Adaptive Facades Performance Assessment

Interviews with Facades Experts

Prepared by:

Shady ATTIA, Senem BILIR and Taha SAFY

Al Bahr Tower, Photo Credit: Terri Boake
Forward and Acknowledgment

This report is the result of a group work that was established with the help of COST Action TU 1403 members. Several discussions and meetings took place in Liege Belgium and other European Cities.

The report is focused on interviewing facades experts and contractors who work with facade implementation. Adaptive facades are advanced solutions that require quality measure to ensure their long-term performance. In this context, we aimed to interview several experts who had experience with adaptive facades realizations.

Part of this work was developed during the investigation of three case studies with adaptive facades. The 3 case study analysis included the AGC Building in Louvain La Neuve Belgium (Attia and Bashandy, 2016), Al Bahr Towers in Dubai, UAE (Attia, 2016) and Swiss School in Dubai, UAE (Bilir and Attia, 2017). The 3 case studies include AF technology and are considered as pilot projects. The case study analysis focused on the project delivery process and in particular before and after construction stages. Several stakeholders involved in the 3 case studies were interviewed and several documents were reviewed to identify key stakeholders and their roles in each project. However, we could not reveal the identity of all interviewees based on their request.
We would like to acknowledge Andreas Luible and the hosting members of the COST Action meetings in Prague, Delft, Bourget du Lac, Luzern, Hamburg, Wroclaw, and Munich.

Also, we would like to acknowledge Work Group 3 members including Aurora Monge Barrio, Christoph Struck, Julen Astudillo, Roman Rabenseifer, Aleksandar Petrovski, Frank Wellershoff and Oliver Englhardt.

Finally, we wish you can benefit from this report and follow the interviews results.

Liege, 6 September 2017

Shady Attia
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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. Interviewees working in academia and practice 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.
Draft Version
Interview with Architect Philippe Samyn, Brussels, Belgium

Name: Architect Philippe Samyn
Date: 08 December 2015
Place: Brussels, Belgium
E-mail: sai@samynandpartners.be

Questionnaire:

A. Background Information

1. What is your core specialization?

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 adaptability to be useful. For example, you have a curtain in your sleeping room to protect 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 estate 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 moral.
   You have to take the time to appropriate the site (quality of earth, wind direction, trees) with the 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>
<thead>
<tr>
<th>Description</th>
<th>Standard</th>
<th>Category</th>
<th>Performance value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMV-PPD indices</td>
<td>Thermal comfort index</td>
<td>NBN EN 7730:2006, NBN EN 1525:2007</td>
<td>ISO B (Normal Level)</td>
</tr>
<tr>
<td>U Value</td>
<td>Thermal transmittance measures the thermal performance of a building component</td>
<td>NBN B 62-002:2008, NBN EN 6946:2008</td>
<td>ISO</td>
</tr>
<tr>
<td>K Level</td>
<td>Global level of thermal insulation of a building</td>
<td>NBN B 62-301:2008</td>
<td>Average quality</td>
</tr>
<tr>
<td>Ew Level</td>
<td>Annual primary energy use under standard operating conditions</td>
<td>NBN EN 13790:2008</td>
<td>ISO</td>
</tr>
<tr>
<td>The Temperature factor</td>
<td>Is a measure of the risk of surface condensation</td>
<td>Belgium’s BBRI</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 2: Air quality Performance value

<table>
<thead>
<tr>
<th>Description</th>
<th>Standard</th>
<th>Category</th>
<th>Performance value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Air Change</td>
<td>NBN EN 13829</td>
<td>-</td>
<td>$n_{50} = 0.77$</td>
</tr>
<tr>
<td>Rate (Envelope)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Humidification</td>
<td>NBN EN 15251:2007</td>
<td>Level B, Normal Quality</td>
<td>40%</td>
</tr>
<tr>
<td></td>
<td>Article 57, General Regulations for work</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Indoor light quality values

<table>
<thead>
<tr>
<th>Description</th>
<th>Standard</th>
<th>Category</th>
<th>Performance value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Daylight Factor</td>
<td>NBN EN 15251:2007</td>
<td>Level B</td>
<td>FLJ ≥ 3%</td>
</tr>
<tr>
<td></td>
<td>NBN EN 15193:2008</td>
<td>Strong Daylight Penetration</td>
<td>3%</td>
</tr>
<tr>
<td>3 Light Reflectance</td>
<td>NBN EN</td>
<td></td>
<td>41%</td>
</tr>
<tr>
<td></td>
<td>15193:2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Light Transmittance</td>
<td>NBN EN</td>
<td></td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>15193:2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 G-Value</td>
<td>To measure the solar energy transmittance of glass</td>
<td></td>
<td>0.17</td>
</tr>
</tbody>
</table>

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 the 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’s. 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, Mechelen, Belgium

Name: Kurt Booms

Date: 08 November, 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 have you 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 one side 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 have 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 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, etc...)

- 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) (normal 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, 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 processes:

- **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 installed. 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 standards did you refer to for testing?

11. 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.

12. How did you do the commissioning process? What standards did you comply with and what tests 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

13. 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.

14. 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:
15. In your opinion what will be the fraction of adaptive façades in today’s market? Why most of the projects are not having adaptive façades?
10 o 15 %, I think cost related.

16. 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 static system with a moveable system: physically, a moveable one will cost 10 to 15% more than a fixed one.

17. 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.

18. 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 have 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.

19. 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:

20. 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 motors 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.

21. 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.

22. 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.

23. 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.

24. What features would you like to find in future in an adaptive façade? What goals should we attain to increase the use of adaptive façade in buildings in the future?
When you set your goals, you achieve them. I would like to try 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, Brussels, Belgium

Name: Claude Pimpurniaux
Date: 19 December, 2015
Place: Brussels
E-mail: c.pimpurniaux@gmail.com

Questionnaire:

A. Background Information

1. What is your core specialization? And what kind of projects have you 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 wall 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 500-700 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 teams.

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 Facades 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

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1 It is to be noted that the information given were exact at the time of the interview. Since then, the management and the strategy of SECO has changed. Value engineering is no longer a current objective of SECO. Productivity and rentability are the motto of the management and objectives are only financial, not technical.
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.

**B. Interviewee definition of Adaptive Façade:**

3. **How do you define an adaptive façade? What is the purpose of an 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 as 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 conditions (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 replace 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 façades, Switchable glazing, Phase change materials, automated louvres) and what is 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.

Draft Version
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 façades:
   - the effects of the wind on the whole façades, or on parts of the façades such as louvers, have to be calculated in order to achieve the stability performance;
   - façades have to be watertight: water leakage can provoke moisture and promote molds and fungus which have a negative action on the health;
   - air tightness influence the inside comfort of the occupants and the energy consumption.

Additional indicators could be:
1- Acoustic behavior is a concern of occupants in term of comfort;
2- Natural and artificial lighting 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;

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NBN B256002-1 Menuiseries Extérieures – Généralités deals with the performances of windows, curtain walls and glass roof canopies and define how to classify a façade system regarding its performances.
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 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, 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 were 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 be 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 softwares 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-know 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 particular 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 conduct the commissioning process? What standards did you comply with and which test did you conduct? Did you develop or use a checklist? What is it about?
What is mainly concerned by the commissioning are the technical equipments, 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-landing\(^3\) 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 identified problems.

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 interesting 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® 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.

\(^{\text{Draft Version}}\)

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\(^{3}\) 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.
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 office 4.

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 of 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.

C. **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 do not have an efficient 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 our first experience and improve the process step by step.
For instance, in 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 system 5.

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.

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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.

5 Tests realized by Scheldebouw, a subsidiary of Permasteelisa Group of companies.
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 factors$^6$ 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.

$^6$ Basic and additional factors are given under paragraph 7.
Interview with Architect Abdulmajid Karanouh, Ramboll, Dubai, UAE

Name: Architect Abdulmajid Karanouh
Date: 30 May 2016
Place: Dubai, 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 is 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 being 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.

   Besides 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 facades. People don't have a 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 tools. 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 subcontractor after two years of operating the building. The process was under paid and had 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 unites, 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 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 before 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 due to 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 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 customisation 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 it 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 adaptive 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 (components 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 conduct 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, The Netherlands

Name: Dr. Thaleia Konstantinou
Date: 24 April 2017
Place: TU-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, automation 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.

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 someone 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 with 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, Grassshopper, 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 at 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 the 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 project. 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 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, Norway

Name: Francesco Goia
Date: 22 June 2017
Place: TU-Delft, the Netherland
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 technology

Architect – Technical – Material science – PhD in energetic

Working on glass part of the facade, project relating glazing facade, transparent ventilated facade...all in one facade modules and also modeling simulation

2. How long have you been in this field?

From 8 years, since 2009

B. Interviewee definiton 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 have a stimulus or a system that control the facade the purpose would be to reduce energy use without impairing comfort conditions 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:

large cavity with 2 story cavity or floor module, single, cell, double skin facade, primary experimentally and also comparing possibility to simulate the system with current simulation tools
• PCM glaze system:
  phase PCM glazed system in combination with smart glazing or switchable
  glazing (thermotropic glass)
  smart glass, after the experiment the PCM glazing alone, by design a system that
  keep the glazing in transition phase.

• Actress Active Transparent:
  responsive facade all in one facade module with ventilated facade with
  intelligent bed to different technology independently with intelligent and automation
  in the beginning with intelligent control behind, have minimum to intelligent the air plus
  basic control function

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)
   When we come for double skin facade for instance we can have different strategies to
   this system, in all the case should be integrated with the building energy concept but I
   could have different interaction between that component and the HBAC, its
   membrane that can be exchange how the building and the facade talk together

7. Can you rank cost, energy, internal satisfaction (view) in order of importance
   for adaptive facades?
   Energy – occupation – 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?
   No

D. Disadvantages of Adaptive Facades:

9. In your opinion what will be the fraction of adaptive facades in today’s market?
   What most of the projects are not having adaptive facades?
   No, I think some of the standard could be used to anyway promote and
   validate dynamic or advance facade its hard proof and document the facade
   performance, modeling the cost, monthly perform, facade capability.

   There is a fear to matrix performance

10. Does the cost impede the market penetration? What is the influence of mass
    customization on cost? (Weaknesses)
    Yes. Rain vert responsive integrated and ventilated windows
11. Do you think that adaptive façade technology is mature to penetrate the market? And Why?
Yes, because there are company selling the system

12. What are the risks regarding life expectancy and maintenance of adaptive facades? (Threats)
Maintenance become a dominant aspect because if I have a shading system I need to see the drivers work efficiently

E. The Future of Adaptive Facades:
13. What needs to be done for better adaptive facades process and performance quality?
No, I think the way to make it working is that they are most customized use a post occupancy evaluation as tools, because if you want to test each individual component you can do that in the lab and you can get members

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's the building owner, because from my understanding it's a part of the building, so its 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 building not just for adaptive facade

16. What features would you like to find in future in an adaptive facade?
I have a vision like a system that can hide what to do with 2 environments, inside and outside. this is a very extreme far idea holistic vision, like it's to thermodynamic system you have borders of the system and that is completely flexible one

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 have when we come to a city
we have cost impact, cost of small sensor very cheap.
I would say people living in better building, it could be a good push to go for these system
another big opportunity is again innovation when it's come to material science, so we now do thing that are incredibly advance for what we were have from 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 like solid state solution when we have an active layer that change its properties because of climatic condition.
Interview with Roel Loonen, Eindhoven University of Technology, The Netherlands

Name: Roel Loonen
Date: 22 Jun 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 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 are 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 is 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 for all those different adaptive façade technologies that we have actually somehow made them 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 and 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 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. Institute 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 façades.

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 methods 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, so 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 this into consideration in a more advanced way. Future adaptive facades should depend on intelligent feedback mechanisms. Ideally, the façade 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 Henk De Bleecker, PERMASTEELISA, Germany

Name: Henk De Bleecker
Date:
Place:
E-mail: h.debleecker@permasteelisagroup.com

Questionnaire:
Interview with Davide Ciavatti, Focchi Facades, Rimini, Italy

Name: Davide Ciavatti
Date:
Place:
E-mail: d.ciavatti@focchi.it

Questionnaire:
References:


(Source: http://samynandpartners.be/design-approach)
Appendix A: 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 adaptive façade?
4. What is the strength 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 you know any standards for dynamic performance values for adaptive façade? How do you think we should validate the adaptive or dynamic performance of adaptive facades?

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?
10. Does the cost impede 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)

F. The Future of Adaptive Facades:
13. What needs to be done for better adaptive facades process and 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 future in an 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 |
|---------------------------------|---------------------------------|
| Adaptive Facade Technologies: | Performance Matrix: |
| Movable Facades: | Functional Performance: |
| Stationary Facades: | Thermal Performance: |
| Electronic Facades: | Resistance Performance: |
| Mechanical Facades: | PV Integrated Facades: |
| Phase Changing Facades: | High Resistance to Environmental Effects: |
| Material: | Solar Thermal Facades: |
| Facades: | Beamency Facades: |
| PV Integrated: | Safety Facades: |
| PV Integrated: | Antireflective Facades: |
| Insulating Nanotech Coating: | Insulating Nanotech Coating: |