines also the g-values. The FC is a German expression it is the value that you put in front of the g-value of the transparent building envelope.

What do you mean by FC?

The g-value is the amount of energy that goes through transparent or translucent building and then the FC value, you put in front. For instance, the FC value of green façade that you put in front of a window has another value than for instance, say a dynamic aluminum lamella. So, this is like, the dynamic aluminum lamella has 0.7 and green façade has 0.5 and fixed louvres has 0.3 or something.

No but I mean that standards at the end they have parameters or indicators and they put a fixed hold that designer should respect that is the classical way we have a fixed value. My question is that did you see any standard that is not working with a fixed value but is working with a range of values telling the design team you can have a variation between this and that achieve what you can achieve? Because the dynamic nature of adaptive facades requires to have also dynamic.

Definitely yes, on building requirements.

For the second part of the question; do you think we need a new standard for adaptive facades performance assessment?

Yes, definitely. As we do have for instance in ASHRAE standards an adaptive comfort model. So, that means that in summer users accept higher temperatures than in winter for instance. So, I think we need also this kind of a dynamic modeling for adaptive facades, definitely.

D. Disadvantages of Adaptive Facades:

9. In your opinion, what is the fraction of adaptive facades in today's European market? And why?

The business models of the real estate industry do not reflect the intelligences of adaptive facades. So, the business models of the real estate market are not taking into account the advantages and the dynamics of the advantages in terms of user comfort and energy consumption.

If you give us a number assessment, how much do you say if we have a percentage in Europe or in Germany?

So, the amounts of adaptive facades in the total market are less than 1 percent. .

Why do you think we have so little market penetration?

Because the business models of the real estate markets are not reflecting the advantages of the adaptive façade. They are focused on the initial cost.

10. Does the cost impede/hinder the market penetration? What is the influence of mass customization on cost? (Weaknesses)

That's an interesting question. I don't think really because I worked on projects that have a very high initial cost of facades, so more than 2000 euros per square meter. They were not adaptive at all and they were not performing at all in terms of energy consumption and user comfort, so, I don't think cost is a major issue. I think it's more, let's say, the marketing itself.

So marketing is the impeding reason?

I think yes.

Can you elaborate on that? Is it the awareness of the architect or it is more the owners or developers? Is it the designers or the developers?

I think designers have a strong push in fact of the market. But I think developers do not understand the advantages and so they cannot transmit those advantages to the user. I think the user must be trained more towards the advantages of those

facades. I think this has to be done by the developer because he has to respect the contract.

We have now a lot of modular adaptive facades solution; do you think they have an influence on cost? That they reduce the cost in the last years.

Yes, I think so.

- 11. Do you think that adaptive façade technology (motors/actuators, sensor, products (e.g louvers) and control strategies) is mature to penetrate the market? And Why?**

Yes, I think there are a lot of systems already on the market, but they are not accepted by the market because the knowledge of the developers and the stakeholders within the real estate market are not sensible for those benefits. So they block those technology choices made by designers. Because there is a lot of products of switchable glazing and sometimes the developers still advice for the mechanically shading device because they know it, and they are familiar with the dynamic glazing so they always like the advice for conservative system.

- 12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)**

The risk of course is that more technology within development increases the risk of failure and also maintenance cost in that way. But I think the way the technology is integrated in the facade is very important to the success and to the life span of the facade. So an example would be that the dynamic façade should always be built as an open system, so that dynamic parts can be easily replaced and not fully integrated into a window for instance where we have to replace the entire window when one component is broken.

So, the replacement should be taken into account and the accessibility to the whole façade solution.

Right, and the openness of the system, I call it the openness of the system. So the system is open enough to be easily replaced so that the sub components can be easily replaced.

E. The Future of Adaptive Facades:

- 13. What needs to be done for a better adaptive facades project delivery process and better performance quality?**

We need to have better standards allowing for open systems, or open systems that its components can be easily replaceable. We need better performance quality also building regulations, it relates to question number 8. That building regulations could reflect also the dynamic aspect of the building envelop.

You said you worked with a special company in the beginning which was Frener & Reifer. What was special about them?

Well, they are very much into the customized façade market, so they do only the very specialized façade. They do not make, produce large scale, standard façade systems, they only compete with, let's say, jewelry. So, they are very creative and artistic at the end.

How they implement the solutions, they are contractors?

They are contractors, right and I think the specialty is that they convince clients to trust them regarding their knowledge and on their capacity to make the adaptive façade work. I think most developers and clients only search for the cheapest solution for investment cost. I think everybody is convinced that it is about the investment cost, but performance in terms of occupant satisfaction is an important aspect. I think then clients will be willing to pay more initially but will have a better building at the end.

Do they do anything special for the product? Do they follow up the façade after the construction?

I think that is also an important point. There is no follow up actually. There is a planning team that hands the buildings on special day and they are judged and paid, within that period and after that they are not related to the building anymore. I think a lot of people who are involved in the process like façade engineers and architects should also be somehow be part of monitoring process.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

I think the business model need to be changed, I think the façade contractor should have a sort of a maintenance contracts, like in the car industry. When you buy a car but you buy also a guarantee. You know that you always can take the car and bring it to BMW and they are going to fix the problem somehow. Otherwise you can get a new car and I think it's somehow could be good thing to do, not only for adaptive façade, but also for building services. Most engineers overhand their designs and then they are gone, they should also be partially responsible for maintenance contract and get paid for. They also learn from the project, because the learning process is chopped if you hand the project and then, you don't know how it works. So you have no connection to long term behavior of that building.

You are almost the only one who selected the contractor. Most people said it is the owner?

Yes, I think the contractor should be responsible and should be paid. We need new business models for those companies and not only ask them to deliver the building product, but also to provide services. The AEC in the USA is more service orientated and there is a potential there more than in Europe.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

Definitely yes.

16. What features would you like to find in the future of adaptive facade?

Self-regulating components, fewer motors, less mechanical engineering, more smart materials and smart applications.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

I think also to train occupants. That is an important aspect because a lot of occupants are trained for the ergonomics of how they sit in front of the desk and they are trained how to use the computer and how to use their mobile phones and their smart phones. But they are not trained to use building actually, I give you an example, if the blinds are down in summer time of a building, most people would turn off the light, instead of removing the blind. I think to train the occupant and to generate sensitivity for easy use buildings is one big aspect.

Interview with Ulrich Knaack, TU-Delft

Name: Ulrich Knaack

Date: 09.01.2019

Place: Delft, The Netherlands

E-mail: knaack@ismd.tu-darmstadt.de



A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

I am an architect and I acted as a facade specialist and as glass structure consultant. The projects I've been involved are various, I acted as a façade specialist, façade consultant, in smaller, complex and larger technically simple projects. So actually, the larger they are the simpler they become. Also, I worked as an architect in similar situation in project more complex and larger project of simple facades systems and in sub-structural design or structure glass design projects.

2. How long would consider yourself in the field of facade?

25 years.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of an adaptive façade?

Actually, every facade is adaptive because its somehow adapt to certain climate situation. It heats up or cools down and transports the energy from the outside to the inside or from the inside to the outside. A façade gets more adaptive if we have a part which is a line to link the inner and the outer climate: for example, a window is an adaptive component. It gets even more complex if we are able to; somehow, adapt the physical performances of the building envelope. This means shading at the inside and adding insulation from inside or outside, being able to integrate energy adsorption options inside or outside as a system with the purpose of an adaptative facades to balance the energy transport between the outside and the inside, which means to balance the temperature differences, the radiation differences, the humidity differences between inside and outside.

Ok, anything related to user?

All the functions, which I listed, are performing for the sake of the user. For example, humidity control and temperature control are meant to support the user through the building's physical approach. I did not include user in my earlier definition (above), but I am aware of the sick building syndrome discussion. So, the user would like, especially Europeans users, to have an opportunity to improve their comfort through the building envelope. Unfortunately, operable window are already enough for improving the comfort, however, operable windows are not used much. Glare has maybe some aspects, which are more important.

4. What are the strengths of adaptive facades? (Strength)

That they can adapt to balance the inside with the outside. So, in Central Europe, we do have variations in the climate and these variations in the climate: winter/summer, day/night, need to be counter-balanced. Mechanical engineers do this by heating and cooling devices. However, we as façade designers can do this, preferably, through the façade design. A proper façade design can improve comfort for the use functions inside and, maybe reduce energy consumption.

C. Advantages of Adaptive Façade:

5. **Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?**

The first project was Debitel headquarter in Stuttgart (Germany), where we have a double façade. It was a combination of the standard openable window with shading device and standard box window. This combination allowed us to use the window during spring/autumn, with some adaptation abilities. The box window was used as an adaptive tool during the summer and winter. So actually we combined these two types of facades which are very performative, during their optimal period of time operation, which created a more adaptive facade. The single operable window works in in spring or autumn and the simple box window does work in winter or summer.

That's the first project I did with few others projects. But this is, from my point of view, the most important one. The project incorporated a solar chimney, which is not part of the façade directly but that was actually the exhaust engine, to exhaust the used air of the building.

Reference: <https://facadeworld.com/2014/02/14/debitel-headquarters/>

Then, there was the Energie Baden-Württemberg (EnBW), which is another headquarter, which is built in Stuttgart where we re-developed this concept of these mixed facade systems. We added, instead of a fully glazed system at the out layer of the double facades, a metal mesh, which allowed the façade system to be more flexible, in the reaction to the outer climate. But also, esthetically driven, the mesh gave a different appearance.

Reference: <https://facadeworld.com/2014/02/15/enbw-city/>

6. **Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)**

You already revised this Table 1, did you find any indicator that at least are missing? these key ones because if you look, there is energy and environment performances buildings control and services, occupants journal experiences and maintenance durability and life cycle.

Money is missing. Money is actually key driver to it. So, money is the decision making thing.

Do you agree that this is enough to talk about, using the metric of: euros per square meter of the facade? That's an enough indicator?

Money per square meter façade, but also money in the means of reduction of energy cost.

So, we can say operational cost and initial cost?

Exactly, and you also maybe need to add wellbeing of user which can be transferred into financial impact.

Just in this case, how much should be the calculation for how many years should be done: 30, 60, 90 years.

15 years. It has to pay back within a lifetime of a typically CEO or a company, otherwise they don't do it.

7. **Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades and justify that?**

- 1) Cost
- 2) Energy
- 3) Occupancy satisfaction

We are living in a developer's world, and developers want to make it as cheap as possible. But it has to follow energy regulation and has to look nice. For sure, the user is assumed to be satisfied and happy. So, there's a difference to create a building for developers or buildings for an owner. If you build for an owner, user satisfaction comes more in position 2 and energy in position 3. But money is always the leading factor. If you as a designer can't market an adaptive facade because it is better for your people, you have to market it because it is financially, within 15 years, more valuable.

And even if there is it occupancy the wellbeing or satisfaction of productivity, it can be quantified financially.

Yes, but that's hard to make.

8. Do you know any performance-based standards (not absolute values) for adaptive façade? Do we need new standard for adaptive facades performance assessment and Why?

No. I am not good with regulations. However, to be politically correct I should say: yes. But as a scientist and an engineer, I would say, this will never happen, because, it's going to make building construction more expensive. That is not wanted. We had the situation some ten years ago when there were discussions that all buildings in Europe should not exceed a maximum temperature of 26 degrees Celsius. This discussed was killed because it was getting clear that's none of building will comply with this rule. So, we ended up having a European adaptive comfort model that tolerates reaching 32 degrees Celsius if it is 38 degrees Celsius outside. So, regulation will also follow market. Sorry, money is leading.

Ok, in this sense, do you have any reference for this evolution or this discussion or this was a project or ...?

From my experience. This is my constant experience during the last 25 years, during my participation in research projects. Money is always leading, then it comes to aesthetics and finally performance comes third to serve the energy reduction target. This was the same order of priority fifteen year ago, when we had the boom of double façade and energy consumption reduction. Today, public buildings try to reach 25 % energy reduction due to the EPBD regulation and to show the public sector is leading by example. However, most investors do the minimum regarding occupants comfort and energy efficiency because the main drive is financial.

D. Disadvantages of Adaptive Facades:

9. In your opinion, what is the fraction of adaptive facades in today's European market? And why?

1% maximum.

10. Does the cost impede/hinder the market penetration? What is the influence of mass customization on cost? (Weaknesses)

We are already mass customizing.

But there is a tendency in today to use adaptive façade as a signature to create signature and iconic buildings and we tend to invent every time, new façade systems.

Yes, but they are not actually new. You in the end, can categorize double facades into five different type of types of façade, as you already did in your extra sheet. You can categorize different materials typologies, technical functionalities which are enclosed in adaptive facades but we are not really creating new systems. It's new assembly of certain components. It's a new configuration of certain technologies which are then, link to each other. But we don't see, yet, a really adaptive insulation for example, something would have a different U-value in summer or winter. That would be a new change but I don't see this now, and even when I observe the

conferences which I follow I don't see someone being actively researching in that. The most adaptive move which we had is liquid crystal. So, they say the switch of the glass to protect for glare which is promoted to be super adaptive but it's actually only glare protection, it doesn't even perform that well in glass that we do often.

But, can we say here that mass customization reaches its limits to reduce the price in European market?

I think so.

if we come up with more modularity and on the shelf solution...?

We are already on that.

11. Do you think that adaptive façade technology (motors/actuators, sensor, products (e.g louvers) and control strategies) is mature to penetrate the market? And Why?

As I said, most of the façades we built are, already to a certain level, adaptive. If they include solar protection, then they are adaptive, if you have operable windows, they are already adaptive. So, penetration is already there, and as mention in the previous question, we have already a lot of technologies and assemble in different façade systems configurations: for example, design wise, engineering wise, performing wise. We create individualized set ups of adaptive facades. We are still not changing much, there is not that much new technologies that emerged during the last ten years. For example, the newest façade technology is crystal glass facades.

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

The more mobile parts you get, the more things brake fast and the more maintenance you need. The more costly it will be the handing over on a long period of time. Solid brick walls last few years if they have not been maintained.

So, there is risk is higher with mechanical movement or mechanical systems?

And electrical system as well. And maybe even, not yet experienced that intensively, but maybe even computational systems. So, we now install devices, which does a sort of control and in 50 years' time, the device is not going to be maintained by the same company that built it because it will not exist anymore. The risk will be how to handle it, and you can't link it to your new device.

E. The Future of Adaptive Facades:

13. What needs to be done for a better adaptive facades project delivery process and better performance quality?

Firstly, education is an important aspect and then integration in the project. Stakeholders say the decision process make us not understanding what the performance is. There are often too complex systems and stakeholders are more interested in simple systems, which they can better control during design process in relation to cost. So, that's why the market is so low, you only get these kinds of complex façades realized in projects where the developer is entirely controlling the total project from the design till the delivery and do understand the potential of an adaptive facade. So for both projects I mentioned in the beginning, I was in the function of being the general planner, which means I was the architect but I also was in charge of all our planning disciplines. So, I supervised the structural design, I supervised the climate design, I supervised the buildings physics design. For that reason, I was in control of the entire design process, and for that reason I was able to come with these complex façades. So the less educated and knowledgably these project manager and architect are, the less they have the control of process, the less they interested in it. In the project of Dr. Tillman Klein, they were trying to do this by changing responsibility for the total functional performance of the building's

envelope, from separated disciplines into one entity, and by that being able to integrate the maximum. So, that's the doing part and the technical part, resulting in better performances and quality. We need simpler technologies more integrated technologies and maybe, what I really miss is adaptive insulation. So, insulation we'll really allow to vary its u-value during the year.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

If this is a building which is owned by the user, then owners should let users being in control of the maintenance because it's their interest. If the building is owned by a fund, which is not using it, then that should be a contracting company. Because the fund will not take care of it, they will be only interested in the financial issues I think, they never see these buildings. Actually, that should be a contracting company, which means that the facade builder who have to take this responsibility. However, general contractors are not interested in maintenance but also they are not reliable for this task. They come and go, they disappear, and they can become bankrupt. Therefore, maintenance services contract can make contracting companies more reliable and have a longer life.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

The politically correct answer is that this is something that would be good to do. But the practical answer, POE is going to make our handling of building so expensive. Therefore, the AEC industry is not going to do that.

The question of how much money do we spend for what purpose. If people die because of comfort problems then this will be something obligatory. This is what you do with a budget. You have to maintain budget and you have to check your operation budget every single year, otherwise people will die. But if it is getting warm in the building or you pay more energy for cooling or heating, POE will not become obligatory. Because it's going to make handling building more expensive and no one will want that.

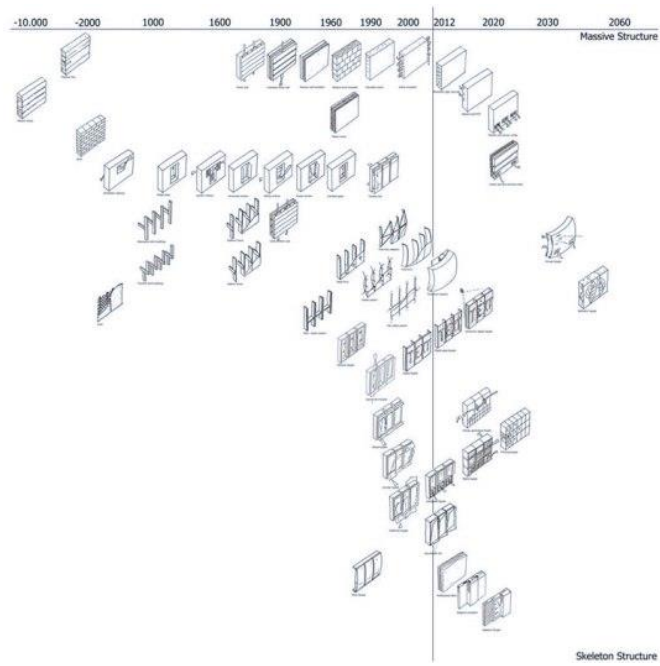
16. What features would you like to find in the future of adaptive facade?

To have adaptive u-values of facades. The opportunity is mainly related to making owners also users so you avoid the different interests. This is an opportunity. So that you create a market of product-developer-user oriented buildings. But I also have to say that a simple window is already part of an adaptive façade, so we actually have by that a lot of adaptive façade in today's market. But the more complex it becomes the more complex it will also be, to integrate in the project, so the more special the situation have to be.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

If we want to create a map of generation of adaptive façade, I think, we will go back to the Egyptians or, I don't know, four thousand years, I don't know if somebody did that but map the first opening window where there was a ...

You remember my façade road map? I am still using it sometimes to explain the different facades generations.



Knaack, U. (2013) Roadmap, Architectural Facades and Products Research Group , available at: <https://facadeworld.com/2013/10/05/roadmap/>, accessed: 30/07/2019.

Interview with Stephen Lo

Name: Stephen Lo

Date: 24.01.2019

Place: Bath, UK

E-mail : S.N.G.Lo@bath.ac.uk



A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

It is mostly teaching, I tend to teach adaptive façade to post-graduate student, and I reviewed a lots of adaptive façade papers as possibly being on the glass & façade technology editorials comity.

I started off a long time ago in architecture and then I moved to mechanical engineering, then energy management, then solar thermal, then photovoltaic, and then facades.

2. How long would consider yourself in the field of facade?

Probably any about 9-10 years, so I can't tell you, I don't know anything about façade.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of an adaptive façade?

It's hard to sum up in one sentence, but I think it's the dynamical respond to both the environment and users to optimize the total performances of the buildings envelope, now the total performances mean a lot of thing but he has to deal it from a daily and a seasonal, and a future point of view. One thing static envelope can't manage to, they can't really future proof an envelope.

4. What are the strengths of adaptive facades? (Strength)

One of their main strength is their ability to adapt to future climate which normal facades can't at the moment, if the climate changes as quickly and as drastically as we expect to, then, adaptive façade may be the only solution in the an overly increasingly hot climate.

If it's able to learn from changing season or annual weather patterns because it got to build not just do with short run terms but long run term as well and which, there are a lot of data there, we talking big data, and try to process all that will help me to deal with different users demand because if you have, it's ok, if you have a building with exactly the same users for 3, 4, 5, 10, 20 years and the demography of these users remains similar then you are likely to get similar performance for that . If you have a building which have an adaptive façade on it with different users changing every 3, 4 years, or shorten than that, then the noise creating by the difference in user tends to offset any benefit in the façade might show you.

So, sometimes improvements only show up in very small amounts where improvement might be quite modest or the optimization might be modest and that can be swamped sometimes by the noise up to the users.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated

louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

I'm afraid I haven't really work on any so I can't.

If we look at adaptive façade they are several technologies: active transfer façade, base change, automated louver for shading, etc.... In your opinion which type of technology you think is the most promising?

I have to deal from the industrial point of view here, my feedback from the industries is they are notoriously conservative in outer look, especially the UK industry, and they tend to see..., they will look at what they currently use. There standards modus operandi are to look at what is done now, look at what they know, or what the façade toy box gives them. If it is suboptimal can outstanding norms active façade help them, so they go on that road, and then, when the cost, comes in and they realize it costs, the cost on the maintenance and benefit issues are starting to become a problem, then they get back to more static solutions.

So, adaptive which don't require them to change the façade that much externally, tends to be more favorite by the industry. Because they are very risk averse and I will explain this.

But they are not obsessed with but they are quite concerned with maintenance related service life. What I mean about obviously is that, you have the service life, but service life can only to be realized if regular maintenance regime can be sort of developed or enabled on that façade and that regime must be invisible on cost effective and their as I said this is very risky for us and anything which is too..., which look also... if they are moving part if there is connection or interface details problem, they just walk away. So, they are, unfortunately, very risky for us, so the much had which don't look are adaptive probably are the most favorite by the industry, I would say.

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

Adaptive Façade Technologies	Energy & Environmental Performance		Protective Performance				Building Control and Services			Occupant Control and Experience			Maintenance Durability and Circularity													
	Energy Consumption	Embodied Energy	Embodied Carbon	Cooling energy	Heating energy	Ventilation energy	Electrical Grid Flexibility	Structural Performance + bonding/fixation	Visual and Acoustic	Water tightness and air permeability	Thermal and Fire Resistance	Radiation properties	Visual Comfort/ Acoustic comfort	Thermal Comfort/ Aspiration comfort	BMS Interaction	HVAC Interaction	Engagement and command control	Action Feedback	Comfort Aspiration	Failure and dissatisfaction	Product take back & global guarantee	Façade Material Durability /	Façade elements	Façade cleaning	Façade Operation Maintenance	
Movable Shading																										
Switchable Windows																										
Complex fenestration systems																										
Adaptive insulation																										
Opaque PCM																										
Transparent PCM																										
Opaque Ventilated Façade																										
Transparent Ventilated Façade																										
Solar Facades																										
Green Facades																										

I had a quick look at it and I think any concerns I have again relates to the sort of questions the industry might ask. Some of these sub sections you've got especially in the life cycle durability and user control, it cannot comes under 'buildability'? they are working on the word buildability, the buildability means a lot of things to different people, but they will ask about on how the interface work with all the façade systems and how do you integrate it into existing building energy models and what is the real service life of this, and they don't, without these questions they can't factoring or the future value of the façade going to be and I think they struggle with that.

So how far it can become apart of the common existing...

Well, I think, if its..., currently if you have a range of different façade system on a single building then the weakest point will always be the interface, obviously. The more systems you have the more different systems you have, then the more problematic that results in the interface problem will be. Now they are very familiar with how to deal with connecting together, currently available facades systems. Ok, but introduce something which is quite radical and quite new, and it may rise you know, I think façade, adaptive façade falls in that category. They remain skeptical, unless its looks like something very conventional, so if you have an adaptive façade system which can be, looks like a normal rain screens or looks like a normal facade, then they don't care quite as anxious about it.

If something looks as if it will fall apart, or require a lot of maintenance, then, again, they will struggle with how to interface that with both the façade and any connection that are required.

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades and justify that?

I will not tend to my experience, the ranking, if you want to rank anything that depends on the client and their brief, brief will, if some client they told about the cost, some occasional enlightened clients will drive the energy agenda.

Sometimes the client, the owner or the developer is the client, they occupied they own building and you see a totally different behavior on change or requirement.

I think if we have to clarify any kind on ranking you tend to find that cost and energy are gonna go together and occupancy satisfaction tend to take us slice more second review but they will always look at that after the cost and the energy, and I think this is it's kind of little feedback loop, if all three should be worked on at the same time but most, a lot of client don't understand how one effect the other simultaneously, I mean, this dynamic responsive of ranking is something people struggle with. When you ask somebody to rank something, you expect one at the top but actually a lot of things but then you have to keep together.

I suppose I would call them like design tensions I suppose, there is always a tension between 4, 5 different variables and if we change one it radically changes the others and you got to know which point they change so much it becomes critical issue, so again I tried not have single, you know, parameters rank.

8. Do know any performance-based standards (not absolute values) for adaptive façade? Do we need new standard for adaptive facades performance assessment and Why?

I am not aware of any, but I haven't, actually, done a lot of work in that area. I tend not do a lot on the modelling performance evaluation.

And do you think, then in this case we need new standard for adaptive façade performances assessment?

Not in standard, I think it depends what the standard is trying to do. If the standard conforms to convention of façade standard, in other words, they include some

industry familiar with. Then they can relate to those standards. If the standards are like, ... right, if you go to, let's say sort of water heating standard, the language they use is basically services and plumbing language. And façade, so that people tend not to be understand fully, so the on standard was useful, may not see sign relevant so, I think if we have standard, I think you a have to make sure that language they use is consistent with common everyday language which that a façade engineer uses so it doesn't scare them off. Anything looks unusual or overly complex they won't just see it as a standard and see it as a standard with problem.

D. Disadvantages of Adaptive Facades:

9. In your opinion, what is the fraction of adaptive facades in today's European market? And why?

Absolutely I have no idea, depend on you ask, if you ask: Sage Glass, they will be able to give you a definitive number but I really don't know, I don't know enough of the industry to answer that question and I think it will require quite a bit survey, I'm sure you must have done the survey.

Yeah, we have very little number honestly. But it depends on the definition, I mean when it called, when we talk about, you know, the Dutch, they insist that an adaptive façade is a manually operable window ...

Well, I don't it deal to the type of façade the question, the question should be to deal with how close to market the façade is. If there a lot of, I mean If you look at the chromogenic windows, most of those are market ready but the market penetration is still quite poor, although you could do a survey and ask the manufacturer and they would tell you. They'd love to tell you, but more dynamic movable facade, because at more prototypes level, it can't really ask, I mean, it tend to be done, it tend to be made as custom adaptive façade for very specific clients and very specific buildings. So, intention of that future penetration of the question of the future market penetration is almost mute because it requires future buildings to have the same budget as that specialist one of that application, and they won't have that. So, it's a very good old question to ask, I would, if you are going to try find out, what the market is, you have to deal by technology. And we can do, it very difficult to group all adaptive façade into same two word.

Yes, the trouble with the sub questions will be massive, so many.

10. Does the cost impede/hinder the market penetration? What is the influence of mass customization on cost? (Weaknesses)

I don't think the absolute cost is the issue, its more to do with the cost of the risk, so people can specify, I don't know, a movable façade in two thousand pounds a square meter and it does other things, it just look nice. If the client wants something which look wonderful and they want these wonderful materials they don't care much in cost, so the cost, the problem with the cost is, its tends only to be seen as what the façade can do for you, other apart from other then what else the façade can do for you. If the cost is based on the savings in energy, then an adaptive façade role would be interpreted the same way as a photovoltaic façade. So, actually allowing having an adaptive façade, which doesn't do more than just save energy, and help the building occupants achieve, suitable environment or whatever is benefit. Thus, having secondary benefit is something which answers to the cost question, and I don't think cost come in terms of just buying the façade. I suppose the, the focus should be on how do you value, the implementation and the deployment of an active façade, value can replace on all the other thing it gives you. That I think is more interesting to me.

And the second part which is talking about mass customization, I mean there is a lot of on the shelf solution for adaptive façade today that already match for buildings without needing to be specifically customized because actually

adaptive façades are more famous on the side of having the “bling bling” iconic building that have specifically tailor made solutions but on the same time there is mass customization now. Do you think the mass customization can influence the market or reduce the cost and increase the market update?

I think yeah in lore customization well, mass customization allows reduce the cost but it allows, I suppose, it's performance its real world performance to be actually quantified more easily, because if more and more people deploy them, or specify them, and they become more familiar, it will become, is almost now it's just to external shading. External shading has a very fixed remit ok but you can make a lot it and it is very repeatable, a standard finish is very repeatable and if you can actually achieve that level of repeatability with an adaptive façade, ok, then you can go to penetration but you limit its flexibility. As soon as you stop mass producing so called customize adaptive façade you almost lose a bit of that adaptability I think, so I describe..., it's a tricky one.

11. Do you think that adaptive façade technology (motors/actuators, sensor, products (e.g louvers) and control strategies) is mature to penetrate the market? And Why?

Again, it depends on the technology. Some particular adaptive façade solutions are very mature, we tried and tested it. And they performance evaluated performance can be, especially the ones which deal with moderating light and sunlight and daylight, because they are much easier to model. The one which manage ventilation, manage flow much harder, so the once which deal with more traditional façade specification promoter are, you know differences, if you have again the chromogenic windows they are much more similar to standard glazing than anything else, I say you can specify them all as the same way. Their adaptability allows them to have different G-values and different U-values depending on how you switch them and that's something which is, you can do in steps, not variable, so the winter you can do one thing, and in summer you can do another thing. Was physically movable adaptive façade but is much harder to take that to market, so something which is not familiar, and not too scary I think will maximize, I think it's considered to be more mature more similar to mature mark or mature technologies so something it looks like, something which is already mature, but even it isn't.

But, I think we can group them, mainly the most mature ones are the shading.

Yes, yes

The dynamic shading systems and the second one everything that has to do with the chroma or the electrochromic or all the other different chromatic or glass, I don't know how to group them.

I tend to called them chromogenic I suppose because the chromic, the chromic part refers to their ability to vary post the spectrum and the general part. I think chromogenic I will classify as electrochromic.

So if we are looking at the chromogenic and to the dynamic shading, both of them they have a certain level of maturity I think they already reach the last level of the TLR which the market..., the maturity, 7 or 8, and even if we talk today of the European union to get innovation to develop any of those they are already there, they finished and we have company that just mention and other... the question is: Why are they not still penetrating in the market?

It goes down to the question about some..., the conservative nature of the market. I think the problem is we, they are, in order to increase market penetration, you need demonstrated market examples or exemplar projects in lots of different climate to show that it really does work. And when people can see, cause the first thing someone..., if you suggest a particularly complex adaptive façade, first they gonna

say: “is anyone have done this before?” and how effective it was and they will ask, in the context of that question, that have to be asked in the context of the right climate. So, have to be, so if..., they will just look, as the first thing you do, they will look to see if a similar technology, ok, in a similar climate to theirs that has actually perform very well. The flip side of that is a lot of architect don't want their building to look the same as someone else building, so that uniqueness, that design intend is sometimes which kicks in because [blank] be something, they don't want to copy something the same way, so, I'm not sure I can run that problem.

So, the main reason is the conservative nature of the market.

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

I think it's mostly to do with moving parts and connectivity, anything which has moving parts and any kind of connectivity with electrical or fluid or other. Its passive to be an extra interface risk. It's more like common sense a lot of sort of will look at something and then the measure that they will know, that is gonna break, or fall off, that would override, require oiling or whatever and then it's up to the industry prove its wrong already.

So in this sense you would say the movable part dynamic type of shading...

Dynamic don't necessary mean movable cause dynamic you know, the electrochromic are dynamic but there are not movable, so I think moving parts and anything which requires service penetration, I think that's a challenge, because they already tried to make buildings as tied as possible but the last thing you need is more moving parts and holes basically.

So there is work to be done with motorization in this area, or should we totally avoid this idea of...

I don't know but I think there are any moving normal shading devices I ever seen after about 10, 15, 20 years, there moving parts don't last that long, and the more often is, if the clients have change during the lifetime of that moving façade. They may not have built a budget to repair that to maintain it and it was, if they don't build the maintenance budget then they repair will follow basically and then just say “sorry im not gonna do it”, I've seen many movable shading systems just left when they failed because they can't afford repair them, so they just leave them and their stuck in their fixed position. And it is almost the trouble is that is sends an advert to not having moving parts. People understand the bad thing, so you only need one bad example and peoples experience is quoted. And It don't depend on how many bad examples you have, that's an issue.

Just to give some direction here, this means that movable shading is having some issues. It requires to be much more mature and robust and we should still believe and invest in it or it is a technology that most probably will not work?

Well, I think it's a question of demonstrating but it can work.

So, this means if we can say we have in the last year X of generation one or two movable we need to move to much robust generation of movable shade.

If it moves, then you gotta make sure if it move repeatability for year and year after year.

E. The Future of Adaptive Facades:

13. What needs to be done for a better adaptive facades project delivery process and better performance quality?

I think definitely more real-world full-scale testing strong exemplars. So, whenever you want build a normal façade they have to build a mockup. And building a mockup of adaptive façade just cost more but if they can show people that they, cause the mockup is normally static thing, “does it look ok?”, for an adaptive facade you go to

make sure the model looks ok, she still keeps working in 5, 10, 20 years times, so again, and it comes of the idea of having real world exemplar in the climate in which that particular client want to build this adaptive façade. They can give a way assurance that someone else is actually taking the risk, taking the plunge and it also gives someone to talk to actually. A lot of client they feel like on the road, they don't want to do to adopt technology that no one else has done, they can't discuss it with. What they don't want adaptive façade, I think they are quite I think I suppose determinate is the wrong word, but they probably can feel intimidated by the research world thinking of all bench PhD students and academics but what it really need is to talks to someone thought them the data date problems and benefits of the adaptive façade, in a balance way, cause there is a lot of very few people can look at both sides of the good bad arguments, a lot of people who'll find one bad thing and think about but not the façade... and I thought they would tell people. But you need people to actually champion about the pros and cons of adaptive façade. And that will then re-assure people that the façade process can be delivered and can be followed to give you the promise you actually say you can.

This is an interesting answer, nobody talk about the mockup and the idea of taking enough time for it and the idea of making them properly and then from there going to assure the improve.

I'm surprised actually because there is a lot of prototypes try mockup that people will be showing people.

But it ends up, most of the time these mockups, a lot of them are only for research and sometimes they are just the general contractor is doing them but, for the purpose of structural safety for air tightness, for this classic...

I think the thing is, what is gonna happen is that we are already pushing forward if, once we have enough exemplar, probably, these are gonna be higher and... the iconography will not just be the language of the façade but the language of the adaptive façade... the thing is, the big problem with all low carbon buildings is how do you know what a low carbon building looks like and now they have new standard look, you can't tell but look at building, how much energy is uses, whereas if you look at the car, you look at an electric car and you see normal car, you look at the electrical car and you assume rightly or wrongly that it's not environmentally benign than the petrol one. Just because we have this image that electric cars are more environmentally benign. All we have to do is somehow make this association between adaptive façade and low carbon and energy use. If you can do that you can (laugh), then it shows people that "oh" he's got an adaptive façade he must have he must prioritize energy in some way.

And, actually make it, whatever its right or not, because your gonna have two buildings with the same adaptive façade and they can both have completely different energy use per square meter depending on users and so on. But in general, if you can convince people that wall has got complex façade it must be save a lot of energy then that can get on the image issue, because they make look beyond all the problems associative with it. If people are very going back to the economic thing, people are incredibly blind to all the deep issues of electrical cars but they like the idea is trying to push, they like what to do. I think that is something we can learn from. People might assume that a timber building is more low carbon than a building made from concrete, you know but its right or wrong they believe that, now we gotta build to do this, adding more confused and that's tricky. So, anyway we have, if we had more exemplars and you get actually benchmark those exemplars against similar other similar office building, you have these benchmark, lots of buildings, and if we can show and demonstrate that, at the top end of the performance benchmarking the

ones with the lowest energy consumption per square meter for any given climate tend to have adaptive façade on them and that might start this way how people think about it.

If it takes them to the next level and they start to approach near zero energy for none investing buildings, then I think that would actually help the adaptive façade calls if you like much more than any other performance. Its perception.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

Good question (laugh). I think, if the requires maintenance routine is similar to standard maintenance, let's say, normal glazing, then it's normal to be the building owner ok, the façade consultant have to deal with to insure them that the maintenance routine is no worse than would normally be the case for non-adaptive façade. As soon as any end that's it will cost twice as much as it maintains then the responsibility of this job will just be lost in negotiation and then someone will forget to include it in, and now just go with the normal [blank] ... important, if the, they have to stand a chance of being maintain. Then the maintenance cost can't be significantly more than standard maintenance budget otherwise it just won't get done.

Well if anyone can't be responsible for the building in the long term then that the was is, they have a duty I suppose to the client and the users of the buildings to maintain the building.

And is there a conflict between the owner and the user?

Well it depends of how many users they have I suppose, if it's a smaller, if it's a very small building, then its tend to be a very much closer relationship between the owner and the user, if it is a very very large building then the owner tend to disappear and then the user tend to be just a number so, I think depend of the size of the building, the scale of the building.

When you have a client and a building owner which are all on the same page, if everybody who is involve in the whole project from start to finish were talking on the same page about energy and carbon and so on. And all the users understand that, then they are all working together on this, there is no sort of tension there, if the company have to be owned by the World Health Organization, they would insure, they would screen everybody who comes into the building, all the people would interviewed have to be on the same mindset has everyone else on the building, was normal if it was insurance they don't care, and that's so...

15. Do you agree that soft landings, POE and monitoring should become obligatory?

Absolutely, yeah, no question there. Especially the POE, I mean it's not enough POE to support a lot of the exemplar work have done out there. There lot of really really good buildings and POE would be monitoring, it is costly but it's, I think again, a cost associative should be taken in the light of the benefit in long term, so the short term cost, they should just take it on the chain, and say we do it now but it well doing.

16. What features would you like to find in the future of adaptive facade?

I think if they could nail the lifetime risk/cost benefit analysis, and actually include that as part as the specifications, I don't know how to do that, but if it's a way of showing the lifetime benefits then. I think again the people who sell this would know this, it's trying to make people who specify understand it, so its not just reduce energy but how it can affect, the building other the lifetime, how it can affect a building over a changing climate, and all these things and they tend not to notice.

So, you are not very much into developing the product themselves or the adaptive façade technologies themselves, no, you are looking to valorize and communicate...

I think he have to, as you say, as to place the value on more what you have its all to deal with, it's like selling fridges to Eskimos, you can have a very average product and you can sell it well, or you can have a really problem sell it badly, or have a good product and sell it well.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

I think it's there, is, I don't know very works we done on studying performance gaps between sort of, at the moment, if we can demonstrate how adaptive façade perform better than the static current existing façade, not just now but in the future, I think that would definitely increase their use, well I don't know, I'm not really sure, it's not my..., I'm very speculating at this point.

Is there any opportunity there that you are missing on the climate change thing, is it regulation thing, is it, or maybe its marketing what you say?

The problem is, it's when you try to increase the use of something, people always tend to use one, they are looking for one thing to do it and it can't..., you don't sell a car on one feature, you sell a car on its balance of feature. And all things in question 1 to 16 in a way contribute to how you try to increase the opportunity in the future. It's like dealing with climate change and energy use, you don't do one thing, you do everything. So that, that is the issue because most people can't hold or can't process more or one than two things at once. How do you increase people awareness of multiple parameters issues? They want something, they want a nice single sound beat they capture all these different parameters in one word. And at the moment, I never found that word.

Yeah, it is very difficult to go beyond three criteria for selection. If it becomes abundance of criteria, we will get lost and I don't know how to make a choice but at the same time this highlight the word of a balance of features.

I think we trying to balance of feature are linked to design tension and I think that's kind of ..., my emphasis because I can't do it as, its change while the market things but I can't do it change what the people are going into that market thing so, I do that through teaching. So, I sneak adaptive façade on as many courses as I can whether it's needed it or not, so, in a way the adaptive façade is the answer to many of their problems they just got to know what the answer is.

Interview with Jan Wurm, Arup

Name: Jan Wurm

Date: 31.012019

Place: Hamburg, Germany

E-mail: jan.wurm@arup.com



A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

First of all, I'm an architect and therefore trained as a generalist. Through my PhD I acquired deep knowledge in the field of glass, glass façade and structural use of glass. My approach is to first understand a material holistically in its properties and characteristics and its potential for architectural applications. Then, I take my understanding as a basis to develop solutions and systems. This sort of interest and approach made me interested in the algae project that we developed.

So, the system we developed is called SolarLeaf, it was first prototyped at the Bio Intelligent Quotient (BIQ) building in Hamburg. Since then we have further developed the system and the business model around it and refer to the system now and market it as the bio-energy façade. So, this is the term you should use.

2. How long would you consider yourself in the field of façade?

I'm working for ARUP for 14 years, but I did my PhD related research studies for 6 years prior to that, so I have around 20 years of experience in the field of glass systems and facades.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of an adaptive façade?

I would say adaptive façade refers to the ability to respond to different contexts and different needs: contexts, in terms of climate, needs, in terms of the user, and the 'beneficiaries' of the façade within the building.

The purpose of an adaptive facade is to increase the wellbeing, the performance of the indoor space, and to unlock all the potential of the activities taking place inside the building. The function of an adaptive façade includes being able to increase flexibility and to adjust to different users' needs according to the changing conditions of the macro-climate.

4. What are the strengths of adaptive facades? (Strength)

It is to create flexibility around its performance and to focus on what it's needed on that point of the day for that user. Simply respond to the needs of the user and the climate conditions.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

The BIQ project in Hamburg features photo bioreactors. They have panels with liquid fluid, basically water, where you cultivate micro algae as biomass, which is a microorganism.

Can you explain what biomass is?

Algae are unicellular micro-organisms that perform photosynthesis to grow and produce biomass by cell—division.

And does the façade in this sense produce these algae?

Algae are cultivated in these panels. Within seven hours, in good condition, the biomass doubles, by absorbing carbon and daylight through the process of photosynthesis. You can harvest the biomass because it is highly valuable in terms of lipids, oils, amino assets, vitamins and its viable resource in the pharmaceuticals industry. It can be harvested every day by using flotation technology and skimming them off the water. In Hamburg, the BIQ has 200 square meter of façade, which is about six kilos a day of production, on a good day. on this small scale it is commercially not feasible to process the yield to products. However, there are clear new business opportunities. We are working on this model to create a bio-chain and having a contracting model where you have a service provider that can create a logistic network and to farm and collect the biomass. Then, harvest the biomass and sell as valuable product.

For the photo-bioreactor you make use of photosynthesis as a biochemical process. So you harness the daylight, you feed in carbon that comes from the building, in order to cultivate algae. Thus, the outcomes are biomass and it is a fast growing biomass plus solar thermal heat. The photo bioreactors facades have two outputs: heat and biomass. There is an additional benefit, that the façade system absorbs carbon emissions to facilitate short carbon cycles. There is other additional benefit to have an adaptive shading system because the transmission of the algae panels varies according to the content of the algae. This can be achieved by controlling the content of algae through the biological process, nutrition and the exposure to daylight. In fact, there could be competing objectives. Would you like to maximize the generation of heat and algae or you like to have it adaptive so you can use it as a shading system? In our project, the focus was on maximizing the efficiency of the systems and the biomass output.

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades and justify that?

For the BIQ we did a two year monitoring campaign. We looked at the technical performance, energy performance and user comfort or acceptance. This project was specific because most of the façade panels are allocated in front of opaque wall areas. They cannot be directly experienced from the inside. However, they do cover part of the loggia and balconies where the user can directly experience the panels. The user satisfaction was very high. Users saw the system as a part of nature, something dynamic, positive and healthy. Feedback was very positive and BIQ building meant to establish and demonstrate the technical feasibility. The next step is the commercial viability. The key point of the first phase was the operation of the system. We did not want to put the system in the hand of the client, or facility manager because we needed to understand how the façade works as a system and how to integrate it with the building services and other technologies.

The business model is based on contractor who would run the system. The owner would receive the heat for free and the biomass will be dealt by a contractor who makes sure that the system is running as it should. I think with this new contractual set up, taking entirely the risk away from the owner was a breakthrough in terms of its commercial viability. In terms of efficiency, the system delivers more energy than you put in. I think that is a positive term because you get a biomass and a surplus of

energy. The façade system generates heat but it needs a very specific concept for the project to make use of that heat. Just generating heat of course is not a benefit if you have no demand. So, it's really about fully integrating the technology in the energy concept of the building. Though, the biggest potential is the integration on district scale. I think there, we would see all these benefits combined.

- 8. Do you know any performance-based standards (not absolute values) that valorize your innovation because you have at the end, consider it as an envelope element of the envelope, I think the U-value ..., Could you find any standard that promote that envelope is active like that? Do we need new standard that encourage such innovative?**

Not really no. For sure we need new standards. Most of the standards are pretty too much prescriptive. We should much more look at performance-based systems and standards. We need to look at façade system's performance on a conceptual manner rather than abstract level of a standard (European standards or national standards). Looking at the digital tools that we have for simulation, I think we should more promote the performance-based design and operation.

D. Disadvantages of Adaptive Facades:

- 9. In your opinion, what is the fraction of adaptive facades in today's European market? And why?**

It depends on which categories to choose from including dynamic shading or chromogenic glazing or solar active facades.

In this sense, energy generating façades and chromogenic and flexible shading, all together how much do think they are penetrating in the mature today?

I think we need to divide the market in segments. If we talk about commercial spaces, I think we that offices have some kind of features, like adapting shading, in order to reduce cooling loads and still allow staff to benefit from daylight.

- 10. Does the cost impede/hinder the market penetration? What is the influence of mass customization on cost? (Weaknesses)**

Yes, I think it does because everything is linked to cost. If you just look at the capital cost, the Capex (capital expenditures) you will find that most developers, who just develop and sell, won't have an interest in an optimal performance and operation benefits. However, if the owners use the building of course, the situation is different. They would invest in such technology because they know they would benefit from it and they will accept higher Capex for that to reduce Opex (operational expenditures). It's really based on the business model of the developer.

Do you think mass customization can influence this cost thing? Or do you other another better idea that we can reduce this cost barrier?

For sure customization is key to reduce cost and give allow more flexibility for architects. However, already, most adaptive facades systems have already a kind of customization.

- 11. Do you think that adaptive façade technology (motors/actuators, sensor, products (e.g louvers) and control strategies) is mature to penetrate the market? And Why?**

For bioenergy façades, we have demonstrated the technical feasibility. If we use the technology readiness level, I would say we have passed the prototype phase (Level 7), which was the BIQ. The BIQ was a 3-year test. Now, are looking for level 8 to reach market penetration.

- 12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)**

Maintenance is key because you have to make sure that you understand the organisms and control the conditions accordingly. So you can't just pass it over, to any sort of facility manager.

So, the efficiency, the appearance anything else related to electronics or mechanics in the system?

Also, the system needs to be operated by specialists. The maintenance of the façade is not that complicated and automated. We have developed solutions for the maintenance to be quite effective and automated. But it has to be maintained in regular way like any façade.

E. The Future of Adaptive Facades:

13. What needs to be done for a better bioenergy facades project delivery process and better performance quality?

We need to have industry partners that are confident to offer this technology. So we need façade contractors who can team up with buildings service teams, because the bio-energy facade is a fully integrated system. In our fragmented industry, where everyone is operating on their own profit margin, you need to collaborate to handle integrated systems. So we need more integration not only on a horizontal level during implementation but also vertically thinking about the system design earlier during the design phase. We need to think about the outcome and the effect of the system on the overall concept of building and operation.

And to make the bioenergy façade more quality, higher quality performance, what's need to be done?

In our case, we have increased the size, we have decreased the weight. Maybe now, we can develop some specific strains of algae species. Or algae species for specific typologies and orientations, that could be the next step.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

In a contracting model, it is the operator. In our case, it is SSC (Strategic Science Consult), who are the experts in terms of bio chemical processes that have developed the system together with us.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

Absolutely, I think so. We all talk about user centered design and user experience. And this raises questions like: How they see this working? How the façade impact the work space? How can we improve the façade system? I think these feedback cycles are key to any innovation. However, I think the building industry is behind with creating these feedback loops. I consider this as a call to create feedback loops within the operation but also feedback loops to improve the system and come up more with platform solutions, which we see in other technology fields to constantly improve user experience and technologies. I think this isn't really happening in the AEC industry, but post-occupancy evaluation is crucial for that.

16. What features would you like to find in the future of bioenergy facade?

We need to improve the efficiency of these systems to decrease the costs further but I think these are technical aspects.

Can we mix them with photovoltaic technology?

yes, in principle. The algae absorb the solar light only in the solar spectrum (green spectrum) of the daylight. All the other part of the spectrum could be harvested by PV. Transparent PV can be beneficial for the microorganism allowing absorbing the rest of the spectrum. So if we would have a system like that then we have triple benefit,

we will generate energy, biomass and heat, increasing the efficiency of such systems further.

17. What are the opportunities to increase the use of bioenergy facades in buildings in the future? (Opportunities)

We need to look at our built environment more holistically and not on the case of individual buildings. We need to look at complex systems where all the buildings contribute to. Understanding such systems and understanding the related technologies helps to start a conversation about energy and water networks. This reflection links building to water networks, to carbon emission, and heat, and energy. On the city scale we need to close loops. Closing resource loops on a city scale of waste water, to take nutrition from the waste water, to feed it into the façade. To take the heat and distribute it to where it's needed and take the emission and feed it back to the façade. So, this closed loop system we can only make best use of it on the large scale, on a district scale. We also might need regulations to push building owners to look for synergies with the neighboring buildings, technologies and typologies. We need to be smarter, have grid smart networks that are distributed network within the city.

Interview with Liam Obrien, Carleton University

Name: Liam Obrien

Date: 31.01.2019

Place: Toronto, Canada

E-mail: LiamOBrien@cunet.carleton.ca



A. Background Information:

1. What is your core specialization? And what kind of projects you have been involved in?

So, my core specialization is the interaction between people, occupants and building systems, which can include thermostat and other automation system input but also blind and window and other façade systems. My work is research oriented and evolves both simulation and monitoring occupancy. But I've also been involved with real projects where I've done things like recommend certain shading systems in the buildings.

2. How long would consider yourself in the field of facade?

11years.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of an adaptive façade?

So to me an adaptive façade is a façade that has a dynamic element, it could mean physically moving but it could also mean chemical changes. And the goal of an adaptive façade is to change according to weather conditions or possibly conditions needed by people inside, in order to try to improve occupants comfort, peak loads and energy use inside the buildings.

4. What are the strengths of adaptive facades? (Strength)

The problem is with non-adaptive façades is that we are stuck with a system that needs to cope with conditions, which could vary significantly over a year. So, the strength of adaptive façades will resolve that issue so that it can adapt seasonally or daily to changing conditions.

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?

So, the most recent real project I dealt with had an adaptive aspect; interior motorized roller shade and an operable window. The added value was allowing people to either manually control shades or to partly, control solar gains during vacant periods. The operable window was intended to provide some relief from overheating when the cooling systems are not yet activated and adjust order. And in Canada, operable windows in modern office buildings are not really common.

6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)

So, the only thing I see that might be missing, I think, under protective performance, some of these systems may also provide thermal comfort benefit, it's under building control and services but for example if someone is directly beside a window on the sun is shining on them they will feel warm actually, so I don't see thermal comfort under protectiveness.

Other than that, I think it's looks ok.

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades and justify that?

So, I think occupant satisfaction, then cost and energy.

I think the value of occupancy has several order of magnitude higher than the value of energy so that's why I would put that first. I mean I would tend to rank cost and energy quite similarly, they are clearly tightly linked. From my experience cost is a big driver, and it's not just the capital cost but also maintenance cost, I suppose a concern for me, for adaptive façades in my climate could be maintenance and liability for instance, freezing rain may interfere with the mechanism of motorization.

8. Do know any performance-based standards (not absolute values) for adaptive façade? Could you find any standard that promote that envelop is active like that? Do we need new standard that encourage such innovative?

No, in fact, standards that I deal with usually tell us to assume no shade presence. Generally, windows are closed so I would say the standard do not address adaptive façades.

So, you suggest that we add new standard for adaptive façade performance assessment?

Absolutely, I mean, architects and engineers should get credit for putting in adaptive façades.

And can you just provide some insight, what is the value of having standard that already promote and define the performance or the expected performance of adaptive façade? Why is it important to have standard for adaptive façade?

The value is that most of industries follows standard quite closely and often times they try to do as little as possible so, we need to mandate these things.

D. Disadvantages of Adaptive Facades:

9. In your opinion, what is the fraction of adaptive facades in today's US/Canada market? And why?

Is the under shading allowed?

Yes.

Then I would have said, 80 percent or something.

And if there is no indoor shading?

I will be including operable window.

No no without manually operated windows.

I would say less than 5%. 5 would be very generous.

But you agree with me that if you take a train from Switzerland to the Netherlands, crossing let's say Switzerland, Germany or Austria, and then maybe Belgium, or Netherlands steady you reach they for example, UK you'll find are going to very high to very low because the UK is almost nothing, 5%.

Traditionally, I think the UK is using a lot of shader but that's sort of... I agree.

I think, I will speak mainly to North America. There is a focus on using mechanical and electrical systems to provide comfort to solve problems that the architects caused through more passive design features. There is also the cost issue, the unfamiliarity. I mean our architects are not really trained to design with these systems. I think there is a mistrust of occupants for manual systems not just mistrust but the idea that occupant don't know how to use them strategically, specifically in a predictive manner. And there is real concern of liability, in Canada, snow loads and freezing rain issue. But there are other climates of course but hurricanes concern. These systems in my view they are little bit more vulnerable than more traditional façades or static facades. There are many concerns. I think standards are probably the least of them. Its important because if there is high demand from industry and from clients for dynamic or adaptive façades then the committees, that write the standards will implement it. So I don't think we can just blame the standards because the standards could change but clearly there isn't enough appetite.

10. Does the cost impede/hinder the market penetration? What is the influence of mass customization on cost? (Weaknesses)

Yes. For my North American context, there isn't much market penetration but if there were, yes, absolutely, mass customization would be quite helpful for reducing cost. Because mass customization, on a building by building case is very expensive, the industry is very risk adverse. Yes, you don't want to try new things, so if there is a product, then they will avoid any risk.

11. Do you think that adaptive façade technology (motors/actuators, sensor, products (e.g louvers) and control strategies) is mature to penetrate the market? And Why?

No, I don't. I don't think its necessarily device problem, its more about integration problem. I worked on this project with motorize shades. I mean it's clear that, there is some integration challenges on the software side Even architecturally they didn't expect to have power and data cables going across the ceiling basically, and a lot of integration challenges. In Canada, there is not very much products that are designed to withstand severe weather conditions so, that's a mixed answer but, yeah.

I would say that industry lacks a bit of experience on how to control these systems if they are automated especially regarding comfort. Industry has a pretty good sense to how to use these systems to save energy but really the priority should be comfort.

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

I mean the big ones are you know really advanced but regular wear and tear from wind and rain and usage and potentially misused by occupancy. Just if they don't understand how the system is working, or it is poorly design, they may literally continue to do things that are not design to do, like overriding the system. I mean, a real fear in Canada is that people open windows and then they leave them open after they leave, and if freezing rain gets into the joints, they might be frozen open. According to one of our, maintenance people it happens. So, misuse by people occupancy is certainly a concern.

B. The Future of Adaptive Facades:

13. What needs to be done for a better adaptive facades project delivery process and better performance quality?

The main gaps are appreciation about how these systems can improve performance and trust in the system that it will improve performance enough to justify the extra

risks and maintenance and capital cost. Also, I suspect esthetics is a big one. I know that in a case of a building I was involved in its design process work, the architect was more interested in the esthetics than the performance. And for exterior shading and louvers, the trend in North America is to have big shiny buildings and these exterior surfaces tend not to be shiny and to be, basically, specularly reflective if anything to, to minimize glare.

The esthetical part, there is a lot of documentation part on it, the architect they don't want to have the customize standardized shading system because they want to every time design they own. But the problem I'm now trying to understand is, why there is not enough studies or proves on the performance improvement on these systems that there is not enough case studies and quantification that have been done properly. DO you know why there is no study on that?

So, some of it are just sort of business case the, definitely more case studies would be good. But I think the building industry generally follows trends so I'm always a big believer in case studies to inspire industry. Probably publishing case studies a bit more would be good. Also, it can be an education thing. I know in Canada we talk about, in university we talk about fixed façades, and we talk about lighting and we talk about HVAC systems. But we don't talk about adaptive facades too much in particular because our climate is heating dominated maybe.

Even in summer there is no overheating issues? Dominating by heating...

Of course, there is, but most educators talk about the annual energy and use that like. Maybe there is just some bias because most courses are taught during heating season and we forget about the cooling season.

14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?

I think, if something actually fails, it should be, either the general contractor or actually the manufacturer of the system, but if its regular wear and tear, after many years it's the building owner. I would say that the façade consultant is probably not liable. I don't know about the legalities. But ultimately it's going to fall on either the general contractor.

And how should the conflict between the owner and the user be resolve in this context? Because if the interest of the owner to reduce the cost, maintenance cost and increase the efficiency of the building and it's the interest of the occupant to have comfort and wellbeing. How do you think we can resolve this conflict?

They both wanted to be fixed but the owner might not be willing to fix it immediately. I think the, the North American solution is to make sure that there is a redundant electrical or mechanical system that provides the same comfort, you know if the window shades remain closed, there still be lighting inside. If the window can open for example, there is still going to be air conditioning so that would be the North American solution, so the occupants will sort of tolerate it. But I really cannot imagine a building owner paying to repair a system outside of one-persons' office.

You need to bring in a crane or something for a high rise building. This is very very costly so I can imagine not doing that more than once every few years.

15. Do you agree that soft landings, POE and monitoring should become obligatory?

I think not universally, probably some buildings are very standard and don't necessary need. If everything is ok then, maybe it's hard to justify the cost. Some kind of level of monitoring would be good though. But I'm not sure they are having a consulting come in and performing a post-occupancy evaluation.

16. What features would you like to find in the future of adaptive facade?

Basically I would like to omit all solar gains, it depends on the building types, for residential buildings, I would like to have sort of blackout condition. If it's in my bedroom I want it to be pitch black. I'd like to be able to redirect sun upon to the ceiling, for example, to get daylight deeper in the space.

And I'd like to be able to open windows to have a breeze on shoulder season days and I would like to make sure that I'm not prevented from doing these things. I actually prefer, like a manual mechanical system, to motorized system.

17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

There are big opportunities to increase the use of adaptive facades. The opportunity is to conserve façades and mechanical and electrical systems simultaneously and really account for the opportunities from adaptive façades. So, daylighting, natural ventilation, solar gain control, these things all affect the buildings loads and the lighting needed. So, I think more seamless integration is a real opportunity.

More seamless integration, you think at what where we are, we can achieve that?

No, so I mean some of the problems are design process problems. The fact that there is big separation between different consultants and sensing technologies. If we want to automate adaptive façades, sensing technologies do not yet indicate whether someone is actually uncomfortable. We can't decide someone's thermal comfort by measuring temperature at one point in the space. Same for visual comfort. We can't measure visual comfort by measuring a luminance on the middle of the ceiling.

So, there is still needed more holistic or multifactorial indicators to really represent user comfort?

Yes.

And maybe this is that more come back to the motor and cable product. Since we are to talking about opportunities, assuming that the cost issue is fix and it's not a burden, should we look at what part following, should you look at more the control side and algorithm to automate the control or should we look at energy, better engines or should we look for better products. What is the area that should be more attention, require more attention in the future?

I think probably materials and sort of manufacturing, not even of the mechanical or **electrical components, but the actual surfaces.**

And why material, did you select material?

Because I think there is some issues with robustness in extreme conditions.

And definitely this include engines, I guess? And actuators and movable parts?

Yes.

And why not control because many people are talking now about control for façade that will solve...

I think it's a problem, it's just that we have many problems, so sure you can add control to my list.

For a priority, is that to make sure that these components, they are operating properly in long time with almost or no need of maintenance?

Yes.

Interview with Tanguy Timmermans, Halio International

Name: Tanguy Timmermans

Date: 21.08.2019

Place: Louvain-La-Neuve, Belgium

E-mail: Tanguy.Timmermans@eu.agc.com



Interview with Manuel da Conceição Nunes, Halio International

Name: Manuel da Conceição Nunes

Date: 21.08.2019

Place: Louvain-La-Neuve, Belgium

E-mail: manuel.conceicao@halioglass.com



Interview with Benoit Domercq, Halio International

Name: Benoit Domercq

Date: 21.08.2019

Place: Louvain-La-Neuve, Belgium

E-mail: benoit.domercq@halioglass.com



A. Background Information (Tanguy Timmermans)

1. What is your core specialization? And what kind of projects you have been involved in, in relation to electrochromic glazing?

Mechanical engineering and more specifically energy and heat transfer. Recently I've been more and more involved with daylight and glare analysis. Most of my work is around evaluating the impact glazing has on the overall performances of a building. In that respect, I mainly focus on the development of Halio proprietary control algorithm. I also support its deployment in the field.

At Halio we do believe that the control strategy is a major aspect of a dynamic façade system and should be an integral part of the solution. In fact, a good dynamic window but poorly used is wasted. This is why we see control as one of the 3 pillars required for a successful system deployment, together with the technology itself, in our case the dynamic glass, and the system architecture to support it.

The biggest project I work on so far is the Gare Maritime in Brussels. This project is currently under construction.

2. How long have you been in this field?

I joined AGC 7 years ago and have been studying the impact of glass on building performances ever since. 3 years ago, I started focusing more on Halio dynamic

glass and that is around the time I started looking into daylight and glare aspects more in details.

And are you on the side of the technology or on the control?

I am probably mostly focusing on the control side. However, I do support development teams or clients when it comes to selecting the most appropriate glazing solution in terms of optical or thermal properties. And I collaborate with the electrical team to deploy it in the field. This is again the 3 pillars story where you cannot develop and design one of the aspects without knowing about the others.

A. Background Information (Manuel da Conceição Nunes)

1. What is your core specialization? And what kind of projects you have been involved in, in relation with electrochromic glazing?

I am an architectural engineer specialized in sustainable building design. At Halio, most of my work is around highlighting the benefits of our solution on both comfort and building energy performances. To show how dynamic solution like Halio can change the way we design building. This involves in depth knowledge of the entire solution including control that I have to design and implement on our projects.

I joined Halio 6 month ago, but in previous jobs I focused on guidance around energy savings and comfort improvements in buildings. Covering various aspect like daylight, HVAC dimensioning, envelop insulation...

And you have a specific project to site in relation to electrochromic glazing?

Together with Tanguy we're setting up the automatic control of Halio at the Gare Maritime currently being installed.

2. And how long do you, do you say, quantify your years of experience? In the domain of sustainable buildings, or green building?

I've been working as sustainable building designer for 11 years now.

A. Background Information (Benoit Domercq)

1. What is your core specialization? And how long have you been working in this domain?

Management with a research and development background. I joined AGC eleven years ago. I have however been involved with electrochromic windows for around fifteen years.

B. Interviewee definition of Adaptive Façade:

3. How do you define an electrochromic glazing façade? What is a purpose of a façade with electrochromic glazing technology? (Manuel da Conceição Nunes)

The first goal of a façade is to protect building occupants from variable outdoor conditions like fluctuating temperature or solar radiation. An adaptive façade like Halio should react to these fluctuations to protect from glare and provide the right amount of daylight while controlling solar gains. This is what we are entitled to expect from an electrochromic façade.

4. What are the strengths of electrochromic glazing in particular? (Strength) (Tanguy Timmermans)

It is the only solution that can adjust to changing environmental conditions in a truly dynamic way. And it needs to cope with the pace at which these conditions change. Electrochromic glazing is used to regulate light and solar heat gains. And these can change rapidly and greatly. For example, when a cloud moves away from the sun you need to react quickly enough in order to guarantee continuous occupants comfort.

Fast action is part of it also?

Fast yes, instantaneous no as it could be annoying for users. It is like switching the light off or entering in a tunnel while driving. You don't see anything for a moment until your eyes adapt to the new lighting conditions. So, what you need is a fast

system to deal with changing environmental conditions but smoothly for people not to realize it is changing and being bother by it.

If you compare to a dynamic shading technology, what's make electrochromic glazing different or standing out? (Manuel da Conceição Nunes and Tanguy Timmermans)

The first one is architectural. It is integrated in the glazing and not added to the façade giving you more aesthetical freedom.

Then you have operational comfort. You do not see or hear it moving. It is doing its job seamlessly without you even noticing it.

On top of this it can be used in any type of weather. Rain, low temperature or wind do not prevent you from activating your windows.

And last but not least, it remains transparent even when activated. This means that even when you need to protect against glare or overheating, you still have access to daylight and view outside.

Overall it provides a higher level of comfort compared to most other dynamic shading technologies.

C. Advantages of Adaptive Façade:

5. **Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?** (Manuel da Conceição Nunes and Tanguy Timmermans)

Let's look at the renovation of the Gare Maritime in Brussels. This building was not classified yet it had a strong cultural identity. The client was looking for a solution to preserve the façade authenticity while adding solar protection. Electrochromic windows are a perfect solution for that.

On top of that, the client wanted a building with a strong accent on circular economy. Integrating daylight and heat gains management in the glazing reduced dramatically the number of materials involved. Indeed, to achieve comparable function (with intrinsically lower performance), one need a handful of materials (metal parts, blinds, cables, motors, ...) whereas in the case of electrochromic glazing, most of it is integrated in the glazing itself.

I didn't hear you talking about the benefit, maybe on energy efficiency, can you elaborate on that? Or, what is the role of electrochromic glazing on improving the overall efficiency of a building? (Manuel da Conceição Nunes)

Heat gains management and energy savings where actually the reason why a solar protection was required in the first place. The elements put forward here are the additional decisive benefits that led to the use of Halio. But of course, the prime requirement was for the solution to reduce the building cooling demand.

So, we can consider it is also useful for avoiding overheating?

Of course, reducing overheating is just another way to look at cooling energy saving. And cooling energy is not the only saving you get. Halio automation actually ensure that the windows are tinted only when glare or overheating protection is required. But when risks are gone, windows are clear to let daylight in. With manual blinds, people most of the time forget to rise them increasing artificial lighting energy consumption. Thanks to its control Halio also saves on lighting consumption.

6. **Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)** (Manuel da Conceição Nunes)

This table only compares technologies all meant to control solar heat gains. But it overlooks the potential impact on other systems elsewhere in the building. This could be misleading. We do believe that each building is too unique to come with generic

statement about specific technologies. You need to look at the entire project and investigate what different technologies leverage overall. After all we do not build to use technologies, we build to provide comfort to occupants in the most efficient way possible.

Also, there is nothing about respiratory comfort or air quality.

7. Can you rank cost, energy, occupant satisfaction (view) in order of importance regarding electrochromic glazing and justify? (Manuel da Conceição Nunes)

Comfort is the primary reason why we have building, and we should keep it in mind when designing one. If we have the cheapest, most energy efficient building but it is uncomfortable it is a failure. Occupants will come up with their own system to restore comfort, but efficiency will most likely be lost.

Cost is an important factor but probably overrated. What we need to focus more on is the overall value and quality of the project. And again, we must look at it from a holistic point of view. For example, electrochromic façade will not only save on cooling, but can also impact HVAC sizing. Imagine that electrochromic facade would render cooling system needless. What impact could it have on the cost discussion?

And all this still overlooks the impact improved comfort has on other aspects like worker productivity. This is nearly impossible to quantify today so most of the time simply neglected. However, this is more likely where the real value lies. We believe mentalities are gradually changing here but it will take time.

The point of a dynamic façade is not so much adding complexity. But moving it to where it makes the most sense.

(Tanguy Timmermans) And façade is the best place to manage daylight and solar gains. It is where problems originate from and addressing a problem at the root is most of the time the best strategy. Otherwise you need to get rid of excessive heat gains using an HVAC system. But it is too late, the problem is already inside.

8. Do you know any performance based standards (not absolute values) for electrochromic glazing? Do you need new standard that regulate the performance and the control for adaptive facades performance assessment and Why? (Manuel da Conceição Nunes)

Glazing properties are already very well covered by existing standards. What is missing is the performance evaluation of the control strategies. As this strongly depends on the specific condition, it can only be evaluated at building level.

And what is the challenge with the control in general. Shouldn't industry have more standards that link this electrochromic glazing technology with also some certain assurance for control? (Tanguy Timmermans)

A standard way to evaluate the performance of electrochromic façade would be useful. However, we must be cautious about what we mean here. We should not standardize the control itself. Imagine we have only 3 options for control in the standard: manual, automatic and automatic with weekends, nobody will bother trying to improve it. And we might lose a lot in performances just because we are not using the product to its full extend.

It would be like saying we have only three possible insulation level values to pick from when evaluating a glazing system. There will be very little incentive in trying to make it better as it would be hard to valorise anyway.

What is needed today in the regulation landscape to make the value of adapted façade more standing forward? (Tanguy Timmermans)

What is missing is a proper way to include the dynamic nature of the electrochromic window in performance evaluation methodologies, so again the control strategy. What I imagine would be a 2-parts standard. First a simplified approach where non-expert

users could pick and apply a simple control. But we need at least a second option where you could valorise a fully customized one.

This would be similar to what is done for the thermal performances of framing systems. You have a first version of the standard with tabulated values. But you have a second part describing how you can use detailed 2D finite element calculation.

Regarding the overall calculation methodology, simplified approaches like monthly calculations in many EPBD today are interesting because easy. But they're not very good to assess the full potential of dynamic systems. We also need more advanced methodologies like dynamic simulations.

D. Disadvantages of Adaptive Facades:

9. In your opinion, what is the fraction of electrochromic glazing in today's European market? (Benoit Domercq)

Less than 5 percent.

And why is it only less than 5 percent.

For two reasons: Electrochromic glazing is a new very advanced solution that was barely available five years ago. The technology has been discovered a while back, in the sixties but it was firstly developed on very small surfaces for automotive application. The challenge was to move to large glass surfaces for windows, with good aesthetic. and this took a lot of time.

The first prototype projects (mostly located in the US) are already ten years old. The first more significant ones appeared 5 years ago, again in the US. So, from a market point of view it is a relatively new technology and a lot of market education is required, especially outside US where significant players have already done the groundwork.

The implementation of such technology in a very conservative industry is always something that is going to take some time. But we are benefiting from the recent trend around green and smart buildings.

10. Does the cost impede/hinder the market penetration in your opinion? What is the influence of mass customization on cost? (Weaknesses) (Benoit Domercq)

It's not only a matter of cost; it's a matter of value. The value that the first generation of electrochromic technologies has provided in the past was not justifying the premium asked for it. We recognized that as a company. I don't think the cost is actually a problem. The problem is more the structure of the value chain and the way the decisions are currently made in the building industry.

Can you elaborate on the word "structure of value chain"? What do you mean by that?

As my colleague already explained, what matters is what you are going to do with the adaptive façade. People in the construction industry today are looking at adaptive facades only for the glass part. For me the glass is only the tip of the iceberg. If you are comparing advanced smart glass versus a regular glass, cost will make people jump out of their chair. However, this is comparing apple and oranges. When we start explaining all the elements you need to consider to compare costs, it will not be a discussion anymore. Another very important aspect is the current organization of the building sector in what I call 'lots'. You have the façade specialist, the electrical specialist, the fluid specialist that are working in 'silos'. Therefore, when you present a product that impacts several silos the comparison becomes very difficult.

That is why I am surrounding myself with people not coming from glass industry. But people from the construction industry that understands the thermal performance of buildings, how to size HVAC, how to impact the control of the building. I also need people to look at the façade, but façade is just an element. I think the best sentence

summarizing what a dynamic façade is, is that it “closes the building as a bonus”. But it does much more than that.

You are talking about the conservative building industry. When we look at mass customization, 3D printing, BIM and all these new project delivery process advancement, do you think they might have a positive impact?

In twenty years, yes. BIM doesn't do anything right now, it's just a gadget. And 3D printing is something that did not prove anything yet. It's a bit provocative but right now it's insignificant.

And the word customization having readymade solutions, where?

It's completely different. That's not mass customization, that's standardization.

Standardization and not customization ?

Mass customization is the MINI car story. When you buy a MINI car, you can customize the paint on the roof. We deliver a product that has some customization features while keeping the bulk, but we are far from mass customization. Frankly, when I read that part of the question, I didn't understand what you meant.

It might be ambiguous, I agree with you, but it's meant by the mass production, the mass production of the construction sector, for example, having more standardized and more modular building.

We do mass production. This is not a problem. The problem is that all projects are customized. Standardization can increase the uptake on the market for the whole construction industry and not only for adaptive façade. This is more a problem of the construction business. Of course, if you can build, based on a couple of models, then, everything is going to be faster and easier.

11. Do you think that electrochromic façade technology is mature to penetrate to market from point of view of components and control strategies? (Benoit Domercq)

No, but what we put on the market is. We are the only one right now on the market able to provide a fully adaptive façade with a true value for the occupants and the building. What I claim is that we are the only system who is truly integrated with a control strategy providing value for the building. We are not an on-off light switch technology. We are making building smarter.

And why did you succeed in doing that?

Because this is what we wanted to do and recognized that was the gap on the market.

So, it was from the beginning, the technology advancement was looking at bridging this gap.

Yes, this is why I say that the glass is only the tip of the iceberg. What matters is the intelligence you put in the control, the intelligence you put in the way you provide comfort to the occupants and increase the performances of the building.

12. What are the risks regarding life expectancy and maintenance of electrochromic glass façades? (Benoit Domercq)

None. The only risk we see is that we integrate everything in a glazing. If something goes wrong, you have to open the façade. When you start to integrate too many technologies within one product and it fails, then you need to intervene at the structural level of the building. Whereas if I look at competitive technologies, such as blinds and motors, you can always access them without impacting the integrity of the façade. That is the risk people can perceive. This is why we decided to remain responsible of the system even after façade delivery.

E. The Future of Adaptive Facades:

13. What needs to be done better so that the project delivery of adaptive façade or electrochromic facades can be better? And the level at the end a better performance for overall building performance. (Benoit Domercq)

I do not believe there is a major problem in project delivery. However, we believe we need to support customers more extensively with advices, field support and an outstanding level of responsiveness in case there are issues, especially for the first projects. When you introduce a new technology, you need to educate and reassure people that there is nothing complicated. We are progressing every day to ensure that guidelines are clearly communicated and strictly followed.

The project delivery is not an issue?

Not if you offer the support described above.

14. Who should be responsible of maintaining the electrochromic glazing performance after construction? (Benoit Domercq)

The electrochromic glazing provider. That's what we do. We provide a complete experience from design down to the usage of the building.

Do you think, or do you agree that the soft-landing or post occupancy evaluation or continuous monitoring should become obligatory for sustainable and green buildings?

Yes, especially to show the benefits of green and smart building.

15. What feature would you like to find in the future in a electrochromic façade or a façade with electrochromic technology? (Benoit Domercq)

More flexibility in the control. Right now, one window is one pixel we could envision having something a little bit more addressable.

Something with a larger range of performances, in term of light transmission. Maybe some colour changing as well.

Systems that are faster to install would be interesting too. I think wireless windows will be something that could be interesting at some points for some applications.

Something thinner and lighter.

Materials

Yes, lighter façade. But also, façades that are easier to recycle. And I think in general for the all construction industry, a real recycling value chain that will allow to truly fulfilling cradle to cradle promises. It is up to the entire industry to invent a building end of life and products recycling strategy.

16. What are the opportunities to increase the use of electrochromic glazing in the buildings in the near future?

I think green buildings, sustainable buildings and smart cities are definitely the three development pillars. And from the user perspective, the recognition that comfort and well-being are the drivers behind the use of smart glazing.

What can make it faster? Or slower? This uptake

Again, coming to the value chain. Today it is extremely conservative. They resent taking risks and I think, if we can find ways to build faster, we will see more and more complex technologies introduced in façades and buildings in general. Modular construction could help here too.

Another opportunity is the uptake of cloud and connected technology as well.

Interview with Stephane Auvray, Saint-Gobain SageGlass

Name: Stephane Auvray

Date: 06.09.2019

Place: Liège, Belgium

E-Mail: stephane.auvray@saint-gobain.com



Questionnaire:

A. Background Information

1. What is your core specialization? And what kind of projects you have been involved in?

I'm a physicist. I have PhD in solid state physics with a specialization in nanostructure and semi-conductors.

Following my PhD, I decided to continue my studies with a post-doc on OLEDs (organic light-emitting diode) with one challenge, "How to produce the maximum intensity of light using a minimum of quantity of energy?".

Then I joined the industrial group Saint-Gobain, as a R&D project manager in the solar business to develop new materials, still sensitive to light, but this time to generate electricity! I managed R&D projects on coatings and glass matrix with key topics like electrode development, anti-reflecting coating layers, thin film materials to increase the efficiency of copper indium gallium selenide CIGS solar modules.

Following my Solar experience, I managed the Glass Façade Business Unit R&D program where the main challenges are how to minimize the glazing solar factor, retaining the highest luminous transmission, and a design aesthetic for the Façade. The key target is delivering products that contribute to reduce the consumption of energy in the building.

Recently, I joined Saint-Gobain SageGlass and to manage the French market. SageGlass is an Electrochromic Adaptive Façade. It is a fantastic product that contains a large range of solar control product from Saint-Gobain Glass in a one unique coating!

2. How long would consider yourself in the field of facade?

13 years in Solar, BIPV and facade business.

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade or an electrochromic glazing facade?

What is the purpose of an electrochromic glazing?

I like to define the concepts one by one.

The Façade is the envelop or the skin of the building. It is the separation between indoor and outdoor. The Façade is exposed to dynamic elements like the sun path, clouds path, weather changes, outdoor noise, etc. The Façade must be responsive to those dynamic elements as well, to manage and control the flow of energy and natural light during the days, the seasons and for different orientations.

An Adaptive Façade is a Façade capable of adapting itself in real time to dynamic elements. A Façade's ability to change or move across a spectrum of responses to dynamic elements at the same time. The responsiveness is the key differentiator. As the sun's path changes so does the Façade as it opens light paths once the sun has

past and predictive closing of solar energy paths in other parts of the Façade to prepare for where the sun is travelling.

One of the key challenge of Adaptive Façades is to contribute to the decrease of energy consumption.

To summarize, the purpose of an Electrochromic Adaptive Façade is to...?

There are different purposes. The purpose most often depends on where you are at in the value chain.

In the last decade, the main challenge for architectural projects was “How can I reduce the energy consumption of my building?”. In other words, “How can I maximize the use of natural light and energy delivered by the sun to minimize the source of energy consumption of the building?”. SageGlass delivers a performance solution for that.

There is now a second purpose, “How to deliver comfort to the end user?” and when I say comfort I mean multi comfort visual, thermal, and acoustic.

Why this trend?

If you analyze the building operating expenses, one can see that energy corresponds basically to only 1% of the total expenses. The rental cost of the building corresponds to about 9% and the remaining 90% correspond to staff costs! So, for an investor the lever with the highest effect is the one touching the satisfaction of the end users. The comfort is then becoming a key driver and our solution SageGlass contributes significantly to improve the quality of life and the wellbeing inside the buildings.

Access to natural light is considered a visual comfort and leads to more productivity and less absenteeism at work. The payback can be quantified and capitalized. We will discuss afterwards on how to quantify occupant comfort, which is an ongoing area of development within the industry.

Optimization of Electrochromic Adaptive Façades does require some conditions. Adaptive Façade means a connection of the Façade with the rest of the building. SageGlass is a building component that must be connected to the other components like HVAC, Lighting, Energy Management through the use of a Building Operating System. Adaptive Façades require stimuli to adapt so all the building components work in concert together like a symphony.

Can I say it is the element number 3? Because one was the energy reduction, two was the comfort and 3 is integrated control.

Yes, the 3rd one is integrated control and is a robust area of development.

Lastly, Sustainability. Sustainability means that we have to deliver solutions with the minimum carbon foot print, or solutions that will simplify the building construction mode by using less material quantity. There is substantial innovation around sustainability goals like the new concept of material leasing in an effort to reuse what was once thought of as a one-time use life cycle.

So the circularity?

Yes. We can imagine a future where a building leases SageGlass and at the building's end of life, SageGlass would be removed and available to be used with a new or existing building that has the same product dimensions. The industry is still a long way from this outcome due to the challenges of custom dimensions of commercial buildings and the need to warranty a product for several decades.

So we have 4 elements: energy consumption, improvement of comfort, integrated control, and finally overall materials sustainability and circularity. Do you have something to add?

I would like to insist on the fact that Electrochromic Adaptive Façades can really change the way we work and live in a building. By its function, SageGlass is a “human centric” product. One source of discomfort is the glare effect. The glare effect is a complex issue. Most of us have been in a situation where we cannot use our computer anymore because of the glare from the sun directly or bouncing off other office materials. Electrochromic Adaptive Façades is a solution for glare control.

A tint level of 1% or below provides glare control management. It improves your work condition regardless of the season. The second aspect is the ability to use of in-pane zoning. The SageGlass in pane zoning (like Light Zone or Harmony) allows a building owner to only tint the part of the window that is directly impacted by the glare, thus allowing the remaining space of the window for daylighting purposes. It is scientifically proven, that the access to natural light contributes to reduce the recovery time of patient in the hospital. Another example of human centric function.

So many purposes!

Perfect, so for the question for the human centric approach on folding is one on the glare effect or controlling the glare effect and second part is improve the access to natural light and the connection the outside.

Exactly. I think I would add a last one, connectivity.

You mean System integration?

Yes, System integration. An interconnected System will generate new types of services. It is a work in progress but everybody is talking about BOS, Building Operating System. New services are coming. Answering questions like “How can I better manage the cooling of meeting rooms?” Sensors can detect the presence of people. When the room is empty, SageGlass can be tinted to the dark state 1% TL, 4% solar factor to minimize the need of cooling.

Can we call that smartness? Or you said connectivity, do you prefer to use connectivity?

I would say it is linked.

Strongly linked, so connectivity and smartness, for example?

Yes, connection is not enough. We can connect different building components that can now talk together. But it is not enough. There is a need of a backbone to organize the way all these elements will interact together. For that, some new scenario of usage must be developed.

C. Advantages of Adaptive Façade:

- 4. Can you describe the projects with adaptive façade features? (with a focus on electrochromic glazing) and what was its main added value (reason) that electrochromic glazing was here introduced (comfort, energy, real state value, image etc...)?**

I imagine you have a lot of project but you can maybe focus on one or two because we want cite them and put a picture for them.

Electrochromic Adaptive Façades is a part of the solution to move from passive to active. I would say SageGlass is disruptive in the sense that the tint and the solar factor of the glazing can be fine-tuned in real time for different areas of the Façade. The fact that SageGlass can meet all three at the same time – no more need of external solar protections, energy consumption is reduced, and integrating occupant comfort – is a compelling product position for consumers. Lidl agreed. More than 50 shops are now equipped with SageGlass in Germany.

And it delivers a lot of positive side effects!

A customer in a comfortable area will have a tendency to stay longer. We see clearly this phenomenon in commercial centers in Paris. A hot shopping space can lead to bad smells and result in occupant discomfort that shortens shopping experiences. On the opposite, if you are in a comfortable space, you could spend more time inside the shop.

This is more the retail and the expensive shopping...

SageGlass solutions can scale with each opportunity. It is a good example that demonstrates that SageGlass is adapted for many segments.

Let's say general shopping.

So we have Lidl. Can we have a building or a specific case just that we refer to or are we just talking as a change of supermarket?

The Lidl model is transferrable to other type of shops. I mention Lidl because we have a strong partnership with them. And it is a very nice story to tell. Lidl retail shops are not an obvious segment for SageGlass. But we demonstrate SageGlass solutions scale with the opportunity.

Other interesting segments include healthcare and airports.

Healthcare and clinic...

The benefit of the natural light is known, and well documented. Access to natural light, without any solar protection that could block the view, is known to help patient to recover.

Reducing stress of travelers at airports. Most travelers have electronic devices with them to use while waiting for their plane. The glare and heat can make the limited seating spaces uncomfortable and cause travelers to concentrate themselves in certain areas leading to an ineffective use of designed waiting spaces. SageGlass solutions have been very successful optimizing traveler comfort and optimal space use. The Minneapolis / Saint-Paul International airport is one such project.

So we can say, we have retail shop (Lidl), we have airport (Minneapolis), and do you have any case of healthcare?

Yes, Clinique La Lignière in Switzerland for instance.

Commercial buildings remain a significant segment for SageGlass.

Okay so it would nice to say "office, for example" and then, the people can say "okay it more about well-being, the productivity, the connection, the outside". That is special type of building. Building they are not just commercially or mass production.

My message is that SageGlass is not dedicated to one specific high end office building segment as people would have tendency to think. SageGlass is adapted for hospitals, retail shop, airport, office building and also specific diffused residential market. We have a strong partnership with a veranda maker in France, named Akena. They see the benefit of Electrochromic Adaptive Façades for veranda, simply because we all know that during summertime, it can be uncomfortable. Integrate SageGlass in the veranda delivers the assurance of four season comfort to customers.

Last but not least, Office building.

Maintenance of the solar protections is a major pain point for consumers. Deliver a solution to simplify the process of maintenance of the Façade, and reduce your OPEX is strongly appreciated in office buildings.

- 5. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)**

Yes, I have some comments about that. I would say, more and more we see the need to think total cost of ownership, TCO. It is an important criterion as it allows to benchmark different solutions in a reliable way; taking into account the life time of the product.

If you are investors and possibly the user of the building, long term payback of your investment is an important criterion of decision.

So, this can be more on the life cycle, durability?

For the life cycle, I would like to propose to add the real frequency for the maintenances.

But you agree to add the TCO to the life cycle or not? Or you want another category?

I think it is another category.

Like maintenance is here, I think.

With the maintenance, the risk here is to evaluate the real maintenance cost coming from real experience.

But just again, total cost of ownership and what is the second one?

The real cost of maintenance based on a real analysis of experience.

Ah so post-construction.

Post-construction yes. For instance, we know that some equipment could have some leak, could have some breakage.

And how long you propose this; 30 years? 50 years?

Between 30 years and 50 years. It depends really of the investment type...

I am in favor to promote 50 years to be aligned with the need of sustainability.

So this kind of, let say, category for assessing technologies will make more transparent to see which technologies is more worth it, or robust actually?

Yes, reliability of different technologies.

Because here we have materials durability, appearance of the facade, easy of replacing elements. This is more circularity, easy of cleaning, product take back and the global guaranty which you provide more service rather than product any sale. But the total cost of maintenance and the real cost, this is like a calculation that it is be done before and this is a post-construction real maintenance analysis.

Yes. It is a calculation that must be done at an early stage of the design of the building based on real figures coming from experience. Frequency of maintenance should be added as well. If you have to change some elements of the Façade considered as being subject to frequent maintenance at a place where there is no easy access, the cost allocated to this operation can become significant. It should be well integrated.

Another aspect that should be integrated, as it is part of the advantage delivered by SageGlass, is the opportunity to go for different states of tint, Light Zone, or a progressive transition with our new product Harmony. It is much more than a pure aesthetic criterion. It may, also, change the way you control the natural light and the dynamic of solar heat gain. Light Zone or Harmony are not reflected well in current modeling tools. Possibility to compute different solutions in a robust way should be added, too.

Okay then I will move it to the future, so, in the software and the modeling. I will not forget it.

Do you have also some indicators on the comfort?

We have functional performance, which is acoustic performance, visual, fire, thermal, structural and then we have the interaction with the building.

Engagement, command control, action feedback, reporting technology for failures...

So I think it's good, the scoring of the comfort is a complex topic. How to do it in a reliable and scientific way.

Yes, this is just a generic at least in Europe. We want to have an agreement from the experts to say "okay, what are the important categories and then the details behind".

6. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades and justify that?

It is a complex question.

But it can be personal, as you like.

There is not one single answer. It really depends to whom we are talking in the value chain.

It is not possible to rank cost vs energy vs occupancy. The value chain is segmented and every player has its own criteria of decision. What I propose, is to try to answer to this step by step.

Investors and Developers.

When we discuss with them, they are interested by the total cost of ownership. They want to know what is the ROI (return of investment) with SageGlass and how many squares meters they can save using SageGlass vs the other systems. Now, we have to say that sustainability and carbon foot print are more and more becoming a topic of discussion, comfort is also part of that decision. There is a simple reason to integrate these new criteria of decisions. A new building that is not smart, sustainable and comfortable will depreciate very fast.

End Users

They do not care about cost. They simply want to work in a comfortable atmosphere. And when we say comfort it includes acoustic, visual and thermal. Electrochromic Adaptive Façades provide a significant advantage because there is no noise generated during the transition.

There is no engine or motor...

Exactly!

If you discuss with architects. They are mostly discussing the language of the design. So, design and all the elements that can deliver innovative design like SageGlass Harmony or Light Zone.

Now, we have to pay attention that architects are in competition for projects. They want to win the contest. So whatever the benefit of Electrochromic Adaptive Façades, they are also sensitive to the price of the solutions. If a solution is considered or perceived as expensive, there is a risk for the architect to not win the contest. Depending of the type of architectural firm some architects could decide to not integrate Electrochromic Adaptive Façades even if it is the best option.

There is need for strong communication to explain, train and educate architects, engineering office, investors on the value of SageGlass. Lidl model is helping a lot.

7. Do you know any performance-based standards (for electrochromic glazing) that allowed for dynamics performance value? Instead of one fix g-value, one fix U-value? Do you have a range that tells you if you are in the morning, it could be like this, and is night like this? or in the summer like this? Could you find any standard that promote that envelop is active like that? Do we need new standard that encourage such innovative?

Unfortunately, no. I do not know any performance standard for EC....

So why do we need to encourage standard to go in this direction?

I would like to add a comment on that.

Electrochromic coating like other solar control coatings faces the cavity of an IGU and can be on face 2 or face 4 depending on whether it is a monolithic or laminate exterior pane.

Currently, the Electrochromic coating complies with EN 1096 for the CE Marking. We support the development of a performance or component standard for active or dynamic coatings to address characteristics that a static coating standard cannot.

Just IGU can you?

Insulating glazing unit.

The disadvantage. The standard has not been written for dynamic facade. So there is something to improve here.

So we need standards that encourage this innovation and allow for variation? depending on indoor and outdoor condition.

Yes, you are right. As we have already discussed, Electrochromic Adaptive Façades are strongly linked to smart buildings and then smart city. This smart city can create lots of coupling and complex relationship between the user and the dynamics elements. People are working on this but there is no yet an existing standard.

D. Disadvantages of Adaptive Facades:

8. In your opinion, what is the fraction of adaptive facades in today's European market? Let's say electrochromic. And why?

It will strongly depend on the country. Less than 1%

Now the question is why it is so little?

Because the real value of Electrochromic Adaptive Façades is not well known by decision makers. SageGlass is perceived as a high-end and high cost technology glazing and not as an active Façade that will deliver comfort to the end user. SageGlass is also perceived as a new product, not yet mature, and investors want to be sure that they are not taking risk. Hopefully the situation is changing.

But not anymore now?

Ten years back, the situation was totally different. We were in a ramp up phase with small volume of production. Now, you are right, we are entering the time where the technology is adopted by main players.

Can we say then the reason is lack of awareness?

Lack of awareness. Decision makers do not know that SageGlass has already delivered more than 200 000 m² of Electrochromic Adaptive Façade projects.

So again it is awareness and knowledge, and to see project.

Yes, that is why we are making lots of communication to educate and break the high price perception.

But also, the industrial in general is conservative. We are not industrial, or automobile. There is also something here.

If you want to push innovation in a conservative business environment, you have to demonstrate the value to the investors. It takes time. Now volumes are increasing significantly. So production cost will continue to decrease and SageGlass is going to become more and more cost attractive.

Okay, now to be more specific. We have developers, we have consultancy firms, we have architects, we have contractors. Is it on all level?

All the value chain must be convinced of the value of the product.

How do you manage it?

We need to discuss with all the actors and explain the value, show projects.

So the overall, let's say, perception is not make it that mainstream.

Not yet.

Because overall, you don't have agreement.

There is no general agreement because decision makers are still partially informed. We push for a complete solution that by some aspects can remind the penetration of the mobile phone 20 years back.

I remember a survey in France, saying that people prefer to keep the local phone cabin and will not pay for a mobile phone.

Lots of reluctance.

And finally the propagation of smartphone was really rapid. Now everybody has a smartphone!

We have to change mind. Whatever the beauty of the innovation, decision makers have to understand the value it can bring to adopt it. And it takes time.

So let's say the market update is low, there is needed to be work to change that.

Absolutely, that is one of my key mission I would say. Communicate to all the players at all of the level of the system. Present to all interested parties in the value chain

In such a way that people know the product and adopt the product.

9. Does the cost impede/hinder the market penetration? Is it a major factor? What is the influence of mass customization on cost? (Weaknesses)

Yes. The perception of the price, not the real market price, but the price you estimate yourself for such a nice technology is clearly one of the key topic of the debate. The perception of the price is sometimes so high that self-censorship happens without a factual basis.

Now we have lots of real examples that contradict this aspect. Once again, Lidl is a key actor of the low-cost retail. They understood the value of Saint-Gobain SageGlass. We have more than 50 references with Lidl. And more are coming.

I am allowed to compare the Electrochromic glazing and the photovoltaic? Because photovoltaic is still now, it is seen that in some place is expansive.

And my student they come from France, half of students are French and Belgium. All French student, I don't know why, they come talk with me about energy and the pollution of photovoltaic. So there is a perception or a mindset.

Can we say that electrochromic is similar to this innovation?

For some of the aspect you are totally right. Like every innovation, there is a resistance at the beginning. I remember really well the debate on the durability of crystalline silicone PV modules versus CIGS. Once CIGS modules have been launched on the market, we had to prove the long term durability of the modules without having installed them on real projects.

Complex...

For SageGlass, we have lots of projects to show, lots of experience to demonstrate that all what we said on long term durability is true. Ten years back, Electrochromic was considered as the technology of the future for the façade.

So now, it is the technology of the present.

So it what you try to ISO committee. It is a technology of the market; mature and...

Yes, when you are speaking about 200 000 m² of installed SageGlass, you can say that the technology is matured.

One remaining blocking point for a large deployment is the size.

What do you mean ?

Electrochromic industry is not yet capable to deliver large scale IGU where solar control products can be supplied up to 18m.

So the size of glazing and we are used in Europe to have huge glass façade, with big span.

This restriction will change; it is a question of time.

What is the latest you talk about? The dimensions of the latest panels? for SageGlass.

3 by 1.5 meters.

So there is another factor.

Yes, it is another factor.

I had a question What is the influence of mass customization; or standardization, or simplification on cost? Informally talk about that you said, more the façade, the simple... the cost is low? Can you reiterate on that?

Yes, for sure. A good way to promote Electrochromic glazing is to optimize the dimension of the glazings to get the highest production yield. It will impact production cost and contribute to the sustainable development.

Unique size and simple geometry.

Yes. Simple geometry. We are capable of delivering other geometry but...the simplest is the best.

I am talking relation to cost.

Yes. It is an important part. Standardization and simplification of the Façades will contribute to reduce the geometric losses.

10. Do you think that adaptive façade technology (specially the control) is mature to penetrate the market? And Why?

Yes, absolutely.

Why?

Because maturity it is related to the volume that you are capable to produce. Now we have installed +200 000 m² of SageGlass. The technology is early in its matured phase.

And regarding to the control?

In case of SageGlass, the System works under a low voltage of around 2.5V. We use low energy components that are durable. The System is usually installed in a dedicated and ventilated room with easy access to allow for fine tuning your set points.

Wiring is not an issue ?

No. There is no issue with wiring.

And I interrupted you when you said that, what it is the connector or the conductor...

The bus bar is the conductive component that carries the electrical current to the Electrochromic coating. A bus bar failure is fatal to the product.

It is just sensitive...

It has been a weakness.

If you cannot supply energy to the glazing, you lose the function.

We had issues in the past like for the Photovoltaic business, but it is now completely solved.

One open question is how the electronics in the System will change in the coming years and what are the new protocols of communication that will be developed?

SageGlass is investing in advancing its controls because interoperability is the future.

11. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

In France, we have the CSTB certification. CSTB is renowned for its expertise in building construction materials and has granted SageGlass a DTA further supporting the reliability of Electrochromic Adaptive Façades. We give a 10-year warranty for the glazing.

Should we worry about electrochromic glazing, is it a risk?

No!

And based on our experience we applied some continuous improvements....

What can occur?

What could occur? For the coating by itself, I would say, nothing. We decided to make a choice to ensure its long term durability.

Like for the photovoltaic, you can use different types of materials to reach the function. In the PV, for instance we can find mono or poly crystalline Si, CIGS, CtdTe,...and also organic materials that are emerging.

The beauty of organic is that you can expect to fabricate transparent or semitransparent PV modules. But with organic molecules, there is something difficult to evaluate....

What is a real life time of the devices?

The SageGlass Electrochromic coating is 100% made using ceramic material. So there is no risk of degradation by the UV. Moreover, low voltage is applied to avoid stressing or altering the material. It is key to delivering a sustainable solution.

No issues with the coating?

No issues with the coating.

Where could be the risk?

There is no specific risk.

Only uncertainty about the possible evolution of protocols of communication that could impact the electronics of the System.

Can people mis-use electrochromic glaze?

No. The control algorithm is built to protect the Electrochromic coating from users overloading the product. If there is no more electricity in the building, we go back into the clear state.

Ah the frequency?

It is not a problem. We have already proven that SageGlass can be cycled 50 000 times without loss of performances.

So the electronic and what you said the bus bar.

The bus bar is the connecting system in between the 2D films and 3D cables. This interface is complex and has been improved. Now it is no more a topic.

So is not a threat anymore on the life expected?

Absolutely not.

How can we calculate it? How many years? If I want to make the calculations?

SageGlass has a 10-year warranty for the Electrochromics and Insulating Glass Unit in Europe.

Based on the different ageing tests performed like the cycling test, we can estimate a minimum life time of 30 years.

F. The Future of Adaptive Facades:

12. What needs to be done for a better adaptive facades project delivery process, it can be the modeling like you talked about, and better performance quality overall?

And you are totally open to discuss on the design face or the construction face or the operation or post operation.

For me, the key point right now is communication and information. Communication at all the steps of the value chain.

We have to deliver the right information to the right person. It's done since years but we have to accelerate. That's why for instance at Saint Gobain SageGlass, we communicate not only dedicated to architects or engineering office, but also to investors that are more and more interested by PropTech congress.

PropTech is what?

Property Technology, that's the technology of the building if you want.

Ah property technology, building property.

That's what we call the PropTech.

We participate in the Smart Building Alliance in France.

Once you are no more talking of materials but global solutions that are part of a new ecosystem of the smart building, you have to be there. One of the channels of communication is also R&D, standardization working groups and labels.

I just came from international conference on building performance simulation. And Saint-Gobain was present on modeling. You mentioned several times this issue of modeling, since we are talking about communication, what is wrong with models simulation? What needs to be improved?

The models are correct, it's not a question about the engine of the software. It's mostly how to integrate dynamic glazing in a robust and reliable way taking in account the DNA the product and not simply the minimum solar factor and the maximum solar factor.

The European regulation today is depending on a static simulation.

Yes. I know.

You strongly urge to use dynamic simulation and benefit from the power of existing software. So that we can quantify the effect on cooling, quantify the effect on comfort, on visual and glare.

Yes. Thermodynamic is key.

It's absolutely key to model the energetic pay back and also the quantity of natural light in a reliable way. It is also important to get a good estimation of the error bar due to a non 100% reliable model.

So, models must be improved!

Moreover, it is important to integrate the tint and the dynamic nature of the glazing and the SHGC, not only the min and the max but the intermediate states.

We have also now Harmony.

Harmony is fantastic because it's a new design element for the façade

Lastly, how to integrate reliable scenario of usage to score the occupant comfort for the end user.

13. Who should be responsible of maintaining an electrochromic glazing after construction? General contractor or building owner or occupant or façade consultant or even I didn't mention it, the manufacturer?

Because this is a question related to moving from product-oriented economy to service.

Absolutely, so, the business model is going to change. For the moment, the situation is simple, that's mostly the facility management that is making the maintenance.

Even for electrochromic glazing? They have to learn about it.

Yes, they have to know about it, for sure. Generally speaking, facility managers like SageGlass as it simplifies the program of maintenance. With Electrochromic glazing, there is no more need of maintenance for movable parts or motorization of the façade. Even if I said before that 200k m² of SageGlass have been installed, we have to accept that it represents a very small penetration vs other solutions

With coming smart buildings, the jobs of the facility manager are going to evolve. Integration of Building Operating System will contribute to plan for predictive maintenance, develop new services. Saint-Gobain is also thinking of what kind of new services we can provide.

Tata already had a building and they are using it as a deposit

Yes. Tata rented the material. Material leasing is a new interesting business model.

So electrochromic glazing can also be part of this model

Material leasing and associated services may be part of a future strategy for SageGlass.

14. Do you agree that soft landings, POE and continuous monitoring should become obligatory for smart building?

Yes, without monitoring you cannot quantify. Post Occupancy Evaluations (POE) should become obligatory to progress. I am really supportive of that.

Now, one of the challenge is on the methodology to evaluate POE in a correct way knowing that a bad evaluation can generate noise. POE has some limits. Noise can be generated depending of the way you collect the data. Experiments, prototypes must be done with POE to learn the limits.

As long as we know them, POE can be very effective.

15. What features would you like to find in the future electrochromic glass?

As with any new innovation, the focus is on product and process.

The future is services.

I would say comfort will be soon a real service to increase the quality of life of the employees and ensure the customer satisfaction.

So kind of comfort glass you will sell or comfort service

We are developing this area.

A take back the materials.

The feasibility of a Take Back program is still being investigated. There are alternate methods to ensure the recycling, recovery, and re-use of construction materials. We must take into account the additional carbon footprint of transporting SageGlass to a central location and then transporting to service providers that could harvest materials. A Take Back program is a complex business decision and not, currently, on a roadmap as a future service for SageGlass.

16. What are the opportunities to increase the use of electrochromic glazing in buildings in the future? (Opportunities)

There are a lot of opportunities. Among all the coming new business models, there is one that we did not mention up to now. The co-working spaces. The principle is simple. To attract new young talents, you need comfortable offices with an easy access.

So, you standardize the comfort quality

Yes, I think comfort is key.

If we more and more EU standardize comfort but not theoretically, in reality, it will be an opportunity to introduce electrochromic glazing as a robust and reliable solution that can support providing these spaces.

Young generation, new profiles like UX designer, working in a startup are sensitive to comfort and want to work in comfortable environments. It is a big trend with lots of positive side effect. It generates creativity, open innovations. SageGlass is part of the solution.

Let's deliver.

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Final Questionnaire

A. Background Information

1. What is your core specialization? And what kind of projects you have been involved in?
2. How long have you been in this field?

B. Interviewee definition of Adaptive Façade:

3. How do you define an adaptive façade? What is the purpose of an adaptive façade?
4. What is the strengths of adaptive facades? (Strength)

C. Advantages of Adaptive Façade:

5. Can you describe the projects with adaptive façade features? (Active transparent facades, Switchable glazing, Phase change materials, automated louvres) and what was its main added value (reason) (comfort, energy, real state value, image etc...)?
6. Can you revise Table 1 and suggest additional indicators that need to be taken account when assessing the performance of adaptive facades? (design, construction, operation, end life)
7. Can you rank cost, energy, occupant satisfaction (view) in order of importance for adaptive facades?
8. Do know any performance based standards (not absolute values) for adaptive façade? Do you need new standard for adaptive facades performance assessment and Why?

D. Disadvantages of Adaptive Facades:

9. In your opinion, what is the fraction of adaptive facades in today's European market? Why most of the projects are not having adaptive facades?
10. Does the cost impede/hinder the market penetration? What is the influence of mass customization on cost? (Weaknesses)
11. Do you think that adaptive façade technology is mature to penetrate the market? And Why?
12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)

E. The Future of Adaptive Facades:

13. What needs to be done for a better adaptive facades project delivery process and better performance quality?
14. Who should be responsible of maintaining the adaptive façade performance after construction? (General contractor or building owner or occupant or façade consultant) and why?
15. Do you agree that soft landings, POE and monitoring should become obligatory?
16. What features would you like to find in the future of adaptive facade?
17. What are the opportunities to increase the use of adaptive facades in buildings in the future? (Opportunities)

TABLE 1	Adaptive Facade Technologies Performance Matrix																									
	Energy & Environmental Performance					Functional Performance				Interaction of façade system with the building				User Experience And Control				Life Cycle and Durability								
Adaptive Facade Technologies	Energy Consumption	Embodied Energy	Embodied Carbon	Cooling Load	Heating Load	Structural Performance	Acoustic Performance	Visual Performance	Fire Resistance	Thermal Performance	Engagement	Command & Control	Action Feedback	Reporting Technology	Failure	Thermal Comfort	Visual Comfort	Aspiration Comfort	Feel & Look	Material Durability	Appearance of the façade	Easy of replacing elements	Easy of cleaning	Product take back	Global guarantee	
Movable Shading Facades																										
Electrochromic Glazing Facades																										
Phase Changing Material Facades																										
PV Integrated Facades																										
High Resistance to Environmental Effects																										
Solar Thermal Facades																										
Biomimicry Facades																										
Self-cleaning Facades																										
Anti-microbial Facades																										
Insulating nanotech coating																										

Relevant Publication:

Journal Papers:

Attia, S., Garat, S., & Cools, M. (2019). Development and validation of a survey for well-being and interaction assessment by occupants in office buildings with adaptive facades. *Building and Environment*, 157, 268-276.

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