MULTI-STOREY BUILDING RETROFIT WITH A FOCUS ON THE FAÇADE SELECTION PROCESS: A UK COMMERCIAL OFFICE CASE STUDY

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Poorly-insulated existing buildings contribute significantly to the energy use of the built environment. In the UK, the existing building stock is replaced at a rate of less than 2% a year; thus, many of today's buildings will still be in use in 2060. Retrofitting aged buildings can significantly reduce their energy use. This paper analyses the selection process and success factors in retrofit façade decision-making. Literature relating to building retrofit and façade selection is reviewed. A case study is conducted on a five-storey 1970s UK commercial office building, retrofitted in 2011. Data is collected via in-depth interviews with key project decision-makers, a documentary evidence review, and thermography of the completed retrofitted façade. The façade evolution is mapped according to seven identified project stages and the RIBA Plan of Work 2007. The retrofit satisfied the client's aesthetic needs, while delivering an 85% reduction in the 'wall' U-value and a 'B' rated Energy Performance Certificate. Value engineering (VE) greatly influenced the façade selection, with less expensive alternatives replacing original elements of the façade design. The façade's thermal success is linked to the VE focusing on façade elements covering only a small extent of the building. Façade success factors key to attracting tenants (lower running costs and aesthetics) may apply to commercial buildings in general. Thermography aided in assessing the retrofitted thermal envelope, but to act as a tool to aid retrofit façade selection, it should ideally involve a 'before' and 'after' survey.

Keywords: decision-making, façade selection, multi-storey, retrofit.

INTRODUCTION

Retrofitting aged buildings can significantly reduce their energy use (Ma et al. 2012) and "work to the outside of the envelope is likely to be sufficient for most existing buildings" (Mara 2010: 37). Retrofit façade decision-making is a complex area, with strategic decisions being made under conditions of uncertainty. The literature gives examples of methods used to aid retrofit façade selection, but also states that decisions are often not based on well-deliberated calculations and instead, can tend to be based on past experience and built-in norms. This paper provides an insight into the process of multi-storey building retrofit façade selection and explores success in retrofit façade decision-making. The multi-storey focus is driven by the tendency for such buildings erected prior to the introduction of energy efficiency regulations to exhibit poor thermal performance (Zavadskas et al. 2008a; Rey 2004); and is defined in this

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paper as any building with more than one storey above ground level. This paper draws on the findings from a critical literature review and a real-life retrofit case study. The case study has two distinct parts: to aid façade selection analysis, data is collected via in-depth interviews and documentary evidence; while to aid façade success analysis, internal and external thermography is conducted. The objectives of this paper are to:

1. Identify what façade decisions are made, when and by whom;
2. Describe and analyse how the façade decisions are made;
3. Assess the thermal performance and success of the completed retrofit façade.

LITERATURE REVIEW

Building retrofit

Two common building energy retrofit classifications are conventional (e.g. replacing inefficient glazing) and 'deep-energy' (e.g. total envelope treatment) (Rysanek and Choudhary 2013). Retrofit strategies are also considered from an architectural view point by Rey (2004): stabilization (not fundamentally modifying the building's appearance); substitution (elements completely changed, transforming appearance); and double-skin façade (glass skin added, metamorphosing appearance). Retrofit is defined in this paper as the addition of a building "component or accessory" not existing when the building was originally constructed (Soanes and Stevenson 2003: 1505). In the UK, buildings are replaced at a rate of less than 2% a year, thus many of today's buildings will still be in use in 2060 (Femenías and Fudge 2010). Retrofitting aged buildings can significantly reduce their energy use (Ma et al. 2012). Moreover, some buildings may exhibit factors such as poor technical quality or a dull external image that trigger the need for retrofit. The retrofit can be a vital spark of life, not only for the building, but for its surroundings too. Disinterest in a building can lead to reduced occupancy, which can create a vicious circle whereby a neighbourhood deteriorates, causing occupancy to fall further still (Bragança et al. 2007). The office building retrofit cycle is around 30-years (Ebbert and Knaack 2007). Two thirds of European office buildings are considered outdated (being 30-years old or more) (Ebbert and Knaack 2007) and most "existing office spaces in the UK are older buildings with lower standards of specification" (Chow and Levermore 2010: 307). In 2010, Chow and Levermore stated that retrofitting existing older offices to Part L 2002 standards enables them to cope with predicted changes in climatic heating and cooling demands up to 2080. Commercial offices account for 8% of energy consumed by the service sector, which itself accounts for 12% of total final energy consumption in the UK (DECC 2012a: 1). These figures may seem low compared to other UK sectors' total final energy consumption: transport (38%), domestic (26%) and industry (18%) (DECC 2012b: 4); however, to reduce carbon emissions by 80% by 2050 "energy efficiency will have to increase across all sectors" (GOV.UK 2012).

Building retrofit façade decision-making

"The need for a decision arises when anomalous events occur" (Beach 1997: 2); which, considering the construction industry's prototypical nature supports research in this context (Sommerville and Dalziel 1998). Human decision-making has three main aspects (Bohanec 2001): normative decision-making (imposes order through the use of structured methods); descriptive decision-making (linked to cognitive psychology); and decision support. This research focuses on the methods it considers to aid façade selection, categorised as follows: decision-making, i.e. normative methods used to generate a decision; and decision-support, i.e. methods used to generate an output to aid decision-making. Descriptive decision-making is omitted from the research, since

AEC industry decisions are complex, and in such situations "confusion can arise if a logical, well-structured decision-making process is not followed" (Šaparauskas et al. 2011: 193). It is known though that "few people make decisions on the basis of well-deliberated calculations", instead making decisions "by following well established and built in norms" (Riabacke 2006: 453). Due to the cost and the long-term nature of their investment, retrofit façade decisions are considered strategic (Arup 2012; Sanguinetti 2012). As such, they are likely to have long-term timescales, a high degree of risk, an ill-defined structure, and to be heuristic in nature (Jennings and Wattam 1998). Heuristics is defined as "enabling a person to discover or learn something for themselves" (Soanes and Stevenson 2003: 815). The fact that retrofit façade decisions are considered heuristic is logical, given that this area occurs under the condition of uncertainty (Sanguinetti 2012). Examples of retrofit façade decision-making are rare in the literature; more so are examples that focus on office buildings. Rey (2004) describes the use of multi-criteria assessment in retrofit façade selection for a 1950s office building; other uses of normative decision-making are in a residential context: decision-making software, with multiple criteria decision-making (Zavadskas et al. 2008b); multi-objective optimization (Asadi et al. 2012); and integrated risk analysis framework (Sanguinetti 2012). Decision support in retrofit façade selection is used in various building contexts: life-cycle analysis (public) (Ardente et al. 2011); weather/building knowledge (theatre) (Pérez et al. 2011); simulation (residential) (Clarke et al. 2004); and image survey (3D laser/photogrammetry) (educational) (Klein et al. 2012).

Thermography in building façade retrofit

Thermography is a relatively new and powerful tool for building investigations, which helps to identify defects such as missing insulation, moisture in walls, ventilation losses, and thermal bridges (Sadineni et al. 2011). The use of thermography for buildings can be split into two specific areas: existing building assessments, and new-build/retrofit quality control inspections (Holst 2000). Using thermography pre-retrofit allows structural details and defects to be identified, sometimes without needing as-built information or destructive investigations (Stockton 2007). It also enables a more accurate and cost effective retrofit solution, with a clearer idea on time scales and efficiencies; and can help verify and record the success of retrofit intervention (Snell 2008). Hart (1991) suggests using thermography as a quality control tool over contractor workmanship, especially for difficult to inspect details. Work in the field of façade retrofit aided by thermography has been undertaken, e.g. Johansson (2012), and Haralambopoulos and Paparsenos (1998). Hopper et al. (2012) study the use of thermography before and after external wall insulation retrofit; suggesting benefits in this technique that targeted key problem areas, and help to show contractors and designers where mistakes had been made, so that similar future retrofit projects can be improved upon. Retrofit work with thermography also identified poorly installed doors and windows (Hayter et al. 2000), masonry cavity wall tie defects (Doran et al. 2009), and evaluated component mock-ups prior to installation (Colantonio 2001).

METHODOLOGY

In order to develop robust guidance in retrofit façade selection for the AEC industry, a real-life case study was conducted. A case study protocol, pre-approved by the case study company prior to commencement, served to guide the investigators (Yin 2009). The case study gathered data from in-depth interviews, documentary evidence, and internal and external thermography. The in-depth interviews were conducted with key members of the case study retrofit project team. The interviewees were selected on the grounds of having knowledge on aspects of the retrofit, to include, but not be limited to: cost, technical function, and aesthetics; and were asked to talk freely about the project, with the aim of capturing the interviewees' opinion of events (Robson 2011). The interviews lasted approx. one-hour and were recorded and transcribed. The interviewees are employees of the case study company and played key roles in the retrofit project: the Managing Director (MD) acted as Developer; and the Group Director acted as Lead Architect from the Technical Design (Stage E in the RIBA Plan of Work 2007 (RIBA 2009)). Two further recorded and transcribed interviews with the MD (one-hour face-to-face and 30-minutes by phone) aided in mapping the façade evolution to the main project points and the RIBA Work Stages. Documentary evidence was obtained from project-related documents, e.g. employer's requirements and tender reports. Internal and external thermography was conducted once on the completed building. A single image walkthrough style thermographic survey was carried out in accordance with BS EN 13187:1999 (BSI 1999). External thermography encompassed the total building façade, with internal thermography on the top floor only. The survey was conducted on 07.12.12, from 6.45-8.45am. Key thermography conditions were met: a 10 degree Kelvin difference between Temperature In and Temperature Out (UKTA 2007); overcast conditions (Hart 1991); and pre-sunrise (Walker 2004). Performing thermography post-retrofit only is a limitation of this study and is due to the case study building having been obtained via convenience sampling. To assess the multiple data sources, qualitative and quantitative methods were adopted. Thematic analysis using the repetition technique (Robson 2011: 482) was used to evaluate the in-depth interviews and documentary evidence, and the thermography findings; while simple spot temperature (quantitative) analysis was used to analyse thermography findings in greater detail where deemed necessary.

CASE STUDY

The case study investigated the retrofit of a real-life five-storey commercial office building, with a focus on the façade selection. The building is located in a waterfront conservation area in the UK, and comprises a central body (3210m2 total lettable floor space), plus two end towers for access to each floor (186m2 total floor space). The building is part-owned by the case study company (an architects practice), who also occupy the top floor. The building was constructed in 1971, from a concrete in-situ frame, with calcium silicate brick infill panels, single-glazed Crittall windows, and no insulation. Prior to retrofitting, the building achieved a 'wall' U-value of 1.49 W/m2K and a 'G' energy performance certificate (EPC) rating. The building was retrofitted in 2011, in line with Approved Document L2B 2006, and using a JCT Design and Build (D&B) Contract - 2005 edition. The work was funded by money borrowed against a group of eight stakeholders' (including the case study interviewees) Self Invested Personal Pension (SIPP). The retrofit aimed to achieve an energy efficient building; and to create a landmark building, thus demonstrating skill as architects.

The completed retrofitted building façade

The upper four floors remained as office use, while the ground floor was converted to retail use. The central body of the building was over-clad with a class '0' insulated render system (comprising 50mm phenolic boards at 0.037 W/m K), with stone tiling to ground floor height adjacent to the main entrances. The south façade was fitted with stainless steel brise soleil brackets (the aluminium louvres are not yet fitted). The two towers are clad with uninsulated two-tone metallic-effect aluminium faced rainscreen cladding. The cavity walls are filled with blown mineral fibre insulation. The window sills have been reduced in height, by removing three courses of brickwork. Thermally broken polyester-coated aluminium double-glazed ribbon windows alternated with coloured insulated spandrel panels have been installed on the upper four floors. The ground floor is single-glazed, with thermal dry-lining to the rear. Other cost-effective building work was conducted internally and to the roof. The four upper floors have a 'wall' U-value of 0.22 W/m2K and a 'B' EPC rating. The ground floor is EPC rated 'C'.

Table 1: Overview of the evolution of the façade elements as the project progressed

Building element	Façade element	1	2	3	4	5	6	7
Cavity walls	Blown mineral fibre insulation	✓	✓	✓	✓	✓	✓	✓
End towers	Zinc sheet cladding (insulated) (VE)	✓	✓	✓				
	Metallic-effect rainscreen cladding		✓	✓	✓	✓	✓	✓
Main central part of the building	Insulated render system (phenolic board, mesh, render)	✓	✓	✓	✓	✓	✓	✓
Main central front façade to ground floor	Ceramic stone-effect tile cladding	✓	✓					
	Real-stone tile cladding			✓	✓	✓	✓	✓
Main central rear façade	Brise soleil brackets	✓	✓	✓	✓	✓	✓	✓
	Brise soleil louvres (VE)	✓	✓	✓	✓			
Ribbon windows to main central front and rear façade	Double-glazed, aluminium	✓	✓	✓	✓	✓	✓	✓
	Coloured clear spandrel glass (VE)	✓	✓					
	Coloured opaque spandrel panels			✓	✓	✓	✓	✓

Notes: The numbered columns indicate the main project points identified by the case study, to which the eleven RIBA (2009) Work Stages (A-H and J-L) are mapped: [1] Initial concept design (A, B, C); [2] Initial tenders received (end of C); [3] Planning application and consent received (D); [4] Technical design and product information (E, F); [5] 2nd tenders received (G, H); [6] Post-tender (J, K); and [7] As-built (L). A tick indicates façade element presence in that evolutionary stage. A 'VE' suffix indicates element removal due to value engineering.

The façade selection process

The façade decisions were made chiefly by the Developer, with Lead Architect input from Technical Design (RIBA Stage E) onwards. The façade decisions did not occur as per the RIBA Plan of Work; instead, seven main project points were identified and labelled, to which the RIBA Stages were then mapped (see Table 1). The final façade changes arose after the 2nd tenders were received (mapped against the RIBA Stages G and H). Façade decisions were observed at all RIBA Stages except J, K and L (this builds on the findings in Garmston et al. (2012) by providing a higher resolution of the process in practice). Due to the UK Government’s strict financial restrictions on SIPP borrowing, this project was extremely cost aware. The decisions that guided the total envelope were driven (in order) by cost, aesthetics, planning, building regulations, and technical issues. The D&B Contractor did not make any post-tender façade decisions, which contradicts Garmston et al. (2012). However, this case study is a potentially unusual example of D&B contracting, in that the MD, acting as the Developer, was also the Client and one of the SIPP stakeholders, and being thus extremely conscious of cost, revisited each element after the initial and 2nd tender stages to identify cost reductions. This behaviour removed any opportunities for the D&B Contractor to make façade cost-saving decisions. A key example is the Developer's decision to use metallic-effect cladding instead of Zinc sheeting: a VE decision that halved the component cost. This decision arose after planning consent had been received for zinc sheeting, but fortunately, Planning accepted the change on the proviso that two-tone metallic-effect cladding was used. VE is a team-led, structured "evaluation of alternative construction materials and systems to save money without major effect on program, maintenance, or appearance, chosen on a priority basis" (Kelly and Male, in El-Alfry 2010: 72); where the essence of 'value', as delivered to the owner, "expresses three main forms: Cost, Function and Aesthetic" (El-Alfry 2010: 72). In a multi-faceted role combining Developer, Client, and SIPP stakeholder, the MD made this, and other VE decisions (see Table 1), by discussing alternatives with the suppliers, and the Lead Architect. Cost effective insulated render was used to wrap the central part of the building. It was not deemed aesthetically acceptable to render the whole building, thus metallic-effect cladding was used on the towers. A robust material (stone) was used to ground floor level, as the render is not impact resistant. In attaching the brise soleil brackets, a small amount of cold bridging was anticipated by the Architect and Developer. However, from a practical point of view, attaching the brackets to the concrete boot lintels was considered to be the best option and unlikely to significantly affect the envelope's performance (as supported by the 'B' energy rating). The façade selection process did not use normative decision-making methods. The decision-makers instead used expert knowledge, in-house, and from suppliers and sub-contractors, to guide their decision-making. Decision support was used in the form of computer analysis (to check dew-point locations) and U-value calculations, both by the insulated render system supplier, to assess the render system's suitability.

The thermographic survey

The external thermographic survey visually reported largely cool temperatures across the main body of the façade. It also showed a few heat loss sources. As expected, the survey highlights localised cold bridging around the brise soleil brackets attached to the original in-situ concrete structure (the brackets and immediate area were approx. 4°C warmer than the other surface render) (Figure 1). Other external features included ventilation losses from trickle vents that had been left open, and gaps in insulation boards behind the render. A distinct difference in emissivity between the rendered and metal clad walls was observed. With much lower emissivity for the metal cladding, it was very difficult to observe potential defects, as much of the radiation received by the camera would have been reflected from other sources (Figure 2). The internal survey identifies ventilation losses from open windows that would be contributing to a reduction in internal temperature. Also, differences in construction fabric were observed (Figure 3) and un-identified areas of heat loss beneath a window (Figure 4).

DISCUSSION

The case study façade selection featured no normative decision-making and little use of decision-support, reflecting the heuristic façade selection process suggested by the literature. Despite this, and the fact that VE greatly influenced the façade selection, the client's satisfaction in the building's aesthetics, and the improved 'wall' U-value and EPC rating demonstrate that success was achieved by the façade decision process. This success may have been helped by the fact that the central part of the building was clad with an insulated render system. As one of the cheapest forms of cladding, this façade choice remained unaltered during the project, ensuring that the larger building part was well insulated, while other parts of the façade (towers, louvres and spandrel panels) were value engineered. It also appears that façade success is linked to building type. In this case, attracting tenants is vital for a commercial building, and so façade decisions were made to ensure the building was attractive to tenants: aesthetic decisions for an attractive façade, insulation decisions for lower running costs, and a structural decision (reduced sill height) for improved internal environment. As money was only released from the SIPP as the occupancy grew, it was essential to pre-let the space. In line with Mara (2010), the façade retrofit has given a new lease of life to this building and enabled it to start functioning while its occupancy gradually increases.

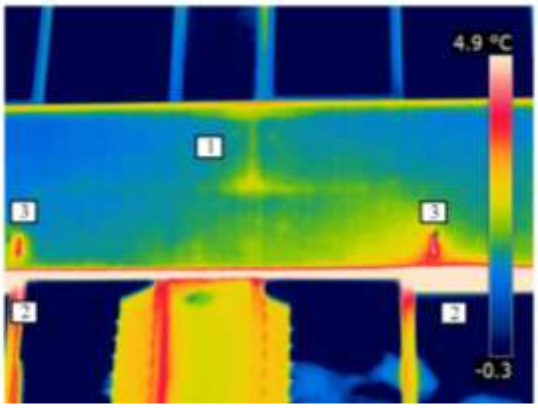

Figure 1: Gaps between insulation boards [1], trickle vents [2] and cold bridging through the brise soleil brackets [3].

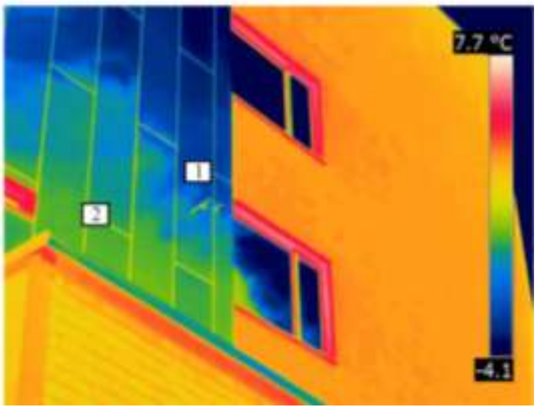

Figure 2: Emissivity difference between render and cladding, note seagull [1] and cloud [2] reflecting off the cladding.

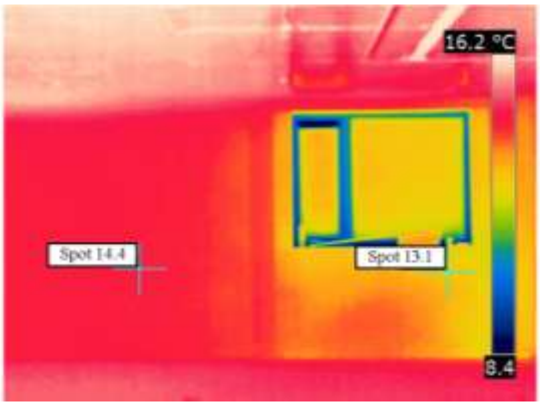

Figure 3: Differences (°C) in construction build-up either side of column.

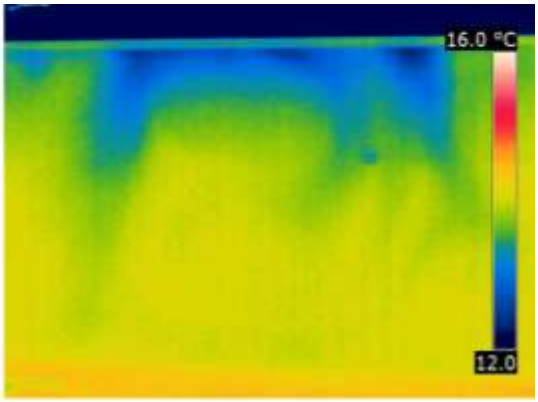

Figure 4: An area of un-identified heat loss below a window frame.

The thermographic survey visually demonstrates general success in the building's new thermal envelope. The survey does, however, also highlight potential quality control issues such as installation of the insulation boards. This information could be used to educate AEC industry members, such as the designer and contractor (Hopper et al. 2000) so that similar mistakes can be avoided in the future. Clients and contractors may be concerned that thermography is too expensive for projects with a tight budget; however, Snell (2008) suggests that using such a survey for retrofit can potentially be cost effective and provide a return on investment. The case study building was empty for 3-years prior to the retrofit, thus 37-years passed from original construction to the point of apparently needing retrofit. This reflects the approx. 30-year office retrofit cycle. The building was retrofitted in line with Part L 2006, so according to Chow and Levermore (2010) should be able to cope to at least 2080 with changes that may occur in climatic heating and cooling. Overheating was considered in the design, with the inclusion of brise soleil on the south façade. The brise soleil louvres were value engineered out (for the time being); however, forethought was shown by attaching the brackets, which were fixed to the in-situ structure prior to applying the render system.

CONCLUSIONS

This paper explores the façade selection process in multi-storey building retrofit. The façade decisions made during a UK commercial office building retrofit were shown as relying on skills and knowledge borne of experience; they were heuristic in nature (as suggested by the literature), but readily utilised decision support from an insulated render supplier. Normative decision-making was not used. The evolution of the case study retrofit façade selection is mapped against the main project stages and the RIBA Plan of Work 2007. Value engineering greatly influenced the façade selection. Despite this, the client's satisfaction in the building's aesthetics, and the improved 'wall' U-value and EPC rating demonstrate that success was achieved by the façade decision process. Some façade success factors appear to be linked to building type; attracting tenants is vital in this commercial building case. Thermography showed the façade to be largely successful, while also identifying some quality control issues in the façade retrofit that AEC decision-makers could learn from when making similar future façade design decisions. Viewing a façade post-retrofit provides only half of the story. It is useful to thermally image a building prior to façade design decisions being made, as the survey can potentially provide a return on investment. Future case study research consisting of 'before' and 'after' surveys could observe how thermography could pinpoint areas for targeted improvements and indicate the success of the improvements. This work could be used to build a database of façade details in a thermal view for use by AEC decision-makers during retrofit façade selection.

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