GLASS FAÇADES DESIGN PROCESS

Interviewing the Experts

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Abstract. Despite the increasing use of glass façades in the past years, both in new construction and in major renovations, there is still a lack of comprehensive design guides and standards and a huge gap with the real-world applications. The presented research aims to identify the major methodological issues to support the development of glass façades design process, through a survey about how façade consultants and experts cope with different design aspects. The purpose is to support the architectural designer to consider the different issues, to be aware of the available solutions and of the main elements that need to be evaluated in the choice of a glass façade. The present work introduces the aspects of integration, identifies some of the key challenges and unfolds a scenario for a novel approach to environmentally sustainable glass systems.

Keywords. Glass design; Façade engineering; Design process; Project management.

1. Introduction

1.1 BACKGROUND

The performance demands of glass in architectural applications are increasing rapidly and the transparent elements of the envelope are growing in complexity. The impact of building envelope has evolved and now represents one of the key-feature of the construction sector, involving different aspects. Façades and building envelopes, which form the outer skins of buildings, project image and creative intent. Increasingly, they are also understood as important environmental moderators and key influencers in project risk and commercial success (Table 1).
1.2 RESEARCH METHODOLOGY

The main hypothesis of the present study is that the current structure of the design and construction process for glass façades influence the constructional solutions and vice versa. The main purpose of the investigation is to get background information on process features and basically on drawbacks, in order to develop better procedures for the design and construction process of façades with glass as a main material. The current methodological research has developed through the following questions: how has the process been evolving? Who are the different professionals that are involved? What are the weaknesses and the challenges for glass façade engineering?

The work has been carried out in 3 main stages:

- Collecting data from literature on glass façade types;
- Quantitative research on drawback cases;
- Qualitative research conducted by interviewing market players and experts in design of glass façades, for an amount of 10 interviews (4 with Italian and 6 with UK-based glass design experts), and discussing design approach on glass design with a special focus on management.
The interviews were carried out in person (except one that was mainly developed by e-mail) and consisted of a 1-hour meeting. The interviewees were asked to comment on the map, to correct and eventually integrate it, talking freely of the topics they consider to be most relevant with respect to the subject matter. Some of the results are already included in a previous report by Marradi and Overend (2014).

Each interview was based on a framework of fourteen questions; seven of them focused on the design and construction process in general façade projects, especially concerned with glass. The other seven questions were mainly related to renovation projects (Table 2).

Table 2: Questions addressed in each interview.

<table>
<thead>
<tr>
<th>General Projects</th>
<th>A1. What does your Company do? What is your role?</th>
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<tbody>
<tr>
<td></td>
<td>A2. In what phase are you normally involved in the field of building façades?</td>
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<td>A3. How many phases do you normally execute? Please choose among the proposed list or name them.</td>
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<td></td>
<td>A4. How has the façade process been evolving? Looking at the table of façade design and construction process, please indicate your interest in cooperate with other stakeholders.</td>
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<td>A5. What are the process steps, and how are they linked?</td>
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<td></td>
<td>A6. What is the role of different stakeholders in this process? Is the cooperation effective?</td>
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<td></td>
<td>A7. According to your experience, what are the weaknesses and the challenges for glass façade engineering?</td>
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<table>
<thead>
<tr>
<th>Renovation Projects</th>
<th>B1. Which percentage of renovation projects do you usually find in your work?</th>
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<tr>
<td></td>
<td>B2. How many kinds of renovation classes can you define? Do you have a procedure to follow for the survey and diagnostic operation? (Structural, energy behaviour, map of decay etc.)</td>
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<td>B3. How do you assess the actual energetic performance of a glass façade and is that measured afterwards?</td>
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<td></td>
<td>B4. Is the demand for energy rating systems increasing or not?</td>
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<td></td>
<td>B5. How did you manage to preserve the original appearance and the quality of the architectural monument?</td>
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<td></td>
<td>B6. Could you please give us any suggestion, recommendation about the process map? Which part would you improve/change/delete?</td>
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In the present work a brief overview on glass facade design process current features and deficiencies, as outlined by the interviewees and collected by the Authors.
2. Analysis of the design process: glass façade as a “high-tech” product

The crucial role of a glass façade in the overall building concept is determined by the fact that its performance affects occupant comfort and productivity, energy use and running costs. Some functions of the entire envelope, and of glass components, need to be controlled or adapted constantly, such as transparency, or sun protection. Some façade systems (i.e. DSF - double skin technologies) integrate ventilation devices with supply or exhaust air or heat recovery. Advance technologies, some of them still at an experimental level, include sensors and metering systems to control and manage the sunlight, rain, temperature, CO₂ content of the internal air. Thus, the main requirement for future transparent façades will be their “adaptability”, since the façade becomes a fundamental part of the climate concept (Andreotti, 2003).

This assumption is not new, since it was first outlined by Mark Davies in his article “The Polyvalent Wall”, dated 1981, and the result is a significant increase of the technological content of glass components. Such development can be compared to what happened in other industry sectors, such as in ship-building, automotive and aerospace industry. As an example, in order to maximize the performance of a sailboat, we do not only increase the sail area, but we also improve the aerodynamics and the shape of the hull, the overall reduction in weight, the properties and the lightness of the materials: it means that each part contributes to the balance and the overall functioning, which can be enhanced only through an integrated approach to the design and construction process.

The skin affects both appearance and performance in such a way that these diverse constitutive features promote new design concepts and spur technical developments for the architecture of the future. The façade, as a part of the building system, requires an integrated design and decision-making approach, with the contribution of different engineering disciplines and knowledge. The effect of this development on the architectural process of glass façade is wide and still much unexplored: then, there are both the interest and the opportunity to explore this issue.

2.1 GLASS FAÇADES, DESIGN PROCESS AND INDUSTRY

The first step is to analyse the current structure of such process, with the links between glass façades, design and construction phases, building industry. The current performance requirements of the glass façade as a product needs to be identified, as well as how it relates to the building market.

The external “skin” of a building can be described as a complex and multifunctional filter between the external environment. The requirements on
façade design and construction process have been increased significantly for the last decades: due to new directives and standards, especially regarding energy performance, the building industry was forced to develop new products and to improve glass properties.

The increased complexity in general of curtain walls and of glass façades caused a development from craftsmen structures, as happened in the ‘50s, to sophisticated building systems, without however excluding the contribution of manual skills in some specific stages of the assembly process. Fully industrialised façade construction is still far off.

The main difference between the façade sector and other building disciplines is the strong relationship with architecture and aesthetic meaning: the building “skin” is always related to a specific context, creates a language with the surroundings and communicates (or even denies!) the building task. The skin of a building is sometimes considered to have a social and cultural role in representing what is inside the building: façades determine the visual identity, character and expression of architecture. In this framework the social/cultural function of the surface of a space is primarily one of defining a relationship of the spatial unit (e.g. house, person, car) to the larger society: thus, the design of building skins also shapes the urban environment.

The design and construction process can be defined as the entire process from the initial concept to the end of the useful life of a façade. From a management point of view, architecture must be primarily project-oriented: this differs from other industry sectors which mainly product-oriented. Such an approach particularly affects the design phase, but it is also important in the developments of tender procedures and, not last, it becomes a fundamental basis in order to transform architectural design into construction.

2.2 ANALYSIS OF THE DESIGN AND CONSTRUCTION PROCESS

The main feature of the traditional design process (Figure 1), that has developed over thousands of years, is the scanning of possibilities, iterative striving for the optimum-specific solution. Specific disciplines and craft skills have developed with a defined focus, from carpentry to plumbing, and with the purpose of providing quality assurance of a specific task.

Basically, the originally “linear” project structure and its division into different disciplines have been the basis for the development of tender procedures and of the construction structure. Roughly speaking, the entire building design and construction process consists of different activities which are planned by different designers, as structural or systems engineers: this is reflected in the tender and construction phases, where different activities can be executed by different companies (Bedard & Rivard, 2003).
The coordination between these parallel activities is carried out by the architect, who guides the entire process to ensure the integrity and inner consistency of the project. The architect merges the different planning and building tasks and resolves conflicts directly on construction site. He ensures that the overall objectives are achieved, reassembling all components that deviate from these. This organisational structure is sustainable only as long as the complexity of the process is not very high and specialized skills can be managed and resolved directly. In this scheme, it is accepted that the level of project definition and detailing are not very accurate, since many of the conflicts can be resolved in the realization phase, case-by-case, thanks to the experience of the architect or team work that manages and coordinates the construction process.

The increasing complexity of modern construction requires that the conventional linear process needs to be complemented by additional, more in-depth skills since the early phases of design. This is mainly true in complex building sector, such as façade design and construction. The variables that occur in the process are numerous, interrelated and often uncontrollable if assessed separately. The process can vary, depending on different cultural areas, but it also reacts on different project goals. The main constraints are related to time scheduling, cost allocation and quality level of the final product/service.

2.3 STAKEHOLDERS

In the façade sector, the involved stakeholders play a different role and have specific constraints and agenda that can conflict with each other. Their interaction must be taken into account: the coordination among professionals with roles and responsibilities is fundamental to create an efficient project team (Kerzner, 2006).

Architects and engineers are regularly involved in consulting the sponsor or the client during the project development, but glass façades have become complicated beyond the skills of architects, structural and mechanical engi-
neers. Thereby, a façade project requires a dedicated engineer with a particular range of skills and experience, who understands their behaviour and can undertake their design, manufacture and installation better, more efficiently and more comprehensively than can a traditional architect, structural or mechanical engineer. Façade engineers come from a range of backgrounds but most usually architectural, structural or building physics. In order then to become a façade engineer, they have then developed a wider breadth of cladding skills and a deeper knowledge than they would encounter within their original discipline.

Many façade engineers will be generalist façade engineers. These are able to advise across the full range of materials, systems and performance types. Specialist façade engineers will typically first have attained a level of knowledge across all façade types and then have chosen to specialise in one particular aspect of façade engineering. Examples are façade engineers whose emphasis is in building envelope physics, using analytical modelling skills; or façade engineers that specialise in a particular cladding material such as stone or glass.

Façade builders and system suppliers can be involved in the development of a new façade system, or can only supply existing components and coordinates different manufacturers in the construction phase. The way how a façade project is awarded is crucial for the way in which the façade builders are involved and interact with the other stakeholders. Open tender procedures imply that the façade construction is tendered on the basis of extensive specifications: the façade builders have normally little influence on the design. A completely different approach states that the façade builder must develop the project of the façade, since the tender document specifies only the functions that the façade itself shall fulfil.

Finally, the involvement of the building users and the facility manager is generally limited to the moment of use and maintenance of the façade, but sometimes it is necessary to obtain information from these stakeholders already in the design phase. This happens when, for example, a glass façade must be renovated and performances need to be improved: the data provided by the facility managers are fundamental to understand the current behaviour of the envelope and what are the possible improvements.

3. Development of a design and construction flowchart

3.1 THE VARIABLES IN THE A FAÇADE DESIGN PROCESS

The variables that are nowadays involved during the D&C process are a multitude and they mutually interact. An appropriate flowchart of the façade
design and construction process needs to be outlined. A first reference in literature is the cladding supply chain steps as described by Ledbetter (2003): in his research the term cladding is used to define non-load bearing façades. Kalian (2001) defines a sequence for rain screen cladding, from design to procurement and installation. The focus of both research studies is on managing the supply chain and not on the construction itself (Voss & Overend, 2012). They also do not include the phases after the installation of the façade. On the basis of literature review and interview results, an integral façade design and construction process can be identified. Theoretically, the sequence of different steps should be linear but actually the relations between sub-sequent phases is iterative and back-coupling. The features of each step can be briefly described in 8 main steps:

1. **Concept System Design**: it is mainly based on the available systems that are developed by system providers. The feasibility study is carried out.

2. **Outline Design Proposal**: in the pre-design phase the basic requirements for the façade are being defining and the concept idea is developed.

3. **Detailed Design Proposal**: the project is subdivided in different aspects that need to be developed and mutually integrated, so they do not develop conflicts between different and potentially conflicting design requirements. Depending on the project features, specific disciplines are involved. Such division is reflected both in drawings and technical specifications.

4. **Tender Documentation/ Execution Design**: depending on the procedures or the types of tender, the façade builder can be involved in different stages of this process. During the execution phase, the manufacturer executes the detailing, in accordance with the working drawings of the design team. Very often, the final decision about which system will be adopted is carried out at this stage. Generally, façade systems are standardised products, since their performances (weather tightness, robustness, thermal and acoustic performances, etc.) need to be assessed by certified tests. Sometimes, however, the façade system can be developed and tested for a specific project.

5. **Manufacturing**: the production of façades is a complex project with high logistic effort. The façade builder receives profiles and fittings from the system provider. Pre-assemble is desirable, in order to reduce to a minimum the on-site operations.

6. **Assembly**: Finishing the façade is a fundamental step in the overall construction process of a building. Time schedule for the assembly depends on whether condition that can represent a potential risk. The
tolerance of the primary structure is often in the range of centimetres, whilst the façade allows few millimetres.

7. **Use and Maintenance:** During the service life, the façade shows its performances: monitoring is an important issue that grows with increasing complexity and the combination with building services facilities. Maintenance and cleaning, especially for glass elements, are considerable cost issues and affect the architectural aspect of the envelope.

8. **End of service life:** In former times, not much importance was given on the end of life scenario of façade, as well as other building components. Nowadays, recycling or reusing elements is a crucial issue to create energy neutral buildings. The end of service life needs to be included as a specific phase of the whole process of the product.

3.3 THE PROJECT MANAGEMENT APPROACH

The design and construction process for façades, and especially for glass façades, complies with the definition of a project as “a temporary group activity designed to produce a unique product, service or result” (PMBOK® Guide, 2004). A project is temporary in that it has a defined beginning and end in time, and therefore defined scope and resources. And a project is unique in that it is not a routine operation, but a specific set of operations designed to accomplish a singular goal (Kerzner, 2006). The design and construction of a façade, that is a complex “product”, must be expertly managed to deliver the on-time, on-budget results, learning and integration that organizations need.

Project management is mentioned as a fundamental strategy in architecture and civil engineering, both for the engineering companies and for the management of public procurement. In this perspective, the concurrent design of the different aspects of the project is abandoned: the design team is coordinated by the Project Manager from the early stages of the project, so that no conflicts arise between different disciplines. The objectives, the constraints, and the milestones that characterize the work, should be clear already at early stage. In addition, the designers needs reliable statements about the performance of systems and products. At the same time, product flexibility needs to be maintained in order to manage possible changes during the design process.

This leads to a modular and circular construction method (Figure 2) in which the design process and its phases are dealt with an iterative and decision-making approach to improve the deliverables for each work package.
Such way of dealing with the problems that arise during the development of a project can be easily compared with quality control methods for management. In this context, the control processes are essential. They include the monitoring and verification of the project in order to identify deviations from the plan. Once the critical analysis of these deviations, corrective measures are implemented.

Figure 3. Iterative and decision-making approach (Image by the Author).

4. Conclusion: weaknesses and challenges for glass façade engineering

The degree of problems and time waste in the process can be identified and measured through the value stream analysis, which focuses on where and how frequently time buffers occur in the curtain wall process. The results show that the time buffers caused by inventory management, excessive lead time, and other delays usually occur between different actors and different phases of the life-cycle (UK Department for Business Innovation and Skills, Bis Research Paper no. 145, “Supply Chain Analysis into the Construction”, October 2013).

In the design phase time buffers occur in the process of approval and transportation of curtain wall plans between designers and manufacturers; in the manufacturing phase they occur in the process of material/parts and information flow among suppliers and manufacturers; and in the on-site construction, they occur in the transportation, inspection and information errors of curtain walls between the manufacturer and installer at the construction site. The main causes of problems are the fragmentation, the lack of collaboration and information share at the early phase of the design, causing changes in the successive next phase; lack of communication and inefficient management among suppliers and manufacturers causing delays and long lead
times in the material/product flow; lack of coordination and inaccurate planning between constructor and manufacture, causing reworks, delays and excessive stocks and conflicts with other work tasks; and information loss especially by fragmentation of the process, redundancy and inaccuracy in the information flow through the life-cycle.

Many authors, as well as by façade design experts, recognize the potential of early stage façade engineering input in delivering high performance/low impact design (Kragh, 2012). Though the analysis of real-world case studies, this approach confirms that integrated design depends on the ability of the design team and the sponsor/client to properly consider to detail since the early design steps (Marradi & Overend, 2014).

The involvement of façade consultants has proved to be useful before the design is progressed in detail, through discussion during periodic meetings and especially through the implementation of models and preliminary studies to evaluate the performance of the proposed design, that can be benchmarked against different façade types or scenarios. The opportunity to have measurable and comparable results during the different states of progress of the design is crucial in performing evidence-based choices during the decision-making process (Figure 4).

![Figure 4. Design process and deliverables (Image by the Author).](image-url)

Such considerations lead to the statement that successful façade projects depend on a high degree of collaboration across the design team and throughout the supply chain. However, construction contracts often isolate packages of work, the success of the façade depends on careful coordination of these various specialised trades. Façade engineering, which is a relatively new discipline, relates to design, certification, fabrication and installation of
the façade, in accordance with the overall objectives of structural adequacy, appearance, quality, performance, cost, durability.

One of the main challenges that emerges from the analysis of the integrated process is the application of glass technologies in existing buildings: well-considered glass façade solutions can add value to new and existing properties, such as enhancing durability and producing energy savings. On the other hand, there is always a need to understand the factors that influence performance and life expectancy of existing buildings.

The replacement or the integration of transparent elements in building skin shall be carefully balanced among different disciplines. The integrated approach for glass façades is mainly influenced by early stages of engineering, in terms of geometry optimisation, structural and energy-performance issues. While projects are made possible by technology, advanced computational tools (i.e. BIM Technologies) pose significant improvements for the coordination across the design team and the entire supply chain. The management of information is primary for the development of the project and the early stage engineering is critical in order to test technical feasibility and budget prevision.

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