Bridging the gap between selection decisions of façade systems at early design phase and detailed engineering phase: issues, challenges and solutions.

Mohamad Kassem[1] and Donald Mitchell[2]

[1] *Technology Futures Institute, Teesside University, Middleborough, UK*

[2] *Department of Architecture and Civil Engineering, Centre for Window Cladding Technology, University of Bath, Bath, UK*

Corresponding author. Email: m.kassem@tees.ac.uk

Dr. Mohamad Kassem is an Associate Professor in Engineering Project Management at the University of Teesside. He has research, teaching and enterprise interest in the field of Building Information Modelling (BIM), Construction IT and Engineering Project Management. He sits on the scientific committees of major Construction IT conferences and a peer reviewer for several journals in this field. He has been consultant to the Brazilian government responsible for developing a policy for BIM adoption in Brazil. He is involved in several R&D projects, in the UK and internationally, amounting for more than €1.8 million and he has published more than 45 conference and journal papers in construction IT and construction management.

Prof. Nashwan Dawood is the Director of the Centre for Construction Research & Innovation (CCIR) and the Technology Futures Institute and a Professor of Construction Management and IT at the University of Teesside, UK. Professor Dawood also has significant and long-standing experience of working with major industrial partners in the UK and internationally to develop and apply research results as part of further collaborative projects. In particular he is currently running international research and development projects in South Korea, Japan, Qatar, Europe and USA in the areas of 5D modelling, serious game engine technology application to training and ICT (Information and Communication technologies) for energy efficient buildings. He is also regularly invited to be a key note presenter in international events. Professor Dawood has published over 180 research papers, and sits on the editorial board of a number of journals and conferences.

Donald Mitchell is a Graduate from the Centre for Window Cladding Technology in University of Bath and Director of Operation at Deepdale Solutions Ltd. He has research interest in the procurement process and design of building envelope elements and has more than 25 years of experience in managing large building façade projects in the UK and overseas.

Abstract

Building façade has a significant impact on the environmental and economic performance of buildings and projects. The specification of their elements at the early design phase depends on numerous technical, environmental and economic factors and involves several stakeholders. The procurement and delivery of the façade work package from the early design phase, through detailed design and manufacture, to installation is a process with several inherent risk factors due to the involved cost, technical and engineering complexities and its position on the critical path in all projects. This research investigates the process of selection and specification of building façade elements at the early design phases with the overarching aim of identifying the issues affecting specification decisions, their root causes and impact on projects. The research utilizes a mixed research approach which combines a retrospective case study and an industry survey as two research methods that build on each other. The findings suggest that the complexity of specification at the early design phases is exacerbated by factors such as the inadequate technical knowledge of stakeholders involved in the decision making process; the non- involvement of building façade consultants; the late involvement of specialist façade subcontractors, and in a few cases by some commercial exclusivity agreements that restricts specification decisions.

Keywords: Building façade, business process, curtain wall.

Introduction

Building envelope (2012), façade (pavitt and Gibb, 2003) or building enclosures (Tran et al., 2014) are interchangeably used terminologies to denote the physical separator between the interior and the exterior environments of a building. The impact of building façade has become more important than ever in determining the operational and economic performance of construction projects. Indeed, the building façade accounts for anything between 15 and 25 per cent of the total construction costs and represents a substantial part of the technical and commercial risk on any given project (Kragh, 2011a). Building façade is also an area of engineering by itself and its elements such as curtain wall systems are being used in various shapes and types, not only in new buildings but also during the renovation of existing structures (Efstathiades et al., 2007). This role is intensified by strict evolving energy performance standards and regulations (Kragh, 2011b). Procuring building façade is perceived as a process with many risks due to the numerous stakeholders, cost, technical and engineering requirements involved and its position on the critical path in all projects. In addition, the broad range of commercial options available with varying economic, environmental and technical performances increase the challenges associated with the selection and delivery of building façade projects. Indeed, devising optimal building façade solution is becoming increasingly difficult due to the growing number of building façade components and systems (Jin and Overend, 2010). Research efforts analyzing decision making in design and construction processes are often concerned with analyzing issues affecting the performance of construction projects at industry-wide level as evidenced from the literature review presented later. As a result, there is limited research focused on analyzing specific design and engineering processes such as the selection of building façade elements at the early design phase. Hence, this research aims to investigate the process of selecting building façade elements at the early design phase, identifies the issues affecting accurate selection decisions and presents recommendations. In the subsequent sections, related research identifying causes of poor performance in the construction industry in general and current research to improve building façade in particular are first presented to understand both the gap and significance of the proposed research. Then, background information about the factors involved in the selection of building façade elements is illustrated to help the understanding of the complexity of selection decisions. Third, the research methodology, which consists of a retrospective case study and an industry survey, is explained to justify both the research design and research methods followed by a detailed presentation of results from both the case study and the survey.

Literature review

Studies investigating the issues that affect the performance of projects have proliferated over the last few years especially within the construction sector. Much of these studies have focused on identifying factors that cause time and cost overruns and quality issues. The majority of these studies is focused at sector level (i.e. construction industry) and is based on quantitative survey approaches. The review of these studies can be classified in terms of '*domain'*, '*granularity*' and '*approach' of investigation*:

- *Domain of investigation:* it represents the sector segment in which the research was conducted (e.g. building, civil, residential, etc.).
- *Granularity of investigation:* it denotes the depth in the exploration of the issues researched structured into three levels namely, country or sector, project and single discipline or trade.
- *Approach of investigation:* it refers to the research methods used in the investigation (e.g. case study, questionnaire, interviews).

A classification of a non-exhaustive list of studies according to these three fields is reported in Table 1. The results (Table 1) shows that the majority of existing studies are focused at sector wide level and there is still lack of studies at building discipline or trade level. Table 2 reports the issues identified as main causes for poor performance in projects from the same studies classified in Table 1. Extensive existing reviews in this domain have also reached similar conclusions. Sun and Meng (2009), in their effort to develop a taxonomy for change causes and effects in construction projects, reviewed 101 articles from the same source used in Table

1[1]. Much of the identified articles have either focused at wide industry scale using a quantitative survey-based approach. Although this research approach, focusing on industry and market level, is valuable in identifying the main areas of deficiencies in the industry that require improvement, it suffers two limitations. The first limitation lie in the nature of causes identified (see Table 2) which are often general statements of the areas where the actual root-causes of poor performance lie (Table 2). The second limitation is the lack of empirical evidence of the issues identified and their impact. From research design perspective, this approach could have unknown, remedial or biased population sampling and data collection methodologies (Succar and Kassem, 2015).

As a result, there is a need the need for complementing the current research approach with a new methodology in which the granularity of investigation is increased from sector and market-level to a single building trade level and combined with case studies to provide the empirical demonstration and support.

One study, specific to the domain of building facades, was jointly funded by the Korean government and large industrial conglomerate in South Korea (i.e. Daelim Industrial Co Ltd; Better Living Space, and Doalltech Co.) and aimed to improve the lifecycle of curtain wall through the integration of the supply chain through information management systems (Chin et al., 2004; Hwang et al., 2006). Factors such as the difficulty of involving the right people at the right time; lack of information sharing and communication; information loss due to the fragmentation of processes; redundancy and inaccuracy in information flow; long lead time between activities in the process, and reworks and errors due to missing and inaccurate

[1] e.g. Journal of Construction Engineering and Management; International Journal of Project Management; Construction Management and Economics; Journal of Management in Engineering; and Engineering, Construction and Architectural Management.

information in the documentation (Chin et al., 2004; Hwang et al., 2006) were considered as issues affecting the performance of the curtain wall industry. However, neither a description of the identification process nor a statistical and empirical evidence of such issues were provided. Other related studies to building façade have focused on design methodologies to achieve specific technical performance such as sustainability and buildability (Singhaputtangkul et al., 2014; Mohsen and Elaheh, 2012).

This paper aims to fill this identified gap while adopting a new research approach. Such an approach consists of increasing the granularity and scale of investigation by focusing on a specific building discipline or trade (i.e. building façade) while considering its interactions with other trades such as architectural and structural. In addition, it combines the survey approach with a retrospective case study to provide empirical evidence of the issues and their impacts.

The complexity of selection of building façade elements: the case of curtain wall

A curtain wall is defined as a thin, usually aluminium framed wall, containing in-fills of glass, metal panels or thin stone in addition to glazed-in window and door openings (Vigener and Brown, 2011). Curtain wall is classified according to the method of manufacture and installation as either stick systems or unit systems (Eastman et al., 2011).

Table 1. Classification of a non-exhaustive list of previous studies according to their domain, granularity and research approach

		Odeh and Battaineh (2002)	Assaf and Al-Hejji (2006)	El-Razeket al. (2008)	Sweis et al. (2008)	Tumi et al. (2009)	Al-Hajj and Hamani (2011)	Zoya Kpamma and Adjei-Kumi (2011)	Shebob et al. (2012)	Fallahnejad (2013)
Domain of investigation	Gas & power industry									●
	Building & Residential			●	●			●		
	Public sector	●								
	Construction (not specified)	●	●			●	●		●	
Granularity of investigation	Sector / Country	●	●	●	●	●	●	●	●	●
	Project						●			
	Single building trade									
Approach of investigation	Questionnaires	●	●	●	●	●	●	●	●	●
	Interviews						●			
	Case study									

Table 2. Types of issues affecting industry and projects

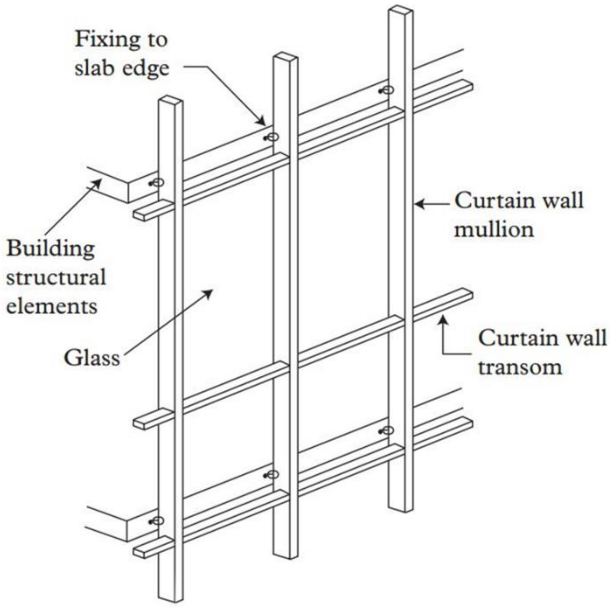
	Issues identified
Odeh and Battaineh (2002)	- Inadequate contractor experience - Client interference - Clients financing
Assaf and Al-Hejji (2006)	- Shortage of labour - Delays in clients payments - Type of project bidding
El-Razeket al. (2008)	- Contractors finance - Delays in client payments - Clients design changes
Sweis et al. (2008)	- Contractor poor planning - Contractors finance - Clients change orders
Tumi et al. (2009)	- Improper planning - Lack of effective communication - Design errors

Al-Hajj and Hamani (2011)	- lack of awareness - excessive off-cuts resulting from poor design - rework and variations
Zoya Kpamma and Adjei-Kumi (2011)	- low recognition of sources of waste - little awareness of waste reduction tools - inadequate familiarity of the firms with lean thinking
Shebob et al., 2012	- Drawing approval delays - Adverse weather conditions - Delays to site handover to contractor
Fallahnejad (2013)	- Problems with importing materials - Unrealistic contract durations - Slow delivery of client materials

A stick system consists of a framework of site assembled components which is used to support glass and infill panels (CWCT, 2000a). A unit or unitised system is prefabricated wall which are transported to site as unitised frames, normally pre-glazed (CWCT, 2000a). The primary structural elements of curtain walls are mullions (vertical elements) and transoms (horizontal elements) (~~Figure~~Fig. 1). Vertical mullion usually spans the full height of the cladding - in the case of stick systems- and they are connected to the horizontal transom using angle cleats, sleeves, spigots or proprietary brackets (CWCT, 1999). The framework of mullions and transoms supports infill panels, which may be glazing units or insulated panels. Mullions and transoms are usually made of extruded aluminium but may be made of steel in some cases (CWCT, 1999). A number of well established suppliers, mostly large and multinational companies, produce and commercialise numerous curtain wall systems. The commercial meaning of a curtain wall system is a collection of curtain wall products (mullions and transoms) having the same section shape but with different dimensions (length, high, width) in order to cover a range of performance required such as: different spans - distance between two mullions, maximum wind deflection, and different glass or infill weights.

The curtain walls and other building façade elements are a prerequisite in achieving occupant satisfaction, building efficiency and economic construction strategies. Their specification and selection is a challenging process due to the numerous architectural, engineering, economic and environmental parameters (Table 3) and stakeholders (i.e. architect, client, engineering consultants, vendors and specialist subcontractors) involved in the decision.

The thresholds of these performance parameters may vary between different countries' national building codes. For example, the air leakage rate through a curtain wall for the United States market is limited to 0.3 litres/sec*m2 at 75 Pa air pressure difference. In Canada, the air leakage rate is limited to 0.1 litres/sec*m2 at 75 Pa air pressure difference (Quirouette, 2013).



~~Figure~~Fig. 1. Main elements of Curtain wall

Table 3. Engineering and environmental parameters involved in curtain wall selection

Water tightness	Curtain wall systems have two different methods to deal with water tightness, namely: face sealed systems and drained and ventilated systems. Face sealed systems have the water penetration line at the front of the system. Drained systems allow a certain amount of water to penetrate past the first weather seal gaskets, but a pressure equalised chamber is formed in the system that causes any penetrating water to be drained back to the outside via drainage holes positioned in the exterior face (CWCT, 2000b).
Air tightness	Adequate air tightness of the curtain walling is required to prevent occupier discomfort that may occur due to draughts and/or noise (CWCT, 2000b). The lack of air tightness can result in air leakage leading to heat loss during winter and excessive energy requirements during summer.
Thermal Performance	Curtain wall systems contribute to building energy efficiencies through their thermal performance such as their conductance which is a function of the frame material, geometry and fabrication (Vigener and Brown, 2012).
Acoustic	The acoustic performance of curtain walls is mainly determined by their infill

Performance	materials. The acoustic performance can also be improved by making the construction as airtight as possible and using sound attenuating glazing and panels (CWCT, 2003)
Movement accommodation	Curtain wall systems are required to accommodate the structural movement of the building they are secured to. The capacity of accommodating building movement depends on the shape and dimensions of the curtain wall section selected (CWCT, 2007).
Wind loading	The ability of curtain wall systems to withstand wind loads depends on their shape and the way they are attached to the structure at floor slab levels through brackets that transfer the wind load to the structure. While transferring the wind loads to the structure, the curtain wall are also subject to deflection and therefore, their shapes and dimensions are crucial to insure that the maximum deflection is not exceeded (CWCT, 2000c).
Fire safety	The installation of curtain wall system influences the passage of fire and smoke. The installation usually leaves gaps between floors horizontally and between party walls vertically to allow the passage of fire and smoke. Many standard products (i.e. fire break materials) are available and are specified by the amount of time they can withstand the passage of fire and smoke (CWCT, 2011).
Maintenance	All curtain walling façades require maintenance during the building operation phase (Vigener and Brown, 2012). The degree of maintenance and inspection depends on the façade type and the intended design life. The early detection of defects can mitigate expensive repairs or even replacement. Therefore, safe and easy access for conducting maintenance operations and possible disruption to occupiers are factors that are considered in the design and selection process.
Buildability	Ease, safety and access methods are all factors associated with buildability. For example, the method of erection must be considered during the design stage by taking into account accessibility and site logistics (HSE, 2007). Regulations issued the Construction Design and Management (HSE, 2007) dictate criteria that go beyond the construction phase and stipulate that the façade must be accessible for replacement and end of life dismantling of the structure.

Research methodology

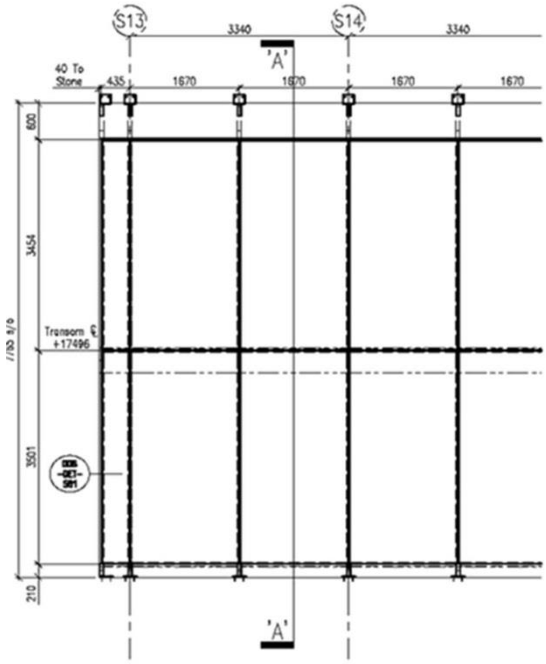
This research aims to investigate the issues affecting the selection process of building façade elements such as curtain wall systems and the impact of selection decisions on projects. To achieve this aim, the research utilizes mixed research methods consisting of retrospective case study and an industry survey of stakeholders involved in selection decisions. This approach is a form of triangulation in which the weakness in each single method is compensated by the counter-balancing strengths of another (Amaratunga, 2002) and enables to elaborate or develop analysis, providing richer details (Rossman and Wilson, 1991). The retrospective case study is used to confirm and introduce, by presenting empirical evidence, some of the issues affecting building façade projects and their impact on project performance. However, case studies are not generalizable to a sampling universe but instead directly confirm or disconfirm theory and hypotheses (Yin, 1994). As such the retrospective case study approach is utilized in this research primarily to confirm the existence of issues in selection decisions and secondly to illustrate the impact of incorrect selection decisions. The case study is complemented with an industry survey followed by face to face and phone interviews with industry experts to identify and analyze the range of issues associated with the early selection of curtain wall systems. Following the retrospective case study, the business process for curtain wall selection adopted on the case study project is also mapped to show the deficiencies of current processes.

Retrospective case study

The case study is a multi-million dollar hotel located in London, UK. Curtain wall is the main element of the building façade with a commercial value just over eight million dollars. This project is representative of the research problem in terms of products (i.e. curtain wall systems) and stakeholders (i.e. client, contractor, and architect) involved. The project's data was obtained through "retrospective story telling" through three interviews with the project manager responsible for the delivery of the building façade . The project manager works for the specialist façade subcontractor responsible for the detailed engineering design, manufacturing and installation of facade. The project manager collaboratively works with the architect, contractor, curtain wall vendors and other subcontractors to resolve every façade related issue on site and it is in his best interest that things go smoothly on site. Therefore, the storytelling by the project manager can be considered unbiased. The three interviews with the project manager respectively addressed three distinct areas: the original specification and issues encountered; the corrective actions, and the impact on the project. Only one part of the building façade , which is at the lower ground floor bar area, is used for this study. It should be noted however, that there were similar issues encountered in other areas of the build. The main contractor for the project was one of the largest contractors operating in the UK and worldwide, and the architects were a major London-based architectural firm. A medium-sized company was employed as a specialist sub-contractor with design responsibility for the building envelope under contract to the main contractor. The curtain wall system used on the project was specified before the specialist sub-contractor was appointed and was supplied by one of the major three vendors which will be referred to in the remaining part of the paper as vendor A, vendor B and vendor C due to confidentiality of commercial information. The three vendors together have more than 70% of the UK market share valued at $250 million in 2008 (Companies House 2008 tax returns) and are multinational companies operating worldwide. The selected curtain wall system was also specified based on a commercial partnership between the main contractor and vendor A, in which the contractor is committed to use vendor's products on all projects. In addition, there were further constraints relating to aesthetic and architectural aspects imposed by the architect and other structural constraints. These factors will be discussed in more detail in the subsequent section of the case study.

The Design Intent and issues faces

The design intent and brief received by the specialist subcontractor for the ground floor bar area from the architects specified structurally glazed curtain wall screens with a span 7.7 meters in height with mullion centers at 1.67 meters (~~Figure~~Fig. 2). A mid transom split the screen at a height of 3.5 meters from the bottom transom and 3.45 meters to the top transom. The selected curtain wall system at the early specification phase was supplied by vendor A.



~~Figure~~Fig. 2. Drawing of the curtain wall screen

When the design brief and early specification was received by the specialist building façade subcontractor for detailed engineering design stage, several issues were encountered:

- Deflection of the selected mullion exceeded the maximum deflection allowed: The selected mullion specifies a maximum deflection as the ratio between the length of the curtain wall screen and '300' which gives in this case a deflection of 25.7 mm (i.e. 7700/300) that exceeds 15mm – the recommended maximum deflection by BS EN 13830:2003. Therefore, the product specified at early design stage does not meet the structural requirement.

- Maximum glass weight supported: The maximum glass weight that the transoms of the selected system could support was 250 kgs accoding to the specification of the vendor. The weight of the glass is usually calculated using the empirical formula that each 1 msq of glass weighs 2.5 kgs per 1 mm thickness. The thickness is a function of the barrier loads. In this case, the barrier loads dictated that the glass thickness required was 10mm outer panes and 13.8 mm inner panes. The section size in this case is 5.84 msq (i.e. 1.67 m x 3.5 m) and the glass weight is 347.5 kgs (i.e. 5.84 m2 x 2.5 kgs x 23.8 mm), which exceeds 250 kgs – the maximum glass weight that could be supported by the selected product.

- Mullions length available: The selected off-the-shelf curtain wall system is supplied by vendor A with mullions having a length of 6.5 meters only. Therefore, this system cannot satisfy the height to the top transom (i.e. 7.005 m) required at the ground floor bar area of the build.

It is important to emphasize that the issues encountered were spotted at the construction stage during which any design change affect the overall project delivery time and cost as widely known in the literature. The subsequent section describes the systematic effort undertaken to explore options to rectifying the identified issues.

Actions taken

A number of actions were systematically undertaken to address each the encountered issues while simultaneously considering commercial, structural and aesthetic constraints:

- Deflection issue: Sections with larger width from a curtain wall system supplied by the same vendor (i.e. vendor A) were examined as an alternative. A 65 mm wide box section was identified. However, structural analysis showed that this box size cannot meet the required deflection even with the inclusion of steel inserts. Another alternative section, whose width is 15 mm larger than the width of the system initially specified, could be meet the deflection requirement but it requires a joint in its length to satisfy the maximum length required. This architect rejected this solution as no secondary steel was allowed to be used between the mullion span points. This would be visible and totally unacceptable to the architectural intent.

- Glass weight: The curtain wall system selected could not support the required glass weight. To overcome this issue, it was proposed to bolt the transom to the mullion's shear jointing blocks. The architects rejected this option as any face fixings on the curtain wall screen was not allowed. Then, an extra transom could be introduced to cut the glass size down and consequently bring the glass unit weight within acceptable limits. The architects rejected also this solution as it affects the initial design intent and requires planning re-approval. Therefore, it appeared that there were no solutions to this problem without the need to reconsider planning permissions.
- Mullions' length available: The mullions of the selected curtain wall off-the-shelf system were available in 6.5 m lengths only. Vendor A was approached to enquire if a special length mullion could be produced. The vendor could not satisfy this requirement. An alternative was to introduce a spigot joint in the mullion at suitable points to achieve the lengths required. The architects rejected this option as a seamless mullion span was a key aesthetic requirement. Then, the technical department of the curtain wall's supplier (i.s. vendor A) was requested whether they can grant a concession for using the selected product with the exceeding glass weight. The supplier did not approve this concession.

Consequences

The issues encountered were not resolved after exhausting all possible solution options. At this stage, it was decided to investigate whether alternative systems supplied by other vendors (i.e. vendors B and C), who are not even part of the project's supply chain, can resolve the issues. An off-the-shelf product, supplied by vendor B, having mullions with standard length of 7 meters, was identified as a potential solution. This product would not also require the use of joints and/or reinforcement. This system was proposed to and accepted by the architects. However, this caused some further commercial issues. The alternative product is supplied by Vendor B – main competitor of vendor A and not part of the project supply chain – required a sign-off from the central control office of the general contractor who has commercial exclusivity with Vendor A whose approval was also needed. This process caused program delays as site curtain wall work package is on the critical path of getting the building weather proofed. In addition to the delays associated with this approval, there exploration of the engineering options discussed earlier had negative on the project program and cost. In particular:

- The project's schedule was delayed by more than four weeks to the extra design and research time spent on looking for alternative systems and in exhausting all possible options based on the preferred selected system. The extra time spent stretched also design resources and had a ripple effect on other areas of design, for the project, that needed to be progressed.
- The architects who were directly responsible to the main client for quality control had to be fully and formally convinced and informed that the original system could not be used. This was a time consuming process that meant reissue of drawings and technical data showing and justifying the issues encountered.
- The new system identified had to be submitted for approval. This included the issue of samples from a new supplier, drawings, technical data and warranties that eventually need to be issued to the client for approval.

Together these consequences, resulted from the inaccurate selection of building façade element, represented a significant wastage of resources and caused time and cost overruns for all the stakeholders involved (i.e. architect, client, contractor, suppliers, specialist building façade contractor and structural consultant).

The current business process for selecting building façade elements

The retrospective case study revealed some issues related to the early selection of building enveloped elements such curtain wall systems. Using the results from the retrospective case study and the experience of the project manager – case study story teller – who has 30 years of experience in managing building façade projects, this section depicts the current business process used to select curtain wall systems in construction projects. This process will be verified with the results from the following industry survey. The selection decisions are represented in business process which is defined as a set of coordinated tasks and activities to achieve a project objective (Kassem et al., 2011). The current business process, reflecting current practices, is depicted in figureFig. 3. FigureFig. 3 shows the key of issue of the late appointment and involvement of building façade specialist consultants and subcontractors which is currently made after the selection decisions have been made at the early and design phases. It is known that design decisions have the biggest impact on the project lifecycle phases and building performance (Schade et al., 2011) and incorrect design decisions bring adverse impact on project participants and are responsible for many of construction failures (Andi and Minato, 2003). Rework, which is often experienced in construction projects, is regularly attributed to errors made during the design process (Love, 2000). These statements were proven in the case study earlier. Together the delayed involvement of façade consultant and subcontractor specialists and the limitations of off-the-shelf building façade elements were very detrimental to projects as evidenced in the retrospective case study. The early opportunity to build for greater flexibility and give broader scope in the selection of building façade elements is missed in current business processes. FigureFig. 3 shows the three entry points (shaded boxes) at which façade consultants and/or specialist subcontractors could be involved to overcome such issues in a proactive manner. A further validation of this business process and a comprehensive overview of the issues depicting current selection business processes will be the subject of the industry survey.

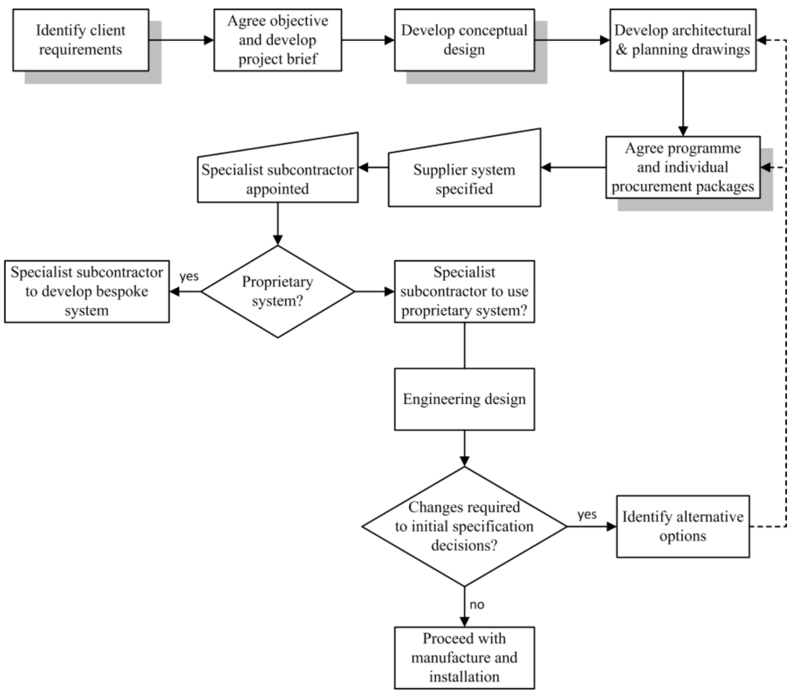


Fig. 3. Business process adopted for the selection of curtain wall systems

Industry survey

The results of the case study cannot be generalised to all projects or to the whole sector. An industry survey, followed by face to face and phone interviews with industry experts, was used for explorative purposes to obtain a thorough understanding of the issues associated with selection and specification decisions of building façade elements. Two criteria in sampling participants and conducting the survey aimed to respectively increase the internal and the external validity of findings. The first criterion is that all participants must be actively involved in or are stakeholders who can influence the early selection of curtain wall systems. The second criterion is that the sample size must allow the findings to be generalised at sector level. To meet the sampling criteria, participants were selected from renowned and leading architectural, consultancy and contracting organizations and included in the sample only if they are actively involved in large commercial and residential construction projects where curtain wall systems are mostly used as main elements of building façade s. According to these sampling criteria, 60 individuals were preselected with the support of two project managers who have more than 20 years of experience in the sector. 54 participants expressed interest in taking part and commitment to give information and came from organisations operating at European and international scale such as Laing O Rourke, Mace, Balfour Beatty, Morgan Ashurst, Bovis Lend Lease, Bennett's Architects, CWA Architects, Axismason Architects, RMA Architects, Galliford Try, Barr Construction, Dandara, and Berkeley First. Both semi-structured questionnaires followed by either a face to face dialogue or telephone interview were used in the industry survey. To increase further the internal validity of the survey, two actions were undertaken. First, a pilot questionnaire was tested with an operation director who has 30 years of experience in the façade industry. This ensured that the questions in the survey were perceived as both clear and relevant. Second, the telephones and face to face interviews were used with most participants to gather more information about the open-ended statements given by participants.

To adequately answer the issues researched, the questionnaire was organised into three sections having distinct objectives:

- Awareness of stakeholders about commercially available curtain wall systems
- Knowledge of stakeholders about the engineering and technical performance of commercially available curtain wall systems that affect selection decision
- Value of available product selection guidance offered by vendors

The commercially available curtain wall system considered in many questions and supplied by vendors denoted as vendor A, vendor B and vendor C statistically represent the curtain wall market as the three companies together have more than 70% of the European market. This was verified in the case of the UK with actual ~~figure~~Fig.s from the Companies House - executive agency of the Department for Business Innovation and Skills – and the three vendors considered in this study had just more than 70% of the UK market valued at $ 250 million in 2008 (Companies House 2008 tax returns).

The questions asked under each section and answers obtained are respectively summarised in Tables 4, 5 and 6 respectively.

Table 4. Awareness of stakeholders about available curtain wall systems

<table>
<tr><td>Q. 1</td><td colspan="7">how well you know the façade and curtain wall industry?</td></tr>
<tr><td></td><td colspan="2">very well (8%)</td><td colspan="2">quite well (70%)</td><td colspan="2">not very well (11%)</td><td>not at all(11%)</td></tr>
<tr><td>Q. 2</td><td colspan="7">do you employ a façade consultant?</td></tr>
<tr><td></td><td colspan="2">yes (6%)</td><td colspan="2">no (65%)</td><td colspan="2">occasional (11%)</td><td>never (18%)</td></tr>
<tr><td>Q. 3</td><td colspan="7">how many curtain wall systems are you aware of?</td></tr>
<tr><td></td><td colspan="2">1 to 3 (24%)</td><td colspan="2">3 to 6 (41%)</td><td colspan="2">6 to 9 (31%)</td><td>more than 10 (4%)</td></tr>
<tr><td>Q. 4</td><td colspan="7">how many curtain wall systems have you had experience of working with?</td></tr>
<tr><td></td><td colspan="2">1 to 3 (78%)</td><td colspan="2">3 to 6 (17 %)</td><td colspan="2">6 to 9 (5%)</td><td>more than 10 (0%)</td></tr>
<tr><td>Q. 5</td><td colspan="7">if asked to name major curtain wall systems used in the UK which would you name?</td></tr>
<tr><td></td><td colspan="3">system A (54%)</td><td colspan="2">system B (42%)</td><td colspan="2">system C (4%)</td></tr>
<tr><td>Q. 6</td><td colspan="7">given the choice which system would prefer to work with?</td></tr>
<tr><td></td><td colspan="3">system A (48%)</td><td colspan="2">system B (39%)</td><td colspan="2">system C (13%)</td></tr>
<tr><td>Q. 7</td><td colspan="7">does the company you work for have a specified system, i.e. the choice is already made due to exclusivity deal with a particular supplier?</td></tr>
<tr><td></td><td colspan="4">yes (6%)</td><td colspan="3">no (94%)</td></tr>
<tr><td>Q. 8</td><td colspan="7">what would be your main criteria for choosing a certain system?</td></tr>
<tr><td></td><td>familiarity and past experience (23%)</td><td>cost (28%)</td><td>recommendation (12%)</td><td>engineering aspects (12%)</td><td>aesthetic (17%)</td><td>technical help (8%)</td><td>lead time (0%)</td></tr>
</table>

Table 5. Knowledge of stakeholders about the engineering and technical performance

Q. 9	when selecting a curtain wall systems at the concept design stage, how confident are you that it will meet the engineering requirements (i.e. accommodate the building movement, deflections and imposed loads etc.)?			
	not confident (15%)	fairly confident (15%)	Confident (61%)	very confident (9%)
Q. 10	who would you rely on to confirm that the system will meet the project needs in terms of engineering capabilities?			
	specialist subcontractor (54%)	own knowledge (31%)	system vendor (15%)	façade consultant (0%)
Q. 11	have you ever had experience of the specified envelope elements being changed due to their incapability of meeting engineering and technical requirements?			
	never (67%)	sometimes (33%)	often (0%)	
Q. 12	do you think you are given enough information upfront - before system selection and specification?			
	yes (31%)	no (69%)		
Q. 13	is the information required in question 12 readily available from suppliers?			
	yes (37%)	no (63%)		
Q. 14	do you think there is a difference in the amount of building movement that can be accommodated between different system supplier's products?			
	yes (18%)	no (15%)	not sure (67%)	

Table 6. Value of available product selection guidance offered by vendors

Q. 15	are you aware of any specifier guidance documentation / technical notes?			
	British standard (8%)	trade bodies (8%)	CWCT (31%)	others (11%)
Q. 16	do these technical notes / guidance information give any specific system advice?			
	yes (8%)	no (72%)	not sure (20%)	

Findings and discussion

The retrospective case study provided empirical evidence of the impact that inaccurate selection and specification of building façade elements can have on program's schedule and costs. The identified issues and challenges are causing time and cost overruns in construction projects in the form of: time to re-producing new drawings or amend existing drawings, suspension of construction works, submission of new planning permissions, delays in procurement and fabrication due to new lead times, and in some cases, commercial issues, when there are exclusivity deals. This is very detrimental, not only to the building façade work package, but to the entire project as curtain wall completion is always on the critical path for getting the building weather-proof in all construction projects. The case study introduced also some of the preliminary issues causing such a negative impact. The results of the survey provide further evidence by showing that cases where curtain wall systems, specified at the early design stage, had to be changed later on in the project due to their inability to meet engineering requirements are not unusual (question 11). One the one hand, this is partly caused by the limited knowledge of stakeholder, involved in the early specification, of engineering performance of curtain wall systems (questions 1, 9 and 14). Similar findings were identified in other studies, where a survey of architects ranked the 'lack of in-house expertise' and 'lack of industry expertise' as major limitations at design stage (Jaillon and Poon, 2010). On the other hand, the appointment of specialist façade consultants and subcontractors is often left until late in the business process as evidenced in the mapping of the business process (~~figure~~Fig. 3) once the opportunity of influencing specification decisions and their impact is already missed. This was also confirmed in the survey where more than 65% of participants acknowledged that they do not appoint a façade consultant (question 2). In follow up telephone interviews, only three participants confirmed that they employ a façade consultant to support the selection of the façade system. Interviewees explained that in the majority of cases consultants are only called in to investigate and solve post, or during construction, unforeseen problems. Most interviewees justified this fact on a cost cutting ground and indicated that they do not deem this initial cost value for money.

Façade consultants were generally seen as a "necessary evil" – as expressed by one participant - once problems had become apparent. Façade consultants are either hired later once the issues have occurred or not appointed at all as occurred in the retrospective case study. Also, in common with the retrospective case study where an exclusivity deal existed between the main contractor and curtain wall system vendors, the survey showed that in some cases (6%) there are commercial influences such as an inclusivity deals between the contractor and the curtain wall vendor (question 7). Participants interviewed confirmed that in those cases, the specification options for architects and consultants are even further restricted and technical issues could become unavoidable in those cases. One specialist subcontractor stated "we have the most to gain if the right system is selected and we can ensure that the right system is selected. However, we have very little opportunity to influence the decision due to our usual late appointment".

The availability of information from curtain wall vendors is inadequate and difficult to obtain (question 12 and 13). Early specifiers are aware of just a limited number of curtain wall systems and usually adopt the system they know best until a problem arises (question 3 and 4) or "specify the systems of those suppliers that appear to offer the most secure warranties and technical assistance", noted one the participants.

The limited awareness of participants of available curtain wall systems can have significant commercial implications on the market share. Vendors with the highest marketing budget and capabilities would have their systems specified on more and more projects and their market share increasingly growing.

Merging together four of the survey findings (i.e. 1- limited knowledge of stakeholders of engineering performance 2- technical guidance and information are either unavailable or not user-friendly 3- the non-appointment of façade consultant and 4- the late appointment of façade subcontractor) give indications of the root-causes of the challenges and risks affecting the selection process in this considerable and expensive industry. If the four issues are seen as constraints in the current industry business processes, a solution that concurrently addresses them is to bring forward engineering information of building façade elements to the early specification phase in a simplified and integrated manner – to cover all commercially available systems – simplistic and user friendly format – to match the limited knowledge of stakeholders.

The first contribution of this research was to provide the empirical evidence, by illustrating a real case study and an industry survey of the major players, of the challenges affecting the selection of façade systems at the early design phase and to identify the root causes of issues creating wastage in the building façade sector. Indeed, together the case study and the industry survey depicted a holistic identification and explanation of both the issues and their implications. The findings from both the case study and industry survey can be used to classify the issues into four distinct categories:

- Limited understanding by the decision makers, involved in the early specification, of the engineering and technical parameters of façade systems;
- Tendency or reluctance to appoint specialist consultants and subcontractors early in the business process;
- Lack of tools or methodologies that provide information in a user friendly and simplistic format that match the level of experience of the early decision makers, and
- Commercial influences that affect the early specification and restricts the available selection options.

Research and development efforts that aim to address the identified issues need to distinguish between the issues that are rooted in the industry mindset and those that are purely related to technical issues. The latter can be addressed in the short and mid-term compared to the former that require a long-term cultural change. Indeed, as noted by three participants in the follow-up interviews, some of the identified issues such as the delayed appointment of specialist contractors and the reluctance to appoint consultants are rooted in the construction industry and could persist in the short and mid-term despite several studies researching and invoking the need for early stakeholder involvement. For example, studies focusing on the importance of early stakeholder involvement (Wikstrom et al., 2010; Kagioglou et al., 2000) and interaction (Tribelsky and Sacks, 2011) and their impact on value creation (Mitropoulos and Howell, 2002) have proliferated since more than one decade and was emphasized in notable industry report (i.e. Egan Report (1994) – Rethinking Construction). However, issues related to the lack of involving stakeholders at suitable decision points in construction projects are still occurring as this case study and survey have demonstrated. Early stakeholder involvement give projects the opportunity to utilize and exploit a richer knowledge base (Ramaswamy and Gouillart, 2010). In the case of building façade, as it was demonstrated in the case study and the survey, the specialist knowledge of building façade consultants and specialist subcontractors is not exploited due to their late or non-involvement.

A recent study, investigating the state of integration in the AEC community concluded that despite integration is important for the industry on the whole, the effort to include integration varies by discipline (Uihlein, 2013). This study unrivalled some of the collaboration issues which are specific to the building façade sector. In the short term, it is challenging to present solutions to rooted issues in the industry such as the culture of non-involving all relevant stakeholders in the early design phase. However, it is possible to address some technical issues such as the lack of simple and user-friendly technical guidance, the complexity and fragmentation of guidance and the limited knowledge of stakeholders involved in early selection decisions. For example, a solution option is to facilitate specification and selection decisions by developing information management and decision support systems that bring forward engineering and technical information in a simplistic and user friendly manner to the stakeholders involved in the specification decisions (Kassem et al., 2012). This solution helps filling the knowledge gap of stakeholders and improving the communication and understanding of engineering performance at the early specification stage.

Very few studies , aimed at addressing the aforementioned issues with the specific focus on the façade industry, are available. Chin et al. (2004) and Hwang et al. (2006) presented a conceptual framework with three dimensions: production management; organization management, and information management. The production management dimension aims at clarifying the performance requirements for curtain wall and reducing design reworks through manufacturability and constructability review. The organization management dimension is tackles the nontechnical issues such as the need to change owner's and architect's attitude, and the need for improving contractual arrangement. Finally, the information management dimension consists of an 'alternative information-based solution' for each of the reported issues. However, subsequent papers published by the authors (i.e. Hwang et al., 2006) have focused only on the processes downstream the design stage (i.e. manufacturing, delivery and installation) and therefore, did not address the specification decisions at the early design phases. Also their framework made no distinction between off-the-shelf and bespoke curtain wall systems. The retrospective case study and survey showed that the use of off-the-shelf systems are a popular choice on projects and due to the limitations of such systems, issues arise in design and construction phases. A proposed decision support system to aid the selection process of off-the-shelf curtain wall systems was developed for the products of three major vendors (Kassem et al., 2012). The system enables users to identify products that meet the project and engineering requirements. However, the development of the proposed system revealed further challenges. One major challenge consisted of the need for a taxonomy that can to be adopted across all vendors' systems to uniquely represent key technical parameters between vendors' systems. Resolving the taxonomy challenge in the representation of engineering parameters and performance of building façade products across different supplies will facilitate information management systems and consequently increase the sharing of information between stakeholders. This will also contribute to unravelling some of the less known building façade systems to the stakeholders involved in selection decisions.

The final contribution and implication of this research is to instigate or complement methodological approaches in the subject area of 'investigating and identifying issues affecting construction projects' with a new approach in which the granularity and scale of investigation is increased to project and disciplinary level (i.e. building façade), without overlooking the link with other disciplines (i.e. architectural and structure). As evidenced from this research, this approach proved to be effective in identifying the very nature of issues and their root causes.

Conclusions

The overarching aim of this research was to empirically identify the issues and challenges affecting the selection of building façade at the early design; the impact of their specification decisions on construction projects, and potential solutions. The use of the retrospective case study, process mapping and the industry survey helped to achieve this aim. The case study systematically demonstrated some of the issues affecting the early selection and building façade elements and their impact. The lack of involvement of façade consultants and specialist façade sub-contractors is resulting in selection of building façade systems that do not meet the project and engineering requirements. Such issues, revealed only at the late construction phase, have adversarial effects not only on the project's schedule and cost but also on the commercial relationships between stakeholders in some circumstances. The industry survey contributed to identify an exhaustive list of the issues affecting the business process of building façade selection and the root cause of such issues. The root cause of issues were classified into four categories, namely: limited understanding of engineering parameters by stakeholders involved in the early selection; reluctance in the appointment of specialist consultants and subcontractors at early stages of the procurement process; lack of tools or methodologies that provide information in a user friendly way to match the limited technical knowledge of stakeholders, and commercial constraints such as exclusivity deals that restricts the options available. In addition to filling this research gap in literature, this study adopted and instigated a new methodological approach in this research domain. This approach consisted of increasing the granularity of investigation by focusing on a specific building trade and providing empirical evidence of the issues and their impacts. This will warrant an incisive inquiry into the very nature of issues affecting the subject investigated. In such a context, this research instigates:

- Domain researchers, who are interested either in exploring issues (time, cost or quality related) in construction projects in general or in understanding how to bridge the gap between early decision design decisions and engineering implications, to increase the depth of investigation from sector-wide level to a more granular level such as a single building trade;
- Industry players to develop methodologies and systems that bring forward engineering information in a simplistic and user-friendly manner to all the stakeholders involved in the selection process, and
- Researchers and industry players to build a taxonomy of technical terms and concepts across all façade systems' vendors to facilitate the comparison of engineering performance at the early design process in a systematic manner.

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