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Evaluation of Adaptive Facades: The Case Study of AGC Headquarter in Belgium

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The evaluation of adaptive facades presents a challenge because there is no established evaluation strategy to systematically reach this goal and many of the available façade performance evaluation tools have limited applicability for such advanced building facades. This paper presents a case study for an adaptive glass façade and evaluates its performance. The evaluation focuses mainly on pre and post construction phase of adaptive facades: The design assist phase (including the durability test, visual mockup, onsite panel mounting and weather stripping), the commissioning phase (field verification and performance testing) and the monitoring phase. The selected project is a nearly zero energy building with unique façade comprising thermal isolated glass sunshades printed with white silk screen. These louvers respond dynamically and automatically to the angle of the sun which improves the control over energy consumption, solar radiation and glare with the ability to admit natural light into the building. The paper is part of the research activities of working group 3 of the European COST Action 1403 on "Adaptive Facades ". Different methods were used for evaluation, this include: interviews with the architect, façade engineer and technical control specialist, reviews of standard and codes and a systematic process mapping. A documentation of the case study describing the post construction occupant comfort and façade operation was prepared. This paper's audience is mainly architects, building façade engineers together with facility managers concerned with the process of design, construction and operation of adaptive glass facades. The outcome of this study identifies effective strategies for the design and performance evaluation of optimal adaptive facades.

Keywords: glass building, design assist phase, commissioning, monitoring, operation and control, interview

1. Introduction

In a world facing climate change, there is an urgent need for dynamic building envelopes that responds to climate in an optimal way providing maximum comfort and indoor environmental quality, while maintaining high efficiency. Adaptive façades can provide step-change improvements in the energy efficiency and the use of renewable energy while improving the comfort of the occupants. Therefore, they are crucial in achieving the Europe 2020 targets (Annunziata, Frey, & Rizzi, 2013). 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 (Luible, 2014). Adaptive facades are multi-parameter high performance envelopes that, opposite to fixed facades, react mechanically or chemically to external climate dynamically to meet internal loads and occupant needs (Loonen, Trčka, Cóstola, & Hensen, 2013).

Numerous already realized projects of adaptive building envelopes are constructed or are in the initial stage. According to the Climate adaptive building shells CABS database, which has been continuously updated, there are at the moment more than five hundred examples of buildings with adaptive facades (Loonen, 2013). However, detailed analyses data on the performance and design and construction process of those facades is not commonly available. Commissioning and construction verification details and performance data about adaptive façade's monitored operational performance and post occupancy evaluations are lacking in literature. Currently, European research in the field of adaptive building envelopes is coined by numerous nationally funded projects. Among those projects that aim to create a knowledge transfer between the individual research institutes amongst each other and the industry is the COST Action TU1403. The initiated COST Action TU1403 "Adaptive Facades Network" aims to pool together the knowledge, technologies and research from across European countries and beyond. The initiated COST Action TU1403 was started in 2014 and will run for four years. Currently 26 COST member countries plus Liechtenstein, China and Australia are involved in this COST Action with more than 80 participants from research institutions and industry (Luible, 2015). The main objective of this action is to harmonize, share and disseminate technological knowledge on adaptive facades at a European level. This shall lead to increased knowledge sharing between European research centers and between these centers and industry, the development of novel concepts, technologies and new combinations of existing technologies for adaptive facades, as well as the development of new knowledge such as effective evaluation tools / design methods for adaptive facades. As part of Workgroup 3, we are willing to address challenges and identify the gaps in the systematic assessment and operation of such solution, both in terms of commissioning and operation, though literature review and mapping analysis (Attia, Favoino, Loonen, Petrovski, & Monge-Barrio, 2015).

In this context, we decided to investigate the adaptive façade of a nearly zero energy building, with unique glass façade, comprising thermal isolated glass sunshades printed with white silk screen. Currently, only a limited number of case studies have been documented. These includes Al Bahr Towers in Dubai (Karanouh & Kerber, 2015), AGC Building in Louvain La Neuve (Samyn & De Coninck, 2014a) and the BIQ house in Hamburg (Wurm, 2013). The decision as to how they are designed, operated, maintained and assessed remains undisclosed and this in turn affects the wide expansion of adaptive façades. The paper is part of the research activities of Workgroup 3 of the European COST Action 1403 on Adaptive Facades, which is mainly concerned with the adaptive facades system design and assessment. The work group is looking to understand how adaptive facades were designed and assessed during the major project delivery phases (I. Predesign and Design Process, II. Schematic and Conceptual Design, III. Design Development and Construction, IV. Design Assist (pre-construction), V. Commissioning, VI. Occupant operation (behavior) and VII. post-occupancy evaluation and monitoring). For this paper different research methods were used for the case study documentation, these include: literature review, site visit, interviews with the architect, façade engineer, glass manufacturer, commissioning agents, reviews of standards and codes and systematic process mapping. Within the scope of this study we present a case study description and technical details for the AGC Building Adaptive Façade. The case study provide significant insights on the design and construction process and the overlap between the glass product development and manufacturing and the building delivery process including mock ups and on site testing and verification. Section 2 starts with describing the research methodology followed of the present work. Section 3 describes the case study and discuss the main findings of the literature review. Section 4 presents the paper findings and results along three themes: (i) process mapping, (ii) interviews result and (iii) performance evaluation. Section and 5 and 6 conclude the article with setting a list of learned lessons, by indicating some of the recommendations and key performance indicators that need to be addressed in order to guarantee a successful performance of adaptive facades.

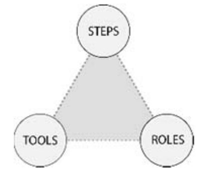
2. Methodology and objectives

The goal of this work is describe in detail the process of design, construction and use of an adaptive glass façade - in this case the AGC head office - and evaluate its performance. As well as to propose a generic performance process map that could be used as a visual guideline support by companies in the building industry. First of all several existing documents were reviewed. The AGC Glass Building book and AGC company brochure have been reviewed as well as the different standards and codes used for the building design and construction, these include: the Belgian Energy Performance Building Directive (EPBD) Annex III and Annex VI and the 'Code de Bonne pratique en éclairage intérieur', published by group of the Belgian lighting institute IBE-BIV. Secondly, a design and construction process map was developed. The development of such a map required more than a literature review. Indeed, the created map had to be validated and tested through life one to one interviews with different project stakeholders. Thus, this case study follow an iterative loop of development, test and review of information as presented below:

- Extraction of the required information on actual integrated processes from the literature with a main focus on the three specific points (Steps, Roles, Tools).
- Development of the maps of the design process based on the previous information.
- Correction of the maps conceived in phase two during interviews of architects or engineers who were involved in AGC Building project.
- Discussion and review of the modifications in phase three. Then comparison with literature back to phase one.

To realize global and specific maps of the project delivery process the software MindMap was used. This software allowed to draw clearly hierarchical scales, task charges suite and information flows. To limit the scope of the process map we focused on the identification and modeling of generic processes that was associated with the AGC Building project delivery. The generic process identification can be generalized and used as a check-list to future designs of adaptive facades. Therefore, we focused on three main questions:

- The Steps: what series of phases an integrated process have to pass through and what are the determinant criteria for each step?
- The Roles: repartition on the responsibilities and scope of work, who must do what, how and when?
- The Tools: which software is used during the process and in what purpose?



Creating a process map involved systematic data-based interviews. Interviewees where asked to explain exactly what they did during the AGC Building project delivery, as well as share their technical challenges and express their expectations. For every interviewee a scope was defined identifying the parameters he or she was dealing with during the project. A technical drawing software program was used to visualize the process. After completing a first round of interviews, interviewees were asked for feedback (reviews) and confirmation to validate the process maps. Finally, a documentation of the case study describing the post construction occupant comfort and façade operation was prepared. The evaluation focuses mainly on pre and post construction phase of adaptive facades. We conducted several interviews with the architect, façade engineer as well as the technical control specialist.

3. Description of the case study

AGC Europe is one of the largest glass manufacturers in Europe. Originally based in Brussels, the company produces, processes and distributes flat glass for the construction industry (both for exterior and interior glazing), the automotive industry, solar applications and certain specialized sectors. In 2013, they moved their offices to the new AGC headquarter located in Louvain-La-Neuve.

Aiming to reduce the annual cost of energy consumption and seeking to have a low impact building with a high degree of indoor environmental quality, the new AGC premises proposes a nearly zero energy building.

3.1 Concept

Being leased to AGC Europe for only 15 years, the building design offers a high level of flexibility, so that future users will not require to perform major structural modifications. For that reason, the design submitted by architect Philippe Samyn offers a simple square building (Fig. 1a) that includes a central gallery that divides the building into 2 unequal parts within two levels. The longer zones on the east side contains the main office functions as well as small meeting rooms and sanitary facilities. While the restaurant, the conference hall and the larger meetings rooms are located in the shorter zones on the west side.

The building is raised on slender columns (Fig. 1b) to allow the landscape to flow. It contains six patios on the east and west facades with different areas and volumes to maximise the light that penetrates through the building's interior as well as to allow light to reach the car park that lies in the ground floor. The choice to stack the offices facilities over two levels, motivates users to use stairs instead of elevators, therefore reduce the energy consumption.

The offices area has been optimized and developed to save more space and energy to facilitate the communication between the employees. Depending on the type of work they need to perform, employees can move to the specified zone for their work's type. As a result, this optimize the surface area used to 70% and therefore, improving the internal communication between their different departments while reducing the building's energy consumption.

Fig. 1a) Aerial photo of the AGC Glass building, b) Western façade, building is raised on slender columns

3.2 The Envelope

What distinguishes this building among others is the extensive use of glass *(13.000 m²)*. The external façade is fully covered with double glazing system in combination with thermally insulated glass sunshades printed with white silk screen. These louvers respond dynamically and automatically to the angle of the sun which improves the control over energy consumption, solar radiation and glare with the ability to admit natural light into the building while affording a view over the surrounding countryside (as shown in Fig. 2).

Fig. 2a) Horizontal louvres installed on the northern and southern facades, b) Vertical louvres installed in the eastern and western facades

Instead of attaching the façade to the edges of the floor plates, a solution was developed that involved hanging the façade from the roof. Steel beams were used to hold the façade structure together. The louvres on the north and south facades are installed horizontally, while those on the east and west facades are vertical. When in the east and west, the sun is relatively low and the vertical louvres are better able to track it. Conversely, with regard to the south façade, horizontal louvres are much more suitable for catching the sunlight when the sun is higher. Fig. 3 shows in detail how the installed glass louvres adapt automatically to different climate conditions.

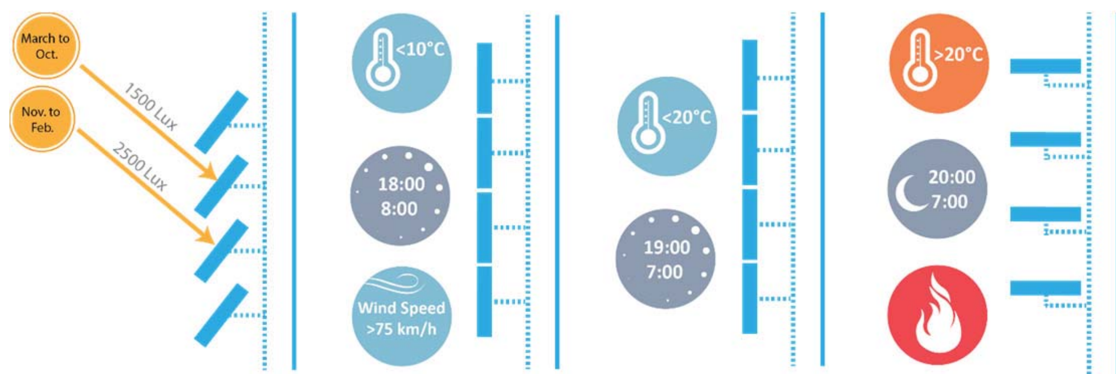


Fig. 3a) During the day, the louvers hit by sun follow the sun's path when natural light is above 15000 lux from March to October and above 25000 lux from November to February. In cloudy weather, the four upmost louvers on each floor on the south and north façades are set in a horizontal position, acting as light shelves. b,c) At night, louvers are closed from 18:00 to 8:00 or from 19:00 to 7:00 when the midday temperature is respectively below 10C or 20C to prevent the building cooling down. Louvers are closed when wind speeds exceed (75 km/h). d) Louvers are opened from 20:00 to 7:00 when the midday temperature exceeds 20C to enable radiation cooling. They are opened in the case of fires to allow the façade to be hosed down.

In special case, louvers are fixed in their open position in the case of rain and when the outside temperature is below 3C: risk of icing.

'TOP on Clearvision', the AGC glass's product was selected after doing several tests and modifications to choose the type of glazing for the adaptive façade. The glass specification are clearly shown in fig 4.

The standard louvres control software was designed by COLT, widely known in the manufacture of solar shading and climate control systems. The system is based on light levels measured by a roof mounted sensor. The louvres of the four facades are thus controlled by 256 actuators: 18*4=72 for each north/south facade and 14*4=56 for each east/west façade (fig. 5a).

Table 1: Top on Clear vision installed glass specification

	Light Transmittance (LT)	Thermal Transmittance (U_g)	Color Rendering Index (Ra)	Solar Factor (g)
TOP on Clearvision	0.81	1.1	0.98	0.63

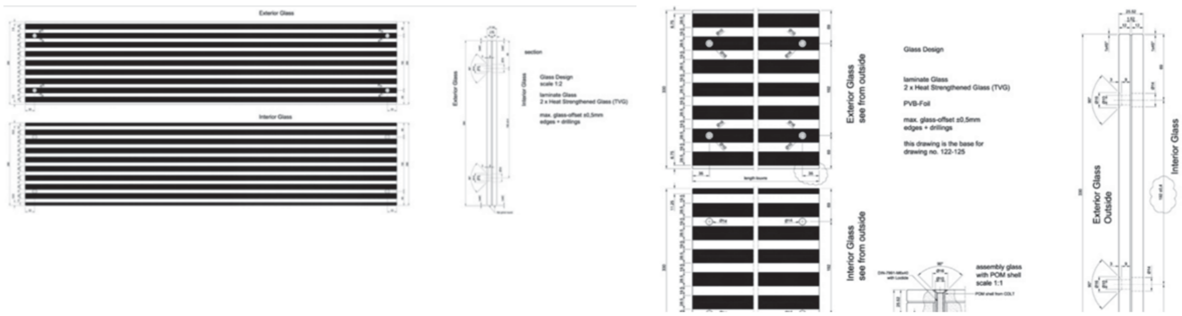


Fig. 4a) Stripes design and spacing on a horizontal and vertical installed louver, b) Section for the Glass louver showing the double laminate glass and spacing between. (For a higher resolution version please follow this reference (Attia & Bashandy, 2015).

3.3 Thermal Comfort

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^2K (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

3.4 Noise Levels

The most important form of sound absorption in the offices, meeting rooms and relaxation areas are the fine baffles made from white melamine foam, which hang from the ceiling in a regular pattern. This solution was chosen because it enabled an effective combination between the working of the concrete core activation and the adequate sound absorption of the largest free surface area, i.e. the ceiling. The linear baffles also enable the simple integration of the lighting and partition walls (Fig. 5b).

Buffer materials were used with wood, steel and glass to create acceptable acoustics, especially the acoustic insulation of the perforated steel deck plates of the roof structure.

3.5 Air Quality

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%

Hygienic ventilation operates during working hours and otherwise when the free cooling has been activated. Heat recovery from exhaust air is done using a heat exchanger wheel with a thermal efficiency of 75% with bypass and 'purge sector' management.

3.6 Light Quality (fig. 5c)

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 Daylight Penetration	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 glass			0.17

Fig. 5a) A close photo of the installed horizontal louvers: the installed actuator can operate a maximum of 10 double pairs of louvers, b) Baffles made from white melamine foam are used in the offices area to absorb the sound , c) Indoor lighting quality during a working day.

4. Results

Several interviews have been conducted to identify exactly the roles of the project's main stakeholders in different stages. This included the architect, energy consultant, building's users, adaptive glass façade sub-contractor, louvers manufactures, commissioning agent and the facility manager. The key steps of the adaptive facades delivery process are identified including decisions, checklists and teams engaged in each stage respectively.

5.1 AGC Building Project Stakeholders and Process Map

The process mapping was completed by interviewing seven project stakeholders representing, the glass manufacturer, architect, general contractor, façade subcontractor, energy and building physics consultant, commissioning agency, and facility manager. Figure 6 shows the results of the interviews and represents the different stakeholders of the project. The process map, shown in Figure 7, indicates that there were seven major design stages in this project, named according to the AIA (AIA, 2007). The figure shows the process map after being validated, illustrating the design and construction stages of the adaptive façade as a whole. Because the layout was large, individual sections are also included in in the final study report (Attia & Bashandy, 2015). These have been given in the best order suitable, starting from the top left hand corner of the chart and ending in the bottom right.

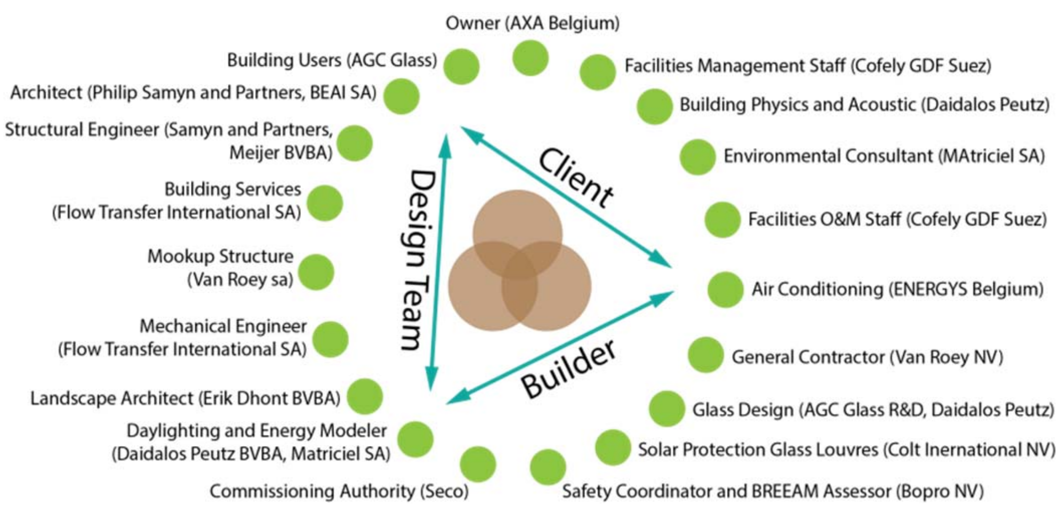


Fig. 6) General composition of an adaptive glass façade team.

5.2 Façade Design Process Description

The interviewees revealed that the AGC building delivery process went through a linear process with experimental validation approach. The linear approach did not allow a holistic integrated and iterative approach. For example, the glass was selected through material identification session to support the glass box concept for the nearly zero energy target prior to the identification of the mechanical, thermal and visual performance of the glass. Thus, the selection of the façade glazing was mainly based on aesthetical reasons during the schematic design phase. The glass façade comprised three layers namely, the primary (internal) curtain wall, the steel structure and the automated glass sunshades. The most critical layer of the façade was the third layer with external automated sunshades. This layer had multi-functional and multi criteria performance requirements including glass transparency, color, weight, size, solar energy transmittance (g-value or SHGC) and movability. However, the project delivery process forced the architect to select the louvers based on their transparency and color neutrality. Later on, the energy and building physics consultant had to optimize the glass louvers to avoid glare and overheat when the louvers are set to block the sun. The energy and building physics consultant had to conduct several simulations models and experiment with a climate chamber and test bed in the Netherlands, to maximize the g-value and come up with a working prototype (see Table 4-6 and Figure 8). Thus, the façade design was detailed and validated in a late stage of the design process. This was until the façade subcontractor was invited, when the final façade system design decision was made. The involvement of the glass façade subcontractor at the end of the design process resulted into a complicated situation. Finally, a silk printed glass with a tempered mesh was finally proposed to address the mechanical, thermal and visual performance requirements. It would be optimal if the glass subcontractor was engaged during the concept development. However, the competition based approached hindered such an approach and kept the responsibility in the hand of the architect. Therefore, it is very important to engage the façade engineers from the beginning of the design to guarantee hands on feedback and follow the shortest and the most cost effective design path.

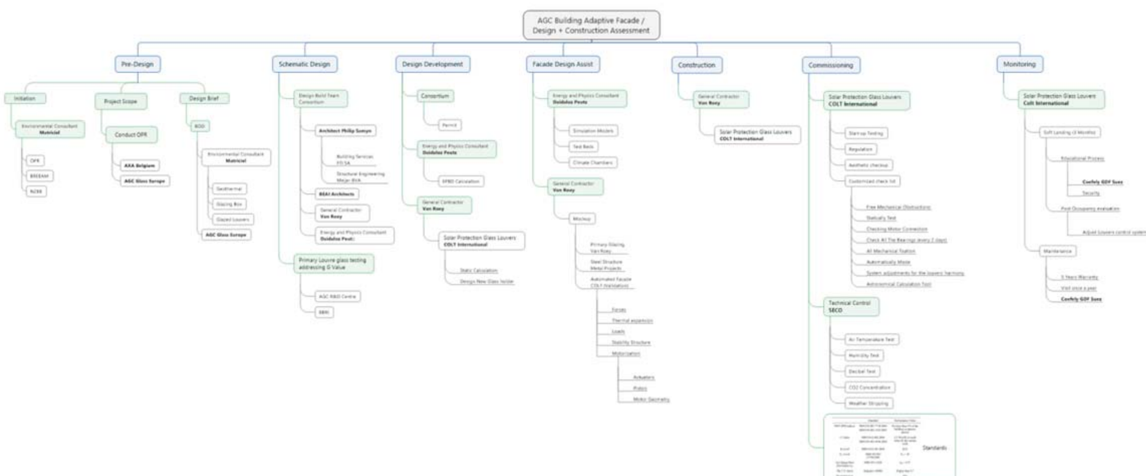


Fig. 7) Process mapping of the integrated design process of the AGC glass building's adaptive façade (For a higher resolution version please follow this reference (Attia & Bashandy, 2015).

Table 4: comparison between louver's design during 1st and 2nd test

	Glass Thickness	Opaque Stripes	Stripes distance between	Add-ons
1st On-site Test	16 mm	17 mm	15 mm	-
2st On-site Test	16 mm	19 mm	13 mm	Inside Blind

Table 5: Test results (measured in a chamber with a table inside)

	Incident solar radiation	Illuminance on horizontal outside plane	Illuminance on horizontal inside plane (middle of the table)	Sky luminance (lower part)	Sky luminance (upper part)	Luminance of the table
1st On-site Test	692 W/m^2	53.349 lux	2162 lux	2232 cd/m^2	4408 cd/m^2	837 cd/m^2
2st On-site Test	752 W/m^2	88814 lux	865 lux	2020 cd/m^2	768 cd/m^2	275 cd/m^2

Table 6: Test recommendations

	1st On-site Test	2nd On-site Test
Recommendation	Value of The maximal luminance is not acceptable and should be divided by four	An inside blind was added. The circumsolar light on the table had disappeared.
	Circumsolar light pass between the opaque stripes when the louvres are at right angles to the direct solar radiation.	The luminance was now acceptable from a glare perspective

Fig. 8a) Onsite mockup for louvers, 8b) test bed for a modular façade assembly, 8c-d) façade test bed from inside (Samyn & De Coninck, 2014b).

5.3 Façade Assessment Process Description

The façade assessment and commissioning was mainly on the hand of façade subcontractor. Despite the expertise of the building commission firm, the façade testing remained in the hand of the adaptive façade supplier. The commission agency was mainly concerned with the curtain wall and steel structure respecting the Belgian Façade Standard NBN B 25-002-1 (NBN, 2011). Also the air tightness of the building envelopes was conducted through a blower door test to measure the building airtightness in accordance with standard NBN EN 13829. The blower door test was applied on the curtain walls of offices, meeting rooms, restaurant and gallery. The results showed a value of 0.77 for the air change rate n_{50}. Prior to commissioning and during the pre-assist phase the main contractor and sub-contractor had to build a test bed for a façade module. For aesthetical reasons the pushing rods position had to be changed from a vertical to a horizontal position but all other performance requirements were in order. The main contractor was responsible for the curtain wall, the steel company was responsible for the steel structure and the façade subcontractor was responsible for the automated louvers. Once the curtain wall and steel structure was fixed the façade subcontractor started to mount the façade louvers. The startup testing was conducted by a visual appearance checkup to make sure that all façade components (earrings, connections, rods, glass holder, fixations, and motor connections) are properly fixed and positioned. Using a particular customized checklist the regulation and control of the automation system was conducted. The control of the façade depends on three main schedules. The first is the weekly schedule which is based on the value of daylight intensity measured at one point at site and the position of the sun (based on a programed astronomical equation). The second is the night schedule which is based on the daily temperature at noon that is set against an average temperature. If the daily temperature at noon is higher or lower than the 20 C^o the louvers are shut down for passive heating or turned on for night cooling.

5.4 Post-Occupancy phase

The final phase of the façade comprised a 3 month soft-landing. The subcontractor provided during three months members from their team to adjust and customize the façade operation modes according to users at each floor and each orientation. This work included the explanation and training of the building facility management team and security team. The customization of the schedule and follow up was the last step in the process. A five year warranty contract guarantees an annual site visit to replace and check any malfunctioning façade component.

5. Discussion and Conclusion

The primary objectives of this study were to present a detailed case study description of an adaptive façade and to derive maps of the underlying decisions on how it was designed, operated, maintained and assessed. From the interview results and process mapping three themes were identified: the adaptive façade design process, the locus of adaptive façade testing (mockups, mounting, regulation & control and commissioning) and the challenges associated with the AGC building adaptive façade.

6.1 Summary of main findings

According to the interviewees the most important factors that ran through the experiences were the team work, integrated design process and façade testing (mockups). The specific nature of this façade and complexity of multi criteria performance requirements forced the customization of the façade solution and the team had to come up with innovative solutions. The mock up resulted in a full redesign of the façade. Without the mockup the design team could not foresee the problems associated with the façade assembly and performance. Simulation tools did not succeed to avoid the linear design approach and achieve an iterative and integrated design process. The experimental assessment procedure was the main decision support tool using three types of testing: 1) outdoor real scale mock ups, 2) laboratory indoor facilities, and 3) outdoor test cells (Causone et al., 2015). The classical problem between the architect and engineers and linear design process were present in this project (Attia, Hensen, Beltrán, & De Herde, 2012). The team took risks and trial and errors were the main decision support aid in this process. The glass louvers formed a serious challenge to achieve acceptable energy and comfort performance requirements avoiding overheating and glare. However, the team succeeded in lowering the risk and the commission process and the checklist approach was very important to guarantee the façade performance. The genuine façade system increased the façade cost by four to six times and part of the stakeholder has little understanding of the time, research and cost constrain. While it was necessary, it was important to measure the effectiveness of the adaptive façade and quantify the performance and the added value of the multi functionality of the façade system through a project follow up (Struck, et al. 2015). The automated glass façade subcontractor conducted a three month soft landing. However, the operational energy cost and occupant comfort needs to be quantified to allow comprehensive adaptive facades *assessment.*

6.2 Strengths and limitations of the study

The methodology used in this study allowed developing a better understanding of the innovation process holistically. The map created in this project gives a basic understanding of the broader development process. However, the glass louver development cycle, on a broad scope, is not well defined. The lack of a self-critique of the stakeholder or fear of exposure with which to describe these process problems has made it difficult to understand. The level of detail and accuracy of the process map created here is also limited by the 3 month time of process mapping. There are several things that have been identified that can be improved in order for the data to be more useful. The map is inherently clear, as there we conducted a systematic way to validate the entire process. However, we had limited amount of time to validate the map by users not involved in the project for easy readability. The process used to collect data was potentially representative of the different paths and processes, and the importance of each stakeholder. The total time of each process was noted whenever possible, but the final map does not have an accurate representation of the flow of time through the entire project delivery process. There was an unexpected level of difficulty in assuring accuracy in a process that is, as a whole, somewhat informal and malleable. It was difficult to determine which processes were concrete, and which were just an author's suggestions or general descriptions.

6.3 Implications for practice and future research

The operational energy cost and occupant comfort needs to be quantified to allow comprehensive adaptive facades assessment. This is why the COST Action TU1403 is going to call for a post occupancy evaluation for the AGC Building and a range of evidence based performance indicators identification for this project. Also the work group 3 is going to evaluate the standards, checklists, protocols that can support adaptive facades evaluation; allowing us to see much more clearly - much earlier on - what type of decision support interventions really work.

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