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# Decision-making in the selection of retrofit facades for non-domestic buildings

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# DECISION-MAKING IN THE SELECTION OF RETROFIT FAÇADES FOR NON-DOMESTIC BUILDINGS

By

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Decision-making in the selection of retrofit façades for non-domestic buildings

## Abstract

In the UK, boom periods of construction combined with typical building styles of the day, have resulted in a large stock of ageing office buildings at risk of structural vacancy and obsolescence. Despite their lack of insulation, high air infiltration, and solar gain, many such buildings from the 1960s-1970s are still in use today. Moreover, with UK buildings replaced at a rate of less than 2% a year, the majority of today's buildings will still be in use in 2050.

Due to the impact of the facade on such aspects as thermal performance and aesthetics, façade retrofit is seen as a key solution to the problem of today's ageing office building stock. Unfortunately, façade retrofit comes with a complex decision-making process. The cost and long-term nature of the investment means that façade decisions are strategic, while the architecture, engineering and construction (AEC) industry is prototypical and multidisciplinary. Decision theory suggests the use of normative decision-making methods to arrive at a well-reasoned course of action; therefore, this thesis aims to discover how decision-making can be improved to support façade selection in non-domestic building retrofit.

A state-of-the-art literature review of office building façade retrofit decision-making only returned nine case studies, of which six reported real-life façade retrofit selection. One real-life and one theoretical case demonstrated the use of normative decision-making in the form of the payback period method, while one theoretical case used multi-criteria analysis. Many sources of information were revealed as guiding the façade selection process in general.

To examine the actuality of façade selection in practice, an exploratory study was conducted. This study involved (1) semi-structured interviews on the topic of façade selection with thirty UK AEC industry members from twelve professions, and (2) a case study of an over-clad 1970s office building, involving in-depth interviews with two UK AEC industry experts, a documentary evidence review, and post-retrofit thermography. Three semi-structured interviewees revealed the use of normative decision-making, in the form of the payback period method, while information sources were greatly used in general. The exploratory case, however, revealed only a minimal use of information and no normative decision-making.

To determine the representativeness of the exploratory case study, an in-depth study of façade retrofit decision-making was conducted. This study involved (1) a specific literature review to set the context of UK university building façade retrofit decision-making and (2)

four exemplifying case studies of real-life university building façade retrofit. The university estate features many ageing buildings from the 1960s-1970s that exhibit the same typical building style as the UK's ageing office stock. The specific literature review found five cases of university façade retrofit decision-making, of which three reported real-life façade retrofit selection. Normative decision-making was revealed in theory, with the two theoretical cases of university façade retrofit using the payback period method. The exemplifying case studies involved eight UK AEC industry experts, a documentary evidence review, and post-retrofit thermography. The case buildings ranged from the late 1950s/early-1960s to the 1970s, with three being over-clad, and one over-clad and re-clad. The exemplifying case study findings support the exploratory case study findings. The key actors in façade retrofit decision-making are the architect, client, and planner. Numerous information sources are used to support the façade selection process, relating chiefly to performance, cost, aesthetics, and collaboration, and the use of normative decision-making is not evident.

From the research findings, it appears the process of façade retrofit selection functions naturally within the realm of the architectural profession. Architects appear to be making initial façade design decisions based on ideas resulting from cognition and drawing on past experience, which become more detailed as the project progresses. The façade selection process is supported by the voluntary use of numerous information sources, many of which are quantitative in nature. This thesis did not find evidence of normative decision methods being used in the current practice of façade retrofit selection. Thus, the recommendations proffered are not characteristic of normative theory, but instead opt to support the façade retrofit selection process by reinforcing current process via the following points: (1) use expertise in the form of advisor-led information sources to guide the façade retrofit selection process; (2) maximise communication by encouraging an ongoing dialogue between AEC industry members involved in façade selection, involving specialist external bodies at an early stage, and documenting the façade selection process; and (3) aid the energy efficiency resulting from building retrofit by engaging stakeholders during design, construction, and in-use, especially in regards to proposed new energy efficiency practices.

This thesis contributes to the knowledge of non-domestic façade retrofit decision-making in actual building design practice. Having found only limited evidence of normative decision-making being used in the non-domestic façade retrofit selection process, it appears that efforts to develop multi-criteria decision-making tools for use in this area may be misguided.

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## List of abbreviations

| | |
|---|---|
| AEC | Architecture, engineering and construction industry |
| AHP | Analytical hierarchy process |
| ARCOM | Association for Researchers in Construction Management |
| ASHRAE | American Society of Heating, Refrigerating, and Air-Conditioning Engineers |
| AUDE | Association of University Directors of Estates |
| BBA | British Board of Agrément |
| BCA | Building and Construction Authority |
| BEM | Building energy model |
| BMS | Building management system |
| BoQ | Bill of quantities |
| BRE | Building Research Establishment |
| BREEAM | Building Research Establishment Environmental Assessment Method |
| BSRIA | Building Services Research and Information Association |
| $CO_2$ | Carbon dioxide |
| CBRE | CB Richard Ellis |
| CIC | Construction Industry Council |
| CIBSE | Chartered Institution of Building Services Engineers |
| CM | Construction Management |
| CPD | Continuing professional development |
| D&B | Design and Build |
| DCLG | The Department for Communities and Local Government |
| DDA | Disability Discrimination Act |
| DEC | Display energy certificate |
| DETR | Department of the Environment, Transport and the Regions |
| EBG | Environmental Building Group |
| ECM | Energy conservation measure |
| EPC | Energy performance certificate |
| EMEA | Europe, Middle East and Africa |
| EMS | Estate Management Statistics |
| EPS | Expanded polystyrene foam |
| EPSRC | Engineering and Physical Sciences Research Council |
| ER | Employer's Requirements |
| ESCO | Energy Service Company |
| EU | European Union |
| EWI | External wall insulation |
| GIA | Gross internal area |
| HEFCE | Higher Education Funding Council for England |
| JCT | Joint Contracts Tribunal |
| ICO | Information Commissioners' Office |

| | |
|---|---|
| IES-VE | Integrated Environmental Solutions Virtual Environment |
| ISSR | Institute for Sustainability Solutions Research |
| IT | Information technology |
| LDF | Local Development Framework |
| LED | Light-emitting diode |
| LEED | Leadership in Energy and Environmental Design |
| LPA | Local Planning Authority |
| MCA | Multi-criteria analysis |
| MD | Managing Director |
| MODM | Multiple objective decision making |
| NDEPC | Non-domestic energy performance certificate |
| NPV | Net present value |
| OR | Operational rating |
| PCC | Pre-cast concrete |
| PIR | Polyisocyanurate |
| PPC | Polyester powder coated |
| PPT | PowerPoint presentation |
| PC | Principal Contractor |
| PCM | Phase change material |
| Pty Ltd | Proprietary limited (abbreviation used under Australian law) |
| PU | Plymouth University |
| QS | Quantity surveyor |
| RC | Reinforced concrete |
| RGF | Revolving Green Fund |
| RIBA | Royal Institute of British Architects |
| RICS | Royal Institution of Chartered Surveyors |
| SBD | Secure by Design |
| SFE | Society of Façade Engineering |
| SIPP | Self-invested personal pension |
| SU | Student Guild |
| SWWIC | South West Women in Construction |
| TRNSYS | Transient System Simulation Tool |
| URL | Uniform resource locator |
| UK | United Kingdom |
| US | United States of America |
| USGBC | United States Green Building Council |
| UWE | University of the West of England |
| VE | Value engineering |
| WBP | Water and boil proof |
| WiTNet | Women in Technology Network |
| WLC | Whole life cost |

## Glossary

| | |
|---|---|
| CarbonLite | The CarbonLite Programme is an initiative from *The Association of Environment Conscious Builders* (AECB) that provides a practical step-by-step guide for practitioners involved in the commissioning, design, construction, and use of low-energy and low-carbon buildings. |
| Class 0 | Class 0 is the highest performance classification for wall and ceiling linings, in regards to the rate of flame spread and surface heat release, in the Building Regulations for England and Wales Part B - Fire Safety. |
| Delta | Term denoting the difference between two temperature measurements. |
| EnergyPlus | This is a whole building simulation software engine used by engineers, architects and researchers, to model energy consumption and water use. |
| Employer's Requirements | Employer's requirements (ER) are typically used in design and build contracts, where the contractor is required to design all of the work, and in traditional contracts, where some contractor-led design is required. The ER provides the contractor with the client's requirements, which can range greatly in their level of detail, from simple to full specification. |
| FLIR | FLIR Systems specialises in thermal imaging cameras, its company name stems from 'forward-looking infrared radiometer' |
| g-value | The g-value is a measure of the amount of heat gain through a window from sunlight, it is also known as the window solar factor. |
| HEFCE RGF | The Higher Education Funding Council for England's Revolving Green Fund provides recoverable grants that are designed to encourage higher education institutions in England to carry out innovative projects to reduce energy use and thus emissions, and to save money. |
| IES-VE | Energy analysis and performance modelling software. |
| RIBA Plan of Work | This is a model of building design, produced by the Royal Institute of British Architects, which can be used to aid the management and design, and the contract administration, for a building project. |
| Salix | Salix Finance Limited provides 100% interest-free capital to public sector institutions to enable them to make energy efficiency improvements and reduce carbon emissions. |
| Therm | Building heat-transfer modelling software. |
| Thermal element | A term that pertains to the walls, roof and floors of a building. |
| Total useful floor area | This is the measurement of a building's enclosed spaces, i.e. its gross floor area, as measured in accordance with the Building Regulations for England and Wales. |
| U-value | A measure how well a product prevents heat from escaping, i.e. a measure of its thermal transmittance. |
| WBP | WBP plywood is made using *water and boil proof* adhesive. |
| WUFI | Software that enables calculation of heat and moisture in walls. WUFI stands for *Wärme Und Feuchte Instationär*, which translates as heat and moisture transiency. |

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The input of the case study companies and interviewees who kindly gave their time to contribute to this study's methodology is acknowledged with grateful thanks. The AEC industry members who took part in the exploratory semi-structured interviews helped guide the investigation, while those involved in the in-depth interviews helped enrich the façade retrofit case study reports. The documentary information pertaining to the façade retrofit projects, made available by the case study companies, also contributed greatly to the case study reports compiled for this thesis. These contributions are not acknowledged individually so as to preserve the confidentiality of the case study companies and AEC industry members involved. Thank you all again – the exploration, discovery, and contribution to knowledge arising from this research could not have occurred without you.

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## Author's declaration and word count

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Committee. Work submitted for this research degree has not formed part of any other degree either at Plymouth University or at another establishment. This study was financed with the aid of a studentship from Plymouth University.

All figures contained in this study, unless expressed otherwise, are by the author.

Thermographic surveys, conducted by Level 2 Thermographer Matthew Fox (assisted by Helen Garmston), and qualitatively and quantitatively analysed by Matthew Fox, contributed to the data collection for the five case studies carried out for this study.

To aid study completion and to improve transferable skills, training courses were attended, including a Level 7 module in 'Research Skills in the Arts and Humanities', and a Level 6 'Postgraduate Certificate in Academic Practice – Stage 1'. Construction-related conferences were attended for which multi-storey façade decision-making related work was presented and papers published. Guest lectures based on office façade retrofit decision-making were given at the University of the West of England and Plymouth University. Poster presentations were made to disseminate the PhD topic. Three journal papers based on previous research by the author of this thesis and published with a member of the PhD supervisory team during the PhD registration period, served to make a contribution to knowledge and to help form the author of this thesis' academic style.

Details of the conference papers, poster presentations, and journal papers are listed overleaf. See Appendix E for a full summary of PhD research dissemination activities, and Appendix K and L for copies of the two published conference papers.

**Peer-reviewed conference papers:**

Garmston, H., Pan, W. and de Wilde, P. (2012) 'Decision-making in façade selection for multi-storey buildings'. In: Smith, S. D. (Ed) *Procs 28th Annual Association of Researchers in Construction Management Conference.* Edinburgh, 3-5 September. Association of Researchers in Construction Management, 357-367.

Garmston, H., Fox, M., Pan, W. and de Wilde, P. (2013) 'Multi-storey building retrofit with a focus on the façade selection process: a UK commercial office case study'. In: Smith, S. D. and Ahiaga-Dagbui, D.D. (Eds) *Procs 29th Annual Association of Researchers In Construction Management Conference.* Reading, 2-4 September. Association of Researchers in Construction Management, 81-90.

**Poster presentations:**

Garmston, H., de Wilde, P. and Pan, W. (2013) Balancing complexity in decision making for façade retrofit. Unpublished poster presentation *at 2nd Annual ISSR Sustainability Research Event*, 29 April 2013, Plymouth University, Plymouth.

Garmston, H., de Wilde, P. and Pan, W. (2013) Balancing complexity in decision making for façade retrofit. Unpublished poster presentation *at 40th Celebration for Environmental Sciences*, 13 September 2013, Plymouth University, Plymouth.

**Peer-reviewed journal papers:**

Garmston, H. and Pan, W. (2013) Non-Compliance with Building Energy Regulations: The Profile, Issues and Implications on Practice and Policy in England and Wales. *Journal of Sustainable Development of Energy, Water and Environment Systems,* 1(4), 340-351.

Pan, W. and Garmston, H. (2012) Compliance with building energy regulations for new-build dwellings. *Energy*, 48(1), 11-22.[1]

Pan, W. and Garmston, H. (2012) Building regulations in energy efficiency: compliance in England and Wales. *Energy Policy*, 45(6), 594-605.

**Word count of main body of thesis: 73,541**

Signed Helen Garmston

Date 24 March 2017

[1] This paper was included in the Plymouth University Environmental Building Group submission for the Research Excellence Framework 2014.

# 1. Introduction

## 1.1 Introduction

The planning and construction of building projects make up a large part of the AEC industry's activities, which, unlike other consumer products have a functional service life that typically exceeds 100 years (Bohne et al., 2015). As the built environment uses over one-third of total final energy and is responsible for around one-third of global carbon emissions (IEA, 2013a), the longevity of the AEC industry products' service life means the AEC industry plays a key part in urban sustainability and climate change mitigation (Bohne et al., 2015).

In the United Kingdom (UK), non-domestic buildings are responsible for around 20% of the UK's energy use and carbon emissions (DCLG, 2015). Non-domestic buildings span the public, commercial and industrial sectors, and include office, retail, school, hotel, hospital, and industrial buildings, and sports and leisure facilities (CIBSE, 2013). Some of these non-domestic buildings, e.g. hospital and industrial buildings, have diverse energy requirements that are strongly influenced by their specific function, while others are seen as having more generic energy requirements, e.g. offices, retail, schools, and hotels (*ibid.*).

Commercial offices were responsible for 9% of the energy used by the UK service sector in 2014 (DECC, 2015a). Office building energy consumption trends are closely linked to economic activity, building type, building age, energy efficiency improvements, and climate (IEA, 2013a). Looking closely at *building age*: from the mid-1950s, the increasing availability of capital saw post-war towns in the UK clamouring to incorporate the latest symbols of commercial success, of which office buildings were a prominent feature (Cherry, 1972). Boom years of commercial building construction in the UK between 1988 and 1991, resulted in vintages of office buildings becoming obsolescent in large cohorts as they age (Ball, 2003). Office buildings built between the mid-1950s and mid-1960s were constructed before the introduction of Building Regulations in energy efficiency[2], and since 1965 in line with the Building Regulation's gradually tightening limiting standards for U-values[3]. This means most existing office buildings in the UK are older buildings with lower standards of specification (Chow and Levermore, 2010), when existing buildings in the UK are replaced at a rate of less than 2% a year (Eames et al., 2014). Building retrofit can significantly reduce energy use in ageing buildings (Ma et al., 2012). Other benefits of building retrofit include improved staff productivity, improved rental value, and keeping buildings in use while the work takes place. In this thesis, *building retrofit* is defined as the use of components or accessories on a building that did not exist on said building when originally constructed, and which enable improved building condition and performance.

The outermost layer of a building, referred to by various terms in the literature (e.g. envelope, skin) and defined in this thesis as the *façade,* plays a key part in a building's thermal performance and aesthetics. Buildings comprise various subsystems that degrade at different rates (Silva et al., 2016; Brand, 1994). The role played by façade cladding in protecting a building's wall and structure from environmental degradation agents, means the outermost layer of a building is prone to defects (Silva et al., 2016). For reasons of speed, airtightness, and the protection afforded to the existing building fabric, façade retrofit treatments such as cladding and render are popular (IEA, 2013a; Carbon Trust, 2012). As well as improving energy performance, retrofitting that extends the life of a building's original fabric and improves building aesthetics can help prevent the early onset of building obsolescence (Menassa and Baer, 2014; Remøy and van der Voordt, 2007).

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[2] Limiting U-values for a building's main thermal elements (walls, roof and floors) were first introduced in England and Wales in the Building Regulations 1965; prior to this point, building construction rarely included thermal insulation (CIBSE, 2013).

[3] The Building Regulations for England and Wales' minimum standards for energy efficiency have gradually tightened over time; thus, since 1965, buildings are likely to have been designed closely in line with the limiting U-values of their time (CIBSE, 2013). However, the Building Regulations' compliance methods that permitted deviations or 'trading off', poor workmanship when the building was constructed, or decay over time will have compromised the actual U-values of many buildings' main thermal elements (*ibid.*).

Due to the impact that can be derived from façade retrofit (Mara, 2010) and the importance of decisions relating to work to the façade on existing buildings (Burton, 2015) this thesis refines its *building retrofit* focus to that of *façade retrofit*. The focus is then refined further to concentrate on two of four façade retrofit typologies described by Richards (2015), namely *over-cladding* and *re-cladding*, which this thesis deems to have the highest potential for improving a building's thermal performance and image.

Façade retrofit selection is largely cost-driven (Menassa and Baer, 2014; Arias, 2013). Due to the cost and the long-term investment nature of their procurement, decisions concerning façade retrofit selection are considered strategic (Sanguinetti, 2012; Arup, 2012; Güçyeter and Günaydin, 2012). Façade retrofit decision-making has to contend with the complexity of the architecture, engineering and construction (AEC) industry. This complex nature results from the prototypical nature of AEC projects (Sommerville and Dalziel, 1998), the fragmented nature of the cladding supply chain (Du et al., 2011), the AEC industry's project-based approach involving multiple actors (Kamara et al., 2002), and the difficulty associated with achieving general consensus in multidisciplinary teams (Šaparauskas et al., 2011). The need to improve the performance and appearance of ageing office buildings, and the benefit to be derived from façade retrofit, combined with the AEC industry's complex decision-making arena, supports the need for effective façade retrofit decision-making.

Decision theory prescribes that the use of structured (normative) decision-making methods enables a decision-maker to arrive at a well-reasoned course of action (Hazelrigg, 2012). Normative decision-making, such as multi-criteria analysis (MCA) enables the comparison of multiple variables (Rey, 2004; DCLG, 2009) and is considered particularly helpful in the early stages of a project (Turskis et al., 2009). MCA can be populated with objective (quantitative) data such as observed prices and subjective (qualitative) data such as the decision-making team's opinions. An example of normative decision-making in façade retrofit decision-making is that of MCA being used in relation to the theoretical façade selection for office buildings in Rey (2004). This decision tool takes multiple variations into consideration for three façade retrofit strategies: *substitution*, *stabilization* and *double-skin façade*, with selected criteria and weight sets for simultaneous consideration focused around the three main fields of sustainability: environmental, sociocultural, and economic (*ibid.*). The different strategies are ranked according to which criteria the decision-maker considers to most important, with options provided for the decision-maker to make the final choice (*op. cit.*). Another example involved the automated calculation of six typical retrofit measures for a theoretical façade retrofit for a university building, which results in up to 64 combinations of measures and apparently illustrates the need for multiple criterion when determining the best retrofit option (Hillebrand et al., 2014). A further example used MCA to evaluate the refurbishment options for a university building, which included window replacement and wall insulation (Kaklauskas et al., 2005). The multivariant design and multiple criteria took into account an evaluation of the economic, technical, and qualitative architectural, aesthetic and comfort aspects, and enabled up to 100,000 alternative versions of the building's refurbishment (*ibid.*).

In contrast, descriptive decision theory estimates how things are behaving in a decision situation (French, 1988). Descriptive decision theory is an informal or qualitative approach that aids the evaluation of a decision situation, but does not prescribe a course of action (Markland and Sweigart, 1987). Descriptive decision theory is closely linked to heuristics (Dietrich, 2010), in which decision-makers' use intentionally reduced cognitive effort (Beach, 1997). Heuristic decision-making is subject to cognitive biases in relation to the heuristic situations of *Representativeness, Availability, and Anchoring and adjustment* (*ibid.*). For example, the heuristic situation of *Representativeness*, where the decision-maker assesses the probability of an event based on its resemblance to another event (*op. cit.*), appears to be reflected by architects' using the experience of the performance of a previous design decision to aid subsequent design decisions (Mackinder and Marvin, 1982).

To meet the aim of this thesis, which is to discover how decision-making can be used to support façade selection in multi-storey non-domestic building retrofit, it was necessary to discover what type of decision-making is used in actuality. AEC industry members were interviewed on the topic of façade selection, and real-life façade retrofit case studies conducted involving industry experts in retrofit façade selection. The findings from the exploratory and in-depth studies were triangulated with the findings from the state-of-the-art account of non-domestic façade retrofit decision-making, with a focus on office buildings. To provide a benchmark for the façade retrofit decision-making practices reported in the state-of-the-art literature review, and revealed by the exploratory and in-depth studies, this thesis chose to define normative and descriptive decision-making as follows: *Normative decision-making* is deemed to be a structured approach, in which mathematically-derived decision-making methods are used to identify a single optimum course of action or a group of options from which the decision-maker can select his/her preferred choice; while *descriptive decision-making* is deemed to be an informal approach, in which the decision-maker uses his/her experience to evaluate a decision situation and identify a course of action. The real-life knowledge of façade retrofit selection gained during this thesis, combination with theoretical findings, enabled the development of recommendations for use by decision-makers in non-domestic façade retrofit practice in the UK AEC industry.

This chapter introduces the context of decision-making in office façade retrofit selection. It then introduces the thesis' aim and objectives, presents an overview of the research design, details the outline methodology, and provides an overview of the thesis structure.

## 1.2 Research context

### 1.2.1 <u>Building façade retrofit</u>

*The building façade*

The purpose of the outermost layer of a building has evolved over time. From initially playing an essentially protective role, i.e. sheltering man from the elements, it now influences building performance, and construction and maintenance costs (Oliveria and Melhado, 2011; WSP Parsons Brinckerhoff, 2015), while also playing a role in the aesthetic expression of buildings (Schittich, 2006; Ali, 2008). This outermost layer plays a key protective function between environmental degradation agents and a building's structure, and is thus very prone to defects (Silva et al., 2016).

The outermost layer of a building is referred to by many terms - skin, building envelope, and façade - of which *façade* typically indicates the application of a non-load bearing element, such as curtain wall or cladding (BSI, 2014), with cladding accounting for a substantial proportion of UK external wall construction (Doran and Anderson, 2011). Since retrofit work to the outermost layer of a building typically involves applications of a non-load bearing nature, the term *façade* is considered most suitable for use in this thesis when referring to the outermost layer of a building.

*Building retrofit*

Variability exists in the definition of the term *retrofit*. According to the definition provided by Soanes and Stevenson (2003), building retrofit can be described as the use of components on a building that did not exist on said building when originally constructed. While, Iselin and Lemer (1993: 68) define retrofit as *"the redesign and reconstruction of an existing facility or subsystem to incorporate new technology, to meet new requirements, or to otherwise provide performance not foreseen in the original design*". Wilkinson (2012) derives her definition of retrofit, for use in relation to the retrofit potential of office building stock, from Douglas' (2006: 1) definition of *adaptation*, which "*includes any work to a building over and above maintenance to change its capacity, function or performance (i.e. any intervention to adjust, reuse or upgrade a building to suit new conditions or requirements)*". Based on Douglas' definition of adaptation, Wilkinson (2012) states that retrofit can occur to parts of a building or to a whole building, which point is reflected by Rysanek and Choudhary (2013), who state that building retrofit often falls into one of two classifications: *conventional* or *deep-energy*. *Conventional retrofit* can include a partial upgrade to services, while *deep-energy retrofit* can include over-cladding a building's existing façade plus fully upgrading the building's services (Zhai et al., 2011); with the two classifications resulting in around 15-25% (*ibid.*) and at least 50% (Muldavin et al., 2013) savings on annual energy costs respectively.

Existing buildings can also be improved via *building renovation* and *building refurbishment*, with variability also existing in the definition of such terms. According to the definitions provided by Soanes and Stevenson (2003), renovation can be termed as restoring a building to its former condition and refurbishment as the redecoration of a renovated building. Douglas (2002: 499) similarly defines renovation as *"upgrading and repairing an old building to an acceptable condition, which may include works of conversion*", but offers a different definition for refurbishment, describing it as *"overhauling a building and bringing it up to a client's requirements. It is usually restricted to major improvements primarily of a non-structural nature to commercial or public buildings. However, some refurbishment schemes may involve an extension*". Richards (2015) describes refurbishment, in relation to the commercial market and the importance of façade design, as the work needed to realign a building's durability with its long-term economic value, i.e. to reinvigorate a building so it lasts longer and is worth more. While towards the upper end of the scale in terms of building intervention, BRE (2000) suggests the addition of a double façade as part of their fourth and most extensive refurbishment level for non-air conditioned office buildings. Dixon (2014: 445) provides a further opposing definition of retrofit, and renovation and refurbishment, in which commercial property retrofit is typically characterised by *"non-intrusive whole system upgrades, or new elements to existing systems"*, and *"commercial property refurbishment (or renovation)…[by] major alterations to fabric and/or services at a systematic, whole building level*". Variability in the terminology can also be seen in practice. For example, a 1980s commercial property transformed into a modern office was awarded 'Refurbishment Project of the Year' at the 2012 CIBSE Building Performance Awards (Pearson, 2012). Yet, the extensive building work included stripping the original external cladding, which was considered to have reached end-of-life (AHMM, no date-a) and replacing it with a high-performance steel-framed curved glazed façade affixed to the retained concrete structure of the building (Pearson, 2012).

Taking into account the variability in the definition of the terms retrofit, renovation and refurbishment, this thesis chooses to define *building retrofit* as: work to an existing building that involves the use of components not present on said building when originally constructed, and which improves the building's fabric, comfort conditions, and thermal performance. This definition is considered as sitting on an individual property level, where each retrofit project has its own discrete set of aims and objectives[4].

*Building façade retrofit*

Work to the façade on existing buildings can be classified by four typologies: over-cladding, re-cladding, refurbishment, and retained façade (Richards, 2015), and from the viewpoint of three architectural strategies: stabilization, substitution, and double-skin façade (Rey, 2004), as described in detail in Section 2.2.4. Taking these classifications into account, this thesis has chosen to focus on the façade retrofit typologies deemed as having the highest potential for improving a building's thermal performance and image: *over-cladding* and *re-cladding*.

A retrofitted facade has the ability to breathe new life into an ageing office building, e.g. in the case of a 1970s office block in Bristol's Broad Quay that was transformed into a 4-star hotel (Femenías and Fudge, 2010). Retrofit that protects and extends the life of the original building fabric and improves a building's appearance, such as an externally applied insulation system, can help prevent the early onset of building obsolescence (Menassa and Baer, 2014; Remøy and van der Voordt, 2007). Avoiding obsolescence is a key consideration for office buildings, where a building's life to the point of redundancy is demonstrated by the office retrofit cycle, which is estimated at around 30 years (Wilkinson, 2012; Wilkinson, 2011; Rey, 2004). Two thirds of office buildings in Europe are declared to be outdated, meaning the façade is 30-years older or more (Ebbert and Knaack, 2008).

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[4] Retrofit on a larger scale can be found, for example, in the *Retrofit 2050 Project: Critical Challenges for Urban Transitions*, which defines sustainable retrofitting on an urban or city scale "*as the directed alteration of the fabric, forms or systems that comprise the built environment to improve energy, water and waste efficiencies*" (Eames et al., 2014: 2).

Retrofitting the outside of an existing building is likely to be sufficient in most cases (Mara, 2010); with a reduction in cooling loads through building envelope improvements seen as the first key step in achieving necessary $CO_2$ emissions reductions, as per the IEA's (2013a) stated goal of limiting the rise in global temperature to 2°C. Many façade-related retrofit measures, e.g. the provision of natural ventilation and daylighting, and the inclusion of solar shading, consistent with good energy performance for cool climate commercial buildings, can also benefit comfort conditions (Baker, 2015); provided the retrofit observes the following principles in combination with the building's existing characteristics: in that it limits the environmental range, e.g. avoids extreme temperature swings; provides sufficient adaptive opportunities complementary to that already in existence to cope with the environmental range; and includes control systems that encourage occupant intervention (*ibid.*).

Façade retrofit can also allow the AEC industry to challenge English Heritage's stance on listed buildings, i.e. when total replacement of the Sheffield Arts Tower's listed façade was permitted due to safety risks (Mara, 2010). And when catastrophic problems occur, façade retrofit can educate the design world, i.e. when marble panels on the 80-storey Aon Center, then known as the Amoco Building, were inadequately specified for Chicago's extreme climatic changes, leading to $80 million re-cladding costs and development of the American Society for Testing and Materials' standardised stone weathering tests (Hook, 1994).

### 1.2.2 Non-domestic buildings: office context

The purpose of office buildings is to provide a working environment for its occupants, with such buildings principally required to contribute to their occupants' comfort, health, and productivity (Burton, 2013). Office workers represent a large and increasing proportion of the European workforce (*ibid.*).

Boom periods of construction in the UK have resulted in large stocks of ageing office buildings (Ball, 2003) that are outdated or of lower standards of specification (Chow and Levermore, 2010), are considered largely obsolete (Burton, 2013), yet many of which are still in use (Rawlinson and Harrison, 2009). Poorly-insulated existing older buildings with inefficient plant and poor controls are also a large contributor to global energy use (Roberts, 2008). As UK buildings are replaced at a rate of less than 2% a year, around 70% of the total UK building stock, as of 2010, will still be in use in 2050 (Eames et al., 2014). Retrofitting ageing buildings can significantly contribute to their reduced energy use, whist giving potential improvements in thermal comfort, staff productivity, and maintenance costs (Ma et al., 2012).

### 1.2.3 Façade retrofit decision-making

Façade retrofit decision-making has a complex nature. According to Du and Ledbetter (2006: 1) "*the cladding industry is a relatively complex and rapidly changing sector of the construction industry*", with the fragmented nature of the cladding supply chain adding further challenges, in terms of ease of communication and making of informed decisions (Du et al., 2011; Pavitt and Gibb, 2003). But it is not just in the field of cladding selection that complexity exists. According to Jin et al. (2011) the façade design process is complex and multi-disciplinary, while Sanguinetti (2012: 97) states façade "*retrofit is a complex problem which could potentially make a significant impact on the overall valuation of the building*".

The design considerations for a retrofitted façade are akin to façade design in general and involve such aspects as: aesthetics, wind resistance, fire resistance, acoustics, condensation, surface temperature, ventilation, solar gain, insulation, cleaning, safe and inclusive usage, façade opening mechanisms, methods of fixing the façade to the building structure, and cost (Richards, 2015; Marley Eternit, 2009; Kawneer, no date). A key difference, however, is that façade retrofit design involves a building already in existence, meaning certain aspects of the building have already been determined.

The initial phase of a building project generally includes concept development, where such factors as the client's requirements (e.g. ventilation, lighting, heating, cooling, and energy requirements, and building design life) and the site information are taken into consideration

(Bragança et al, 2014). In façade retrofit design, the façade resulting from an existing building's original initial project phase can be 'revisited'. However, the extent to which the original façade can be 'revisited' depends on the degree of retrofit (e.g. over-cladding versus re-cladding, as discussed in Section 2.2.4), and the presence of fixed or difficult-to-amend building parameters (e.g. building orientation, floor-to-floor height, and floor plate depth) that can heavily influence the façade retrofit design.

When a building retrofit is to be undertaken, the building must first be evaluated. According to Asadi et al. (2012: 81) "…*a thorough building's retrofit evaluation is quite difficult to undertake, because a building and its environment are complex systems (since economical, technical, technological, ecological, social, comfort and esthetical aspects, among others must be taken into account)*…". Moreover, "*designing an effective building retrofit requires an exhaustive study of all solutions involving planimetric and volumetric changes and exclusion of the obsolete building elements*" (Ardente et al., 2011: 461). The interdependence of a building's sub-systems and their influence on a building's overall performance (Asadi et al., 2012) supports the need for effective decision-making in building façade retrofit selection.

Due to the cost and long-term nature of the investment, façade retrofit decisions are considered strategic (Sanguinetti, 2012; Arup, 2012). Examples of façade retrofit decision-making appear to be rare in the literature, more so are examples that focus on office buildings, highlighting a gap in the knowledge that warrants further study. This thesis wishes to examine decision-making associated with work to the façade of existing buildings that can potentially result in a step-change improvement in building performance and aesthetics; thus, façade retrofit decision-making relating to over-cladding and re-cladding is of particular interest. In light of the variability associated with the terms *building renovation* and *building refurbishment*, this thesis also includes in its examination, any studies reported under the banner of renovation or refurbishment that involve façade over-cladding or re-cladding.

## 1.3 Aim and objectives

Based on the research context, this thesis investigates the complex arena for decision-making in the AEC industry with the aim of discovering how decision-making can be used to support façade selection in multi-storey non-domestic building retrofit. This aim is met by three research objectives, which are to:

1. Review the literature on decision-making in multi-storey building façade retrofit;
2. Explore the actuality of decision-making for multi-storey building façade retrofit in practice;
3. Recommend how decision-making should be used in multi-storey building façade retrofit.

These objectives will be met by exploring the opinions of AEC industry members and AEC industry experts involved in façade retrofit decision-making. The objectives determine the data collection activities as follows: **Objective one** establishes the state-of-the-art in multi-storey non-domestic building façade retrofit decision-making via a literature review and specific literature review, which serve to determine the current situation in the knowledge. The literature review examines building façade retrofit; building typology, prevalence and retrofit in relation to the initial office context; normative and descriptive decision-making theory, and the sources of information used in decision-making; and office building façade retrofit decision-making within the complex, multi-disciplinary AEC industry arena. The specific literature review examines building typology and prevalence, and façade retrofit decision-making in relation to the subsequent university building context. **Objective two** includes an exploratory and in-depth study of real-life decision-making in multi-storey building façade retrofit, which together serve to establish what decisions are made, by whom and when, and what problems and potential solutions exist in multi-storey building façade retrofit decision-making in practice. The exploratory study includes semi-structured interviews and a case study, involving in-depth interviews, documentary evidence review, and thermography; while the in-depth study includes four exemplifying case studies, involving in-depth interviews, documentary evidence review, and thermographic surveys. **Objective three** draws on the literature review and exploratory and in-depth study findings to aid the development of recommendations for use in practice by AEC industry building façade retrofit decision-makers.

## 1.4 Outline of the research design and methodology

### 1.4.1 Overview of the research design

The overview of the research design (Figure 1-1) illustrates the three main research steps in this investigation, in relation to the actions required to fulfil each step. The first step, an exploratory study, involves 30 semi-structured interviews with members of the AEC industry and a façade retrofit case study; while the second step, an in-depth study, involves four exemplifying case studies of façade retrofit. The case studies in these steps are aiming for a convergence of evidence, whereby the empirical findings from a wide array of sources are triangulated to "*understand a real-life phenomenon in depth*" (Yin, 2009: 18). The third step involves a critical review of the research findings.

The overview also illustrates the role played by the state-of-the-art literature review, and the conclusions drawn from the exploratory and in-depth studies of façade retrofit decision-making in practice, in the production of the contributions to knowledge.

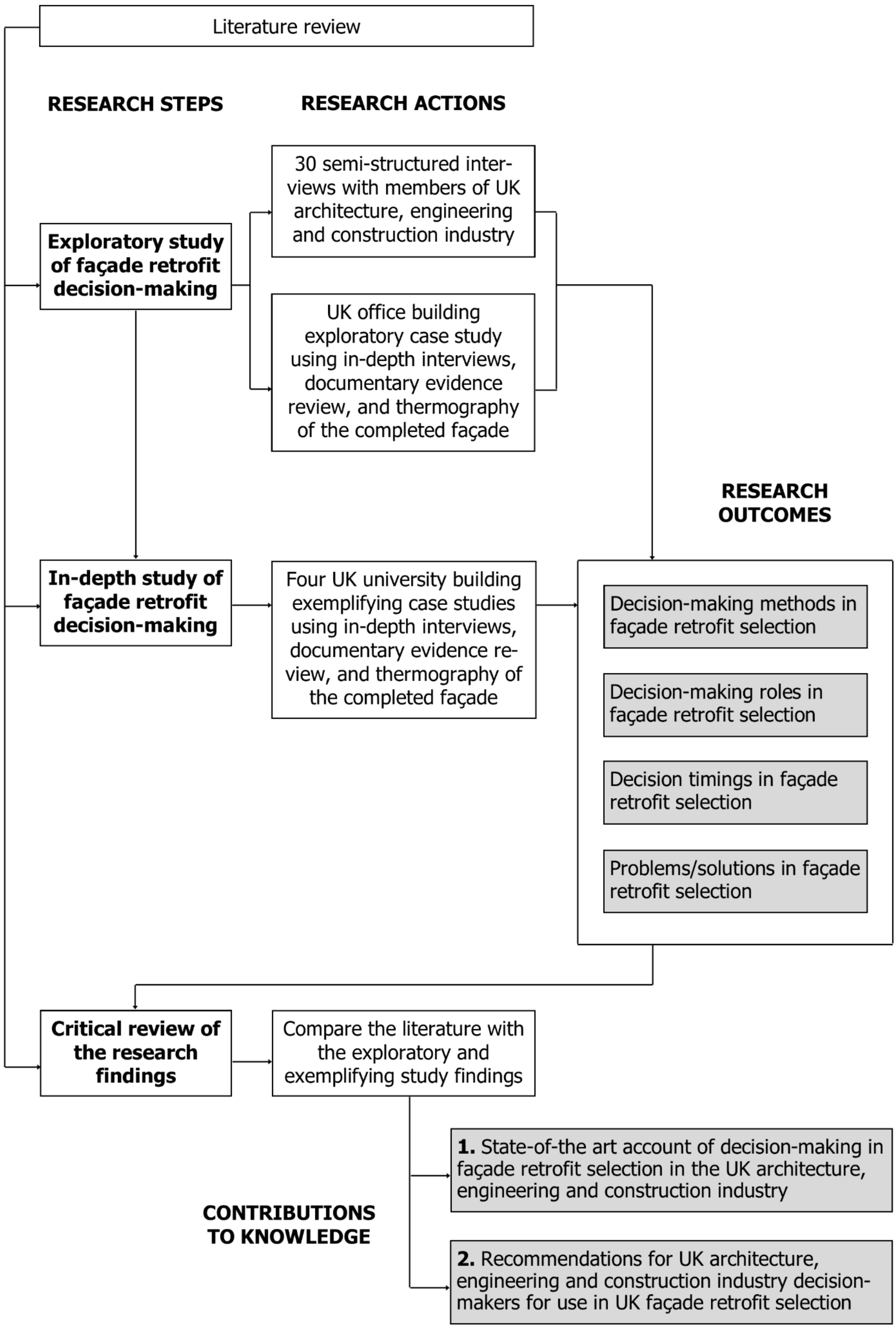


Figure 1-1  Overview of the research design

The research design for this study has a two-stage approach. An exploration of building façade selection, which evolved to focus on office building façade retrofit, is followed by an in-depth investigation that centres on university building façade retrofit (Figure 1-2).

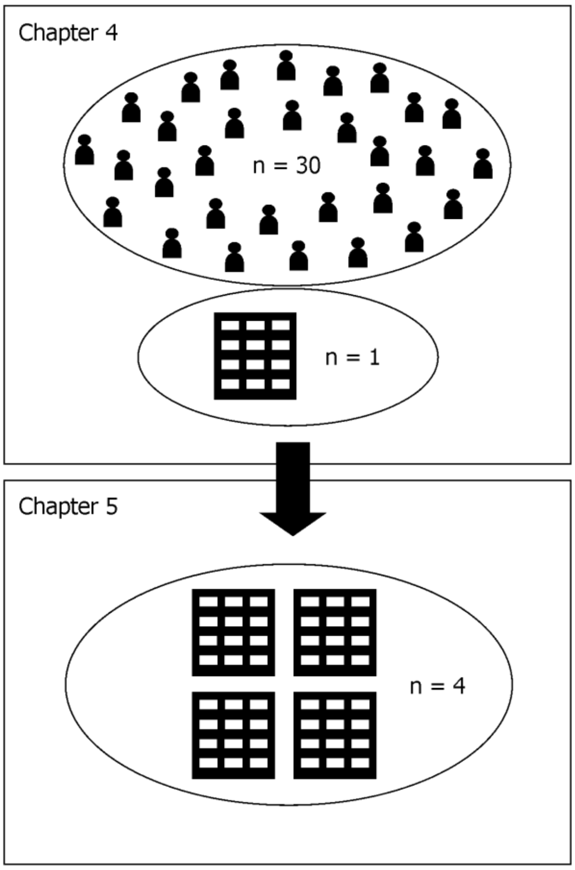


Figure 1-2  Two-stage approach to data collection

The research methods and sampling strategy used for each stage are detailed below:

### *Exploratory study*

This stage explores façade decision-making[5], and façade retrofit decision-making in practice, via semi-structured interviews with AEC industry members and an office building case study respectively. The exploratory case study involves in-depth interviews with key members of the retrofit project team, a review of documents relating to the retrofit project, and internal and external thermography of the completed retrofitted façade. The office building investigated for the exploratory study was obtained via convenience sampling.

[5] The exploration of façade decision-making occurred in the early stages of the study, prior to the retrofit focus.

***In-depth study***

This stage deeply investigates the real-life phenomenon of façade retrofit decision-making. It includes a specific literature review to present its university building façade retrofit context, plus four exemplifying case studies of university building façade retrofit. The case studies: an office and laboratory building; music facility; office and music building; and an arts and media building, involved in-depth interviews with key members of the retrofit project team, a review of documents related to the façade retrofit projects, and internal and external thermography of the retrofitted façades. The university buildings investigated for the in-depth study were obtained via a combined sampling strategy.

### 1.4.2 Data collection and analysis

This thesis adopts a mixed methods approach in which quantitative and qualitative data collection and analysis are used together, and also combined, i.e. qualitative data is converted into numbers: 'quantitised' (Saunders et al., 2009) (Table 1-1). The mixed methods approach relies on neither quantitative nor qualitative research alone, but uses a combination of the two to provide the best information to answer the aim and objectives (Creswell, 2009). Qualitative data collection and analysis play a large part in this thesis' mixed methods approach, which is apt, as one of the chief reasons for conducting a qualitative study is for exploratory research (*ibid.*). The overall strength of the investigation is then enhanced by the inclusion of quantitative descriptive methods (*op. cit.*). The qualitative and quantitative data is collected from primary and secondary sources (Jupp, 2006) via the literature and semi-structured interviews, and via façade retrofit case studies, involving in-depth interviews, documentary evidence review, and thermography.

Qualitative data comprises the chief part of this thesis' data collection, with thematic analysis, by means of the repetition technique, used to evaluate the majority of the qualitative data from the literature, interviews, and the review of retrofit project-related documents. "*How many repetitions are enough to constitute an important theme…is an open question which only the investigator can decide*" (Robson, 2011: 482), but the apparent uncertainty of this qualitative technique should not be allowed to detract from its usefulness. In discussing the challenges of qualitative analysis, Patton (2002: 433) states that *"in short, no absolute rules exist except perhaps this: Do your very best with your full intellect to fairly represent the data and communicate what the data reveal given the purpose of the study"*. For this reason, qualitative analysis is used to interpret the complexity of the research area (Creswell, 2009).

The quantitative data, plus some quantitised qualitative data, is described using descriptive methods (Saunders et al., 2009). Groups or individuals with interval/ratio variables can be described using descriptive analysis, e.g. by means of frequency distribution and measures of central tendency (Jupp, 2006; Bryman, 2012). In this thesis, the participant frequency distribution, and the mean and median interview length for the semi-structured interviews are analysed descriptively. The in-depth interviews are however not analysed as such, because only two retrofit project team members were invited to participate in the exploratory case study, of which both accepted; and nine retrofit project team members were invited in total to participate in the exemplifying case studies, of which eight accepted.

Nominal or ordinal variables whose categories cannot be rank ordered can be described diagrammatically, e.g. by use of a bar chart or pie chart (Bryman, 2012). This thesis uses bar charts to describe the UK service sector's annual energy consumption, and the pre- and post-retrofit building energy ratings for the exemplifying case study buildings; plus, a stacked bar chart to describe the semi-structured interviewees' façade decision observations against the Work Stages from the Royal Institute of British Architects (RIBA) Plan of Work 2007[6] by construction industry function. The evolution of each case study's façade elements as the retrofit projects progressed is also described graphically in tabular form.

[6] The RIBA Plan of Work is the definitive UK model used to guide the building design and construction process (RIBA, no date). At the time of writing, the latest version is the Plan of Work 2013, which contains eight work stages: 0. Strategic Definition, 1. Preparation and Brief, 2. Concept Design, 3. Developed Design, 4. Technical Design, 5. Construction, 6. Handover and Close Out, and 7. In Use (RIBA, 2013). When this thesis' data collection was conducted, the research participants were using the Plan of Work 2007; its eleven work stages are described in Section 4.2.2, plus all references to 'RIBA Stage/s' in this thesis relate to the Plan of Work 2007.

A mixed methods approach is not uncommon in construction industry research. In their paper discussing mixed method research in the area of construction research, Abowitz and Toole (2010: 108) state that "*combining quantitative and qualitative approaches in research design and data collection…should be considered whenever possible. Such mixed-methods research is more expensive than a single method approach, in terms of time, money, and energy, but improves the validity and reliability of the resulting data…*". Fellows and Liu (2008) discuss the use of quantitative and qualitative approaches in their book *Research Methods for Construction*. Quantitative research is seen as a scientific method that produces an outcome akin to a snapshot of what is happening, while qualitative research is seen as going deeper, seeking not just to determine the *what*, *how much* and *how many*, but also *why* things are happening (*ibid.*). Fellows and Liu (2008) consider the research question and constraints to be fundamental to the research design, and state that qualitative research must not be assumed the easy or soft option, due to the intellectually demanding nature of executing a worthwhile qualitative study.

Table 1-1 Mixed methods data collection and analysis

| Research activity | Description | Thesis reference | Data type | Qualitative | | Quantitative | |
|---|---|---|---|---|---|---|---|
| | | | | Collection | Analysis | Collection | Analysis |
| **Literature review** | State-of-the-art literature review | Chapter 2 | Secondary | ■ | ■ | ■ | ■ |
| **Semi-structured interviews** | Interviewee participation | Table 4-1 | Primary | | | ■ | ■ |
| *AEC industry members' opinions* | Interview length | Section 4.2.2 | Primary | | | ■ | ■ |
| | Interview responses, questions 1-3 | Table 4-2 | Primary | ■ | ■ | ■ | |
| | Interview responses, questions 4, 5, 7-10 | Section 4.4.1 | Primary | ■ | ■ | | |
| | Interview responses to question 6, which asked in which RIBA Work Stages façade decisions were observed | Figure 4-2 | Primary | ■ | | | ■ |
| **Exploratory case study** | In-depth interview responses | Section 4.4.2 | Primary | ■ | ■ | | |
| *Includes AEC industry experts' opinions* | Documentary evidence review | Section 4.4.2 | Secondary | ■ | ■ | | |
| | Thermographic survey | Section 4.4.2 | Primary | ■ | ■ | ■ | ■ |
| | Evolution of the case study façade elements | Table 4-7 | Primary | ■ | | | ■ |
| **Exemplifying case studies** | University building façade retrofit literature review | Section 5.2 | Secondary | ■ | ■ | | |
| *Includes AEC industry experts' opinions* | In-depth interview responses | Section 5.4 | Primary | ■ | ■ | | |
| | Documentary evidence review | Section 5.4 | Secondary | ■ | ■ | | |
| | Thermographic surveys | Section 5.4 | Primary | ■ | ■ | ■ | ■ |
| | Evolution of the case studies' façade elements | Tables 5-10 to 5-13 | Primary | ■ | | | ■ |
| | Pre- and post-retrofit building energy efficiency ratings | Figure 5-12 | Primary | ■ | | ■ | ■ |

### 1.4.3 Ethical approval

Ethical approval for this research has been received from the Plymouth University Faculty of Arts Research Ethics Committee.

The approved ethical application can be seen in Appendix F, while a summary of the basis of the ethical approval is as follows: The research sample for this research will be obtained from the UK AEC industry. Participants who are invited to take part in the research will be fully informed as to the nature of the research, withdrawal procedure, and contact details of the persons (the author and academic supervisory staff) from whom they may obtain further information and future updates on the research. The author will ensure the confidentiality of the participants' involvement in this research, including the research materials resulting from that involvement, e.g. audio recordings, in line with Plymouth University policy.

## 1.5 Structure of the thesis

This remainder of this thesis is organised over seven chapters, as presented in Figure 1-3.

**Chapter 1** introduces the research context, the aim and objectives of the study, an overview of the research design, and the outline methodology.

**Chapter 2** reviews the literature pertaining to office building façade retrofit decision-making to provide a state-of-the-art account of façade retrofit selection. This chapter investigates the existing body of knowledge on office building façade retrofit and decision-making (both in general and in relation to façade selection). The literature review contained in **Chapter 2** is complemented by a specific literature review in **Chapter 5**, which addresses some of the peculiarities of the building type studied in that chapter.

**Chapter 3** provides a detailed account of the overall research methodology. This thesis used semi-structured interviews and a case study for its exploratory stage, and exemplifying case studies for its deeper examination of façade retrofit, all of which are further described in the specific methods section in **Chapters 4** and **5**.

**Chapter 4** explores façade retrofit decision-making in industry. This chapter includes semi-structured interviews with UK AEC industry members and a UK office building façade retrofit case study, featuring in-depth interviews, documentary evidence review, and thermography of the retrofitted façade.

**Chapter 5** examines façade retrofit decision-making in industry. This chapter includes a specific literature review that presents the context of university building façade retrofit, plus four exemplifying UK university building façade retrofit case studies, featuring in-depth interviews, documentary evidence review, and thermography of the retrofitted façades.

**Chapter 6** conducts a cross case comparison of the exploratory and exemplifying case studies from **Chapters 4** and **5**, and presents a critical review of the exploratory and in-depth study findings.

**Chapter 7** presents recommendations for use by UK AEC industry decision-makers in façade retrofit selection. This chapter also reviews the thesis' aim and objectives, discusses the research contributions, and offers recommendations for future research.

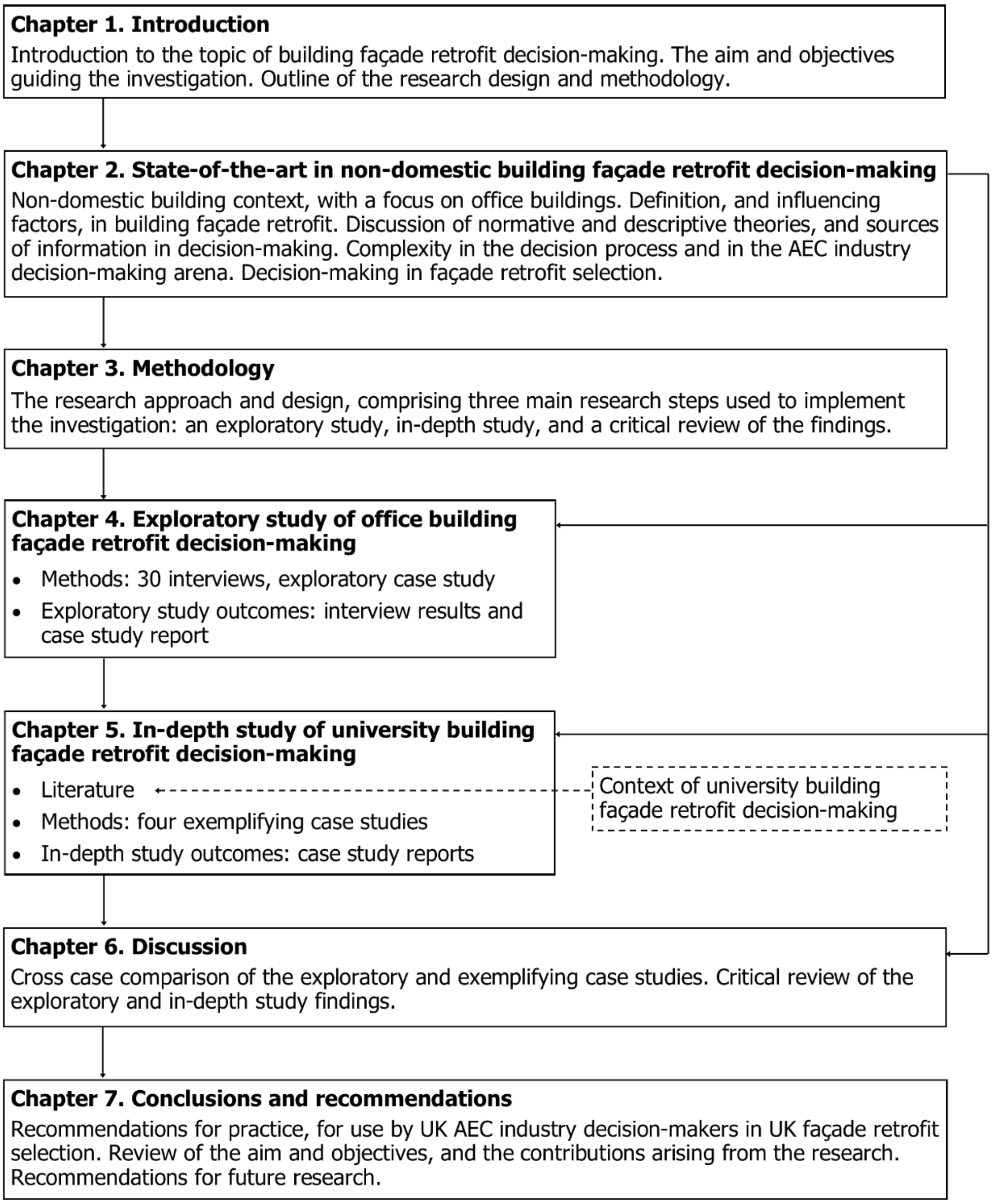


Figure 1-3 Structure of the thesis

## 1.6 Summary

This chapter introduced the context of multi-storey building façade retrofit decision-making, which proves to be a complex area and which reveals a gap in the knowledge that warrants investigation. This chapter then presented the aim and objectives, an outline of the research design and methodology, and the structure of the thesis. The following chapter presents the state-of-the-art literature review in non-domestic building façade retrofit decision-making.

# 2. State-of-the-art in non-domestic building façade retrofit decision-making

## 2.1 Introduction

The previous chapter sets the context for an investigation into non-domestic building façade retrofit selection, which features two independent studies and a critical review of the findings.

This chapter reviews the current knowledge on office building façade retrofit decision-making. It starts by describing and defining the key concepts that play a role in this decision: ageing office buildings, the building façade, and building façade retrofit. It then moves onto the topic of decision-making, with a focus on the theories of normative and descriptive decision-making, and the sources of information used in decision-making. Finally, this chapter zooms in on the decision-making process involved in façade retrofit selection: the AEC personnel involved in such decision-making and the methods used to aid façade retrofit selection, including a summary of key findings from previous studies. In this chapter, the literature is critically examined by means of thematic analysis using the repetition technique.

## 2.2 Building façade retrofit

### 2.2.1 Building retrofit

*Building retrofit, renovation and refurbishment: terminology*

Existing buildings can be modified to varying degrees by such means as retrofit, renovation, and refurbishment. Variability exists in the definition of such terminology, as mentioned in Section 1.2.1. Taking this variability into consideration, this thesis has chosen to use the term *building retrofit*, which is thus defined as: work to an existing building that involves the use of components not present on said building when originally constructed, and which improves the building's fabric, comfort conditions, and thermal performance.

According to Rysanek and Choudhary (2013), building retrofit often falls into one of two classifications, *conventional* or *deep-energy*, as described as follows:

**Conventional retrofit** (also known as *conventional* or *upgrade*) is likely to see discrete construction works conducted on parts of a building, e.g. to upgrade a portion of the services or lighting, which result in about a 15-25% saving on annual energy costs, and is thus considered to give an attractive financial return (Zhai et al., 2011). While conventional retrofit could involve the replacement of windows, it is not considered cost effective to do so if energy savings are the primary goal (IEA, 2103a). If, however, existing windows require replacement due to e.g. being in a dangerous condition for users, then upgrading to more efficient windows during the replacement process is usually cost effective (*ibid.*). An office-related example of a conventional retrofit is the lighting upgrade carried out at the Citigroup Centre Europe, Middle East and Africa (EMEA) Headquarters in London, UK, in which light-emitting diode (LED) based fittings and lighting controls were installed on two floors in one tower, significantly reducing energy consumption and carbon emissions (UKGBC, 2013). The dimmable LED luminaires dim in relation to the natural daylight which influences around a third of each of the two floors, plus a lighting control system controls the luminaires in relation to occupancy (*ibid.*). The new LED lighting and controls use around 45% less energy than the fluorescent luminaires previously located at the perimeter and main body of each floor, plus the financial benefits of enhanced capital allowances[7], combined with energy and maintenance cost savings will see a return on investment in about 3.5 years (*op. cit.*).

**Deep-energy retrofit** (also known as *deep retrofit*) takes a whole-system approach, seeking to minimise a building's overall energy consumption, while maximising value, and results in at least a 50% saving on annual energy costs (Muldavin et al., 2013). This form of retrofit brings the building on a par with a new-build, and involves an integrated approach to the retrofitting of multiple building systems, e.g. building envelope (walls, window, and roof) and services (lighting, cooling equipment) (Zhai et al., 2011). They are most cost effective

[7] When plant and machinery is purchased for use in a business, capital allowances, i.e. a deduction of some or all of an items value, can be claimed from said business' profits before tax. Certain energy/water efficient equipment qualify for 'first year allowances', meaning 'enhanced capital allowances' can be claimed; if such a qualifying purchase is made, a business can deduct the full cost of said purchase from profits before tax (GOV.UK, 2016a).

when the building in question has poor energy efficiency and features building elements and services that are nearing end-of-life (Zhai et al., 2011), with deep retrofits to buildings with no or low insulation giving the highest energy savings (IEA, 2013a). Certain retrofit activities are usually only cost effective if conducted as part of a deep retrofit, e.g. combining the application of an exterior insulation system with a major overhaul of services should enable space conditioning to be reduced (*ibid.*). "*Deep retrofit value can be broadly defined as the net present value (NPV) of all of the costs and benefits of a deep energy and sustainability investment. This distinction is important because, while deep retrofits generate substantial energy cost-savings, they also create substantial value beyond energy cost-savings typically ignored in most retrofit decisions*" (Muldavin et al., 2013: 245). An office-related example of a deep retrofit is that of the Empire State building, described as the world's most famous office building by Bloomfield (2011) and as perhaps the most famous commercial building to have received a deep retrofit by Muldavin et al. (2013). The Empire State Buildings' deep retrofit reduced its energy costs and carbon emissions by around 40%, and enabled the building to be repositioned as Class A office space[8] (*ibid.*). The overall retrofit consisted of eight projects that were deemed as providing the optimum combination of the most cost-effective and impactful measures: window upgrade, insulation, tenant lighting power reduction, upgrading the building control systems, chiller plant retrofit, new air handling layout, demand control ventilation, and tenant energy management (ESRT, 2016). The façade-related measures saw 6500 windows upgraded by the addition of suspended coated film and a krypton/argon blend gas fill, during which process 96% of the existing insulated glass and panes were re-used, and the installation of over 6000 insulated reflective barriers behind the radiator units located on the building's perimeter (*ibid.*)

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[8] Office space in the United States of America is grouped into three classes in accordance with one of two alternative bases - *metropolitan:* Classes A-C, with Class A being the most prestigious; and *international*: investment, institutional, and speculative, with investment quality properties being those that have qualities such as location, design and construction quality, and solidity of tenants that make them stand out as leaders in both their own metropolitan area and in the international investment community (BOMA, 2016).

Another type of building retrofit found in the literature is that of green retrofit. Drawing on the definition provided by the United States Green Building Council (USGBC), CBRE (2011) describes green retrofit as serving to improve energy efficiency and environmental performance, reduce water use, and improve indoor comfort and quality of space (natural light, air quality and noise) in a financially beneficial way to the building owner. Green retrofitting can be applied to a building in either a partial or whole manner, with work sometimes conducted in stages; however, it typically involves work to improve air conditioning, lighting, lifts, and in some cases, the façade (*ibid.*). The BCA (2010) retrofit guide takes a green approach to retrofitting existing buildings and draws on two documents which focus on refurbishment that utilises natural ventilation: a Building Services Research and Information Association (BSRIA) guide to the *Refurbishment of Air-Conditioned Buildings for Natural Ventilation* (Kendrick et al., 1988), and a Building Research Establishment (BRE, 2000) guide to *Comfort without air-conditioning in refurbished offices – an assessment of possibilities*. There is an apparent overlap between deep retrofit and green retrofit, as demonstrated by the Empire State Building, as mentioned above, which in addition to having received a deep retrofit (Muldavin et al., 2013), is described as a high profile green retrofit (CBRE, 2011). The Empire State Building retrofit resulted in a high-performing, energy-efficient green building that was awarded a USGBC Leadership in Energy and Environmental Design (LEED) Gold Certification for Existing Buildings (Bloomfield, 2011).

*Multi-storey building retrofit*

Due to the increasing prominence of multi-storey buildings, as a result of the "*global trend towards urbanisation*" (UNESCO, 2010), and the poor thermal performance of the existing stock of such buildings (Zavadskas et al., 2008a), this research focuses on multi-storey building retrofit. Again, an exact definition for *multi-storey buildings* is not readily available and the labelling of such buildings is to some degree contentious. For example, Yang and Lim (2007) describe a commercial building with seven office levels and four parking levels as medium-rise; CIBSE (2013) describes office buildings as low-rise: one to two storeys, medium height: three to seven storeys, and high rise: eight or more storeys; the Energy Saving Trust (2006: 2) states that high-rise buildings are "*usually defined as blocks of six or more floors served by lift*"; and Nguyen and Altan (2011) consider high-rise buildings as those with more than twenty stories. The Council on Tall Buildings and Urban Habitat (2011) however, considers the number of floors in a building as a poor way of judging the 'tallness' of a building, due to changing floor to floor heights in differing buildings, and in buildings of differing uses, e.g. residential versus office space. Height thus appears to be another important defining characteristic for a multi-storey building, as further supported by the statutory requirements in the Building Regulations for England and Wales' *Approved Document B (Fire Safety)*. Large dwellings[9] and buildings other than dwellings[10] with a storey at more than 18 metres above ground level, must conform with specific guidance in *Approved Document B - Volume 2* regarding materials of limited combustibility for the buildings' external walls (DCLG, 2007; DCLG, 2006), to guard against the "*increased risks associated with external flame spread on buildings of this size*" (Baker, 2012). For the purposes of this study, *multi-storey buildings* are considered as containing two or more storeys above ground level, with consideration also given to the important defining characteristic of height as identified in this section.

*The building retrofit process*

According to the Building and Construction Authority (BCA, 2010), the sustainable building retrofit process can be broken down into six steps (Table 2-1). These steps are described as an adaptable framework that can be applied to one property or an entire building portfolio, with the process set down in the guide considered integral for enabling informed decisions. Ma et al. (2012) consider the retrofit process as divided into five key phases (Figure 2-1), in which a building's retrofit measures are determined, implemented and verified. The process is summarised as follows: In Phase one, the building owners (or their agents) set the project

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[9] Dwellings are usually covered by *Approved Document B - Volume 1*.

[10] Non-dwellings normally conform to *Approved Document B - Volume 2* regardless of building height.

targets, with it being common practice for the building owner to appoint an Energy Service Company (ESCO) to lead the retrofit planning and implementation. In Phase two, energy auditing is used to determine the building's energy use and areas of energy waste, for the purpose of proposing no-cost or low-cost energy conservation measures (ECMs). Phase three involves identifying retrofit options for which performance is quantitatively confirmed via the use of suggested appropriate methods and tools, before prioritisation on the basis of energy and non-energy related factors. Phase four sees the on-site implementation of the selected retrofit measures, with test and commissioning to ensure optimal performance. In the final phase, the performance of the commissioned and well-tuned retrofit measures is used to verify the energy savings, while post occupancy evaluation is used to determine the building occupants' and owners' satisfaction with the retrofit (Ma et al., 2012). This final phase appears a useful addition over and above the BCA (2010) process, in that by verifying the energy savings, and thus the suitability, of the retrofit measures, learnings can potentially be applied to other buildings in an owner's portfolio. By comparison, the built environment interviewees participating in research by Strachan (2013) stated that non-domestic building refurbishment tended not to follow a standard process, checklist, or structured approach.

Table 2-1 Sustainable building retrofit process (compiled from BCA, 2010)

| Building retrofit steps | Description of each step | AEC personnel who can help at each step |
|---|---|---|
| 1. Determine the baseline | To understand a building's current performance and operation and how it compares to current building codes and regulatory requirements, audits should be conducted of the following: energy, water, waste, building condition, indoor environmental quality, and occupant satisfaction. | Facility Manager; Sustainability Consultant; Engineering Consultant; Architect; Energy Manager; Energy Service Company (ESCO); Services, Structural and Façade Contractor. |
| 2. Review maintenance, purchasing and energy procurement | Performance improvements can be derived by conducting a maintenance and purchasing review, and putting into place improved maintenance regimes, making repairs/re-commissioning, and updating the procurement of energy. | Facility Manager; Sustainability Consultant; Engineering Consultant; Energy Manager; ESCO. |
| 3. Establish the targets and goals | Define your organisations' goals, e.g. brand value, reducing carbon footprint, improving customer experience. Set targets, taking constraints into account. To progress with the plan, involve relevant stakeholders as soon as possible. | Facility Manager; Sustainability Consultant; Engineering Consultant; Architect; Quantity Surveyor; Project Management Consultant. |
| 4. Crunch time: refurbish or demolish? | A decision has now to be made regarding the level of refurbishment required or whether to demolish and re-build. Tools are provided to help the decision-making process, e.g. a matrix of refurbishment levels and a table for the simplified assessment of building performance. | Building Performance Consultant; Facility Manager; Sustainability Consultant; Architect; Quantity Surveyor; Project Management Consultant; Services, Structural and Façade Contractor. |
| 5. Select the optimal upgrade initiatives | A decision having been made to refurbish the building, specific upgrade initiatives now need to be identified. An initiatives summary, provided to guide the upgrade, must be tailored and evaluated to each specific building. | Facility Manager; Sustainability Consultant; Engineering Consultant; Architect; Quantity Surveyor; Project Management Consultant. |
| 6. Make it happen | The financial and non-financial returns (e.g. reputation, increased amenities) must be demonstrated to build the business case for refurbishment, and to support the building's ability to compete with the qualities of a new-build. The proposed intervention's cost must be more accurately ascertained and sequencing determined, e.g. a phased approach or all carried out at once. | Appointed Consultants. |

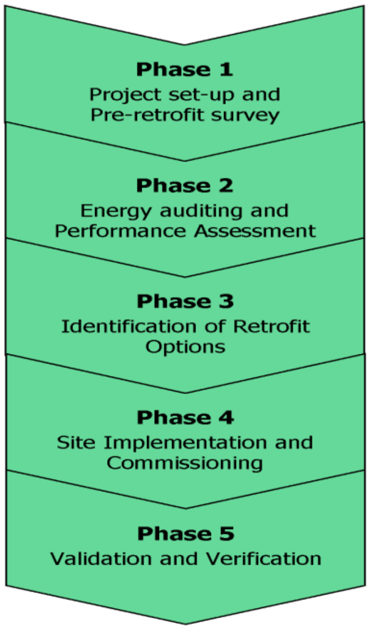


Figure 2-1 Key phases in sustainable building retrofit (after Ma et al., 2012)

Furthermore, Zhai et al. (2011: 426) summarise the deep energy retrofit process in terms of process differentiators that assist in the achievement of deeper savings; these differentiators are considered to exist throughout the entire retrofit process, and include, for example:

- "*A continuously collaborative team;*
- *The advantage of a highly informed and motivated client;*
- *The existence of a fully budgeted 'baseline' capital improvement plan (to enable piggybacking on planned equipment and infrastructure upgrades);*
- *The more extensive and integrated investigation of potential energy efficiency measures;*
- *The development of the theoretical minimum energy use or stretched technical potential;*
- *The evaluation of opportunities in tenant spaces;*
- *The establishment of a sophisticated yet digestible business case to compel the owner to push for deeper energy savings.*"

### 2.2.2 Factors influencing building retrofit

Of the many factors influencing building retrofit, cost appears to be the strongest driver. The financial benefit to be derived from the improvement to a property's value is expressed by Arias (2013), while *"the main incentives for developers are financial as retrofitting can improve the value their property. The bottom line is the main driver"* (CBRE, 2011: 11).

Typically, the cost of retrofitting is approximately one-third, to around half the cost of demolishing an existing building and replacing it from new (Yang and Lim, 2007). For example, the demolition and re-build of the 50-storey China Resources Building in Hong Kong would have cost around twice as much in construction costs alone, in comparison to its retrofit cost[11] (CBRE, 2011). Building retrofit can also enable occupants to remain in-situ (Baker, 2009), thus avoiding the cost associated with decanting occupants to a temporary location, and ensuring rental streams are uninterrupted. Decanting occupants could result in landlords missing out on as much as four to five years' rental income, as would have been the case with the China Resources Building (CBRE, 2011). Retrofit can also offer shorter completion times over demolition and re-build (Kendrick et al., 1998).

Furthermore, stakeholders asked to consider the economic, environment and social aspects of sustainable retrofit, a combination of which must be achieved for a truly sustainable retrofit, perceived economic considerations as the most important reason for the retrofit, followed by social well-being and environmental benefits (Menassa and Baer, 2014). Another example supported this order of importance (economic, social, then environment) in relation to building retrofit: *"a case study focusing on the dynamics and retrofitting of non-domestic buildings in Bristol, UK showed that commercial objectives and local community regeneration are more prevalent in practice than environmental protection and carbon reduction*

[11] This retrofit, which resulted in a Grade A office building, included a façade that optimises daylight while allowing only 5% of solar energy to be transmitted indoors, thus helping to conserve energy that would have been consumed for cooling purposes (CBRE, 2011).

*objectives. This situation is supported by current regeneration policies and commercial interests*" (Femenías and Fudge, 2010: 117).

Retrofit may be triggered by a buildings' poor thermal performance or poor structural condition; alternatively, a building may function satisfactorily, but exhibit factors such as poor technical quality or a dull external image that may trigger retrofit, thus demonstrating the onset of structural vacancy as opposed to the end of operational life. Reasons why occupants may choose to vacate an office building include its "*negative image or identity through a bad spatial-visual quality, decay and shabbiness of the building or evidence of vandalism*", or out-of-date or malfunctioning services (Remøy and van der Voordt, 2007). Structural vacancy, where a building is vacant for three or more years, links back to the key influencing factor for building retrofit – *cost* – in that, in addition to the societal problems associated with vacant buildings, its empty state can also cause loss of value (Remøy, 2010).

The adaptability of a building influences how it can be retrofitted. Some authors claim that "*adaptable buildings are sustainable buildings*", with adaptability being one way of avoiding early obsolescence (Arge, 2005: 127). For example, an office building's functional lifespan is over if it cannot meet the requirements of new office space, e.g. if it lacks flexibility in its rearranging of space (Remøy and van der Voordt, 2007). In relation to a building's physical design, the three concepts of *generality*, *flexibility*, and *elasticity* serve to describe the extent of a building's adaptability. Table 2-2 provides the concepts' definition, their application in architectural terms, and the most important measures for office buildings. Further flexibility, in the form of performative adaptability, can be incorporated into a building's design via the use of phase change material (PCM). PCMs utilise latent heat between the solid and liquid phase change; they are classified according to their materials' nature, with each different group offering its own advantages and limitations (Gracia and Cabeza, 2015), and are seen as a feasible means of improving energy efficiency in buildings (Struck et al., 2015a). PCMs can be incorporated in construction materials by various means, e.g. direct incorporation, immersion, and encapsulation, with internally applied wallboards traditionally the best means of incorporating PCM in building walls (Gracia and Cabeza, 2015). The simulated internal application of PCM on a Mediterranean climate office building is deemed by Ascione et al. (2014) as providing useful information in the use of PCM in building envelope refurbishment.

Table 2-2 Concepts of adaptability: definition, and measures for office buildings (compiled from Arge, 2005: 121-2)

| Concepts | **Concept definition**<br>Building adaptability is defined by its ability to: | **Architectural design terms**<br>For building adaptability concepts: | **Office building adaptability**<br>The most important measures: |
|---|---|---|---|
| Generality | Meet *"changing functional user or owner needs without changing its properties"* | "*A building and its space and services is designed for multifunctional use*" | Building width<br>Floor to floor height net<br>Technical grid |
| Flexibility | Meet "*changing functional user or owner needs by changing its properties easily*" | "*A building has built-in possibilities to re-arrange, take away or add elements and systems, when the needs of the users change*" | Modularity<br>Plug and play building elements<br>Flat and soundproof suspended ceiling |
| Elasticity | "*Be extended or partitioned related to changing user or owner needs*" | "*The possibility of dividing the building into different functional units or to extend the building horizontally or vertically*" | Building form/ organisation of space<br>Functional organisation<br>Fire sprinkling |

The drivers typically influencing the need for refurbishment in commercial office buildings include: organisational efficiency, limited development options, transformational change, minimising running costs, minimising environmental impacts, civic responsibility, and regeneration (Rawlinson and Harrison, 2009). The impending expiration of a lease may also trigger retrofit, this being an opportunity to carry out work, which may also be used as a potential incentive to encourage a major tenant to stay (CBRE, 2011; BCA, 2010). Baum (1989) described the concern that was felt over the standard 25-year lease, and the need for shorter leases for industrial and office properties in particular, given that they may require refurbishment after 15-years. In the early-1990s, the majority of office leases were at least 20-years in length (GVA Grimley, 2010), meaning that certain office buildings could still be approaching the approximate 30-year office retrofit cycle (Section 2.3.2) at lease expiration. The 1990s saw leases originating in the 1960s and 1970s coming to an end, which increased the quantity of available old office space in an already depressed rental market (Gold and

Martin, 1999). Analysis of lease length in 2008/9 however, showed that office lease lengths were becoming shorter, with two-thirds of new leases being for less than five-years and more often to contain break clauses (GVA Grimley, 2010).

Also influencing the decision to retrofit are the benefits that can be derived from such work. A retrofit can be a vital new 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 can then deteriorate, causing occupancy levels to fall further still (Remøy and van der Voordt, 2007). By contrast, a well-planned retrofit can increase the quality grade of a commercial office building, plus its rental and capital value, though these improvements are dependent on the building's condition and location (Wilkinson, 2012).

Retrofitting ageing buildings can lead to significant improvements in thermal performance (Ma et al., 2012). From an environmental viewpoint, building retrofit can also conserve embodied energy contained in the building, avoid/minimise demolition waste, and conserve the energy and resources normally drawn on when constructing new buildings, such as the quarrying, transporting and processing of raw materials (CBRE, 2011). Green retrofit can also include reductions in energy, utilities and water consumption, plus, indoor environment quality improvements, coupled with reductions in the negative impact of the building on its occupants, e.g. work-environment related illnesses (or 'sick building' syndrome) (BCA, 2010).

### 2.2.3 The building façade

"*Our concept of what a building should do is much more than what would be found in a dictionary definition of shelter. Functionally, a building is what we expect it to be, and our expectations have grown very large*" (Allen, 2005: 25). These expectations are divided into two categories by Allen (2005), with the first category containing expectations arising primarily from human needs in response to the outdoor environment, and the second containing expectations arising from needs created by the building itself and which relate only in a secondary way to human needs (Figure 2-2).

A building is a complex object consisting of many elements working together accordingly to ensure the expectations of the building are met. A building achieves the provision of shelter for its occupants via construction that is "*usually partially or totally enclosed*" (BSI, 2014: 2). Within the literature, a number of terms exist to define the enclosing element in relation to the other main building elements. Brand's (1994) concept of Shearing layers describes the components of a building as layers that evolve at different rates; within this concept, the term *skin* is used for the outermost layer of a building, which is stated as changing every 20-years approximately in response to fashion, technology, and the need for wholesale repair (Figure 2-3). Though, according to Juan et al. (2010), building support systems such as the exterior skin and the structure can have a lifetime that potentially exceeds 50-years.

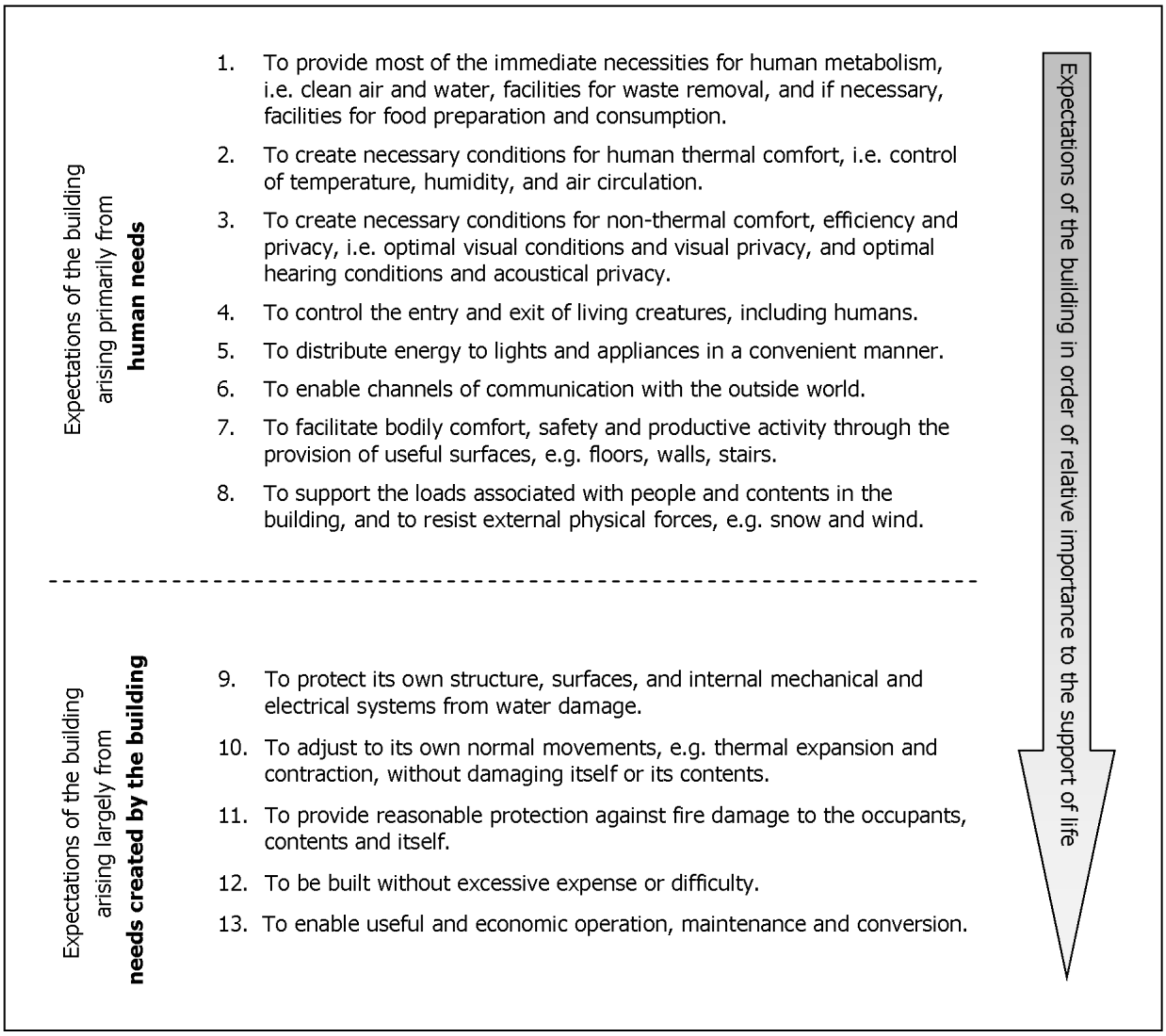


Figure 2-2 Functional expectations of a building (created from Allen, 2005)

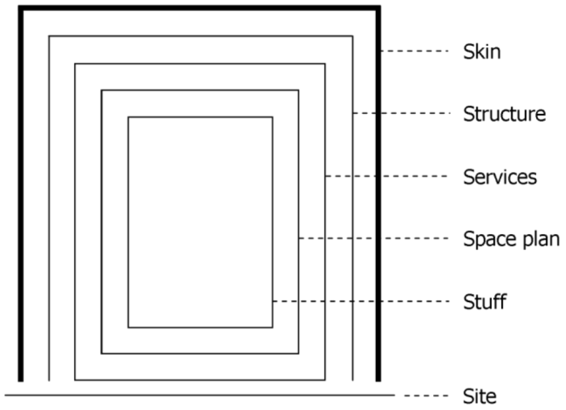


Figure 2-3 Component layers in a building (after Brand, 1994)

Menassa and Baer (2014) consider a building to consist of four main technical components in their House of Quality model for sustainable retrofit: *mechanical*; *electrical*; *plumbing*; and *external skin*, further defined as *building envelope*, and comprising of walls, windows, doors, roof, and shading. The term *building envelope* is also used by the IEA (2013a) in relation to a number of primary elements, i.e. roofs, walls, windows, foundations, and air leakage, which are considered as impacting on a building's heating, cooling and ventilation load. It is noted that BSI (2014) does not define the terms *building skin* or *building envelope*.

The term *façade* is used in BSI (2014: 32) to describe the "*exterior surface of a wall enclosing a building, usually non-loadbearing, which can include a curtain wall, cladding, or other exterior finish*". Since this thesis centres on retrofit, where non-load bearing materials are commonly applied to the existing building envelope, the outermost layer of a building, excluding the roof, will be referred to henceforth as the *façade*. There appears to be some contention regarding the number of building faces associated with the term. According to Soanes and Stevenson (2003: 617) a *façade* is "*the principal front of a building, that faces on to a street or open space*"; while in a case study by Pritchard (2014), a new office building is described as having three facades, of which two are classed as primary façades. BSI (2014), however, make no reference to a particular building face or number of building faces in relation to the term *facade*, which stance is thus taken by this thesis. In tall buildings, where roof area becomes insignificant, the façade can account for 90-95% of a building's external surface (Ali, 2008).

In addition to providing shelter for building occupants, the building façade performs many other functions (Figure 2-4). A number of these functions relate to the expectations of what a building should do, as described by Allen (2005), namely aiding: the creation of necessary conditions for human thermal and non-thermal comfort, efficiency, and privacy; the control of entry and exit to the building; the support of internal loads and the resisting of external forces; and the protection of the building and its contents from water, movement, and fire. In addition to the supporting the façade's role in the exclusion of weather and the provision of a comfortable internal environment, the Centre for Window Cladding and Technology (CWCT) (2001) also states that a building façade is required to be safe during construction and in use, and to retain its appearance during its life. Furthermore, the CWCT (2001: 5) states that "*the installation of façades and façade elements is one of the more complex operations on a construction site. It requires a range of skills and knowledge yet has not been recognised as a particular skills or trade. Façade failure, particularly water leakage, is the most common cause of failure in new buildings*".

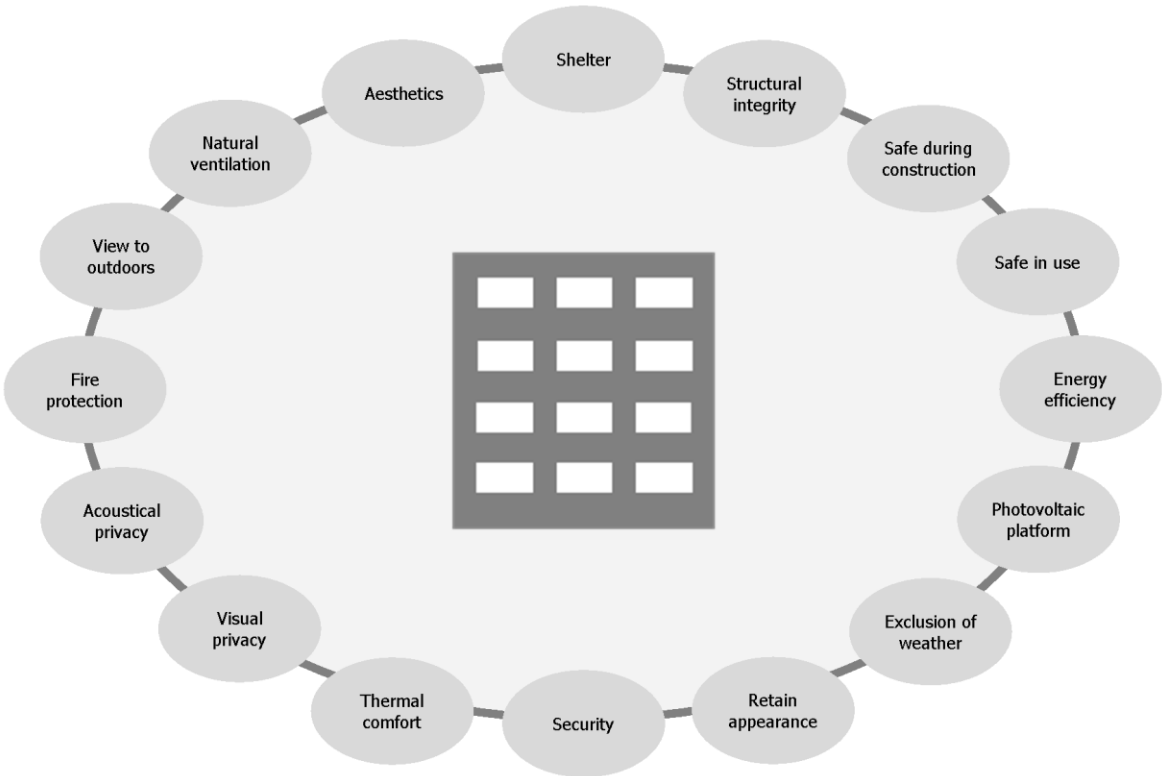


Figure 2-4 Functions of the building façade (IEA, 2013a; Ali, 2008; Allen, 2005; CWCT, 2001)

### 2.2.4 Building façade retrofit

Updating a building's façade is not a new occurrence. Building façades have been modified throughout history for many reasons, for example, to solve fabric problems resulting in water ingress or in response to changing fashions in building aesthetics (Martinez et al., 2015). The façade's importance in relation to the energy efficiency that can be gained from building retrofit is now however also recognised (Martinez et al., 2015; IEA, 2013a), with the Carbon Trust (2012) estimating 10-15% of the total energy costs for commercial buildings are wasted in the form of heat loss through the building fabric. This wasted cost equates to commercial buildings losing around 60% of their heat through the building fabric: ventilation and air infiltration (35%), windows (26%), roof (22%), walls (9%), and floor (8%) (*ibid.*). An efficient building envelope retrofit involves the control of one, all, or a combination of the following thermal characteristics: transmission (reduction), infiltration and ventilation losses (reduction), and solar gain (increase or reduction) (Güçyeter and Günaydin, 2012).

Work to the façade of existing buildings is always specific to each project and often involves a mixture of approaches depending on a building's original façade type (Richards, 2015). The work can be classified by four generic typologies – *overcladding*: installing a new façade over the existing façade; *re-cladding*: removing the existing façade and installing a new façade system; *refurbishment*: repairing and re-glazing an existing façade; and *retained façade*: the existing façade is kept and repaired, while a new building is constructed behind it (*ibid.*). The four typologies of façade work are described further in Table 2-3, while an office-related example for each typology is shown as follows:

**Over-cladding** Lloyd's TSB, Bournemouth, UK: Signs of deterioration and water ingress were solved and thermal performance improved, by a new façade of insulated steel cassette panels, with new double-glazing following the original fenestration pattern, supported on a light steel sub-frame and attached through the building's existing tiled cladding to its concrete wall panels (Lawson, 2008).

**Re-cladding** Angel Building, London, UK: The original cladding was replaced with a high-performance steel-framed curved glazed façade, transforming the appearance of this 'drab' building, while improving its energy efficiency and comfort conditions, and extending the structure to maximise internal space (Pearson, 2012).

**Refurbishment** Lloyds building, London, UK: Window replacement increased the ratio of vision to sparkle glass on the floor-to-ceiling glazing of this Grade I listed building, improving its thermal/solar performance and natural lighting, while allowing tenants to remain *in situ* during the work (Richards, 2015).

**Retained façade** Unilever House, London, UK: The thermal performance of the retained stone-clad, Grade II listed façade was upgraded with insulation, vapour barriers, and high-specification glazing (Richards, 2015), and its congested 1930s interior replaced to improve space efficiency (Spring, 2005).

Façade retrofit is also considered from an architectural viewpoint by Rey (2004), who identifies three retrofit strategies: *stabilization strategy*, in which interventions do not fundamentally modify a building's appearance; *substitution strategy*, where elements are completely changed, transforming a building's appearance; and *double-skin façade strategy*, where a new glass skin is added, metamorphosing the building's appearance. Taking into consideration the typologies of work that can be carried out on the façade of an existing building, this thesis choses to complement its definition of building retrofit (in Section 1.2.1) by focusing on the façade retrofit typologies deemed as having the highest potential for improving a building's thermal performance and image: *over-cladding* and *re-cladding*.

As the façade covers the majority of a buildings' exterior surface (Ali, 2008), it is unsurprising that work to the outermost layer of a building can be sufficient to produce the desired effect in most retrofit projects (Mara, 2010). A typical major refurbishment of a 1970s concrete office building is likely to include façade replacement (Gold and Martin, 1999); while the condition of 1960s and 1970s façades, and the drive towards improved energy efficiency, means that over-cladding or re-cladding is required on most refurbishment projects (AUDE, 2008). A major retrofit typically involves more than just work to the façade (Martinez et al., 2015), with synergy observed for example, in the fact that *"deep envelope retrofits can have major systems benefits that reduce the capital cost of mechanical equipment"* (IEA, 2013a: 117).

Decisions relating to work on the façade of an existing building are of primary importance (Burton, 2015). Common issues exist that need to be taken into account when carrying out the sustainable retrofitting of façades on cool climate commercial buildings: natural ventilation, solar gain, winter ventilation, surface temperatures, mechanisms for opening the façade, and insulation and detailing (Richards, 2015), as described further in Table 2-4.

One of the commonest ways of reducing heat loss through the external walls of commercial buildings is via the use of an insulated render system, comprising insulation board attached a building's external surface and coated with specialist render (Carbon Trust, 2012). This method of external wall insulation is common in Europe, as well as on services sub-sector buildings in North America (IEA, 2013a). The application of an external insulation system protects a building's structure from solar gains, provides new weatherproofing to degraded walls, and in most cases, eliminates cold bridges without creating new cold bridges, as can result from internally applied insulation (Baker, 2009). Furthermore, the use of such a system corresponds with the energy-efficient façade technologies deemed suitable for use in cold-climate building retrofit (IEA, 2013b):

- highly insulated windows;
- low-e storm or internal panels;
- insulated shades;
- insulating attachments (low-e films);
- exterior insulating wall systems;
- interior high-performance insulation;
- plus, the inclusion of insulation, air tightness solutions and double-glazed low-e windows for all cold-climate retrofitted buildings.

Table 2-3 Generic typologies of the work conducted to the façade of existing buildings (compiled from Richards, 2015)

| Façade work typology | Description of the façade work to an existing building |
|---|---|
| **Over-cladding**<br>Existing façade remains in place, while a new system is installed over it | Usually the lowest cost option, due to the avoidance of demolition costs and the new system utilising the existing façade's performance. The original geometry of the building is retained, plus if desired, its solidity and transparency, while allowing it to take on a new image via the use of colour and texture. Further benefits include: tenants remaining *in situ* while the work is being conducted, embodied carbon savings from avoiding demolition waste, and a potentially smoother path through the planning process. The decision to over-clad must be well considered, with particular attention to the building details, e.g.: the structure's ability to support the additional load of a new façade, including attaching fixing points/brackets for the new system to the existing façade; changes to the condensation risk location; interfaces between new glazing and the existing façade; and changes in façade maintenance, such as the need for new cleaning cradles. The success of over-cladding depends highly on the details. When considering over-cladding, the existing façade must be surveyed to confirm its condition and performance, and the condensation risk location analysed by calculation. |
| **Re-cladding**<br>Existing façade is removed and a new system installed | Perhaps the most common option, but also probably the most expensive. It allows a building's image and value to be reinvented within the geometric confines of the original building, while also enabling the redefinition of its environmental performance, e.g. natural lighting and ventilation, and improved thermal performance. The improvements in condition and performance are made easier through the use of a completely new façade; however, it is likely that this option would see tenants having to vacate the building while the work is being conducted, thus interrupting the rental stream, and have the highest embodied energy due to demolition of the existing façade and the new materials in the replacement system. When considering re-cladding, the existing structure's edge conditions must be surveyed to allow the new façade's support to be detailed and the existing building's overall structural ability to support the load of the new façade system confirmed. |
| **Refurbishment**<br>Upgrading the windows in an existing façade | Probably the simplest option. It can improve a building's carbon performance, while producing least impact on its external appearance, making it a suitable option for buildings with heritage value. Due to the solid elements of the façade remaining intact, this is also the lowest cost option; plus, it can probably be done with the tenants *in situ* or with a rolling decant, and is likely to have the smoothest path through the planning process, with planning permission potentially un-needed. When considering window refurbishment, the interface between the new glazing and the existing façade must be carefully detailed to ensure the windows' optimum thermal performance; it should also be recognised that by only replacing the glazing, the remainder of the façade's performance is unaltered, e.g. the presence of poor insulation levels and cold-bridging, that daylight levels may be affected by the glazing treatment, and that supervision of the on-site work must include monitoring the quality of any site-applied wet sealants. |
| **Retained façade**<br>Preserving an existing façade, while erecting a new building behind it | This is a skilled, specialist practice that preserves façades with great heritage value. In such cases, it is the façade's appearance and cultural history that gives the existing building its value, thus façade retention often goes hand-in-hand with planning and conservation restrictions. Carbon improvements via window upgrades are generally limited, with aesthetic needs often governing the use of narrow, less thermally efficient framing and limited glazing tints. If the project scope is wide, it may allow improvement to the façade's carbon performance via the replacement of windows and the addition of insulation, with any potential changes in condensation risk location due to the latter change requiring analysis by calculation. |

Table 2-4 Existing façades on cool-climate commercial buildings: common issues (compiled from Richards, 2015)

| Common issues | Description |
|---|---|
| **Natural ventilation** | In temperate climates, openable windows provide a better experience for the building occupants, while saving energy by reducing the need for air conditioning. Natural ventilation uses air as it naturally occurs outside a building for the building's cooling and ventilation needs, with cooling being a key issue for office buildings. Successful natural ventilation is based on two principles: internal comfort measured by Operative Temperature; and occupants having the necessary control of their own environment and connection to the outside to engender adaptive comfort, i.e. the tolerance of warmer inside temperatures as outside temperatures rise. In using natural ventilation, it is important the façade design considers: summer solar gain limitation, winter ventilation, surface temperature control, and façade-opening mechanisms. |
| Solar gain | An important aspect regarding the use of natural ventilation is the control of internal heat gains from lighting, computers, people, and summer solar gain through the façade, with the latter being the largest and most variable heat gain. Façade design should include analysis to help limit the overall solar transmission to ideally less than 15%. External shading to aid the management of solar gain ranges from fixed overhangs to moveable louvres. External shading has the further benefits of allowing optimum daylight and clear views to the outside. Glare should also be considered. |
| Winter ventilation | When deciding to use natural ventilation, the façade design needs to ensure a fresh air supply in winter to avoid stuffiness. This can be supplied via: operable vents with a minimum winter setting, which suit transient spaces such as entrance lobbies, rather than office space that could experience uncomfortable draughts; trickle vents, which suit residential construction due to the loss of effectiveness in floor depths greater than 4 to 5-metres from façade to the limit of the space; and mechanical ventilation, which enables even distribution of ventilated air in commercial space where floor depths exceed 4 to 5-metres, resulting in no need for an intermediate winter mode and a façade that can be well sealed when the windows are closed. |
| Surface temperatures | Further to the use of natural ventilation, the temperature of the inside surface of the façade needs to be controlled to ensure it does not cause discomfort. Opaque façade elements can be controlled by the inclusion of sufficient insulation to ensure their surface temperature is close to the room temperature. Glazed areas can experience surface temperatures that are as high as 45°C and may therefore require a combination of the following controlling elements: double or triple glazing, low-emissivity coatings, internal blinds, and an internal or external ventilated cavity. |
| Opening mechanisms | A further consideration for the use of natural ventilation is the design of operable elements to allow air in and out. These mechanisms need to take the following issues into consideration: opening style, e.g. high and low-level to encourage ventilation by natural buoyancy, or single tall openings; lower daytime vents, potentially manually controlled, complemented by motorised high-level night vents; motorised, automatic window opening activated by the building management system; and frame parameters that allow independent framing for the operable elements and thermal break. |
| **Insulation and detailing** | Insulation levels need to be determined on a case by case basis, in accordance with minimum standards in local energy codes or via analysis in relation to the project goals and budget should higher insulation levels be required. The thermal performance of uninsulated existing façades can be improved by insulating externally, internally, or within the wall build-up, depending on the room available for the insulation, with U-value calculations aiding the balance between insulation thickness and cost. The insulation level of window frames in relation to the use of increasingly high-performance glass is an important consideration that can be assessed by means of finite element analysis. Thermal bridging also requires close analysis, as older buildings are prone to direct thermal bridges where the façade meets the end of the floor slab, which can be difficult to resolve architecturally if the slab is exposed or if floor-to-floor heights are restricted. Adding insulation to a façade also requires analysis to calculate the change in condensation risk location, with internally-added insulation especially affecting the vapour pressures and temperature of the original façade elements. |

## 2.3 Non-domestic buildings: office context

### 2.3.1 Office buildings: typology and prevalence

Demand for buildings specifically for administrative work started in the 1950s (Rey, 2004). *Urban Change and Planning – A history of urban development in Britain since 1750* sets the context of UK office buildings as one of the urban status symbols of the mid-1950s:

> "*A form of post-War development which is particularly striking is the commercial redevelopment of town centres. In the mid-1950s there was increasing availability of capital for commercial projects. The replacement of war damaged sites was an obvious spur…[added to which] was the demand for new forms of commercial property; different shop design, better utilization of floor space or new commercial functions such as the enormous growth of office employment. Virtually every town in the country prepared schemes of comprehensive development hopefully incorporating the latest symbols of commercial success: the supermarket, bowling alley, offices and perhaps hotel…[of which the] tall office block has been the most noticeable feature*" (Cherry, 1972: 190-192).

Most existing UK office space is now however outdated or of lower standards of specification, with offices built prior to the introduction of Building Regulations in energy efficiency tending to demonstrate poor thermal performance (Chow and Levermore, 2010). The existing UK office stock is considered largely obsolete; in particular, those offices built in the 1960s, whose original poor methods of construction and craftsmanship are causing their rapid deterioration and prompting an urgent need for retrofit (Burton, 2013). Many office buildings built in the 1960-70s are however still in use today, and "*many organisations, particularly in the public sector, continue to occupy ageing and increasingly unsuitable stock, which can affect productivity, staff morale and an organisation's brand*" (Rawlinson and Harrison, 2009). The Chartered Institute of Building Services Engineers (CIBSE) (2013: 3) states that "*non-domestic buildings constructed between the 1960s and 1990s…are those most commonly encountered in UK non-domestic refurbishment projects*". Of the office premises in England and Wales, 33% are of mid-1950s to 1990 construction (Table 2-5).

Table 2-5 Age distribution of England and Wales' office stock (after Pout et al., 1998)

| Age of Premises | Number of Premises | Area (1000m$^2$) |
|---|---|---|
| Pre 1900 | 109,503 | 16,575 |
| 1900-1918 | 26,721 | 4,074 |
| 1919-1939 | 25,014 | 4,783 |
| 1940-1954 | 10,934 | 2,379 |
| 1955-1964 | 20,948 | 6,750 |
| 1965-1970 | 17,957 | 6,327 |
| 1971-1975 | 9,804 | 4,583 |
| 1976-1980 | 8,478 | 4,345 |
| 1981-1985 | 10,306 | 4,649 |
| 1986-1990 | 24,337 | 10,421 |
| 1991 Plus | 12,529 | 5,312 |
| Unknown Age | 864 | 538 |
| All Age Groups | 277,395 | 70,736 |

Notes:

1. This office building stock information does not include all office buildings existing in England and Wales in 1994, due to its 'Bulk Class' grouping (see Appendix D for further information).

Office buildings from the late-1950s/1960s buildings were typically constructed from steel frame or reinforced concrete (RC), and curtain wall, while 1970s offices typically featured steel frame or reinforced concrete (Kendrick et al., 1998). Fully glazed façades were characteristic in office buildings from the 1970s (Gold and Martin, 1999). When highly glazed facades became common on office buildings, their often poor shading coupled with the extra heat gain from electric lighting necessitated by deep floor plans, contributed to the increased risk of overheating and the corresponding need for cooling (Gratia and De Herde, 2007). Office buildings in the early-1980s often featured un-openable windows; however, operable windows were re-introduced later in the 1980s for occupant well-being (Remøy, 2010). The 1990s saw an increased concern of environmental issues, which led to a greater awareness of the benefits of solar shading, but also a re-evaluation of cooling techniques enabled by technological advances in computing resulting in lower associated internal loads (Gold and Martin, 1999). From 1995, standard U-values for windows were introduced via Part L of the Building Regulations for England and Wales, which represented a general requirement for double-glazing in office buildings from that point on (CIBSE, 2013). Hard to treat properties, e.g. those of solid wall construction, are typically associated with pre-1919 construction domestic stock, yet hard to treat solid wall construction is evident in later properties, such as purpose built office buildings found in major UK city centres, occupied by public and service sector businesses (Strachan, 2013). The typical construction and building characteristics of office buildings from the late-1950s to the 1990s are presented in Table 2-6.

The prevalence of office buildings in England and Wales is greatest in and around London, with 68,554 in *Greater London*, followed by 16,002 in *Greater Manchester*, and 11,709 in the *West Midlands*; which *counties* are located in the South East, North West, and West Midlands regions of England respectively (Pout et al., 1998). The England and Wales' counties holding the greatest number of buildings reflect those with the greater share of office floor area (*ibid.*). The number and floor area of office buildings for the nine regions of England and Wales are shown in Table 2-7. This stock information dates from 1994, yet holds relevance. Existing UK buildings are replaced at a rate of less than 2% a year (Femenías and Fudge, 2010), with annual new builds equating to around 1-2% of the total building stock (Eames et al., 2014) and typically around 2% of the service sector (Pérez-Lombard et al., 2008).

The UK office market is renowned for its cyclical behaviour in building construction, which results in large numbers of office buildings of a certain age alternating between much smaller numbers, and vintages of existing offices becoming obsolescent in large cohorts as they age (Ball, 2003). The UK recession in 1982/83 resulted in an emphasis on office building refurbishment rather than new build (Gold and Martin, 1999). However, the late-1980s boom saw the construction of many new office buildings, often combined with the demolition of office buildings from the 1950s and 1960s, whose construction did not easily accommodate the growth in information technology (IT) and the associated air conditioning loads (*ibid.*). A noticeable peak in the construction of new UK commercial buildings occurred in 1990 and lasted about five-years; office building order information, available from 1985 as part of this commercial output, showed that office orders featured a corresponding upswing (Ball, 2003).

Table 2-6 Office building typology from the late-1950s to the 1990s

| Period | Typical construction [a, b, c, d, e] | Building characteristics [a, b, d, e] | Structural vacancy by building period [1, c] |
|---|---|---|---|
| Late-1950s /1960s | Steel frame or reinforced concrete, curtain wall; relatively lightweight construction; insulation levels probably poor; large glazed area; likely single-glazed; majority having some form of internal solar shading | Narrow floor plate; open plan layout; low floor loading; low floor to ceiling height; not designed with raised floors/suspended ceilings; commonly heated until the early-1960s using coal fired boilers, after which oil fired boilers were common; various ventilation systems common (fresh air/all air/air and water) | 1965-1980<br>This building period makes up a large number of the structural vacant and obsolete offices |
| 1970s | Steel frame or reinforced concrete; lightweight construction; insulation is a standard feature in the façade, but probably of a poor level, with the façade also likely allowing a high degree of air infiltration; likely single-glazed; towards the end of the 1970s often un-openable windows; completely glazed curtain wall; majority having some form of internal solar shading; façades tending towards greater proportion of heavyweight cladding and less glazing in line with uniform artificial lighting | Larger floor to ceiling height than 1960s (for routing of services); design strategy moved towards the comfort-controlled box characterised by deep plan space and a greater reliance on artificial lighting and mechanical ventilation; focus on uniform lighting design; open plan layout; commonly heated using oil fired boilers until mid-1970s, after which either oil or gas fired boilers were common; various ventilation systems common (fresh air/all air/air and water) | |
| 1980s | Two dominant types of simple standard office shape: tall, and low-rise rectangular, both constructed as floor and columns; often un-openable windows from early-1980s, with operable windows re-introduced later in the 1980s; majority having some form of internal solar shading; likely single-glazed until late-1980s; some double-glazing from 1980-onwards | Potentially over-serviced in terms of power/cabling and air conditioning requirements; commonly heated using natural gas non-condensing boilers; various ventilation systems common (fresh air/all air/air and water) | 1980s-1995<br>This building period makes up the main share of structural vacant offices |
| 1990s | Two dominant types of simple standard office shape: tall, and low-rise rectangular, both constructed as floor and columns; generally double-glazed from 1995-onwards; majority having some form of internal solar shading, but increased awareness of solar gain, means that from the 1990s some may also have fixed external solar shading | Commonly heated using natural gas non-condensing boilers until the mid-1990s, after which natural gas non-condensing or condensing boilers were common; likely consideration of alternative cooling techniques, e.g. chilled ceilings, fabric energy storage, evaporative cooling; various ventilation systems common (fresh air/all air/air and water); active chilled beam ventilation common from the mid-1990s | 1995-onwards<br>Offices constructed in this period are more popular |

Notes:

1. Structural vacancy is defined by Remøy (2010) as building space that is vacant for three or more years.

Sources: (a) Kendrick et al., 1998; (b) Gold and Martin, 1999; (c) Remøy, 2010; (d) CIBSE, 2013; (e) AUDE, 2008.

Table 2-7 Regional distribution of England and Wales' office stock (after Pout et al., 1998).

| Region | Number of Premises | Area (1000m$^2$) |
|---|---|---|
| Northern | 12,768 | 1,399 |
| Yorkshire and Humberside | 22,061 | 6,151 |
| North West | 31,837 | 7,200 |
| East Midlands | 16,415 | 3,631 |
| West Midlands | 22,568 | 5,036 |
| East Anglia | 10,259 | 2,267 |
| South East | 125,978 | 37,610 |
| South West | 23,016 | 5,192 |
| Wales | 12,493 | 2,251 |
| Total Premises/Area | 277,395 | 70,737 |

Notes:

1. This office building stock information does not include all office buildings existing in England and Wales in 1994, due to its 'Bulk Class' grouping (see Appendix D for further information).

During the boom years from 1988 to 1991, office orders were around 55-60% of the total commercial orders, compared to just over 20% during the depressed years of the mid-1990s (*ibid.*). The office building stock figures from Pout et al. (1998) reflect the late 1980s boom and 1990 peak, with the number of premises in the 1986-1990 age bracket (24,337) being more than double that of the 1981-1985 age bracket (10,306). The structural vacancy experienced in office buildings constructed from 1965 to 1995-onwards is described in Remøy (2010), by whom the term is defined as building space that is vacant for three or more years. The period featuring the highest level of structural vacancy, from 1980 to 1995, is not known for its interesting architecture or beauty (*ibid.*) and closely reflects the timings of the 1988 to 1991 boom period for office building construction (Ball, 2003). The period from 1965 to 1980 exhibits both structural vacancy and obsolescence, while offices built from 1995-onwards appear more popular (Remøy, 2010) (Table 2-6).

### 2.3.2 Office retrofit cycle

As office buildings age, they can be subject to such works as are associated with building retrofit, renovation, and refurbishment (Wilkinson, 2012). The scope of this thesis excludes the terms renovation and refurbishment in general, thus the office retrofit cycle is examined.

As opposed to treating offices at the end of their operational life, building retrofit can be used as prevention against building redundancy, and therefore, may be repeated during a building's life as required to meet the needs of the owner/occupier (Nilsson et al., 1994). The office retrofit cycle is estimated at around 30 years by Wilkinson (2011; 2012) and Rey (2004). Literature that supports this estimated office retrofit cycle is as follows:

- Research into the sustainable retrofit potential of lower quality office buildings found a median retrofit age of 31-years (Wilkinson, 2011);
- Research into the sustainable retrofit potential of premium office buildings found the "*median age of the retrofitted stock during the time period was 31 years which meant the buildings were at an age where retrofits were required to upgrade them to meet market expectations*" (Wilkinson, 2012: 403);
- Swiss office buildings' external retrofit cycle estimated at 25-30 years (Rey, 2004);
- Sparkasse Vorderpfalz and the Angel Building were 35 and 26-years old respectively in the year their façade retrofit projects commenced, see Table 2-15 for details relating to their façade retrofit selection;
- Research by Yang and Lim (2007) into an integrated approach for office building retrofit states that new commercial office building construction growth in Australia since the 1970s has resulted in a large stock of ageing buildings – this research featured two retrofit cases studies on buildings of 30 and 35-years in age;
- Kendrick et al. (1998) state that building plant reaching the end of its economical lifespan – approximately 20-25 years – can be a contributory factor in the decision to carry out office building refurbishment;
- The China Resources Building in Hong Kong was 25-years old when its phased retrofit commenced in 2009, see Section 2.2.2 for more details on this retrofit project;
- A condition survey is often a starting point in building refurbishment to highlight key requirements that ensure a "*property will function within its required capacity until it is no longer required, typically twenty to thirty years*" (Strachan, 2013: 34).

The estimated cyclical pattern for office retrofit reflects global findings which state that "*large-scale opportunities for a holistic approach in existing buildings do not come often since major building upgrades may occur only every 30 years or so*" (IEA, 2013a: 121). The pattern also suggests that a commercial structure's economic life could be lower than the 59-

years UK national statistics data assumes such buildings to last on average (Ball, 2003), if building retrofit was not conducted to engender a new lease of life.

### 2.3.3 Energy use in office buildings

The total final energy consumption[12] of UK energy products is divided into four sectors, as follows, with each sectors' share of energy use in 2014: transport (38%), domestic (27%), industrial (17%), and service (13%), plus 5% for non-energy purposes (DECC, 2015a). Of the UK service sector's energy use in 2014, commercial offices consumed 9% (Figure 2-5).

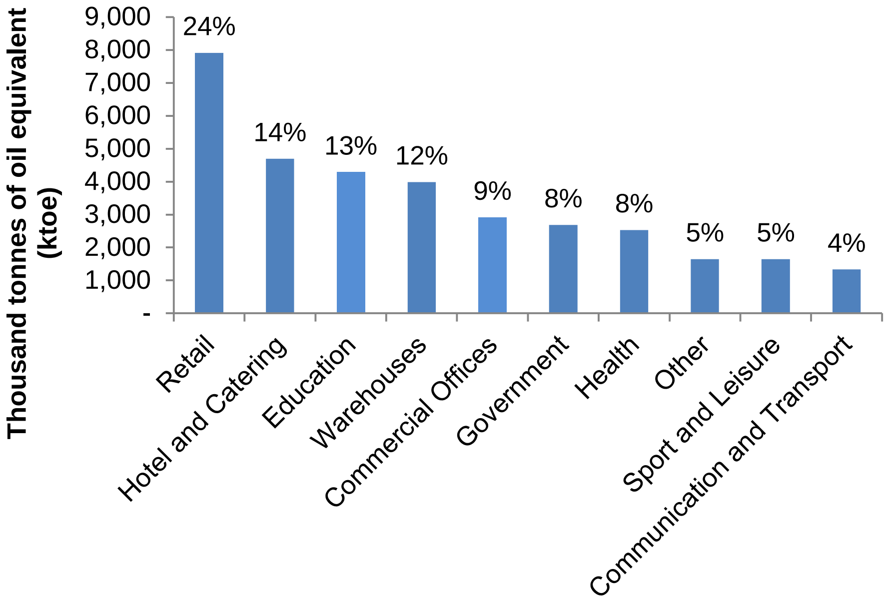


Figure 2-5 UK service sector energy consumption by sub-sector (chart developed from data given in DECC, 2015b)

The energy consumed by the UK service sector and by commercial office buildings may seem low in comparison to the major user of energy in the UK built environment: the domestic sector (27%) (DECC, 2015a). However, when the 2010-2015 UK Conservative and Liberal Democrat coalition government declared its aim to reduce carbon emissions by 80% by 2050, it stated that "*energy efficiency will have to increase across all sectors to the extent that energy use per capita is between a fifth and a half lower than it is today*" (GOV.UK, 2012).

[12] Total final energy consumption is the energy consumed by the final end user after it has been transformed from its original state. The primary energy equivalent, consumed by a sector prior to transformation, will include losses incurred during the transformation process and any energy used by the energy industry (DECC, 2015a).

As such, research into any building sector that has the potential to help reduce energy use, e.g. discovering how decision-making can be used to support façade selection in non-domestic building retrofit, with a focus on office buildings, would appear to represent a valid contribution to knowledge.

There has been rapid growth in office building energy consumption since the 1970s, which is reflective of the expansion in floor space, and the increased use of lighting, IT, and air conditioning (A/C) (Wade et al., 2003). Letting agents became powerful in the 1980s, often setting the specification for large offices, which then became the norm for many office buildings constructed in this period (Gold and Martin, 1999). As a result, many office buildings constructed in the 1980s are now considered over-serviced (*ibid.*). DETR (2000) reported that the specification of A/C, when sometimes not required, was a contributory factor in the increased use of energy in offices, but that this trend in energy consumption was offset by improvements in insulation, plant, lighting and controls.

Current trends in office building energy consumption are closely linked to economic activity and the related increase in floor area, building type and age, climate, and building energy efficiency improvements (IEA, 2013a). The inclusion of building age in this explanation of office energy consumption trends is of interest to this thesis, in regards to the retrofit potential of the ageing office stock. Moreover, offices appear to offer a good potential for energy saving, because despite the heterogeneous nature of buildings (Ball, 2003), "*the range of technical solutions is not too large as the nature of energy service demands in offices is relatively homogeneous*" (Wade et al., 2003: 4).

With particular regards to the increased use of IT, the first E-commerce Inquiry conducted by the Office for National Statistics (ONS), covering the year 2000, showed 92% of UK businesses as using PCs, workstations or terminals (Williams, 2001). This percentage applied to most industries and most size of businesses, with the exception of smaller businesses in manufacturing, and in hotel and catering, where it was around 70% (*ibid.*). The E-commerce Inquiry showed the percentage of businesses with internet access (63%) as lower than those with computing power (Williams, 2001). In 2014, 95.8% of businesses had internet access (ONS, 2015). Increased computer use in relation to office buildings is demonstrated by Martinez et al. (2012) in their investigation into energy-saving façade retrofit options for a 12-storey 1970s office building. Few or possibly no computers were present in said building when it was first designed, but it now hosts more than 500 personal computers, as well as other modern electronic equipment (*ibid.*). Computers and other such equipment add to the operational energy consumption of office buildings via their direct usage, but also through the cooling/conditioning required to manage the associated internal heat gains and to maintain a healthy and stimulating work environment for the buildings' occupants (Gratia and De Herde, 2007). In stark contrast, "*1960s office buildings were designed in the era of the typing pool where offices had literally no internal gains from electrical equipment apart from electric lighting*" (CIBSE, 2013: 16). However, advances in computing and other office equipment by the 1990s led to lower internal loads and enabled the re-evaluation of cooling requirements in office buildings (Gold and Martin, 1999).

UK service sector energy consumption in 2014 is shown by end use in Figure 2-6, where it can be seen that heating (39%) and lighting (25%) are the largest users of energy in this sector; with cooling and ventilation, together with computing, responsible for 10% of the sector's overall energy consumption (DECC, 2015b). Figure 2-7 shows UK service sector energy consumption in 2014 by sub-sector and end use, where the impactful nature of heating and lighting energy consumption in each sub-sector is clearly demonstrated. In line with the other sub-sectors, the largest uses of energy in commercial offices are heating and lighting, with these end-uses responsible for 43.3% and 21.2% of the overall energy consumed by commercial offices respectively (DECC, 2015b). In addition, commercial offices are shown as using the largest combined amount of energy for cooling and ventilation, and computing, with these end uses responsible for 14.1% and 9.8% of the overall energy consumed by commercial offices respectively (*ibid.*).

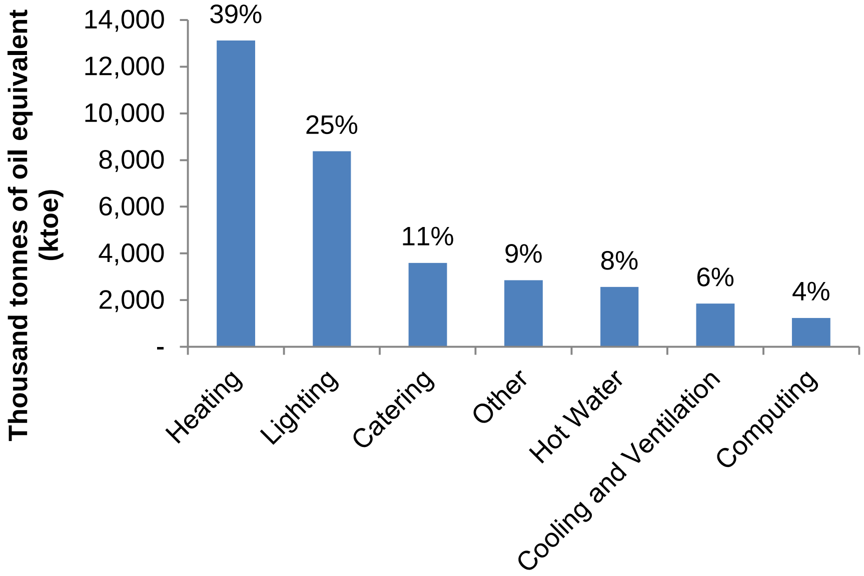


Figure 2-6 UK service sector energy consumption by end use (chart developed from data given in DECC, 2015b)

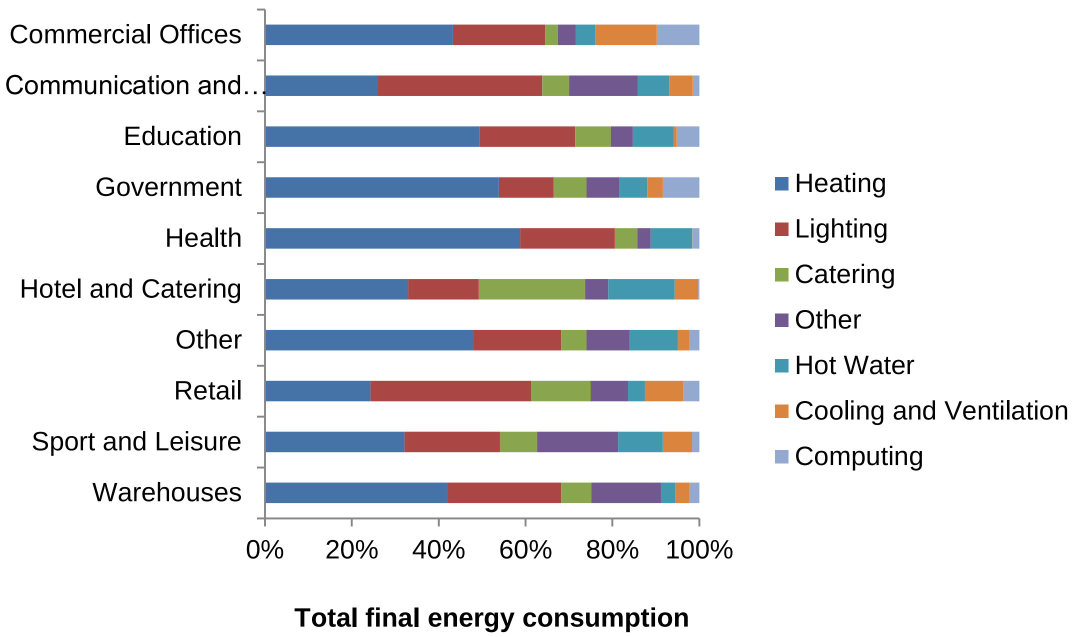


Figure 2-7 UK service sector energy consumption by sub-sector and end use (chart developed from data given in DECC, 2015b)

The typical approach to building retrofit (Section 2.2.1) appears to be targeting the largest consumers of energy: heating and lighting, as deep retrofit typically includes work to the thermal elements and services, while the less impactful, but still worthwhile conventional retrofit typically includes work to upgrade part of the lighting.

### 2.3.4 Building energy labels

To help reduce the energy consumed by non-dwellings, including office buildings where applicable, the non-domestic energy performance certificate (NDEPC, also often referred to as EPC) and the display energy certificate (DEC) were introduced as follows:

*Non-domestic energy performance certificate*

To inform potential buyers or tenants about a building's predicted energy efficiency, the EPC was introduced for the construction (or modification), sale or rent of non-dwellings in England and Wales from 6 April 2008. EPCs are required in accordance with the Energy Performance of Buildings Directive (EPBD) and were introduced using a phased approach by the *Energy Performance of Buildings (Certificates and Inspections) (England and Wales) Regulations 2007* (DCLG, 2012). Of particular interest to this study, is the extent to which a non-dwelling must be modified for it to require an EPC, for which DCLG (2012: 12) states: "*If a building is modified to have more or fewer parts than it originally had and the modification includes the provision or extension of fixed services for heating, air conditioning or mechanical ventilation (i.e. those services that condition the indoor climate for the benefits of the occupants) then an EPC will be required*".

The EPC presents a building's predicted energy use in the form of an energy rating scale from A+ to G, with an A+ rating being the most efficient and the most likely to have lower fuel bills; this scale relates to the 'running costs' of a building and is akin to the rating used for such items as electrical appliances. The EPC also indicates the building's energy performance in terms of carbon dioxide ($CO_2$) emissions, based on the energy used for space and water heating, ventilation, and lighting, less any building-generated renewable energy. The $CO_2$ emissions are represented in the form of a rating scale from zero to over 150, for which the lower the number, the lower the typical $CO_2$ emissions; an A+ energy rating reflects net zero $CO_2$ emissions and thus features above zero on the scale. The energy performance rating is adjusted according to the building's total useful floor area, thus the performance of different sized buildings of a given type can be compared. EPC assessments must be carried out by an accredited energy assessor, and unless replaced by a newer version, are valid for 10-years (DCLG, 2012). As per the current conditions (at the time of writing), a non-dwelling is required to display an EPC on its premises if it meets all of the following requirements: its total useful area is above 500m$^2$, the building is visited frequently by the public, and an EPC has previously been produced for the building (DCLG, 2014).

Building energy labels can have financial implications. Kok and Jennen (2012) found in their study of 1100 commercial office leasing transactions, that the less energy efficient buildings (EPC-rated D or below) commanded rental levels of around 6.5% lower than similar, but more energy efficient buildings (EPC-rated A-C). This finding reflects an improved state in regards to the understanding and appreciation of energy efficient commercial buildings, when just over a decade earlier, Gibson and Lizieri (1999) reported that UK valuers were adopting a highly conservative stance when confronted with non-standard corporate buildings and were as a result marking down the value of said buildings. This meant UK corporate buildings could be considered of investment quality even if they inefficient, and offered occupants uncomfortable and unhealthy conditions (Wade et al., 2003). Further energy label-related financial implications are to be expected, since from 2018, provisions in the Energy Act 2011 mean it will be illegal to let out a non-domestic building with an EPC rating of E or below (UKGBC, 2015). It is thought that these regulations, once in force, will be a powerful driver for non-domestic building retrofit (*ibid.*).

*Display energy certificate*

To raise public awareness of building energy use and to inform visitors to a public sector building of its specific energy use, the DEC was introduced for public sector occupied buildings in England and Wales from 1 October 2008, in accordance with the EPBD (DCLG, 2008). The specific building focus for the DEC is explained by DCLG (2008: 2), where it states that "*it is important that the public service sector leads the way in the campaign to tackle $CO_2$ emissions. DECs show the public how efficiently public service organisations are using energy in their buildings*".

The DEC indicates the actual (metered) energy used by a building over the previous 12-month period. This energy use is indicated by an operational rating (OR) from zero to over 150, which numerically represents the $CO_2$ emissions resulting from the energy use, and which is an adjusted combination of the building's energy use from different sources, to enable comparison between different buildings (DCLG, 2015). The OR is also represented on the DEC in the form of a corresponding letter rating scale from A to G. Buildings with the lowest $CO_2$ emissions, and thus the best annual energy use, are represented by an A rating, while a G rating represents the highest $CO_2$ emissions and thus the worst annual energy use (DECC, 2013). G-rated buildings can have a corresponding numerical OR in the region of 151 to 1000+ (*ibid.*). Though, according to a review of DECs dating from 2008 to 2012, carried out by Hong and Steadman (2013: 8), "*the highest OR values observed in valid DECs are of the order of 700 or 800, and values over 1000 are therefore likely to be errors*".

The DEC assessment must be carried out by an accredited energy assessor and the DEC must be accompanied by an advisory report giving recommendations to improve the building's energy performance. The validity of the DEC and advisory report, from its nominated date, differ according to building size: for buildings over 1000m$^2$ total useful area, the DEC is valid for 12-months and the advisory report for seven-years; while for buildings with between 250m$^2$ and 1000m$^2$ total useful area, the DEC and the advisory report are valid for 10-years (DCLG, 2015). As per the current conditions (at the time of writing), a building is required to have a DEC, if: it is occupied by a Public Authority or an Institution providing a public service, its total useful area is above 250m$^2$, and it is visited frequently by the public (*ibid.*). The DEC should be permanently displayed in the building's reception area, where it can be seen and read by the public; the certificate should be no smaller than 297mm wide by 420mm high (CIBSE, 2009).

## 2.4 Decision-making theory

### 2.4.1 Decision-making

Decisions are part of everyday life. Generally, most of these decisions are so unimportant that they can be taken on impulse; however, some are deemed sufficiently important as to require careful consideration prior to deciding on a course of action (French, 1988).

Every decision contains three key elements: 1) the presence of alternatives from which the decision-maker can make his/her choice; 2) for each possible choice, the decision-maker holds some expectation on the future; and 3) the decision-maker has a preference over the possible outcomes of the various available choice (Hazelrigg, 2012). A *decision* can be said to have occurred, when a course of action is chosen by an individual or group from a number of alternative options, after consideration of the options (Hazelrigg, 2012; Soanes and Stevenson, 2003). The making of a decision signals a commitment to action in response to a situation[13] requiring of consideration (Hazelrigg, 2012).

According to Hazelrigg (2012: 8), a decision is made by an individual, since only an individual can commit his or herself to an action and "*groups have emergent behaviours, they do not make decisions*". However, decision-making is often a group activity, with bodies such as committees, boards of directors, and parliaments usually responsible for making decisions (French, 1988). Important decisions in many everyday situations, affecting the lives of many people, are made by groups rather than individuals, and while an individual may bear responsibility for the decision, many participants will have contributed to the chosen course of action (Orasanu and Salas, 1993).

Three types of situations generally exist in which decisions are made according to the decision-maker's attitude to risk. Hence, decisions are generally made under the conditions

[13] Hazelrigg (2012: 14) points "*out some salient differences between problems and decisions. Problems are solved, decisions are made. The solution to a problem is an answer, the result of a decision is an outcome. Answers are right or wrong. Decisions are good or bad. …Problems are solved in the absence of preferences. One cannot make a decision in the absence of preferences*". Thus, Hazelrigg (2012) does not use the word 'problem' in any context where 'decision' is meant.

of either *certainty*, *uncertainty* or *risk* (Riabacke, 2006). When decisions are made under the condition of *certainty*, the true state is known to the decision-maker before a choice must be made, i.e. the consequences of the decision-maker's actions can be predicted with certainty (French, 1988). Thus, decisions made under certainty are generally straightforward (*ibid.*). "*Uncertainty refers to our inability to predict the future with both precision and certainty*" (Hazelrigg, 2012: 161). When decisions are made in a state of *uncertainty*, the decision-maker's actions may result in a number of outcomes, but the probability of those outcomes is unknown (Riabacke, 2006). Uncertainty in decision-making derives from two sources: exogenic, i.e. from within the system (e.g. cash flow calculations) and endogenic, i.e. from outside the system (e.g. the physical behaviour of building components) (Sanguinetti, 2012). In Figure 2-8, uncertainties relating to façade retrofit selection are classified in accordance to their impact on investment performance, the construction process, and building performance. The making of decisions under the condition of *risk* is also the result of uncertainty; it "*is the variability in the objective function for a decision, both positive and negative. That is, risk refers to the possibility that the outcome of a decision can be better than expected as well as worse*" (Hazelrigg, 2012: 161).

A decision can be strategic, tactical or operational. Without clearly identified strategies and systematic planning (at the heart of which lies finance), whatever a business hopes to achieve in the future, is unlikely to succeed (Atrill, 2014). Strategic decisions are defined by Eisenhardt and Zbaracki (1992: 17) as "*important, in terms of the actions taken, the resources committed, or the precedents set*", which they equate to "*those infrequent decisions made by the top leaders of an organization that critically affect organizational health and survival*". According to Mintzberg et al. (1976: 250), strategic decisions are characterised by "*novelty, complexity, and open-endedness…[with an organisation usually beginning] with little understanding of the decision situation it faces or the route to its solution, and only a vague idea of what that solution might be and how it will be evaluated when it is developed*".

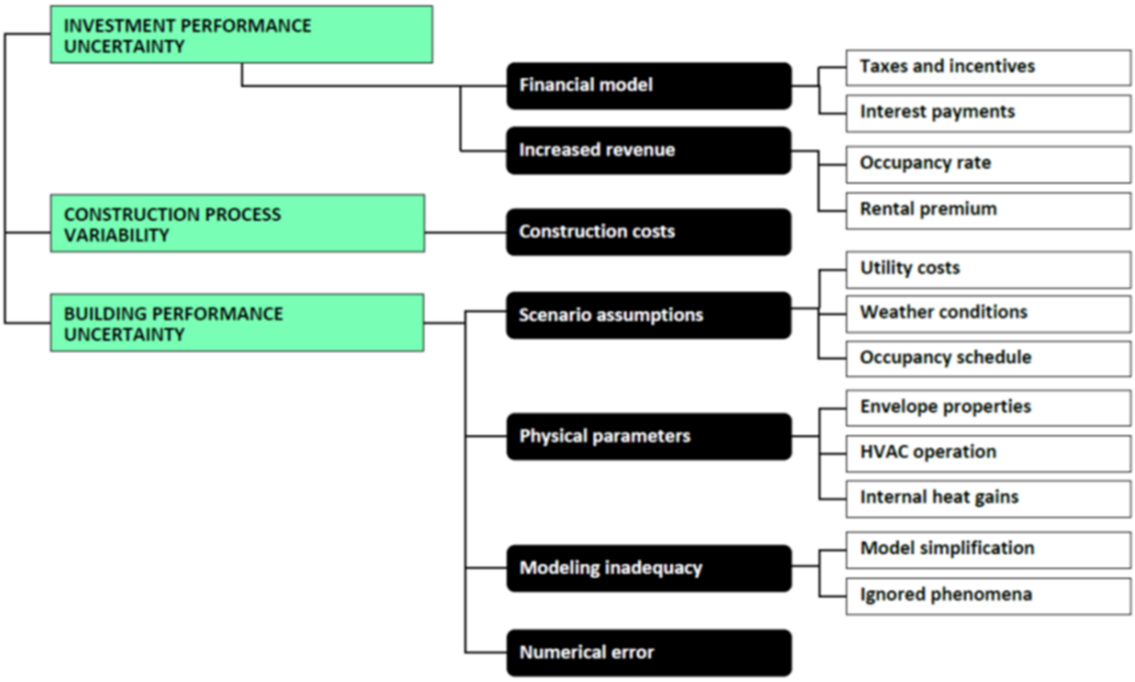


Figure 2-8 Uncertainties in façade retrofit selection (reproduced with kind permission from Sanguinetti, 2012: 49)

Moreover, a strategic decision is described by most theorists as having a long-term impact (Harrington and Ottenbacher, 2009). In construction, most strategic decisions have to be made during the early stages of a project when uncertainty abounds, with the selection of a procurement system deemed as one of the most significant strategic decisions occurring at this stage (Cheng and Proverbs, 2014). Due to the cost and long-term nature of their investment, decisions concerning façade retrofit selection are deemed strategic (Sanguinetti, 2012; Arup, 2012). Within the framework of an organisation's strategic plan, there normally exist short-term tactical plans that help ensure management decisions are consistent with the long-term plan (Atrill, 2014). Also required to adhere to the strategic plan, are the operational decisions business managers make to exert day-to-day control over various business functions, in response to events not conforming to earlier plans (*ibid.*). Whether a decision is strategic, tactical or operational depends on certain timescales, risks, structures, and control characteristics being exhibited (Table 2-8). The final result of a decision is the outcome, which for example, could be the successful completion or failure of a construction project (Hazelrigg, 2012).

Table 2-8 Decision characteristics (reproduced courtesy of Jennings and Wattam, 1998: 24)

| | Timescale | Nature of risk | Structure | Control |
|---|---|---|---|---|
| **Strategic** | Long term | High | Ill defined | Heuristic |
| **Tactical** | Medium term | Moderate | Variable | Qualitative |
| **Operational** | Short term | Low | Well defined | Quantitative |

### 2.4.2 Normative and descriptive decision theory

The decision-making process can be examined from two distinctly different viewpoints: how people *should* make decisions, i.e. normative (or prescriptive) decision theory; and how people *do* make decisions, i.e. descriptive decision theory (Hazelrigg, 2012).

**Normative** (or prescriptive) decision theory involves the use of structured methods to arrive at a well-reasoned course of action; it is a thoroughly vetted, well accepted, mathematically derived theory that has no credible counter arguments (*ibid.*). The overlying assumption is that the decision-maker is striving to do what is best for the organisation for which they are making decisions (Beach, 1997); it is how the decision-maker should behave in ideal circumstances (French, 1988). In modelling terms, a normative model is quantitative and describes functional relationships between the variables of a system, prior to prescribing a course of action for the decision-maker to follow (Markland and Sweigart, 1987). A number of examples of normative decision-making methods are described in Table 2-9.

A structured comparison process which takes into account multiple variables is MCA (Rey, 2004). MCA closely involves decision-making teams' opinions via their choice of objectives, criteria, and relative scores and weighting, and is thus viewed as a highly subjective form of decision-making (DCLG, 2009). The MCA process can however be tempered with some objectivity by including objective data such as observed prices and by assigning the task of setting performance measurements to experts out with the decision-making team (*ibid.*). Despite its risk of subjectivity, MCA provides positivity in its provision of openness, analysis, and structure to the decision-making process, and in aiding the means of communication, over and above some other forms, such as cost benefit analysis (*op. cit.*). MCA is considered particularly helpful in the early stages of a project (Turskis et al., 2009).

Utility theory is among the best-known MCA procedures used in public body decision-making typically involving finite alternatives (e.g. choosing between alternate types of tax system), which said procedures include linear additive models, the analytical hierarchy process, and outranking methods (DCLG, 2009). Utility theory is considered to be the cornerstone of normative decision theory (Hazelrigg, 2012). Decision-making with finite alternatives can feature small or large numbers of options, however as the performance of each criterion in each option must be appraised, the options' magnitude will impact on the choice of decision method and the data collection/processing resources required (DCLG, 2009). In design and engineering, where some decision situations involve infinitely variable outcomes, the selection of a procedure that enables adequate numbers of alternatives to be appraised is an important initial consideration (*ibid.)*. Such situations, involving infinitely variable criteria, multiple objectives, and which are subject to constraints, are termed multiple objective decision making (MODM) *(op. cit.*). MODM situations are ill-posed from a mathematical point of view, because apart from trivial cases, they have no unique solution; thus, it is usually assumed that the decision-maker should select one of the efficient solutions resulting from the decision-making process (Czyżak and Jaszkiewicz, 1997).

Table 2-9  Examples of normative decision-making methods

| Normative method | Description of method |
|---|---|
| Analytic hierarchy process (AHP) | The measurement of intangibles in relative terms, via pairwise comparisons using priority scales derived from the judgment of experts (Saaty, 2008), e.g. in the decision support framework used to assist retail companies in the complex decision-making task of selecting innovative sustainable technologies (Dangana, 2015). AHP results in the development of a linear additive model (DCLG, 2009) (see below). |
| Cost benefit analysis | This technique can be used to compare the benefits and associated costs relating to a change that is under consideration (OECD, 2005), e.g. where the value of the health, energy and environmental benefits of retrofitting insulation was analysed by assessing the possible benefits, such as a reduction in visits to the doctor, days off school/work, and energy and $CO_2$ savings (Chapman et al., 2009). |
| Linear additive models | This type of model is applicable where criteria are proven or reasonably assumed to be preferentially independent. Linear models use a simple arithmetic approach in which the value score on each criterion is multiplied by the criterion weighting, and then adds the weighted scores to produce one overall value that represents an option's value. Most MCA approaches incorporate this additive model (DCLG, 2009). |
| Multi-criteria decision analysis (MCDA) | Used to order options from most to least preferred via eight key steps: Establish the decision context; Identify the options for appraisal; Identify objectives and criteria; Criteria 'scoring'; Criteria 'weighting'; Combine scores and weights for each option; Examine the results; and Sensitivity analysis (DCLG, 2009). Due to its structured, transparent approach to complex decisions involving a large number of criteria, MCDA is used as the framework for a build system selection tool in Pan (2006). |
| Outranking methods | "*One option is said to outrank another if it outperforms the other on enough criteria of sufficient importance* ***and*** *is not outperformed by the other option in the sense of recording a significantly inferior performance on any one criterion*" (DCLG, 2009: 27). While outranking methods can be effective for exploring how preferences between options are formed, there are concerns regarding its somewhat arbitrary definitions, and the setting and manipulation of parameters in the approach (*ibid.*). |
| The payback period | This method compares the time projects take to break even and could be said to reduce risk if the time an investment is outstanding is minimised; however, one of its faults is it cannot distinguish between projects with the same payback period (French, 1988). A survey of 100-firms found the payback period was the most widely used decision rule, with 80% of the firms using it when deciding to invest in energy efficiency (Harris et al., 2000). It is probably the simplest method to use to rank projects in accordance to timestreams of costs and benefits (French, 1988). However, while many people are drawn to simple decision methods, "*quite often these are the very approaches that are not valid*" (Hazelrigg, 2012: 17). |
| Utility theory | Keeney and Raiffa's breakthrough work consists of three steps: the performance matrix, procedures to determine whether criteria are independent of each other, and a mathematical function that allows parameters to be estimated in the form of a single number index (DCLG, 2009). |

**Descriptive** decision theories conjecture how things are behaving in a decision situation (French, 1988). In modelling terms, a descriptive model is informal or qualitative; it aids the production of a description of the decision situation, but does not prescribe a preferred course of action (Markland and Sweigart, 1987). Moreover, a descriptive method can be a useful starting point in a decision situation, to determine the basis for progressing onto other decision support and/or decision-making methods (*ibid.*). Examples of descriptive decision theory include the Satisficing model, which posits that decision-makers choose a course of action from alternatives that exceed a criterion or standard; and the Conjunctive/Disjunctive 'combination' model, in which the Conjunctive model chooses a course of action from alternatives that exceed a threshold or aspiration level, and the Disjunctive model evaluates the alternatives based on their best attributes, rather than all their attributes (Dillon, 1998).

Descriptive decision theory is closely linked to cognitive psychology, a form of which is heuristics (Dietrich, 2010). Defined as "*enabling a person to discover or learn something for themselves*" (Soanes and Stevenson, 2003: 815), heuristics is referred to as a situation where decision-makers use cognitive shortcuts, or in other words, intentionally reduced cognitive effort (Beach, 1997). Heuristic decision-making is subject to cognitive biases, which can be grouped under the three heuristic situations from which they are presumed to arise: *Representativeness*: the decision-maker assesses the probability of an event based on its resemblance to another event; *Availability:* the decision-maker assesses the probability of an event, based on the ease in which instances of similar events comes to mind, thus events that are familiar tend to be judged more probable than events that are unfamiliar; and *Anchoring and adjustment:* this situation has similarities to the *availability* heuristic, in that the decision-maker selects an initial starting point (the anchor) which is often based on a previous event, from which the decision-maker's assessment is adjusted upward or downward as deemed appropriate in light of the considerations available to the decision-maker (*ibid.*).

Heuristic decision-making is not uncommon in the AEC industry. Mackinder and Marvin (1982) found that architects use experience to aid design decisions, its advantage over other forms of information being its readily availability from memory. Three main types of experience were identified by Mackinder and Marvin (1982: 2):

> "*(a) experience of the* ***decision-making process****, enabling the architect to predict in advance what problems might arise and to be aware of information sources which might be appropriate,*
>
> *(b) experience and general* ***knowledge of building construction*** *gained from both education and practice, enabling design decisions to be made in terms of what would normally be appropriate to the requirements of brief and site, and*
>
> *(c) experience of* ***performance*** *of a design decision taken previously*". "E*xperience of performance is usually negative, as the designer's attention is more commonly drawn to failures than successes*", while "*positive feedback is most often used to make decisions about visual aspects*" (*ibid.*).

Other examples of heuristic decision-making can be seen in the selection of energy saving building components (de Wilde, 2004) and housebuilding system selection (Pan, 2006).

Research in the field of naturalistic decision making (NDM) has greatly contributed to the understanding of how people make decisions in real-world settings (Klein, 2008), particularly in "*complex real-world uncertain contexts that can require real-time decisions in urgent situations with significant implications for errors*" (Gore et al., 2015: 223). NDM took a new approach to discovering how people made such decisions. Rather than starting with formal decision making models, to see how people did not comply, field research set out to discover the strategies people did use when making "*tough decisions under difficult conditions such as limited time, uncertainty, high stakes, vague goals, and unstable conditions*" (Klein, 2008: 456). Thus, the key characteristics related to NDM "*include ill-structured problems; uncertain dynamic environments; shifting, ill-defined or competing goals; action/feedback loops; time stress; high stakes; multiple players; and organizational goals and norms*" (Orasanu and Connolly, 1993, in Gore et al., 2015: 223). The use of NDM in urgent situations is demonstrated in the following examples: military application (Militello et al., 2015), intraoperative challenges (Sayra et al., 2013), expert badminton players (Macquet and Fleurance, 2007), and accident response (Johnson et al., 2009).

According to Lipshitz et al. (2001), the recognition-primed decision (RPD) model serves as the prototypical NDM model. The RPD model shows decision-makers using their experience to describe the primary causal factors in a decision situation, with their experience used "*in the form of a repertoire of patterns…[that] highlight the most relevant cues, provide expectancies, identify plausible goals, and suggest typical types of reactions in that type of situation*" (Klein, 2008: 457). The decision-maker's learned patterns can be quickly compared to the situation at hand, and if a clear match is found, the decision-maker can rapidly carry out the most typical course of action (*ibid.*). "*The RPD model explains how people can make good decisions without comparing options*" (*op. cit.*).

For the purpose of benchmarking the façade decision-making practices observed in the state-of-the-art literature review, and the exploratory and in-depth studies, this thesis has chosen to define normative and descriptive decision-making as follows:

- Normative decision-making is a structured approach, in which mathematically-derived decision-making methods are used to identify a single optimum course of action or a group of options from which the decision-maker can select his/her preferred choice.
- Descriptive decision-making is an informal approach, in which the decision-maker uses his/her experience to evaluate a decision situation and identify a course of action.

### 2.4.3 Sources of information used in decision-making

Sources of information are what a decision-maker uses to base his or her decisions on (Hazelrigg, 2012). In organisational science, the use of information in strategic decision-making is widely accepted as serving to reduce or remove uncertainty in the decision-making situation (Frishammar, 2003). In construction industry terminology, *project information* refers to information produced for or used in a particular project, while *information* has the homograph definition of "*facts which are communicated*" and a "*message used to represent a factor or concept within a communication process, in order to increase knowledge*"; project-related drawings are described as technical information (BSI, 2014: 70).

*"In an ideal situation, decision makers would select their information from those sources perceived to offer the highest quality information"* (O'Reilly, 1982: 757-8)*. "Quality information allows a decision maker to justify the basis of the decision to others, arguing that if the information used is timely, accurate, and reliable, then any decision made is likely to be a good one*" (*ibid.*). However, information in real-life decision situations may be contradictory or vague and from sources of varying credibility, while the decision maker may be distracted, time pressured, and pursuing multiple objectives (O'Reilly, 1982). NDM, for example, as mentioned in Section 2.4.2, typically takes place in a world of incomplete and imperfect information, where the decision maker has information about some part of the problem, but not about others, while information may also be ambiguous or simply of poor quality (Orasanu and Connolly, 1993).

The information needed to support the performance of individuals and teams can differ depending on what tasks are being undertaken. Rouse and Valusek (1993) state that humans do not correspond to the stereotypical view of proceeding from one decision event to another, but actually, spend the vast majority of their time doing routine activities, with actions (*execution*) following well-worn patterns, and observations (*monitoring*) agreeing with expectations. Within this routine activity, expectations are updated accordingly in response to acceptable levels of deviation; however, occasionally, non-routine activities occur in which sufficiently large deviations from expectations result in the need for *situation assessment*. Typically, the information chosen for use in situation assessment is obvious and information seeking is likely to be virtually automatic. Once in a while, a situation can be sufficiently puzzling to require less familiar sources to be sought, for which information seeking is likely to be a more conscious activity. The sources of information accessed during situation assessment provide a basis for humans to recognise or devise an explanation for the observations occurring in said situation. Rarely, an assessed situation may require a new or revised plan of action. In such circumstances, decision-makers may commonly resort to well-worn alternatives, where the choice of alternative action is so obvious that plans do not need to be explicitly evaluated. Occasionally, however, explicit *planning and commitment* are required to choose the alternative action for dealing with the assessed situation (Figure 2-9).

In regard to the types of information used by decision-makers, Frishammar (2003) (Table 2-10) draws on previous research to provide a useful frame of reference, as to *what* kind of information is used in strategic decision-making: i.e. soft or hard; *how* such information is obtained by decision-makers: i.e. solicited or unsolicited; and *where* decision-makers obtain such information: i.e. from external or internal sources. O'Reilly (1982) found four sources of information in use by decision-makers in an office environment by: 1. *Files* – handbooks and procedures, 2. *Updates* – memos and newsletters, 3. *Group* – peers and supervisors located internally to the work environment, and 4. *External* - others located outside the unit and in other organisations. The frequency of use in three out of the four sources was linked with accessibility, rather than quality, with the exception of *Group*, which was a highly accessible source of information for all 163 participants in the research (*ibid.*).

In a retrofit scenario, information is sought to enable the diagnosis of an aged building prior to developing a list of the retrofit work required, including an evaluation of the state of the building components and information on energy use (Flourentzou and Roulet, 2002). Built environment interviewees in a study by Strachan (2013), stated that non-domestic building refurbishment often begins with a condition survey of the building to be upgraded, and an options appraisal involving either design team brainstorming or referral to the client's design guide. Though in relation to retrofitting old office buildings, Yang and Lim (2007: 3) found that "*owners, designers and contractors alike were often troubled by the poor building documentation… [and as] a result, designers may not foresee all of the potential problems while the contractors apply huge mark-up for having to deal with the risks*".

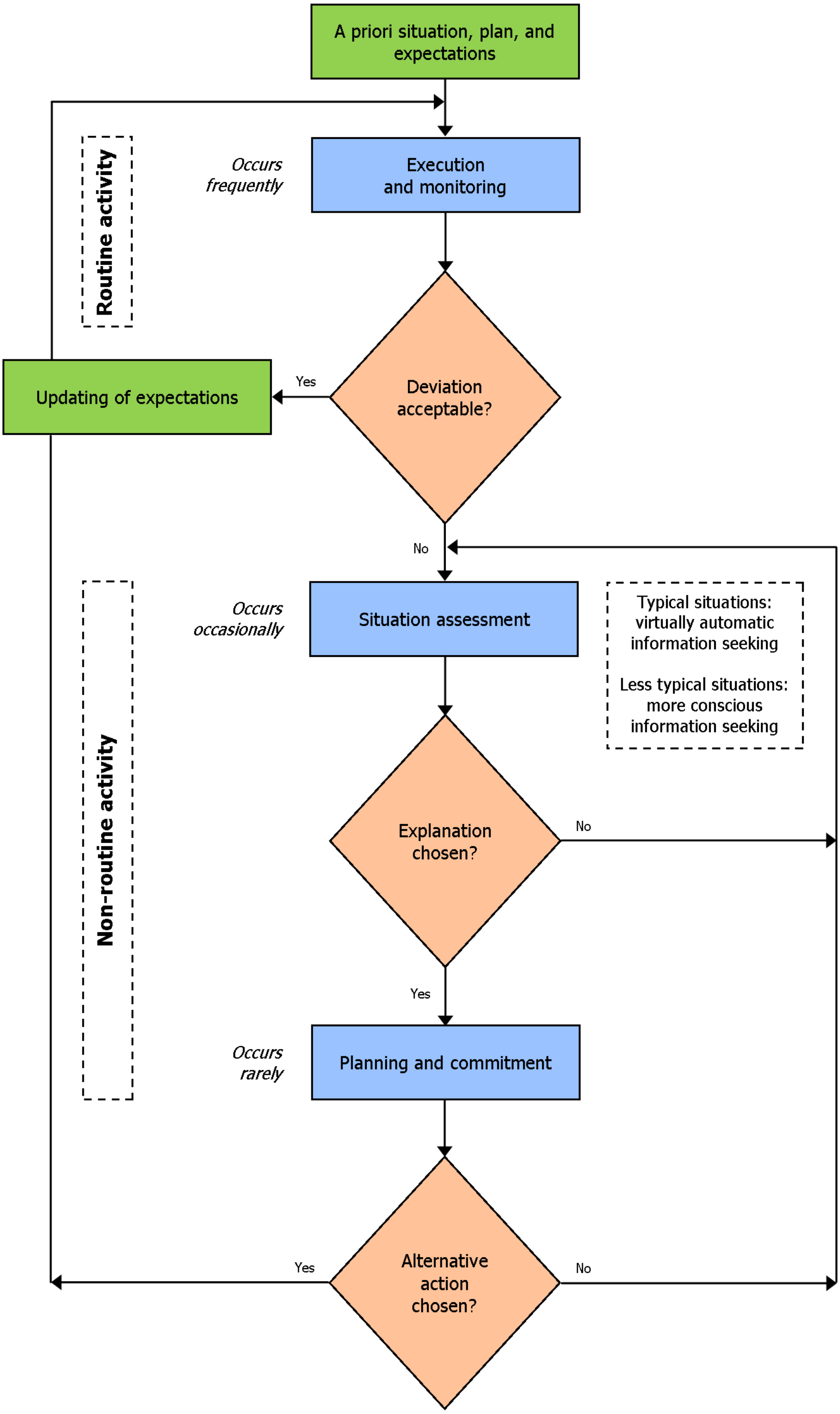


Figure 2-9 Decision-makers' tasks (after Rouse and Valusek, 1993)

The importance of keeping building as-built plans up-to-date following building closeout or after major renovation is highlighted by Klein et al. (2012). While in regards to the calibration of whole building energy models used to identify and estimate savings, and support investment grade energy conservation measures by analysing retrofit options in detail, information obtained by measurement is assumed to be more reliable than as-built documentation (Raftery et al., 2011).

Table 2-10  Information used in strategic decision-making (compiled from Frishammar, 2003)

| Aspects of information use | Description |
|---|---|
| **Why** is information used | In organisational science, the use of information in strategic decision-making serves to reduce or remove uncertainty in the decision-making situation. |
| **What** information is used | Soft information stems from an individual person, and may be broad, general, and subjective. Hard information is generally expressed in numerical form, which thus enables it to be easily quantified/processed using analytical means. Examples of soft information include: images, visions, ideas, cognitive structures, worldviews, gossip, hearsay. Examples of hard information include: numerical data used, generated or reported in such locations as company financial accounts, cost accounting systems, and production control systems; and statistical data from various sources. |
| **How** is information obtained | Information may be solicited or unsolicited. The former denotes information explicitly sought by the decision maker or given to the decision maker because of organisational requirements; while the latter denotes all other information, which may also be classed as directed or undirected communications. |
| **Where** is information obtained | Information obtained by decision-makers originates from external sources, i.e. from outside the organisation, and from internal sources, i.e. from within the organisation. Both external and internal sources of information can be further classified as stemming from personal, i.e. from direct human contact, and impersonal sources, i.e. written/non-verbal. |

Bloom and Wheelock (2010: 3) found a lack of information could be a barrier to deep retrofit in commercial buildings, with survey respondents reporting the usefulness of "*case studies on typical retrofit characteristics, an inventory of common deep retrofit efficiency measures, and improved energy modeling tools*", and about half the respondents who expressed a low interest in deep retrofit stating that information sources could increase their level of interest. Websites/online media, conferences/seminars, and industry training were cited as the most useful ways to access information (*ibid.*). Some information may however simply be unobtainable, as for example, according to Struck et al. (2015b: 1), "*engineers, architects* *and facility managers have currently no means to test a design (new build/renovation) with regards to its resilience concerning climate variability and user behaviour*".

Rivard et al. (1999) recommend the use of a shared repository in which each participant's contribution to the design can be stored, as otherwise information sources resulting from projects can be limited to paper drawings and reports which are an inefficient form of data exchange. On an industry level, *facaderetrofit,* a retrofit façade project database, aims to help other such projects in the construction industry, by enabling information (e.g. materials used, reasons for retrofitting) to be recorded in one online location (Busta, 2015). This energy performance-focused database contains details of more than 500 commercial and multifamily building projects, and is free to access (*ibid.*). The database can be searched by, among other topics, *façade design*, i.e. concrete wall, masonry with punched windows, precast concrete, steel, curtainwall, and highly glazed curtainwall; and *activities*, i.e. acoustic analysis, daylighting design, durability planning, façade systems commissioning plan, indoor air quality management planning, interior or exterior glare analysis, life cycle assessment, life cycle costing analysis, post occupancy evaluation, thermal comfort modelling, and whole-building energy modelling (Facaderetrofit, no date). The details for many projects on *facaderetrofit* are however incomplete; plus, the database does not appear to prompt the addition of details relating to the façade retrofit decision-making process nor to have a presence of buildings retrofitted with insulated render despite this façade system's popularity.

In the increasingly complex and fragmented cladding supply chain, Du et al. (2012: 4450) found that "*in-house information sources mainly include library, intranet, specialist, project or section manager, line manager and knowledge network; while external knowledge sources comprise standards, trade association literature, manufacturer literature, manufacturer technical advisory service, certification schemes, and consultants*". Their findings draw heavily on qualitative data from semi-structured interviews with 34 senior practitioners, including architects, façade consultants, engineers, and main and specialist contractors[14], covering cladding industry topics, and in particular, those relating to communication and decision-making. The nature of the practitioners work was found to influence the information sources used: clients had the most limited information sources on cladding, due to having no façade knowledge network and their relatively infrequent use of cladding information sources; main contractors had no company libraries due to the temporary nature of their offices on construction sites; while consultants had company libraries due to the stable nature of their offices, and with the most balanced information sources, due to their frequent role of co-ordinator. In general, most respondents (other than clients) had in-house specialists; plus, "*the majority of the consultants, manufacturers, and specialist contractors frequently use standards and other external sources…[reflecting] their roles of cladding-focused service providers in the supply chain and their need for more specific information than clients, architects and main contractors*" (*ibid.*). Similar to O'Reilly (1982), the matter of accessibility was raised by Du et al. (2012), who ranked the barriers to accessing information sources in the cladding supply chain in descending order of frequency as: work load, time scale, conflicting information, inability to access, and inability to agree.

Building information modelling (BIM) can handle numerous types of data in the design and construction process, aiding information management via the production, sharing, and analysis of building models (Khaddaj and Srour, 2016). However, "*the application of BIM to retrofit existing buildings faces challenges which could be due to the multi-disciplinary nature of information exchange, the timeliness of the exchange, and the wide array of technical components that are needed to ensure an optimal exchange*" (Khaddaj and Srour, 2016: 1526). State-of-the-art BIM literature "*suggests little maturity in deploying BIM to retrofit existing buildings*" and a need to further examine the area (Khaddaj and Srour, 2016: 1529).

A number of examples of sources of information that could be used in decision-making in the built environment are presented in Table 2-11.

[14] A shortage of clients and main contractors in its respondents was acknowledged as a limitation of the research.

Table 2-11 Examples of sources of information in built environment decision-making

| Sources of information | Description of source |
|---|---|
| Brainstorming | Creating an output called 'option generation', brainstorming aims to enhance a group's creativity by encouraging a free exchange of ideas, though controversy exists regarding validity of results in the support of decision-making (Beach, 1997). |
| Building energy models (BEMs) | Used widely by building services' professionals in large-scale renovations, BEMs can simulate building physics in detail (Rysanek and Choudhary, 2013). The Building Energy Software Tools Directory (no date) lists over 120 programs, from free to commercial products, to aid the promotion of simulation for the improved design, construction, operation, and maintenance of new and existing buildings. |
| Building plans | A key source of input information, e.g. for BEMs, it is important that building plans are kept up to date, as according to Klein et al. (2012: 161) "*changes that occur during construction are often…not transferred to complete as-built documentation handed over to owners during building closeout or after major renovation*". |
| Building regulations for England and Wales | Mandatory standards for the construction and extension of buildings, e.g. replacing a thermal element on an office building must adhere to *Approved Document L2B Conservation of fuel and power.* |
| Product certification | Source of input information, e.g. for BEMs. Two key UK-based certification bodies: Building Research Establishment (BRE, 2016) and British Board of Agrément (BBA, 2012) assess products in relation to building regulations, standards and policies. |
| Decision support systems (DSS) | DSSs do not make decisions, but support decision-making by enabling "*a single decision-maker to meaningfully combine*" large quantities of information via computerised-means in the pursuit of an informed decision (Pan, 2006: 72). |
| Delphi method | A group communication process that provides qualitative data in the form of expert opinions from the field of interest. Delphi Exercise is the most common form and involves an evolving questionnaire format (Linstone and Turoff, 2002). |
| Expert panel | A group of individuals with expertise and professional experience in a specific field of interest, who can support decision-making by deriving conclusions and recommendations through consensus (European Commission, 2006). |
| Façade engineering companies | "*Façade engineering is the art of resolving aesthetic, environmental and structural issues to achieve the enclosure of habitable space*" (Kragh, 2010: 32). Eminent providers of specialist façade engineering knowledge are, e.g. ARUP (2012), Buro Happold (2013), Schüco (2013), and WSP Parsons Brinckerhoff (2015). The Society of Façade Engineering (no date) helps 'regulate' the façade engineering industry. |
| Life cycle analysis (LCA) | LCA can be used to inform decision-makers of the environmental impact from buildings. An LCA study contains four phases: 1) goal and scope definition; 2) inventory analysis; 3) impact assessment; and 4) interpretation (BSI, 2006). |
| Measured building surveys | Often conducted manually to capture data about dimensions and additions made since the original construction, the efficacy of image-based surveys using laser and photogrammetric means is being researched, e.g. Klein et al. (2012). |
| Professional bodies | Expert guidance provided within specific fields, e.g. CIBSE, who are a prime source of building services information in the AEC industry and provide such guides as the *Refurbishment of non-domestic buildings - TM53* (CIBSE, 2013). |

## 2.5 Façade retrofit decision-making

### 2.5.1 The complex nature of the AEC industry

The construction process consists of diverse and fragmented sub-processes (Azam et al., 1998) that result in an overall complex process (Lidelöw and Simu, 2015). This complexity is compounded by the prototypical nature of AEC industry projects (Strachan, 2013; Hopfe et al., 2006; Sommerville and Dalziel, 1998); the complex nature of buildings and building retrofit (Asadi et al., 2012); and the difficulty of achieving a general consensus in multidisciplinary teams (Šaparauskas et al., 2011), while the use of such teams is recommended in façade design (Jin et al., 2011; Oliveira and Melhado, 2011).

Certain factors exerting an influence on the AEC industry's decision-making arena can be described as mandatory or voluntary. Mandatory influencing factors must be incorporated in a construction project in line with corresponding legislation, while voluntary factors are not mandatorily required and offer, for example, an optional opportunity for the incorporation of good working guidance. Examples of mandatory and voluntary influencing factors pertinent to the area of building façade retrofit are presented in Table 2-12. These selected examples represent just a small number of the mandatory and voluntary factors that must and can influence decisions in the AEC industry respectively, thus reinforcing the complex nature of the AEC decision-making arena.

Furthermore, the construction industry's complex supply-chain is considered to impact on the diffusion of new knowledge (Peterman et al., 2012), with the fragmented nature of the cladding supply chain influencing the ease of communication and informed decision-making in relation to cladding selection (Du et al., 2011; Pavitt and Gibb, 2003). As a result, "*decision-making problems in construction management often involve a complex decision making process in which multiple requirements and conditions have to be taken into consideration simultaneously*" (Zavadskas et al., 2008b: 85), with the AEC industry deemed to benefit from well-structured decision-making (Šaparauskas et al., 2011).

Table 2-12 Examples of influencing factors pertinent to building façade retrofit

| Influencing factors | Description |
|---|---|
| **Mandatory** | |
| Building energy labels | EPCs and DECs were introduced for non-dwellings to inform buyers/tenants of a building's energy efficiency and visitors of a building's energy use respectively, as mentioned in Section 2.3.4. |
| Building Regulations for England and Wales | Disseminated in practice via the Approved Documents, which offer practical guidance to aid compliance, e.g. Approved Document B - Fire, as mentioned in Section 2.2.1 in relation to multi-storey buildings. |
| Listed building consent | Permission must be obtained prior to undertaking any work or invasive investigations on a listed building, as in the case of the façade retrofit of the University of Sheffield's Arts Tower, as described in Section 5.2.4. |
| Planning consent | The Local Planning Authority (LPA) must be satisfied that any planning conditions have been met, e.g. approval of the colour of cladding panels, prior to work commencing, as demonstrated by this thesis' case studies. |
| **Voluntary** | |
| BRE design guides | Independent, impartial, research-based built environment expertise that aids government, industry, and businesses (BRE, 2016), e.g. BRE Information Paper IP11/02 *Retrofitting solar shading* (Littlefair, 2002). |
| British Standards | The "*distilled wisdom of people with expertise in their subject matter*" (BSI, 2015), this voluntary guidance is also used to support mandatory influencing factors such as the Approved Documents mentioned above. |
| CWCT standards | Standards e.g. for systemised building envelopes, written under the guidance of the CWCT Standards Committee comprising architects, consultants, contractors, and manufacturers (CWCT, no date-a; no date-b). |
| RIBA Plan of Work[15] | Can be used to guide the management and design of building projects, and contract administration (RIBA, 2009). The RIBA Plan of Work is considered "*the most widely used model of building design*" (Austin et al., 1999: 281). |

### 2.5.2 The AEC industry's multidisciplinary approach

*Roles encountered in construction projects*

The AEC industry's inherently complex project-based approach (Lee et al., 2006) means teamwork is essential for delivering the clients' requirements (Kamara et al., 2002). As with other project-based environments, construction teams are often characterised by unfamiliar groups of people coming together for short periods before moving onto other work (Dainty

[15] At the time of writing, the latest version is the RIBA Plan of Work 2013 (RIBA, no date). However, at the point of participating in this research, the research participants were using the RIBA Plan of Work 2007; thus, all references to 'RIBA Stage/s' in this thesis relate to the RIBA Plan of Work 2007.

et al., 2006). Research by Hughes and Murdoch (2001), based on a desk study, analysis of plans of work and focus group data, brought unprecedented clarity to the description of the roles and responsibilities of participants in project teams and other roles usually encountered in construction projects, for which the overarching terminology is presented in Table 2-13.

Table 2-13 Construction projects: terminology (after Hughes and Murdoch, 2001)

| Construction project categories | Construction project roles |
|---|---|
| Project team | Client<br>Advisors<br>Constructors |
| Regulators | Local Authority |
| Dispute resolvers | Adjudicator<br>Arbitrator<br>Mediator |

The **client** initiates the project and sets its objectives, appointing the early consultants (advisors) with whom they develop the objectives (Hughes and Murdoch, 2001). The client plays a vital role in establishing an appropriate project team "*to deliver the right product at the right time for the right cost*" Cheng and Proverbs (2004: 936). One of the earliest appointments includes the client representative, who acts as a primary interface between the client organisation and the project team (Hughes and Murdoch, 2001).

**Advisors** consist of a variety of roles engaged by the client to provide information and advice either across the whole project or for specific aspects of the project. The advisor role can involve a complex relationship between design and management, as some aspects of design work involves co-ordination of others. Of the advisor roles, the *design leadership* role is the most important function in the project; this role has responsibility for generating the brief in dialogue with the client, and then developing and implementing the design, including negotiating with the LPA and inspecting the construction work as it progresses. For building projects and civil engineering works, the design leadership role is played by an architect or civil engineer respectively. Other advisor roles include *management*, e.g. project manager, such as the client representative, who has the authority to manage the whole project; *design*, e.g. consultant designers and designers, with the former role denoting mechanical, civil or structural engineers, who provide advice and information about building services installations, civil engineering aspects, and structural strength and stability aspects respectively, and the latter relating to any person with responsibility for part or all of the design; and *financial*, e.g. lead cost advisor and cost planner, with the former role having overall responsibility for the project and co-ordination of various inputs of cost advice, and the latter providing early stage advice about expenditure patterns (*ibid.*).

The **constructor** is the person or organisation that takes on the general responsibility for managing the resources required to erect a building to the required design. Depending on the procurement route, i.e. general or design and build, a *main contractor* is a builder who conducts the whole of the building work, while a *design-build contractor* is one who designs *and* erects the building. The constructor will usually have a number of key staff involved in the construction project, e.g. construction manager, construction planner, and site agent. A construction project may also involve the separate contracting of persons or organisations, to that of the main contract, for the supply of goods and/or services; these generally take the form of supplier or preferred supplier, with the latter denoting one with whom the client is developing a medium to long-term business relationship. Furthermore, a construction project may involve organisations who provide building work for part of a project, and which can take the form of specialist design and installation, e.g. domestic sub-contractor, specialist supplier, named sub-contractor (*op. cit*). According to Cheng and Proverbs (2004), many clients recognise the need to involve constructors and manufacturers from an early stage of the construction project, though this is not always achieved.

**Regulators** are not appointed by the client, but become involved in construction projects by virtue of regulatory functions. Regulators consist of two categories: *statutory authorities* and *local authorities*, and have the power to issue or withhold consents necessary to a construction project that may result in such a project being changed or even abandoned.

*Statutory authorities* are responsible for ensuring areas of activity governed by statutes are carried out accordingly, e.g. organisations that govern what is permitted in terms of the design and construction of buildings, and the standard of utilities, such as water and sewage disposal. *Local authority* represents government at a local level and become involved in construction projects as a result of legislation governing such aspects as building control, planning, environmental health, and fire safety (Hughes and Murdoch, 2001).

**Dispute resolvers** are introduced into a construction project in the event of a dispute between parties to a contract; they are an independent third party that aims to help resolve the situation and thus avoid the cost and delay of litigation (*ibid.*).

**Stakeholders** in a construction project can include any person who has an interest or concern in the project, or who will be affected by the project in some way (*op. cit.*; Lester, 2007). These can be divided into two main groups: direct and indirect (Table 2-14), of which both can contain positive and negative stakeholders who support or do not support the aims and objectives of the project respectively (*ibid.*). The direct stakeholder group, concerned with completing the planning, administration, and execution of a project within the specified parameters of time, cost and quality, contains mainly positive stakeholders, though it may also contain negative stakeholders, such as end user employees who fear the completed project may lead to relocation or redundancy (*op. cit.*). "*Sometimes, stakeholders are able to contribute to the briefing and design process. In major developments, the planning process will ensure that such people are given a voice*" (Hughes and Murdoch, 2001: 151).

*Roles encountered in building façade retrofit*

The importance of the design team in relation to buildings in general is highlighted by Allen (2005: 27) who states that, despite the "*complex functional expectations of our buildings and complex ways of meeting some of the expectations, most of the expectations can be met by any well-informed designer, even in very large buildings*". The architect is seen as playing a key role in façade retrofit by Mara (2010) and Rey (2004), and according to Burton (2015: 3) the architectural profession is a major player in the sustainable retrofit of commercial buildings, as while "*designing to reduce the emissions that drive climate change, the architect must also focus on adaptation, designing maybe in a different way to take proper account of the changes underway and make the building resilient to climate change*".

Table 2-14 Main stakeholder groups in construction projects (compiled from Lester, 2007)

| Stakeholder group | Stakeholder group roles, including: |
|---|---|
| **Direct** (or primary) | |
| This group contains the stakeholder roles directly associated or involved in all or some of the phases of a construction project: planning, administration, and execution; plus, end users. | Client; project sponsor; project manager; technical and financial services; consultants; material and equipment suppliers; site personnel; contractors; sub-contractors; end users. |
| **Indirect** (or secondary) | |
| This group contains the stakeholder roles, such as managers and support staff, not directly associated with the construction project; plus, representatives from the following sub-sectors: | Human resources department; accounts department; senior management not directly responsible for the project; families of the project manager and team members. |
| Regulatory authorities | Government; inspecting organisations; public utilities; technical institutions; professional bodies |
| Personal interest groups | Stockholders; labour unions; pressure groups |

The architectural design process involves an iterative method based on incoming information, stated principles, and mental schemes (Ochoa and Capeluto, 2009). "*The procedure to reach a certain facade configuration follows that of architectural design: its beginning concentrates on working with ideas and concepts that have simple graphical representation but no precision. Only later in the design process, it passes to a level of detail that can be understood or is relevant to other building professionals*" (Ochoa and Capeluto, 2009: 480).

To aid accuracy in a building's performance, in regards energy use and indoor climate, and life cycle costs, the design team should take the design constraints into account at an early stage of the façade decision-making process, namely: *climate* (e.g. solar radiation, outdoor temperature), *the site of the building* (e.g. local daylight availability, exterior obstructions), *building use* (e.g. operating hours, activities), and *building and design regulations* (Poirazis, 2008). And while architects are likely to call on consultants to assist in meeting the stringent performance criteria required in façade design, they themselves need to know Building Regulation requirements, especially Parts L, B, E, and K, relating to the conservation of fuel and power, fire safety, resistance to sound, and protection from falling respectively, as well as safety legislation and CWCT standards (Mara, 2011). While incorporating information into the façade design in the early project stage, it is probable that cognitive processes will be adopted, since Attia et al. (2009) found that most building performance simulation tools were found not compatible with architects' working methods. Communication and co-ordination among designers is also highly important, as a lack of such behaviour has been the cause of building envelope failures (Rivard et al., 1999).

The process of façade design is complex and requires a multi-disciplinary approach (Jin et al., 2011; Oliveira and Melhado, 2011), with project teams recommended to comprise of the design team, project owner and assistants, design coordinator, façade supplier, contractor, and assembler (Oliveira and Melhado, 2011). The cladding supply chain is also multidisciplinary, with participants including the client, design team, main contractor, specialist sub-contractors, and manufacturers (Du and Ledbetter, 2006). Moreover, "*the complexities and diversification of cladding techniques and materials result in that few architects have sufficient knowledge to design the cladding independently and other designers from different parties are involved, particularly cladding specialists, making the cladding design a cooperative work*" (Du and Ledbetter, 2006: 1).

According to Silva et al. (2016), construction industry stakeholders currently select façade cladding systems according to such factors, as: visual appearance, thermal performance, acoustic performance, the type of support required, and the cost of the materials applied, with designers generally basing decisions on commercial documents that enable the ready fulfilment of performance requirements from the point the building is put into use. Moreover, designers apparently rarely "*consider other properties, whose analysis is more complex, such as: (i) the ageing of materials in situ, i.e. the interaction between time and the elements that constitute the cladding system; (ii) the interaction between the materials applied in the* *cladding and environmental exposure conditions; (iii) the potential effects of changes in material's performance in the overall performance of the assembly*" (Silva et al., 2016: 4).

The building retrofit process includes various AEC industry roles, the building's owner, and sometimes also the building's occupants. BCA (2010) describe the AEC industry personnel that are deemed to aid each step of their six-step retrofit process, including such roles as: facility manager, architect, engineering consultant, and façade contractor (Table 2-1 in Section 2.2.1). For their five-phase retrofit process, Ma et al. (2012) mention the building owner/agent and ESCO in relation to Phase one, and the building owner and occupants in relation to Phase five (Figure 2-1 in Section 2.2.1). Stakeholders, whose cooperation and participation is required for sustainability retrofit, are listed by Miller and Buys (2008) as being: owners, managers, occupants, and contractors. Menassa and Baer (2014) report the involvement of five main stakeholder categories of in building retrofit: tenant, owner, facility manager, designer, and environmental compliance representatives. While, Strachan and Banfill (2012) state that improving non-domestic building energy performance through energy-led refurbishment is usually the responsibility of property or facility managers.

With regards to office building retrofit, the stakeholders include owners, designers and contractors (Yang and Lim, 2007). Furthermore, Shao et al. (2014) list such stakeholders as including, but not limited to: owner, tenant, design team (consisting of designers and consultants from multiple disciplines), and the maintenance and operational team.

### 2.5.3 Methods used to aid office building façade retrofit decision-making

A review of literature pertaining to office building façade retrofit decision-making found few studies that met the criteria required by this thesis. Of the retrofit studies in the literature, not all include work to the façade, as decision-makers can choose to target other aspects (e.g. lighting) to reach required results, and of the studies that featured façade retrofit, not all describe the decision-making process leading to the façade selection. Femenías and Fudge (2010) for example, outline various non-domestic building retrofit projects, including the addition of a super-insulated glass façade to Hamilton House, a 1970s office block in Bristol, but provide no details of the façade decision-making process. Other such real-life examples are the re-cladding of Madou Tower in Brussels (Lawson, 2008), No.1 Neathouse Place in London (Gold and Martin, 1999), and 35 Newhall Street in Birmingham (ARUP, 2009); and the over-cladding of Fitzrovia in London (Connolly, 2009), CIS Chief Office in Manchester (ARUP, 2009), and Warwickshire Borough Council Offices (Kingspan, 2011).

Nine case studies were found to meet this thesis' requirements for studies of office building façade retrofit decision-making (Table 2-15). Six cases report the façade selection process for retrofit projects that occurred in real-life[16], while three cases are theoretical. Normative decision-making was demonstrated in the form of the payback period method by one real-life and one theoretical case, and by multi-criteria analysis by a further theoretical case. The decision-making process for the real-life cases is discussed below, following which, the theoretical cases are discussed.

*Real-life cases of office building façade retrofit decision-making*

The real-life cases – Elizabeth II Court (Bunn, 2011), North Wales Police (Bunn, 2012), Sparkasse Vorderpfalz (Ebbert, 2013), the Amoco Building (Hook, 1994), First Canadian Place (Chodikoff, 2012; Vossoughi, 2012), and the Angel Building (AHMM, no date-a; no date-b) – showed the use of numerous information sources in the façade retrofit selection process, relating chiefly to performance, aesthetics, collaboration, and cost.

The performance-related information included U-values, glazing ratios, energy calculations, building modelling, site visits, weather data, building use study, target air permeability, $CO_2$ emission targets in relation to Energy Consumption Guide 19, pre-refurbishment occupancy survey, 3D computer analysis, pre-construction engineering analysis, local climatic conditions, comparison with historical studies, material specifications, using lessons learned from the

[16] This thesis defines 'real-life' case studies as involving a façade retrofit that has taken place, and thus describes decision-making methods and sources of information that have been used in practice in the AEC industry. The theoretical cases studies may use real-life building data, but the retrofit scenarios have not occurred in actuality.

past, and finite element analysis. For the North Wales Police building, "*it was vital that the main contractor took ownership of the carbon dioxide emission reduction target, and that no decisions adverse to that target were taken*" (Bunn, 2012: 5).

For Sparkasse Vorderpfalz, the original building and the refurbishment design were tested via thermodynamic simulation, so as to enable an evaluation of the building's future energy-saving potential. While, for the 82-storey Amoco and the 72-storey First Canadian Place, field and laboratory tests were conducted on the existing cladding, to determine the reason for the marble failing in-use, prior to specifying the replacement material. These tests included in-situ load testing, wind tunnel tests, and a laboratory accelerated weather test. The failed Carrara marble panels on the Amoco building were replaced with thicker and stronger panels of Mount Airy granite, while on First Canadian Place, the new façade materials featured triple laminated tinted glass panels.

With regards to aesthetics, the Angel building façade design originated from massing studies and comparisons with early modern buildings, while physical and computer modelling were used at a later stage to explore such aspects as façade colour, height and depth of entrances, and frit banding. Mock-ups of the Sparkasse Vorderpfalz building's original façade panels with different new coatings were used to evaluate colour, reflectivity, and weather resistance. While due to the iconic appearance of the Amoco building and First Canadian Place, the colour of the original Carrera marble cladding guided its replacement with white Mount Airy granite for the former and tinted glass panels for the latter.

Collaboration was shown in relation to the facades' aesthetics and technical performance. The architect and the mechanical and electrical engineer, for the Elizabeth II Court retrofit project, "*had worked together before and were familiar with blending architecture and engineering*" (Bunn, 2011: 2). For the Amoco building, the building's owners and the engineers collaborated to evaluate replacement material. While for First Canadian Place, the design team had extensive discussions with the glass manufacturers to confirm the material selection. According to Vossoughi (2012), "*communication, a collaborative team effort, and* *input from the many stakeholders in the decision making process is key to success*" in complex projects, such as the re-cladding of First Canadian Place.

In regards to cost, a Velfac panel based system was chosen over aluminium curtain walling for Elizabeth II Court on grounds of cost, while its project design team were described as committed players who were able to cope with challenges within the project, e.g. cost and value engineering. Life cycle costs, combined with simulation, formed the basis of the decision-making for Sparkasse Vorderpfalz; while the preliminary cost estimate for the North Wales Police building, calculated at the feasibility stage, included capital and whole-life cost.

*Theoretical cases of university building façade retrofit decision-making*

The theoretical cases – a bank data centre (Fabrizio et al., 2006), an office building (Martinez et al., 2012), and Cours de Rive (Rey, 2004) – used normative decision-making, in the form of the payback period method and multi-criteria analysis, for the comparison of façade retrofit scenarios, with input information relating chiefly to performance and cost.

For the bank data centre, the payback period method is used to compare three re-cladding options. Building simulation was used to model the building to determine heating and cooling demands, while the calculations also included hourly weather data. Performance and cost are the focus of the façade retrofit; however, it is expected that other benefits will result from the retrofit, e.g. reduced maintenance, improved building image, and increased occupier comfort, though these aspects do not appear to be included in the options' evaluation.

The payback period method is again used for an office building in Los Angeles, in which different levels of exterior insulation were evaluated using cascade analysis, with the best option shown to involve the application of two-inch thick polyisocyanurate. In modelling the building, for carrying out the analysis, input information included original drawings, site visits, real weather data, energy bills for electricity and gas, and building codes.

For the Cours de Rive building, three strategies were evaluated from which the double-skin façade strategy was found to represent the highest level of performances for each weight.

This structured multi-criteria method of assessment simultaneously takes into account environmental, sociocultural, and economic data, for which the building was modelled using existing data and cost estimations.

Table 2-15  Examples of office building façade retrofit decision-making

| Source | Building name | Building location | Original build date | Façade typology[1] | | Decision-making methodology[2] | | | Decision-making context[3] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Over-cladding | Re-cladding | Normative | Descriptive | Information sources | Real-life | Theoretical |
| Bunn, 2011 | Elizabeth II Court (East) | Winchester, UK | 1960s | - | ✓ | - | - | ✓ | ✓ | - |
| Bunn, 2012 | North Wales Police | Colwyn Bay, UK | 1970s | - | ✓ | - | - | ✓ | ✓ | - |
| Fabrizio et al., 2006 | Bank data centre | Torino, Italy | 1970s | - | ✓ | ✓ | - | ✓ | - | ✓ |
| Martinez et al., 2012 | Office building | Los Angeles, USA | 1972 | ✓ | - | - | - | ✓ | - | ✓ |
| Ebbert, 2013 | Sparkasse Vorderpfalz | Ludwigshafen, Germany | 1974 | - | ✓ | ✓ | - | ✓ | ✓ | - |
| Hook, 1994 | Amoco Building | Chicago, USA | 1974 | - | ✓ | - | - | ✓ | ✓ | - |
| Chodikoff, 2012; Vossoughi 2012 | First Canadian Place | Toronto, Canada | 1975 | - | ✓ | - | - | ✓ | ✓ | - |
| Rey, 2004 | Cours de Rive | Geneva, Switzerland | 1978 | - | ✓ | ✓ | - | ✓ | - | ✓ |
| AHMM, no date-a; AHMM, no date-b | Angel Building | London, UK | 1981 | - | ✓ | - | - | ✓ | ✓ | - |

Notes:

1. The façade retrofit typologies are defined in Section 2.2.4.
2. The decision-making methodology presented in this table reflects the methods and information sources as reported in the cases, with no implications drawn from the data source.
3. This thesis defines 'real-life' case studies as involving a façade retrofit that has actually taken place; thus, the decision-making methods and sources of information have been used in practice in the AEC industry. The 'theoretical' cases studies may use data from 'real-life' buildings, but the reported retrofit scenarios have not occurred in actuality.

## 2.6 Summary

Due to the ageing stock and associated poor levels of specification, many existing office buildings in the UK are likely underperforming in energy efficiency terms, while also being at risk from structural vacancy and obsolescence. Ageing buildings can benefit from retrofitting, with work to the façade sufficient in producing desired results for most existing buildings.

Variability was found to exist in the terminology used to describe the terms building retrofit, renovation and refurbishment, thus this thesis has chosen to define *building retrofit* as: work to an existing building that involves the use of components not present on said building when originally constructed, and which improves the building's fabric, comfort conditions, and thermal performance. Work carried out on the façade of an existing building can be described by four generic typologies: over-cladding, re-cladding, refurbishment, and retained façade. To complement this thesis' chosen definition of building retrofit, this thesis includes in its focus the two façade retrofit typologies deemed as having the highest potential for improving a building's thermal performance and image: *over-cladding* and *re-cladding*.

Decision-making is shown to be a complex area, with decisions often made under conditions of uncertainty. Decisions are based on internal and external sources of information, for which in some cases, the frequency of use was linked to accessibility, rather than quality. Decision theory prescribes that structured (normative) decision-making enables a decision-maker to arrive at a well-reasoned course of action. However, the literature shows that rather than basing decisions on well-deliberated calculations, people can tend towards basing decisions on past experience and built-in norms. Personnel involved in the realm of façade retrofit are typically: client/owner, architect, design team, advisors (e.g. structural engineer, quantity surveyor), façade/cladding supplier, contractor, regulatory bodies such as planning and building control, and tenants/occupants. The presence of so many different roles in construction, coupled with the difficulty associated with achieving a general consensus in multidisciplinary teams, such as those required for façade design, adds to the complexity of the AEC industry decision-making arena.

The literature revealed nine cases of office building façade retrofit, which contained both a description of the retrofitted façade and the decisions leading to the façade selection. These cases featured one incidence of over-cladding and eight of re-cladding. Six of the cases were real-life and three were theoretical. Normative decision-making was demonstrated in the form of the payback period method by one real-life and one theoretical case, and by multi-criteria analysis by a further theoretical case. The real-life cases showed a widespread use of multiple sources of information, such as U-values, energy calculations, building modelling, site visits, and weather data. Overall, case studies of successfully completed office building retrofit projects that describe both the façade retrofit and the decision-making process leading to the façade selection are scarce, highlighting a gap in the knowledge[17].

Office façade retrofit selection is an important task, which is carried out under challenging circumstances. Hence, this thesis aims to discover how decision-making can be used to support multi-storey non-domestic building façade retrofit selection in the UK AEC industry. The following chapter sets out the methodology for conducting this investigation.

[17] A lack of studies relating to the practices and successful projects in building retrofit, office retrofit, and façade retrofit was highlighted by Ardente et al. (2011), Yang and Lim (2007), and Martinez et al. (2015) respectively.

# 3. Methodology

## 3.1 Introduction

The previous chapter reviewed the state-of-the-art in ageing office buildings, façade retrofit, and decision-making. The ageing nature of office buildings, together with their typology from key eras of construction, energy use and retrofit cycle, were first examined. This highlighted the necessity of façade retrofit, which was defined and its influencing factors and benefits discussed. The nature of decision-making, both in general and in façade retrofit, coupled with the AEC industry's complex prototypical project-based approach, was then found to indicate an environment that was deemed to benefit from structured, normative forms of decision-making. Decision theory however suggested that decision-making in reality tends towards unstructured, descriptive methods, though this latter finding was not evidenced in the literature pertaining to office building façade retrofit. It was thus concluded from the state-of-the-art review that a gap exists between office building façade retrofit decision-making in knowledge and in practice that warrants further investigation.

This chapter presents the methods that are used to implement the investigation within the framework of three main research steps: an **exploratory study**, involving semi-structured interviews and a case study; an **in-depth study**, involving a specific literature review and case studies; and a **critical review** that draws recommendations following a comparison of the findings from the literature review, and the exploratory and in-depth studies.

## 3.2 Philosophical considerations

In presenting the methodology or the "*philosophical stance or worldview that underlies and informs*" the style of this investigation (Sapsford, 2006: 175), this section first describes the proposed "*philosophical worldview*"; it then presents the defining characteristics of this worldview and describes how it informed the research (Creswell, 2009: 6).

This thesis is concerned with exploring and understanding the decision-making processes used in façade retrofit selection for non-domestic buildings. The overarching worldview of this research is thus social constructionism, a worldview that believes in a subjective reality, in which the researcher, helped by the research participants, using research methods such as interviews, seeks to understand "*the multiple social constructions of meaning and knowledge*" (Robson, 2011: 24). Social constructionism is a very open approach that "*does not proscribe or prescribe any specific or particular way of doing research*" (*ibid.*). The exploratory and in-depth studies conducted for this thesis adopt a mixed methods approach to data collection and analysis, which has a strong qualitative nature "*that honors an inductive style, a focus on individual meaning, and the importance of rendering the complexity of a situation*" (Creswell, 2009: 4). Within the mixed methods approach, the qualitative research is complemented and strengthened by quantitative data collection and descriptive methods of analysis (Creswell, 2009). The empirical nature of the overall research approach uses "*data based on direct or indirect observation as the main way to find out about the world*" (Dunbar, 1995: 12).

### 3.3 State-of-the-art literature review

The aim of the state-of-the-art in non-domestic building façade retrofit decision-making literature review is twofold: firstly, it identifies literature, in particular other studies, which are of relevance to the area of investigation; secondly, it provides a benchmark to which the semi-structured interview and case study findings from this thesis can be compared (Creswell, 2009). The review was ongoing for the duration of the investigation.

The review examines literature pertaining to non-domestic building façade retrofit decision-making, with a focus on office buildings. The characteristics of the office building stock are discussed. Building façade retrofit, the factors influencing the decision to retrofit, and the retrofit cycle are reviewed. The use of normative decision theory that states how decisions *should* be made is reviewed in parallel with descriptive theory, which is how decisions are *actually* made (Hazelrigg, 2012). The exemplifying case studies' sampling (Section 3.6) resulted in the in-depth study focusing on university buildings (Figure 3-1). A specific literature review, complementary to the state-of-the-art review, is thus conducted to present the context of university building façade retrofit decision-making (Section 5.2).

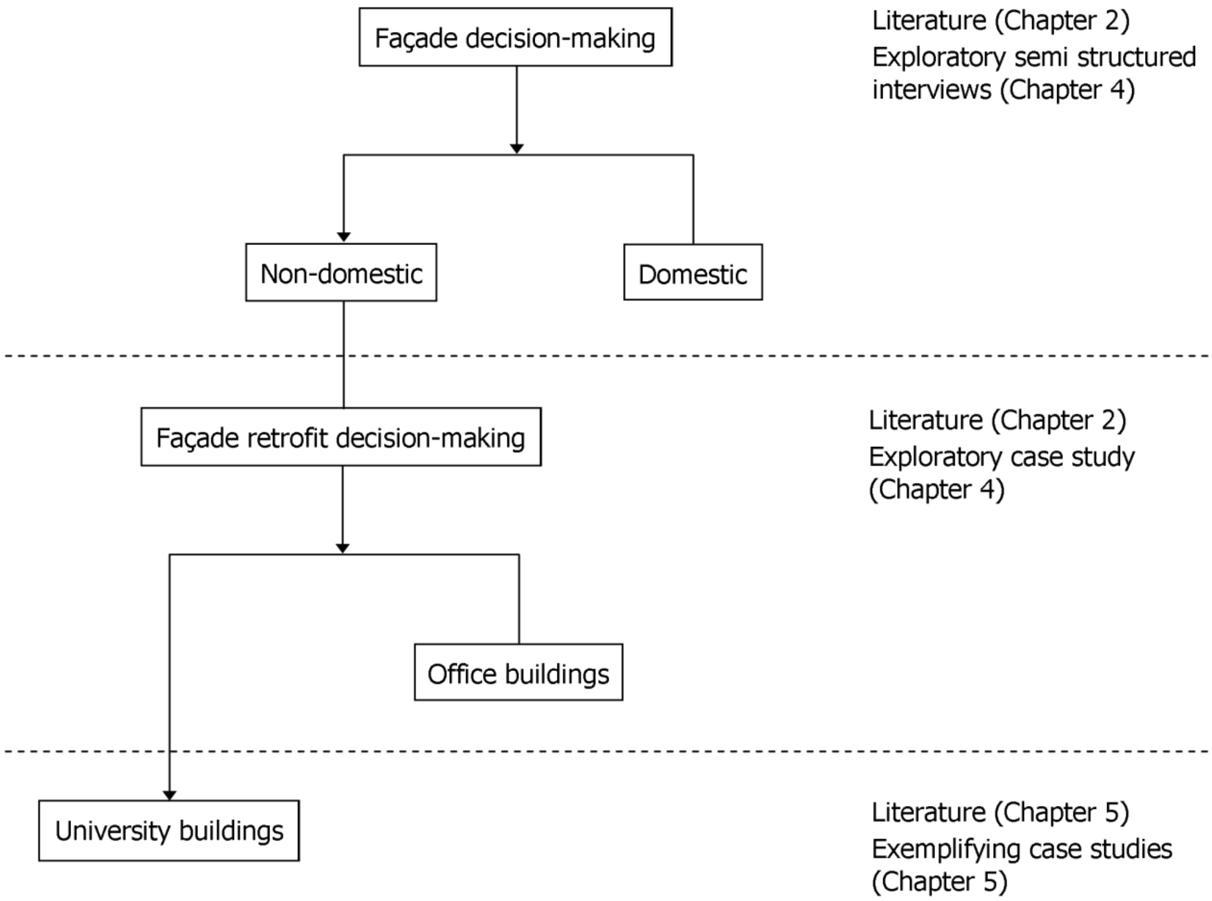


Figure 3-1 Evolution of the unit of analysis

### 3.4 Research design

Combining the research aim and objectives, with the state-of-the-art literature review described in Chapter two, the following research design has been developed (Figure 3-2):

The **first step** explores real-life façade decision-making in UK practice through 30 semi-structured interviews with members of the UK AEC industry, and façade retrofit decision-making via a UK office building façade retrofit case study. The **second step** facilitates an in-depth study of façade retrofit decision-making via four exemplifying building façade retrofit case studies located in three UK universities. The case study data collection for **steps one** and **two** involve real-life façade retrofit selection in UK practice, with case study interviewee sampling consisting of AEC industry experts with specific knowledge in façade retrofit. The case study interviewee findings, combined with a documentary evidence review of project-related information, e.g. the Employer Requirements and procurement documents, and thermographic surveys of the completed retrofitted façades enabled data triangulation, for corroboration of the research findings. The **third step** critically reviews the research findings from the state-of-the-art literature review and the exploratory and in-depth studies, including a cross case comparison of five typologically-similar façade retrofit projects, to gain a deep understanding of the real-life phenomenon of façade retrofit decision-making. This final step aids in the development of recommendations for use in practice by UK AEC industry façade retrofit decision-makers in UK building façade retrofit selection.

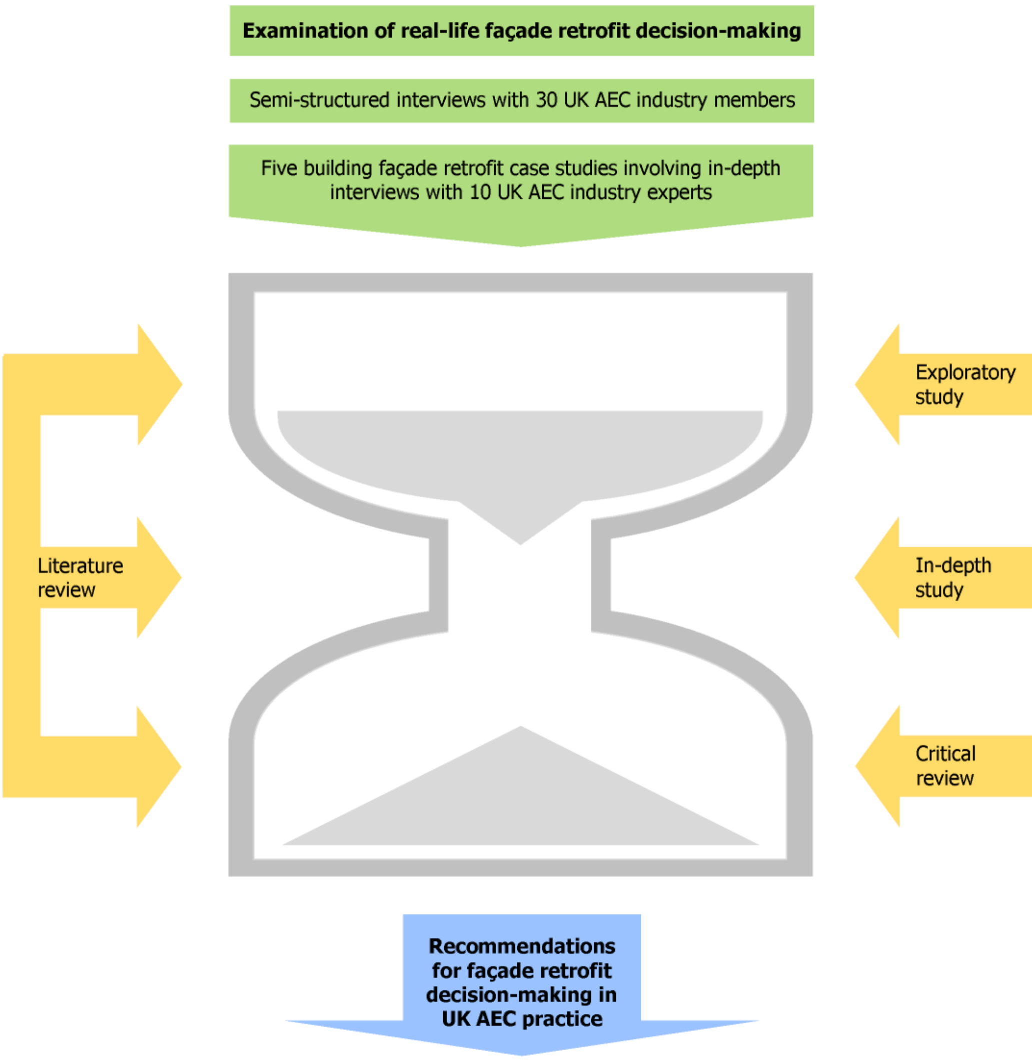


Figure 3-2 Research design

### 3.4.1 Exploratory study

In order for this investigation to produce robust results that are of benefit to the UK AEC industry, an exploratory study is first used to discover the state of façade retrofit decision-making in today's AEC industry (Davis, 2006). This study involves semi-structured interviews with AEC industry members and a case study of a building façade retrofit project.

To gain an insight into multi-storey building façade decision-making in practice, the opinions of 30 UK AEC industry members are explored using semi-structured interviews[18]. The reason being that semi-structured interviews enable the interviewees to reveal their opinions of the decision-making process, while allowing the investigator the necessary "*latitude to ask further questions in response to what are seen as significant replies*" (Bryman 2012: 212).

To investigate the real-life phenomenon of façade retrofit decision-making, a case study is carried out to explore the façade selection for a UK commercial office building retrofit project. The exploratory case study building was recruited via convenience sampling. A convenience sample is one that is available to the researcher because of its accessibility (Bryman, 2012). Convenience sampling may not always result in an ideal sample in terms of the population it represents, but it does not follow that the sample will be unacceptable (*ibid.*). Convenience sampling is an accepted method when "*getting a feeling for the issues involved*" is the chief aim of an exploratory study (Robson, 2011: 275). The case study building's convenience sampling was conducted in line with specific search criteria, as mentioned in Section 4.3.2.

The exploratory case study involved in-depth interviews with two UK AEC industry experts, a documentary evidence review of project-related documents, and thermography of the retrofitted façade. According to Yin (2009: 106), interviews are "*one of the most important sources of case study information*", of which one type is the in-depth interview[19]. In-depth interviewing is also known as unstructured interviewing (Legard et al., 2003; Berry, 1999),

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[18] The semi-structured interviews were conducted in the early stages of the study, prior to the retrofit focus.

[19] Other types of case study interview include the focused interview, which is likely to follow a set of questions, and the formal interview, which is similar to a survey in that its questions are more structured (Yin, 2009).

though the term is becoming more commonly linked to both semi-structured and unstructured interviewing (Bryman, 2012).

In-depth interviews are used to ask "*key respondents about the facts of a matter as well as their opinion about events*" (Yin, 2009: 107) and are most suited to situations requiring depth of information to be elicited from relatively few people (Guion et al., 2011). Four key features exhibited together by in-depth interviews mean they are almost always conducted face-to-face: 1. the interview combines structure with flexibility, with even the most unstructured interview based around an issue/s that the researcher wishes to explore; 2. the interview is interactive in nature, with the interviewee encouraged to speak freely in response to an initial question/topic and their response determining further interventions by the interviewer; 3. the interviewer uses probes to explore beyond an interviewee's initial surface level response to achieve a better understanding of the interviewee's answer; and 4. the interview is likely to aid in the generation of new knowledge or thoughts as a result of interviewees being invited to explore new avenues of thought, to put forward ideas and suggestions on a topic, or to propose solutions to a problem (Legard et al., 2003).

In-depth interviewing usually produces qualitative data and is thus also called qualitative interviewing (Berry, 1999). Patton (1987) describes three basic approaches to qualitative interviewing: 1. *the informal conversational interview*: resembling a chat, the interviewer is at liberty to ask questions as necessary, making this form of interview useful for exploring topics; 2. *the general interview guide approach*: commonly known as a guided interview, a pre-prepared basic checklist is used to ensure specific topics are covered, but the interviewer is still free to explore and ask questions as required; and 3. *the standardised open-ended interview*: open-ended questions are prepared in advance to minimise variation in the interview delivery, making this type of interview suited to situations where two or more researchers are involved, though probing is still possible. This thesis' in-depth interviews follow the guided interview approach, with an interview sheet being used to guide the dialogue on two specific topics: the building retrofit and the selection of the building façade (see Appendix F). In line with Corbin and Strauss (2008), the author only probed for deeper meaning on points arising in the interview after the interviewee had finished their narrative.

Depending on the level of assistance received from an in-depth interview participant, their role in the case study may be considered that of an informant rather than a respondent (Yin, 2009). However, care must be taken to avoid becoming overly reliant on the information received from one key informant, and thus, the inclusion of other data sources is recommended for corroboration purposes (*ibid.*). Hence, this thesis' case study design involves the collection of data from other sources for the purpose of data triangulation.

Data triangulation is a "*valuable and widely used strategy*" (Denzin, 1988b, cited in Robson, 2011: 154) in which information is collected from a variety of sources with the aim of *corroborating the same phenomenon* (Yin, 2009). While "*triangulation can help to counter all of the threats to validity…[it also] opens up possibilities of discrepancies and disagreements between the different sources*" (Robson, 2011: 158). The potential for disagreement between sources is however seen as an acceptable risk in this case. The retrofit project was completed prior to the case study taking place; thus, any data sources were welcomed during the data collection stage that could assist in corroborating events where memory recall is concerned. Data sources exhibiting discrepancies during the analysis stage may require further data collection for clarification, e.g. by the conducting of further in-depth interviews. If, after the analysis has been conducted, "*events or facts of the case study*" are not supported by more than a single source, the data could be said not to have been "*really triangulated*" (Yin, 2009: 116). To optimise the quality and appropriateness of the data to be used in the triangulation process, and thus minimise the possibilities of discrepancies between sources, the case study was conducted in accordance with a pre-agreed case study protocol. The protocol, which was approved by the case study company prior to commencement of the case study, also served to guide the investigators in the overall case study process (Yin, 2009). The protocol can be seen in Appendix G.

The exploratory study's data collection and analysis adopts a mixed methods approach, as mentioned in Section 1.4.2. The qualitative data arising from the semi-structured interviews, and from the case study's in-depth interviews and documentary evidence review, is evaluated using thematic analysis. The quantitative data arising from the documentary evidence review, and the quantitative and quantitised qualitative data arising from the semi-structured interviews and in-depth interviews, is analysed descriptively.

The methods used for the exploratory study's data collection and analysis are presented in detail in Sections 4.2 and 4.3. The findings are presented separately for the semi-structured interviews (Section 4.4.1) and the case study (Section 4.4.2). In line with the ethical stance adopted by this thesis, the identity of all research participants is anonymised during the presentation of the results and in the discussion of the findings. Interviewee reference numbers have been applied for use when referring to individual participants' responses. As the level of confidentiality promised to the participants includes non-use of direct quotes, any interviewee responses, including the raw data derived from the participants' responses to the full set of interview questions (as provided in Appendix I) are summarised. In addition, the case study building's name and location are not given, the building's post-retrofit image is presented in partial form, and the EPC source is not cited, to maintain the confidentiality of the case study building. Note: where EPC information was not received from the case study company, it was obtained via the Non-Domestic Energy Performance Certificate register, which is operated by the Landmark Information Group on behalf of the UK Government.

### 3.4.2 In-depth study

This study seeks to obtain an in-depth understanding of the complex nature of façade retrofit decision-making via the exploration of exemplifying case studies. The case study recruitment involved a combined sampling strategy. The recruitment process initially adopted purposive sampling, whereby specific individuals were contacted and invited to participate because of their relevance to the research (Bryman, 2012). Purposive sampling is a form of non-probability sampling, in that samples are not chosen at random and thus do not exhibit a known probability of being selected from a population (*ibid.*). These contacts, on having no suitable building projects to case study, recommended other projects that may be of interest, and other AEC industry companies or members to contact, thereby introducing convenience and snowball sampling to the strategy. Convenience sampling, as mentioned in Section 3.4.1, and snowball sampling are further forms of non-probability sampling, with snowball sampling also being a form of convenience sampling commonly associated with qualitative research in which individuals, contacted because of their relevance to the research, assist in establishing contact with others (*op. cit.*). Snowball sampling is a useful method where difficulty is experienced in identifying members within a research population (Fellows and Liu, 2008; Oliver, 2006). However, due to the way the sample is selected in convenience and snowball sampling, there may be the possibility of significant bias (Fellows and Liu, 2008). The changing nature of the exemplifying case studies' sampling strategy influenced the unit of analysis' evolution from office buildings to university buildings, of which the latter is an acceptable exemplification of the office building typology (Ebbert, 2010). Thus, four exemplifying case studies, from three UK-based universities, are conducted: an office and laboratory building; music facility; office and music building; and an arts and media building.

The rationale for conducting four exemplifying case studies is based around the issue of time. Time constraints are a valid and practical consideration in research, as described by Monette et al. (2013) in relation to five factors: 1) the readily availability or sparseness of the target population, and the related ease or difficulty and time required to obtain subjects; 2) the time required to develop and refine the data gathering techniques; 3) the time required for the actual data collection; 4) the time required for the data analysis, which generally sees less structured data requiring more time; and 5) the time required to write up the research. In this thesis, factors 1, 3 and 4 were particularly pertinent; especially factor 1, which influenced the use of a combined sampling strategy for the exemplifying case study buildings, as described above.

To produce findings that facilitate comparison, the exemplifying case studies are conducted in-line with the exploratory case study protocol (see Appendix G). The exemplifying case studies thus adopt a mixed method approach, as mentioned in Section 1.4.2, involving the collection of qualitative and quantitative data from in-depth interviews with UK AEC industry experts, a documentary evidence review, and thermography of the retrofitted façades. The qualitative data is analysed thematically, while the quantitative and quantitised data is analysed descriptively. The in-depth study's research participants, and methods for data collection and analysis, are presented in detail in Section 5.3. Data triangulation is used to corroborate the case study findings, as mentioned in Section 3.4.1.

The in-depth study findings are presented in the form of individual case study reports in Section 5.4. In line with the ethical stance adopted by this thesis, the identity of all research participants is anonymised during the presentation of the results and in the discussion of the findings. Interviewee reference numbers have been applied for use when referring to individual participants' responses. As the level of confidentiality promised to the participants includes non-use of direct quotes, any interviewee responses are summarised. In addition, the case study buildings' name and location are not given, the buildings' post-retrofit images are presented in partial form, and the EPC and DEC sources are not cited, to maintain the confidentiality of the case study buildings. Also, the titles of the case study thermographic survey reports have been changed to avoid mentioning the names of the case study buildings and companies; permission to adopt new anonymised titles for these survey reports having been granted by the report authors. Note: where the EPC or DEC information was not received from the case study company, it was obtained via the Non-Domestic Energy Performance Certificate register, which is operated by the Landmark Information Group on behalf of the UK Government.

### 3.4.3 Critical review

The critical review of the research involves comparing the findings from the state-of-the-art literature review, with that of the exploratory and in-depth studies. The critical review is conducted by means of thematic analysis using the repetition technique.

Owing to the AEC industry's prototypical nature, this thesis acknowledges a potential difficulty in drawing comparisons from its research findings with the 'population' as a whole, being that its literature reviews, semi-structured interviews, and case studies pertain to discrete AEC industry projects. A case study typology used during the exemplifying case study sampling process, as mentioned in Section 5.3.2, assisted in the case studies exhibiting similarities that are deemed to somewhat eradicate the difficulty in drawing comparisons. Thus, the five studies are representative of multi-storey office buildings, are of similar construction date and type, and have received a similar level of retrofit (Table 3-1).

Table 3-1 Case study building typology

| Case building[1] | Case reference | UK-based, maritime climate | Represents office buildings | Structural concrete[2] | Exterior insulation system[3] | Over-cladding | Re-cladding | Number of storeys | 1960s-1990s construction | Original construction date |
|---|---|---|---|---|---|---|---|---|---|---|
| Commercial office | Exploratory | ✓ | ✓ | ✓ | ✓ | ✓ | - | 5 | ✓ | 1971 |
| Office and laboratory | A1 | ✓ | ✓ | ✓ | - | ✓ | ✓ | 4 | ✓ | 1962 |
| Music | B1 | ✓ | ✓ | ✓ | ✓ | ✓ | - | 2 | ✓ | late-1950s/early-1960s |
| Office and music | B2 | ✓ | ✓ | ✓ | ✓ | ✓ | - | 2 | ✓ | 1969/70 |
| Arts and media | C1 | ✓ | ✓ | ✓ | ✓ | ✓ | - | 7 | ✓ | 1971 |

Notes:

1. Each case building's façade retrofit had been completed prior to case study commencement.

2. The case buildings' structural concrete ranged from in-situ to pre-cast concrete (PCC) panels, with each building featuring either partial or completely exposed concrete elements.

3. The original façade was removed from case study A1's south and north elevations, and retrofit components, which included insulated panels, were externally fitted into the framework of the existing structure. Uninsulated over-cladding was added partially to its east and fully to its west elevations.

From the outcome of the critical review, recommendations are developed for use by UK AEC industry decision-makers in UK building façade retrofit selection. The recommendations are considered as complementing certain aspects of façade retrofit selection: (i) aiding the façade retrofit decision-making process; (ii) helping to provide the right context for the achievement of good decisions; (iii) helping to ensure success in the completed retrofitted façade selection; and (iv) helping to engage building users in the changes associated with building retrofit.

### 3.5 Summary

This thesis seeks to deeply explore the theory and practice of decision-making in façade retrofit selection, and how it can be used to support façade selection in multi-storey non-domestic building retrofit. This thesis uses a mixed methods approach comprising chiefly qualitative data collection and analysis to enable the deep exploration of the unit of analysis. Mixed methods research is highly suited for determining why things are happening in a given situation and its use is not uncommon in the field of construction industry research.

This chapter presents the overarching methodological approach used to implement the three main steps in this thesis' research design: an exploratory study of façade retrofit decision-making, an in-depth study of façade retrofit decision-making, and a critical review of the research findings. Further details of the research methods used for the exploratory and in-depth studies' data collection and analysis are then presented in Sections 4.2 and 4.3, and Section 5.3 respectively.

This number of case studies conducted for this thesis is limited by the exemplifying case study building typology (as described in Section 5.3.2) and the need for completed cases. By enabling deep exploration, the research design however seeks to maximise the value to be gained from what could be viewed as a relatively small set of case studies. And moreover, as a result of using a case study typology, the case studies buildings are deemed typical of office buildings originally constructed from the late-1950s/early-1960s to the early 1970s, representative of the age of non-domestic buildings most commonly refurbished in the UK, and representative of the boom era in university construction, meaning this thesis' research findings are deemed as having relative value to their given populations.

In terms of the key players involved in the façade selection process, the architect and client were shown by the literature review as playing a key role in the decision-making process, thus these roles were set as the minimum interviewees per case study. Four of the case studies thus feature in-depth interviews with both the retrofit project's architect and client. One case study (A1) did not feature an architect interviewee (difficulties were experienced in general with the data collection for this case); thus, the findings from this case rely heavily on the in-depth interview with the client, meaning the case could be deemed limited in value.

Planners were identified by the literature review and semi-structured interview findings as being key to the façade selection process and described as playing a commanding role in the decision-making process. However, due to the difficulty in obtaining LPA input for the semi-structured interviews (n=3 planning officers invited, with zero response), it was decided the case study planning input would be taken from each case studies' planning application documents. The planning documentation is deemed by this thesis as clearly evidencing the building work requested by the client and the LPA response, in terms of conditions, etc.

The ethical stance taken by this thesis (as outlined in Section 1.4.3 and described in greater detail in Appendix F) has guided the way its raw data is presented. Due to the confidentiality promised to the participants, the semi-structured and in-depth interview participants' names (interviewees and companies) are not given. Moreover, the responses gathered from the semi-structured interviews are presented in summarised form. The interviewees have been assigned reference codes to enable cross-referencing between the participants' profile (e.g. organisation type, as provided in Table 4-2) and the anonymised, summarised responses. To aid case study participation, this thesis did not record precise values associated with façade retrofit, instead choosing to use the term 'cost' in relation to this key influencing factor.

The following chapter presents the thesis' exploration of building façade retrofit decision-making in the UK AEC industry.

# 4. Exploratory study of office building façade retrofit decision-making

## 4.1 Introduction

The previous chapter presents the overarching methodology of this research. This chapter presents the first of the three main research steps used to implement this investigation: an exploratory study of office building façade retrofit decision-making.

## 4.2 Research methods: Semi-structured interviews

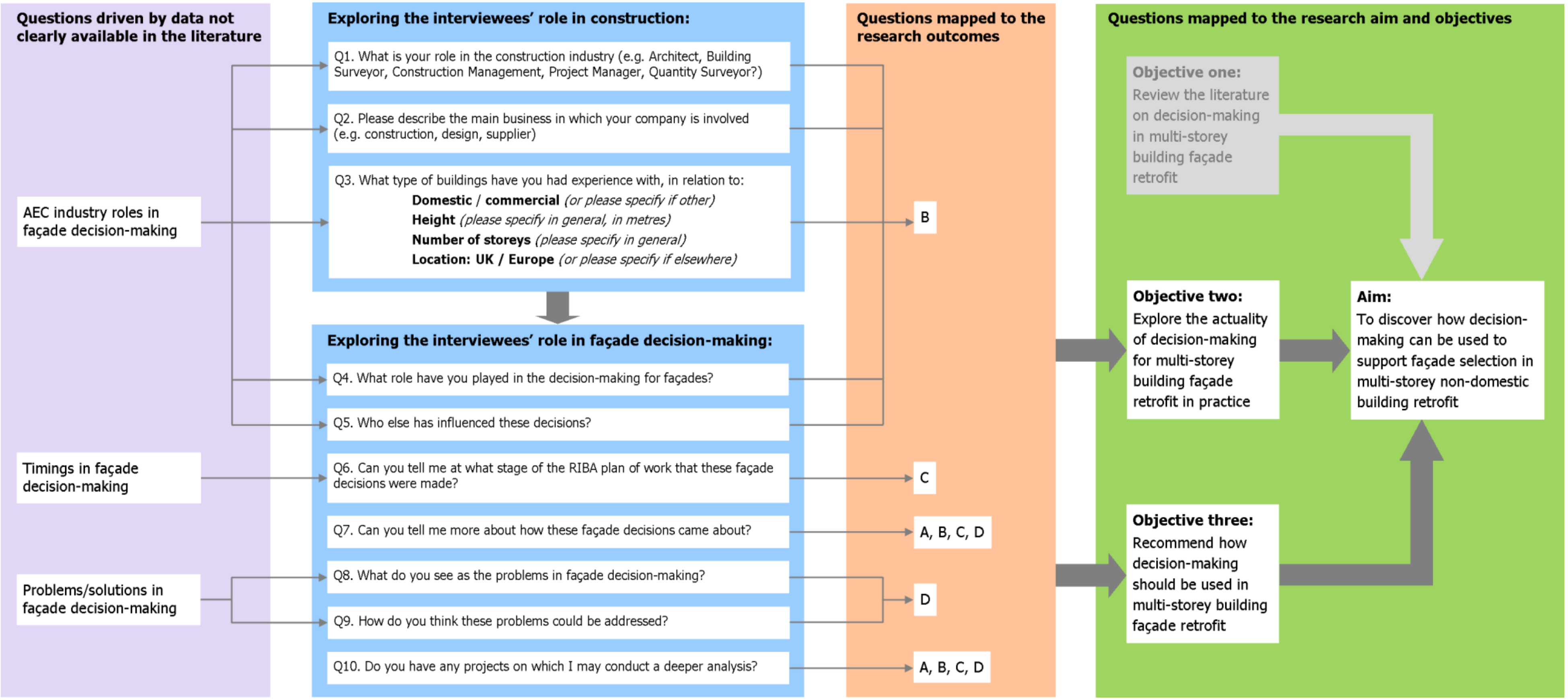
### 4.2.1 Aim and objectives

The semi-structured interviews assist in meeting this thesis' aim and objectives by helping to establish who makes façade decisions and when, and by helping to identify the problems and potential solutions in façade selection for multi-storey buildings in the UK AEC industry[20].

### 4.2.2 Data collection

The semi-structured interview is laid out over two sections (Figure 4-1). The first section uses open and 'semi-open' questions to ascertain the interviewees' construction experience, while the second section uses open questions to explore the interviewees' opinions of façade decision-making in the UK AEC industry. Open questions do not present the interviewee with an expected range of answers and are therefore highly suited to the exploration of a subject area (Bryman, 2012). Open questions can have the disadvantage of being time-consuming to analyse, since the interviewees are likely to provide much longer answers than with closed questions (*ibid.*); however, this disadvantage is deemed acceptable by the author in the face of the richness of the data that is likely to be derived. The 'semi-open' questions are not closed questions in the strictest sense, with a set number of responses (*op. cit.*), but were assigned suggested responses for the interviewee to either choose from or to act as a guide in making their response. Thus, questions 1-3, which are designed to ascertain the interviewees' construction experience, are termed 'semi-open'.

[20] The interviews assist in setting the context of façade decision-making in practice, prior to the evolution of this study's façade retrofit focus.




Notes: Research outcomes relating to the decision-making methods (A), decision-making roles (B), decision timings (C), and problems and solutions (D) in façade retrofit selection.

Figure 4-1 Semi-structured interview questions mapped to the aim and objectives

The design of some of the questions was driven by the literature review in Chapter two. While the literature provides a wealth of information relating to the AEC industry's multi-disciplinary approach and the team players/stakeholders involved in the process of constructing a building, data was not clearly available on the AEC roles involved in façade decision-making; this apparent lack of data drove the inclusion of Questions 1-5. Questions 6, 8 and 9, were likewise driven data relating to the timings, and problems/solutions in façade decision-making respectively not being clearly available in the literature. Moreover, to help determine the points (*timings*) at which façade decisions are made, Question 6 asks when façade decisions were observed in relation to the Royal Institute of British Architects (RIBA) Plan of Work 2007[21] (RIBA, 2009). Comprising of eleven stages, A-H and J-L, grouped under five headings, the RIBA Plan of Work 2007 serves to guide the management and design of building projects, and the administration of building contracts (RIBA, 2009):

| | |
|---|---|
| Preparation: | A - Appraisal, B - Design Brief; |
| Design: | C - Concept, D - Design Development (includes *Application for detailed planning permission*), E - Technical Design; |
| Pre-construction: | F - Product Information, G - Tender Documentation, H - Tender Action; |
| Construction: | J - Mobilisation, K - Construction to Practical Completion; and |
| Use: | L - Post Practical Completion. |

Question 7 is intentionally broad to allow the interviewee the freedom to expand on any aspect of façade decision-making they have encountered in the AEC industry. While Question 10, via access to a real-life case study, was expected to provide information on various aspects of façade decision-making: roles, methods, timings, and problems/solutions present.

The interview questions produce qualitative and quantitative data. The interview format was designed to support the achievement of the research aim, research objectives two and three, and the four research outcomes. Participants were provided with the question sheet and ethical information sheet in advance of the interview, to address the issue of memory recall

[21] At the time of writing, the latest version is the RIBA Plan of Work 2013 (RIBA, no date). However, at the point of participating in this research, the semi-structured interviewees were using the RIBA Plan of Work 2007.

and thus maximise the accuracy of the responses (Bryman, 2012). The question sheet was also sent in advance to help minimise the data collection time required of the respondents, with the aim that each interview should take approximately 20-minutes, though several interviewees kindly gave time over and above this target interview duration. Copies of the question and ethical information sheets can be seen in Appendix F.

Interviewee recruitment was conducted by means of purposive sampling (Robson, 2011), whereby members of the UK AEC industry, from categories identified from the literature as containing persons involved in building façade selection or construction project teams, were invited to participate in the research. The sampling thus targeted potential interviewees who were deemed to have the requisite knowledge to answer the questions (Bryman, 2012). The interviewee recruitment method also included an element of convenience sampling, as some individuals were known to the interviewer. Forty-nine UK AEC industry members were invited to be interviewed, of which 30 participated, giving a 61% participation rate (Table 4-1).

The number of industry members taking part in the semi-structured interviews (n=30) is acceptable in terms of achievability, while not being so large a number as to inhibit in-depth analysis (Warren, 2002, in Bryman, 2012; Adler and Adler, in Baker and Edwards, 2012). Twenty-six interviews were conducted face-to-face and four by telephone. Twenty-four face-to-face interviews and two of the telephone interviews were audio-recorded. The interview length ranged from just over 11 minutes to almost one-hour. The mean interview length was just under 34 minutes, while the median interview length was 29 minutes. Further details relating to how the interviews were conducted, i.e. interview date, length, and format are provided in Table 9-1.

The responses to questions 1-3: the semi-structured interviewees' industry position, plus an overview of their experience according to building type, and building height in metres and number of storeys are presented in Table 4-2. The interviewees' experience all relates to UK-based buildings. The responses to questions 4, 5, and 7-9, which reveal the interviewees' involvement in façade decision-making, are summarised in Table 9-8 and discussed in

Section 4.4.1. The responses to question 6 are presented in Figure 4-2 and discussed in Section 4.4.1. Tables 4-2, 9-1 and 9-8 show the reference assigned to each interviewee for ease of analysis.

Table 4-1 Industry category, role and function of the interview invitees and participants

| Category | Role | Function | Invited (no.) | Participated (no.) | Role/function participation rate (%) |
|---|---|---|---|---|---|
| **Project team** | **Client** | | **3** | **2** | **4** |
| | Representative | Client Representative | 3 | 2 | 4 |
| | **Advisor** | | **28** | **20** | **41** |
| | Design Leadership | Architect | 6 | 3 | 6 |
| | Design | Designer | 2 | 2 | 4 |
| | | Services Engineer | 1 | 1 | 2 |
| | | Structural Engineer | 2 | 1 | 2 |
| | Management | Construction Manager | 1 | 1 | 2 |
| | | Design Manager | 2 | 2 | 4 |
| | | Project Manager | 8 | 6 | 12 |
| | Financial | Quantity Surveyor | 6 | 4 | 8 |
| | **Constructor** | | **13** | **6** | **12** |
| | Overall responsibility | Contractor | 5 | 2 | 4 |
| | Direct contractor | Façade specialist and supplier | 8 | 4 | 8 |
| **Regulators** | | | **5** | **2** | **4** |
| | Local Authority | Building Control Officer | 2 | 2 | 4 |
| | | Planning Manager | 3 | 0 | 0 |
| **Totals** | | | **49** | **30** | **61** |

Table 4-2 Semi-structured interviewees: industry role, position, and experience

| Interviewees' industry role | Interviewees' industry position | Interviewees' industry experience | | | Interviewees' organisation type, size[2] and function | Interview reference |
|---|---|---|---|---|---|---|
| | | Building type[1] | Height - metres | Storeys | | |
| **Client** | Head of Estates Operations | C | ≤ 30 | 4-8 | Local, large, specialist | SS3 |
| n=2 | Energy and Environmental Manager | C | ≤ 30 | 4-8 | Local, large, specialist | SS10 |
| **Advisor - Design Leadership** | Architect | D | 5-8 | 2-3 | Local, small, specialist | SS2 |
| n=3 | Architect/Managing Director | D&C | 21 | 5-6 | Local, small, specialist | SS15 |
| | Architect | D&C | 15 | 2-5 | Local, small, specialist | SS23 |
| **Advisor - Design** | Senior Architectural Technologist | D&C | ≤ 100 | ≤ 23 | Local, small, specialist | SS7 |
| n=4 | Services Engineer/Regional Director | D&C | 9-12 | 3-4 | International, large, interdisciplinary | SS8 |
| | Structural Engineer | D&C | 12-15 | 3-4 | Local, large, specialist | SS20 |
| | Design Delivery Director | D&C | 24-27 (av. 8) | 2-9 | Local, small, specialist | SS21 |
| **Advisor - Management** | Project Manager | C | ≥ 28 | ≥ 8 | International, large, interdisciplinary | SS1 |
| n=9 | Chairman - Europe, Middle East and Africa | C | 75-100 | ≤ 26 | International, large, interdisciplinary | SS4 |
| | Project Manager | D | ≤ 48 | 2-20 | International, large, interdisciplinary | SS5 |
| | Building Surveyor | C | 5 | 2 | Local, large, interdisciplinary | SS14 |
| | Building Surveyor | D&C | 135 | 30 | National, medium, interdisciplinary | SS18 |
| | Senior Construction Manager/Estate Manager | D&C | ≤ 40 | 4 | National, medium, specialist | SS19 |
| | Design & Build Manager | D&C | 15-20 (max. 30) | 3-6 (max. 10) | National, medium, interdisciplinary | SS22 |
| | Contract Manager | D | 9 | 2-3 | Local, micro, specialist | SS26 |
| | Design Manager | C | 18 | 2-3 | International, large, interdisciplinary | SS27 |
| **Advisor - Financial** | Principal Surveyor | D | 20 | 5 | National, medium, interdisciplinary | SS16 |
| n=4 | Senior Quantity Surveyor | D&C | <20 | 1-5 | National, medium, interdisciplinary | SS17 |
| | Senior Quantity surveyor | C | 3-6 | 1-2 | National, medium, interdisciplinary | SS28 |
| | Senior Associate Director | C | 5-25 | 2-5 | National, medium, interdisciplinary | SS29 |
| **Constructor - Overall responsibility** | Managing Director | D | 12 | 4 | Local, small, specialist | SS6 |
| n=2 | Senior Project Manager | D&C | ≤ 72 | 3-24 | National, large, interdisciplinary | SS12 |
| **Constructor - Direct contractor:** | Senior Sales Executive | D&C | 4.8 | 2 | National, medium, specialist | SS9 |
| **Façade specialist and supplier** | Director of Business Development | D&C | 7-70 | 3-18 | National, micro, specialist | SS13 |
| n=4 | Specification Sales Representative | D&C | 9-18 | 3 (max. 6) | International, large, interdisciplinary | SS24 |
| | Sales Manager | D&C | 35-40 | 16-18 | National, large, interdisciplinary | SS30 |
| **Regulator - Local Authority** | Principal Building Control Surveyor | D&C | ≤ 18 | 2-4 | Local, large, interdisciplinary | SS11 |
| n=2 | Associate Surveyor | C (some D) | 9 | 3-4 | National, medium, specialist | SS25 |

Notes: 1. Domestic (D), commercial (C), and domestic and commercial (D&C); 2. Organisation size described in line with European Commission (no date) business class guidelines.

### 4.2.3 Data analysis

A mixed methods approach is used to analyse the multiple sources of data arising from the exploratory semi-structured interviews, as mentioned in Section 1.4.2. To prepare the semi-structured interviews' raw data for analysis, the interview audio-recordings were listened to and relevant sections typed up. The resulting qualitative data is evaluated thematically using the repetition technique, while the interviews' participation and length characteristics are descriptively analysed, and some qualitative responses to Question 6 are quantitised to allow graphical representation of the RIBA Work Stages in which façade decisions were observed (see figure 4-2 in Section 4.4.1).

## 4.3 Research methods: Exploratory case study

### 4.3.1 Aim and objectives

The exploratory case study assists in meeting the aim and objectives of this thesis by enabling an exploration of multi-storey building façade retrofit decision-making in practice in the UK AEC industry.

### 4.3.2 Data collection

*Exploratory case study building selection*

The case study exploration focuses on the decision-making involved in the selection of a new façade for an existing building. To achieve this focus, a case study building was recruited via convenience sampling, in line with specific search criteria. The case study building was required to be a UK office, with two or more storeys, which had received a façade retrofit; the retrofit project must be finished, to allow the whole façade selection process to be explored; and the project team involved in the façade selection needed to include players who were willing to talk, which at a minimum should include the Client and Architect.

*Exploratory case study data sources*

The exploratory case study aims to "*understand a real-life phenomenon in depth*", that of decision-making in office building façade retrofit selection (Yin, 2009: 18). To this end, the case study incorporates data triangulation, as mentioned in Section 3.4.1, for which data is gathered from multiple sources: in-depth interviews with key members of the project team involved in the façade retrofit selection, a documentary evidence review of project related documents (see Appendix J for a list of documentary sources reviewed), and thermography of the retrofitted façade (Table 4-3).

Table 4-3 Exploratory case study data collection

| In-depth interview[1] | | Documentary evidence review | Internal and external thermography of the retrofitted façade |
|---|---|---|---|
| Client | Architect | | |
| ✓ | ✓ | ✓ | ✓ |

Notes:

1. Further interview details, i.e. the length of interview, date conducted, and the reference assigned to each interviewee, are provided in Table 9-2 of Appendix A.

In recruiting interviewees from the resulting commercial office building retrofit project, any participants were required to have knowledge on various aspects of the case study façade retrofit, to include, but not be limited to: cost, technical function, and aesthetics. Two AEC industry members from the façade retrofit project team were invited to take part in the research, of which both accepted the invitation to participate. The two interviewees held roles in both the case study company[22] and the *retrofit project team*, as follows: 1. Managing Director (MD) *(Developer)* making decisions on material choices and external cladding during the planning stage, and carrying out value engineering (VE) to reach a build cost that met with the UK Government's financial restrictions on Self Invested Personal Pension (SIPP) borrowing[23]; and 2. Group Director *(Lead Architect)* involved from the Technical Design stage, which is from Stage E in the RIBA Plan of Work 2007 (RIBA 2009)[24]. 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*"

[22] The building is part-owned by the case study company, an architects practice, who also occupy the top floor.

[23] The retrofit project was funded by money borrowed against a SIPP, comprising a group of eight stakeholders that included the two case study interviewees: the *Developer* and the *Lead Architect*.

[24] The Work Stages in the RIBA Plan of Work 2007 are briefly described in Section 4.2.2.

(Kelly and Male, in El-Alfy 2010: 72); where the essence of 'value', as delivered to the owner, "*expresses three main forms: Cost, Function and Aesthetic*" (El-Alfy 2010: 72). Using European Commission (no date) business class guidelines to aid the description of the case study company's organisational size, the two exploratory study in-depth interviewees are deemed as coming from a local, small enterprise of a specialist nature.

The in-depth interviews, as mentioned in Section 3.4.1, provide one of the most important sources of information for this case study (Yin, 2009). The initial in-depth interviews (each approximately one-hour in length, conducted face-to-face and audio-recorded) invited the interviewees, the *Developer* and the *Lead Architect*, to talk freely on two specific topics: the building retrofit, and the selection of the building façade. To further explore the data gained from the initial in-depth interviews and the documentary evidence review of project-related documents, two further in-depth interviews were conducted with a key contact for the retrofit project, the Client[25]. The first of the additional interviews is one-hour in length and conducted face-to-face, while the second is 30 minutes in length and conducted by telephone; both were audio-recorded. A number of details from the exploratory in-depth interviews, i.e. interview length, date conducted, and the reference assigned to each interviewee for ease of analysis, are provided in Table 9-2 of Appendix A. The interview and ethical information sheets can be seen in Appendix F. Note: any identifying references to the case study building/company have been removed from these sheets.

A thermographic survey was conducted on the case study building to obtain an indication of the success of the retrofitted façade. As the case study building's retrofit project was completed prior to being recruited for this thesis, only post-retrofit thermography was conducted. For the survey, external thermography was conducted on the building's total façade, while internal thermography was conducted on Floor 4 only (the floor occupied by the case study company). A physical inspection of the case study building was carried out by

[25] In a multifaceted role, the MD for the case study company, which was part-owner of the case study building, acted as the *Client* and the *Developer* for the retrofit project.

the author and Matthew Fox on 20.06.12 to review the building's interior and exterior details in preparation for thermography. Architect's drawings of the case study building were also reviewed by Matthew Fox.

The thermographic survey was conducted by Matthew Fox (using a FLIR T620bx infrared camera) and assisted by the author, who made notes against the internal floor plans, site plan, and elevation drawings. The survey was conducted using a single image walkthrough-style thermographic survey, in accordance with BS EN 13187: 1999 (BSI, 1999). The survey was conducted pre-sunrise so as to capture images at a point when the building surface temperatures were equalised (Walker, 2004), and when a 10-degree Kelvin temperature difference existed between Temperature In and Temperature Out (UKTA, 2007) to aid the image resolution (see Table 4-4). See Appendix B for important notes regarding the case study thermography, plus Table 9-4 of Appendix B for further information on the key conditions required for thermography and the use of thermography in façade retrofit.

Table 4-4 Commercial office building thermographic survey conditions (compiled from Fox, 2012a)

| Survey conditions | Details |
|---|---|
| Survey date | 07.12.12 |
| Sunrise on the day of survey | 0752 |
| Survey start times | Start of the external survey: 0645<br>Start of the internal survey: 0730 |
| Survey end time | 0845 |
| Survey temperature In (°C)[1] | 19-20 |
| Survey temperature Out (°C) | About 5 |
| Survey weather conditions | Quite windy. Plus, it had been raining prior to the survey being conducted. |

Notes:

1. The exploratory case study building's normal daytime temperature was confirmed by the case study company Group Director, who was *Lead Architect* of the case study building's retrofit project.

### 4.3.3 Data analysis

A mixed methods approach is used to analyse the multiple sources of data arising from the exploratory case study, as mentioned in Section 1.4.2. To prepare the in-depth interviews' data for analysis, the interview audio-recordings were listened to and relevant sections typed up. Thematic analysis using the repetition technique is used to analyse the qualitative data arising from the in-depth interviews and the documentary evidence review, while descriptive analysis is used to graphically present the evolution of the façade elements as revealed by the in-depth interviews and documentary evidence review. The thermography findings are in the majority qualitatively assessed, while quantitative (simple spot temperature) analysis is used for the thermography findings identified as benefiting from closer analysis. Note: the thermography analysis was carried out by Matthew Fox and provided in note-form to the author, who then incorporated said analysis into this thesis.

Yin (2009: 119) extols the virtues of producing a "*formal, presentable database*" of case study findings so that "*other investigators can review the evidence directly*", rather than being limited to viewing a written case study report. However, the ethics for this study promise anonymity to the participants, including non-use of direct quotes, so preventing the inclusion of a database of 'raw' case study data in this thesis. The exploratory case study is thus presented as a written report (Section 4.4.2). Summaries of the case study's façade retrofit details, and decision-making methods and information sources, are also presented in Table 9-5 and Table 9-6 of Appendix C respectively. Note: this case study was reported in a conference paper by Garmston et al. (2013).

## 4.4 Exploratory study outcomes

### 4.4.1 Semi-structured interview results

*Decision-making in façade selection*

The semi-structured interview findings did not show widespread use of structured decision-making methods for choosing an optimum façade system from a number of alternatives or to produce a group of options from which the client could choose his/her preferred system. The interview findings revealed one method of normative decision-making being used by 10% of the interviewees; the payback period method was mentioned by two university estate client roles (SS3 and SS10) in relation to the façade system applied during individual cases of real-life[26] university building façade retrofit, and by a façade specialist and supplier (SS13) in relation to façade retrofit in general.

The use of informal decision-making was not explicitly evidenced; however, findings from the semi-structured interviews suggest the use of heuristic decision-making. For example, one architect (SS15) mentioned keeping square foot value in mind to guide the money available for materials, while another architect (SS23) said MCA or decision trees were not used, as this kind of process was carried out by architects. Moreover, a design manager (SS27) commented that past experience is used to guide which façade option is perceived to be the cheapest, while a design and build manager (SS22) mentioned using the previous experience of stakeholders, in terms of what they are comfortable with, to help guide the façade choice.

Nearly all the interviewees mentioned one or more information sources being used in relation to the façade selection process. These information sources are categorised by this thesis according to the aspect of the façade selection process they are deemed to support, namely: *project analysis and evaluation*, and *façade design* (Table 4-5).

In relation to *project analysis and evaluation*, one financial advisor (SS28) described the architect as having an idea at the feasibility stage as to what façade will be used, while another (SS29) described the feasibility stage as including an assessment of cladding types in relation to the structural frame type, to see which cladding suits the frame. It was mentioned by a design advisor (SS20) that the business plan can drive the façade decision.

In relation to *façade design*, four sub-categories of information sources were identified from the semi-structured interviewee responses: *cost*, *performance*, *aesthetics*, and *collaboration*,

[26] This thesis defines 'real-life' cases as involving a façade retrofit that has taken place and thus describes decision-making that has been used in practice in the AEC industry.

of which the interviewees both most frequently mentioned and most heavily emphasised the involvement of the cost and performance-related information sources in the façade decision-making process, with commercial decisions appearing to greatly affect the material choice. Whole life cost (WLC) analysis was the most frequently mentioned cost-related information source, though one interviewee (SS27) felt there are so many factors involved in WLC analysis that people do not take them all into account. Moreover, one interviewee (SS20) felt that quantity surveyors lack knowledge of façade systems and have too much dependency on the 'Black Book'[27]. The use of Excel in relation to conducting WLC weights/parameters was mentioned by one interviewee (SS22). Thermal and environmental performance were the most frequently mentioned performance-related information sources, while safety, environmental performance, cleaning and maintenance needs, and the façade's impact on occupant activities, were also mentioned as informing the façade selection. The use of simulation software was mentioned in relation to thermal modelling. According to several interviewees, the façade selection process involves weighing up design criteria against cost, e.g. cost versus aesthetics, cost versus performance, and performance versus performance; however, no reference was made to assigning weightings to the criteria or what methods were used for the comparison process.

*Influential roles in façade selection*

The interviewees generally considered that architects were responsible for the initial and ongoing façade decisions in a construction project, reflecting the key advisor role of *design leadership*, as defined by Hughes and Murdoch (2001). The client and planner were seen as having most say in façade decision-making, with the planner deemed to play a 'commanding' role (the need for approval from English Heritage was also mentioned in relation to listed buildings). Several interviewees expressed frustration at the time-scales involved in the planning process, though the interviewees' response in relation to planning was divergent.

[27] The term 'Black Book' refers to a suite of guidance notes that include technical standards for quantity surveyors (QS) (RICS, 2016).

One interviewee perceived that planning officers lack experience and knowledge in key areas such as material longevity, yet have inordinate power to block façade proposals made by experienced architects, while another perceived that planning officers have 'rules' that do not appear to be written down. This latter point is reflected by two interviewees expressing that it would be helpful if planning guides were easier to find. In contrast, other interviewees felt planning officers should not act any differently to how they already do, as it was perceived to be correct that they work to preserve the integrity of a geographical area. One interviewee saw the planning process as a challenge, rather than a problem. Excepting the architect function, the advisors described as playing influential roles in façade decision-making chiefly included quantity surveyors/cost consultants, structural engineers, and mechanical engineers.

Table 4-5 Façade selection information use: identified by the semi-structured interviews

| Categories | Sub-categories | Information sources |
|---|---|---|
| Project analysis and evaluation | | Business plan |
| | | Feasibility study |
| | | Feasibility estimate if the budget is finite |
| Façade design | Cost | Whole life cost analysis |
| | | Square foot value |
| | | Capital cost |
| | | 'Black Book' |
| | Performance | Building condition survey |
| | | Structural stability of the building |
| | | U-value calculations, in line with or exceeding Building Regulations for England and Wales, as required by each project |
| | | Thermal mass |
| | | Local climate knowledge |
| | | BRE Green Guide to Specification |
| | | BREEAM assessment |
| | | $CO_2$ emissions targets |
| | | Thermal performance |
| | | British Standard regarding wind-driven lift |
| | | Building Regulation Part C regarding wind-driven rain |
| | | Building occupant activities, e.g. in terms of lighting requirements |
| | | Cleaning and maintenance needs |
| | Aesthetics | Architect sketches |
| | | Architect visuals |
| | | Full-size façade mock-up |
| | Collaboration | Design team meetings |
| | | Architects' ongoing dialogue with Planners |
| | | Public consultation process |

Advisor roles in façade selection that were less frequently mentioned by the semi-structured interviewees were: building control, facilities manager, and main contractor. Contractors were seen as trying to make façade decisions at a later stage (post-tender) with the aim of achieving cost and time reductions in the overall build.

*When façade decisions are being made*

To learn at what points in a project façade decisions are generally made, the semi-structured interviewees were asked to state at which stages in the RIBA Plan of Work[28] they observed façade decisions taking place. The observations reflect the interviewees' general building experience and do not relate to specific building projects; thus, while they can be considered indicative, they cannot be used to draw definite conclusions as to the point at which decision-making might occur in a project. Twenty-seven interviewees responded with a total of 87 observations. The façade decision observations are presented in Figure 4-2 in relation to the interviewees' construction industry function, as categorised according to Hughes and Murdoch (2001). Three interviewees: façade specialist and supplier (SS9), building control officer (SS11), and project manager (SS18) were in roles that did not result in observing the RIBA Plan of Work. The fact only three interviewees do not have exposure to this voluntary tool could be said to reinforce the RIBA Plan of Work as "one of the best known" (Hughes, 2001: 281) and "*most widely used model[s] of building design*" (Austin *et al.* 1999: 281).

The results show the majority of the façade decisions were observed as occurring during the early project stages relating to *Preparation* (RIBA Stages A-B) and *Design* (RIBA Stages C-E), with the greater number of these decisions occurring at RIBA Stages C and D, *Concept* and *Design Development* respectively. Moreover, all twelve construction industry functions represented by the semi-structured interviewees observed façade decision-making at RIBA Stage D, in which the project brief is completed and the concept design developed to include updated cost and performance parameters, and the application made for detailed planning

[28] At the point of participating in this research, the semi-structured interviewees were using the RIBA Plan of Work 2007.

permission (RIBA, 2009). The semi-structured interview findings thus reflect Kolokotroni et al. (2004: 2), who state that "*key decisions about the building facade are usually taken during the concept design stage of a building*", with the exception that façade decisions were observed at each stage of the RIBA Plan of Work by the semi-structured interviewees acting in a *design leadership* role, namely the three architects, and by the construction manager.

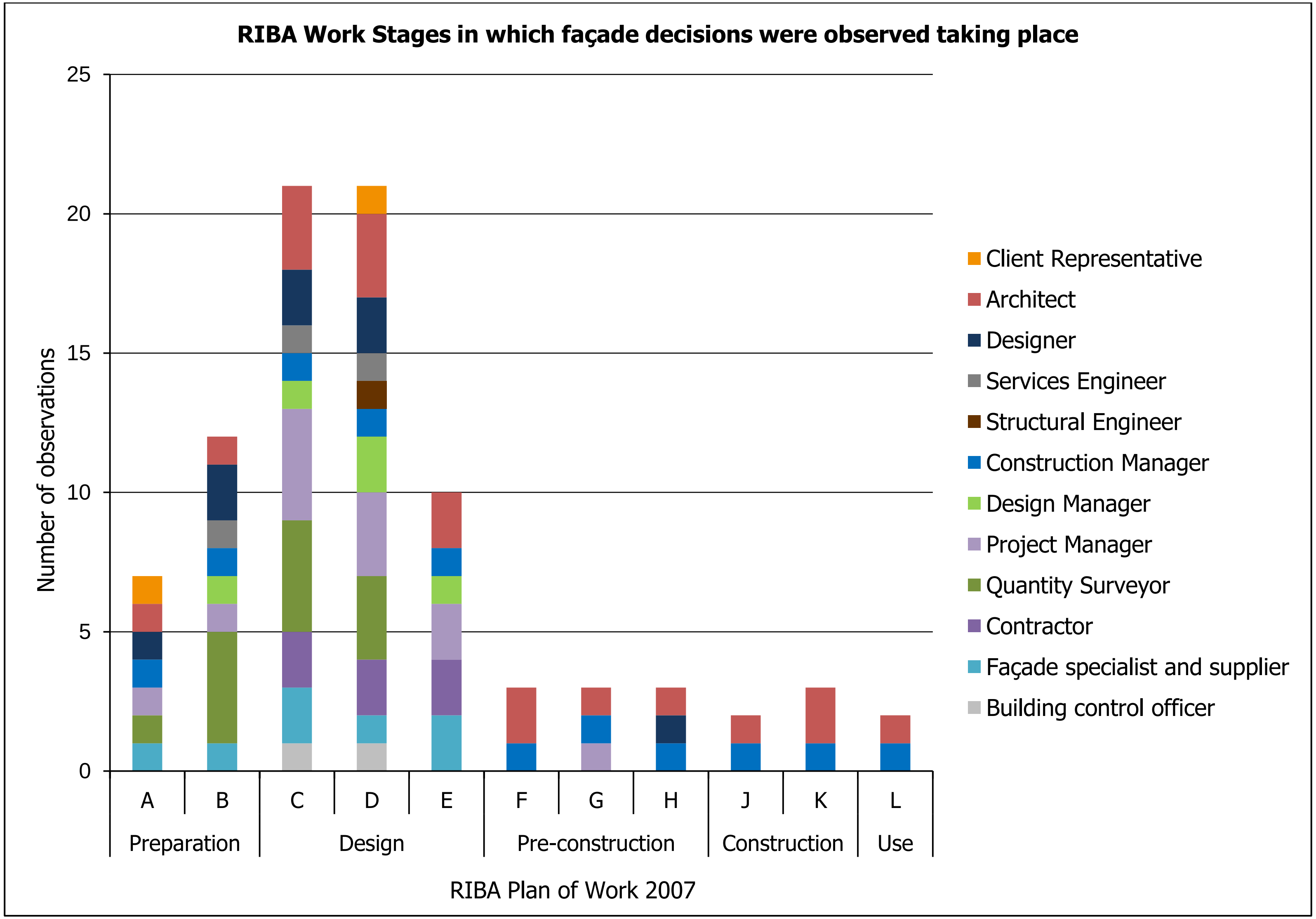



Figure 4-2 Façade decision observations relative to the RIBA Plan of Work 2007

*Problems perceived in façade decision-making and suggested solutions*

The problems the interviewees perceived as occurring in façade decision-making are shown together with suggested solutions in Table 4-6, listed alphabetically by 'Problem Theme'.

Cost was identified as a key potential problem in the façade decision-making process, but not simply the total cost of procuring the façade. Important cost factors also include: paying adequate fees at an early stage in the design process to ensure the right decision is made by the right people; analysing the expected payback in terms of energy saving, but accepting it might not 'win' the business case in the face of less tangible gains, e.g. maintaining company brand, occupier satisfaction; weighing up cost versus other criteria such as material life, aesthetics and performance; and demonstrating best value for money. Value engineering was mentioned as both a potential problem and a suggested solution.

Collaboration appears to be a way in which perceived problems in façade decision-making can be mitigated. This collaboration can be among many roles and in varying combinations: architect and planner, lead architect with colleagues from the design team, client and consultant, or indeed, a whole project team of construction professionals collaborating at a project workshop dedicated to the façade.

Table 4-6 Façade decision-making: perceived problems and suggested solutions

| Problem Theme | Perceived Problems | Suggested Solutions |
|---|---|---|
| Business case | Justifying the re-cladding of buildings; short-term view when making façade decisions; identifying what is important to stakeholders by whoever is procuring the project | The driver is not always cost; benefits can come from other areas, such as managing company brand, attracting customers, and retaining staff; use whole life cost analysis |
| Cost | Inadequate capital; demonstrating best value for money; underestimated cost at outline design stage - QS can lack façade knowledge and overly depend on the 'Black Book'[29]; VE needed after design agreed; weighing up criteria, e.g. cost versus aesthetics/performance; design longevity, e.g. long-lasting cladding versus render; lack of understanding regarding material choices; well-researched design changed by contractor purely based on cost | Intelligent use of materials, use specialist advice; VE design if necessary; QS roles may need greater knowledge of façade systems; phase the build; take performance away from the façade; architect needs full awareness of budget and client expectations; collaboration to help weigh up alternatives; better co-ordination between different people involved in the design; greater control by the specifier, in conjunction with other key roles, e.g. architect, LPA |
| Energy Efficiency | The client needs the building as energy efficient as possible; increasingly stringent standards | A business case for refurbishment may see aesthetics as secondary to performance (though some architects may not think this way); evolution - embrace the changes |
| Fees | Making the wrong decision; having to value engineer at a later stage to reduce costs | Paying fees up-front so client gets the right advice and the right decision; paying for a full consultant team at the start, so that a quantity surveyor is involved from the outset |
| Planning | Façade material rejected for not being local enough; planning approval delayed due to other complications; planners lacking knowledge in material durability; planners lacking an understanding of the architects' design intent; difficulty understanding planners 'rules'; satisfying the planning requirements | Get planner on-board early in design stage; produce options; produce a mock-up of the façade for the planner to review; increase the number of project design workshops purely devoted to façades; create a project checklist of façade design issues; take time to consider the options; no one system will fit all projects; client-responsive design that is sympathetic to the building's location |
| Quality | Façade system must be well built; design and build procurement allows flexibility for the contractor to cut corners; material faults; led by aesthetics rather than function; installation standards; buildability; ease of maintenance in-use; weather suitability of façade design; dying skills in maintenance of listed buildings; contractor awarded under-priced contract - specifications can be broken too easily; preventing damage | 25-year guarantee; collaboration to make a proper informed decision; pay for a full design team up-front so full details are already produced when the job goes to tender; increase number of project design workshops devoted to façades; Clerk of Works' role important to installation quality; craftsmanship - go back to grassroots; ensure façade is fit for purpose; take into account local weather, 3D modelling to predict wind movement; apprenticeships/ training in listed building maintenance; specify high impact façade layer, e.g. impact board behind rendered finish on ground floor |
| Specialist advice | Lack of choice in the façade specialists available; infinite variety of systems and products, so much complexity, difficult to understand | The specialists mentioned were all deemed of excellent quality, but where a job is small, may only provide off-the-shelf options; employ consultant as an independent specialist to review local suppliers and to prepare tender; development of a free web-based tool to aid façade selection |

[29] The term 'Black Book' refers to a suite of guidance notes that includes QS technical standards (RICS, 2016).

### 4.4.2 Commercial office case study report

This case study explores the decision-making process used to select a façade retrofit for a UK commercial office building located in a waterfront conservation area in a maritime climate.

*The building pre-retrofit*

The exploratory case building was constructed in 1971 from an uninsulated exposed in-situ concrete frame, calcium silicate brick cavity infill panels, and single-glazed steel ribbon windows. The main body of the building is 14.6 metres in height and contains five-storeys. Two access towers located one at either end of the building, each hold a stairwell and a lift shaft. Pre-retrofit, it achieved a G EPC rating and a 'wall' U-value of 1.49 $W/m^2K$.

*The retrofitted building*

The exploratory case 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 building stood empty for three-years prior to retrofit and was circa 37-years old at the 'point of retrofit'[30]. The work was funded by money borrowed against a SIPP whose group of eight stakeholders included the case study interviewees. The retrofit aimed to achieve an energy efficient building; and to create a landmark building, thus demonstrating the case study company's skill as architects. The building comprises a central body with $3204m^2$ total useful floor area, as per the building's current EPCs (at the time of writing). Two towers that both provide access to each floor contain a further total floor space of $186m^2$. The elevation containing the main entrance faces north-west.

In addition to the case building receiving a full façade retrofit, any pre-let floors also received an internal fit-out[31] and work was conducted to the roof. However, as this thesis focuses on

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[30] As it stood empty for 3-years, the building experienced structural vacancy (Remøy, 2010). It was technically 40-years old when the retrofit started; however, its age 'at the point of retrofit' is taken from the start of its vacant period, when the author considers the building as requiring retrofit.

[31] At the point of conducting the case study, four of the five floors had been fitted out.

façade retrofit, the elements included in the internal fit-out and roof work, and the process involved in their selection are out with the scope of this case study report.

Post-retrofit (Figure 4-3), the upper four floors, which remained as office use, achieved a B EPC rating, with the following energy performances: $1^{st}$ floor (46), $2^{nd}$ floor (44), $3^{rd}$ floor (44), and $4^{th}$ floor (41), and a 'wall' U-value of 0.22 $W/m^2K$; while the ground floor, split into two retail outlets, achieved a C (54) and C (55) EPC rating for outlets 1 and 2 respectively. The case building is not occupied by a public authority and thus has no DEC requirement.

Figure 4-3 Commercial office building post-retrofit (Fox, 2012b)

*The completed retrofitted building façade*

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, and the cavity walls filled with blown mineral fibre insulation. The window sills were reduced in height, by removing three courses of brickwork. Thermally broken polyester powder coated (PPC) aluminium double-glazed ribbon windows, alternated with coloured insulated spandrel panels, were installed on the upper four floors; while the ground floor was fitted with single-glazed windows, with thermal dry-lining to the rear. The south façade was fitted with stainless steel brise soleil brackets in readiness of the future fitting of the aluminium louvres. The towers were clad with uninsulated two-tone metallic-effect aluminium faced rainscreen cladding.

*The façade selection process*

The façade decisions were made chiefly by the Developer, with Lead Architect input from Technical Design (RIBA Stage E[32]) onwards. The façade decisions did not occur as per the RIBA Plan of Work 2007; instead, seven main project points were identified by the Developer, to which the RIBA Stages were then mapped (Table 4-7). 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. 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 conditional planning permission stated LPA approval must be received for the materials used on the building's external surfaces prior to any work commencing; the reason being to ensure the materials were in keeping with the area's character, as per the core strategy of the area's LDF.

The D&B Contractor did not make any post-tender façade decisions. This retrofit project is a potentially unusual example of D&B contracting, in that the Developer, being also the case study company MD, a SIPP stakeholder, and the retrofit project Client, was extremely conscious of cost and revisited each element after the initial and 2nd tender stages to identify cost reductions. This behaviour removed any opportunity 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 approval had been received for zinc sheeting, but fortunately, the LPA accepted the change on the proviso that two-tone metallic-effect cladding was used. The Developer made VE decisions for this project by discussing alternatives with the suppliers and the Lead Architect.

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[32] At the time of writing, the latest version is the RIBA Plan of Work 2013 (RIBA, no date). However, at the point of participating in this research, the exploratory case study interviewees were using the RIBA Plan of Work 2007; thus, all references to 'RIBA Stage/s' in the exploratory case study report relate to the RIBA Plan of Work 2007.

Table 4-7 Commercial office building: evolution of the façade elements

| 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: Seven main project points identified by the Developer, are mapped to the eleven stages of the RIBA Plan of Work 2007: [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) (RIBA, 2009). A tick indicates façade element presence in that evolutionary stage. A 'VE' suffix indicates element removal due to value engineering.

Cost effective insulated render was chosen from the outset to wrap the central part of the building. Dew point location and U-value calculations were conducted by the render system supplier to assess and confirm the system's suitability. Metallic-effect cladding was used on the towers, as it was not deemed aesthetically acceptable to render the whole building. A robust material (stone) was used to ground floor level, as the render is not impact resistant.

Overheating was considered in the design, with the proposed inclusion of brise soleil on the south-east elevation. Though the brise soleil louvres were value engineered out for the time being, forethought was shown by attaching the brackets, which were fixed to the in-situ structure prior to applying the render system. 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 the best option and unlikely to significantly affect the envelope's performance, as supported by the B EPC rating. Note: The aluminium brise soleil louvres were added three-years after the retrofit project was completed and over a year after this case study was conducted.

*The thermographic survey*

<u>Summary</u>: The thermographic survey visually demonstrates general success in the building's new thermal envelope. The survey does, however, also highlight some potential quality control issues such as the installation of the insulation boards.

<u>Key findings</u>: 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 point where the brise soleil brackets are attached to the original in-situ concrete structure - the brackets and immediate area were approximately 4°C warmer than the other surface render (Figure 4-4 – image 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 (image 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 (image 3) and un-identified areas of heat loss beneath a window (image 4).

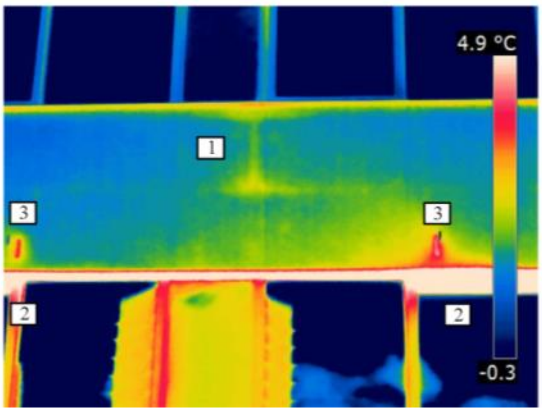


Figure 4-4 Commercial office building thermography - image 1

*Gaps between insulation boards (1), trickle vents (2) and cold bridging through the brise soleil brackets (3)*

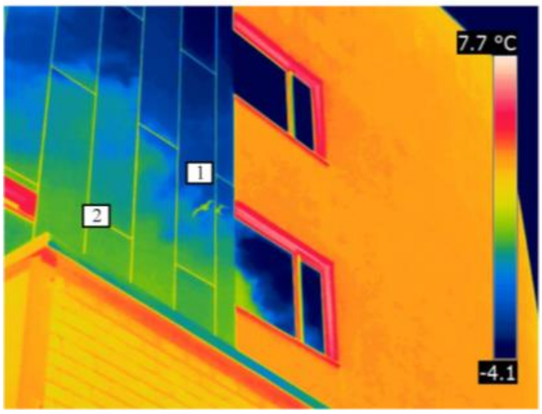


Figure 4-4 Commercial office building thermography - image 2

*Emissivity difference between render and cladding, note seagull (1) and cloud (2) reflecting off the cladding*

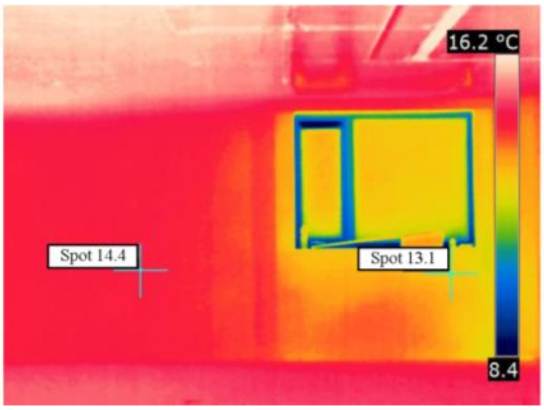


Figure 4-4  Commercial office building thermography – image 3

*Differences (°C) in construction build-up either side of column*

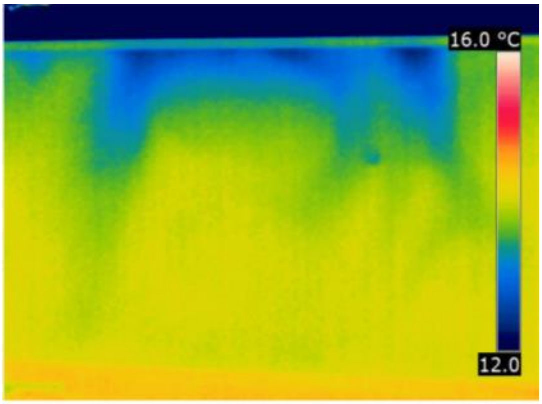


Figure 4-4 Commercial office building thermography – image 4

*Area of un-identified heat loss below a window frame*

### 4.4.3 Exploratory case study results

The exploratory case study building was over-clad with a Class 0 insulated render system and rainscreen cladding. The decisions leading to the façade selection were made chiefly by the architect, who also acted as client and developer for the project, with LPA approval of the external building materials. The exploratory case façade selection did not show the use of any structured or informal methods to produce a final façade choice or a group of options from which the architect could choose one façade system. Information utilised during the façade selection related to façade performance: dew point analysis and U-value calculations.

The exploratory case façade evolution shows the majority of the decisions occurring in the early project stages. The exploratory case façade selection was influenced by aesthetics, thermal performance, and energy efficiency, and the need to attract tenants, with budget serving as a key constraint. Attracting tenants is vital for a commercial building, so façade decisions were made to ensure the building was attractive to its target audience: aesthetic decisions for an attractive façade, insulation decisions for lower running costs, and a structural decision (reduced sill height) for improved internal environment. Money was released from the SIPP as occupancy grew, so it was essential to pre-let the space.

Changes to reduce the façade cost occurred early in the project, with no façade changes observed after RIBA Stage F. Despite value engineering greatly influencing the exploratory case study façade selection, success was demonstrated by improved U-values and the EPC rating, and the client's satisfaction in the building's aesthetics. 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 the larger building part was well insulated, while other parts of the façade (towers, louvres, and spandrel panels) were value engineered.

## 4.5 Summary

This chapter presents an exploratory study of façade decision-making. Thirty semi-structured interviews and an exploratory case study were carried out to seek the opinion of UK industry members involved in façade and façade retrofit selection, with the aim of discovering the current state of façade decision-making in today's AEC industry.

The semi-structured interviews revealed little evidence of normative decision-making, with only the payback period method stated as being used by three interviewees. The presence of descriptive decision-making, in the form of heuristics, is suggested by some interviewees describing the use of past experience in the façade selection process. In contrast, the interviewee group as a whole reported numerous sources of information, relating chiefly to cost (e.g. whole life costing) and performance (e.g. U-values), being used in the façade selection process. In regards to the timing of façade decisions, the semi-structured interviewees observed façade decisions as mainly occurring in RIBA Stages C and D, in which the concept design is prepared and developed in line with implementation and completion of the project brief.

The semi-structured interview findings suggest the façade selection process is affected by three key problem themes relating to the cost of procuring the façade system, the planning approval process, and the quality of the façade. Other problem themes relate to building the business case, energy efficiency, project fees, and the use of specialist advice in façade selection. Collaboration between the client, advisors, and regulatory bodies was suggested by the semi-structured interviewees as a key way of solving several problems perceived in façade selection. Other suggested solutions include ensuring adequate funds for a project, advisors having full awareness of the clients’ expectations and the project budget, greater knowledge of façade systems by advisors, and value engineering.

The exploratory case study findings also did not reveal the use of normative decision-making methods in the façade retrofit selection process. However, the fact a façade system was selected and progressed to the as-built stage indicates the use of cognitive action by those involved in the façade selection, and as such, some form of descriptive decision-making will have taken place. Dew point analysis and U-value calculations represent the information sources used. The exploratory case was found to have experienced two of the key problem themes revealed by the semi-structured interviewee findings – cost and planning, while of the suggested solutions, value engineering and collaboration were apparent. The exploratory case is a potentially unusual project, as the case building is part owned by the case study company, an architects practice, and the MD of this practice acted as Client, Developer and Architect for the retrofit. The fact that multiple roles were played by the same project team member is likely to have naturally improved budget awareness and collaboration in the project realm, and may have helped the company work effectively within the tight parameters of cost and planning. Further natural benefit is likely to have been brought by the multiple roles all being played by an architect, since according to the semi-structured interview findings, the architect leads the initial façade decisions and the client makes the final façade decisions prior to planning approval.

The following chapter presents an in-depth study of façade retrofit decision-making, which features four case studies of building façade retrofit that enable deeper exploration of the project team roles and their contribution to the façade decision-making process, as well as further exploration into the façade decision-making process as a whole.

# 5. In-depth study of university building façade retrofit decision-making

## 5.1 Introduction

The previous chapter presented the methods and results of the first of three main research steps used to implement this investigation: an exploratory study of office building façade retrofit decision-making. It is suggested from this first main step that architects, clients, and planners play key roles in façade decision-making, and that a range of information sources pertaining chiefly to cost and performance are used to guide the decision-making process. However, while the exploratory case study appears to support the semi-structured interview findings, it is a potentially unusual project, in that the same one architect played three key roles in the project team; and moreover, it is a single example of a certain building typology.

To determine if the exploratory case is representative of façade decision-making in the UK AEC industry, it is necessary to conduct further case studies of typologically similar buildings. This chapter thus presents the second main research step: an in-depth study of university building façade retrofit decision-making, with the focus evolving from office to university buildings as a result of case study building availability (as explained in Section 5.3.2). This second main step commences with a specific literature review that presents the context of university building façade retrofit decision-making. Four exemplifying case studies are then used to drill down into the arena of university building façade retrofit, to deeply investigate the roles involved in and contributing to façade decision-making, and the decision-making methods and sources of information used to guide the façade selection process.

## 5.2 University buildings: façade retrofit context

### 5.2.1 University buildings: purpose, typology and prevalence

> "*The UK's universities are among the best in the world – they have an impact on all aspects of life in the UK, and they're vital for our future. They educate the skilled professionals, carers, teachers and entrepreneurs that we all need. They drive the economy by encouraging investment and fostering innovation. They provide jobs, facilities and resources, putting them right at the heart of their city or region. UK universities' world-leading research changes the world. And higher education is more inclusive than ever, giving all those with the desire and ability the opportunity to go to university*" (Universities UK, no date-a).

In the UK, all universities and some higher education colleges are termed as *recognised bodies,* which is a term used to describe institutions granted degree-awarding power by a Royal Charter, Act of Parliament or the Privy Council (GOV.UK, 2015). The majority of *recognised bodies* can award full-degrees, while five can only award foundation degrees (GOV.UK, 2016b). In the UK, as of 9 June 2016, there were 166 recognised bodies in total[33], equating to 139 in England, 9 in Wales, 16 in Scotland, and 2 in Northern Ireland[34] (*ibid.*).

This thesis chooses to base its definition of *university buildings* chiefly on the set of higher education institutions termed as *recognised bodies*, as they feature all university institutions from the UK, which are collectively known as having a property portfolio that contains a large number of buildings constructed and planned during the 1960s and 1970s (AUDE, 2008). For example, Estate Management Statistics (EMS) shows that over 40% of the non-residential stock for universities in England was built between 1960 and 1979 (*ibid.*). In the UK, higher education institutions (HEIs) that provide full courses leading to a degree of a recognised body are known as *listed bodies* (GOV.UK, 2015); as of 9 June 2016, there were 650 listed bodies (GOV.UK, 2016b). This specific review includes literature pertaining to HEIs

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[33] The Association of University Directors of Estates (AUDE) supports estates professionals in the effective running of university estates, and the provision of a high quality staff and student experience; AUDE has 156 university institutions in its membership, which equates to almost the entire sector (AUDE, 2015).

[34] See Appendix H for the full list of UK *recognised bodies* as of 9 June 2016 (GOV.UK, 2016b).

and higher education providers (HEPs), which the author of this thesis recognises to contain some or all listed bodies in addition to recognised bodies. It is also noted that due to some HEIs/HEPs' evolution in recognised and listed body status, the literature in this review is likely to contain differing levels of recognised and listed bodies; thus, wherever possible, this thesis clarifies the HEIs/HEPs upon which the information used in this review is based.

In the academic year 2014-2015, there were 198,500 academic, and 205,500 non-academic staff employed at UK universities; and 2.27 million students studying at UK higher education institutions, from undergraduate to postgraduate, full to part time, and UK and non-UK locales (Universities UK, no date-b).

Quality estates and facilities play a critical role in the success of university institutions (Wates Construction, 2012), with university buildings shown as playing a significant role in the recruitment, retention and performance of staff and students (CABE, 2005; AUDE, 2008).

*Recruiting staff and students:* Around 60% of the staff and students[35] participating in CABE's research into the value of good building design in higher education indicated that the quality of building design positively impacted their decision to study or work at their chosen university (*ibid.*). Cosmetic and environmental features (e.g. cleanliness, feeling of space, bright working areas) were influential to staff, while structural/functional features (e.g. the quality of facilities, such as the library and lecture rooms) were influential to students (*op. cit.*). Furthermore, good physical environments can "be attractive to *prospective employees and students, who increasingly seek out universities and colleges whose values reflect their own, and in whom they can take pride"* (HEEPI et al., 2008: 3).

*Retaining staff and students:* The functions and facilities of university buildings were found to positively impact on how their occupants worked and studied (CABE, 2005). The staff members' own office and workspace, as well as the size, proportion and openness of the

[35] The research conducted by CABE (2005) involved a three-strand approach: a literature review, qualitative interviews and focus groups, and surveys; the research participants comprised students and staff from five higher education (HE) buildings, with four of the buildings in England and one in Wales.

building they worked in were seen as contributing positively to how they felt and behaved; situational features, such as external views and surroundings were also important to staff, while not so to students (*ibid.*). The majority of students and staff were however in agreement of the impact of cosmetic and environmental features, both positive (e.g. decoration, furnishing and furniture) and negative (e.g. problems with heating and ventilation, plus acoustics and noise) (*op. cit.*).

*Staff and student performance:* Good physical environments can aid high quality learning experiences and research, while also improving productivity and attendance (HEEPI et al., 2008). Buildings were found to have greatest impact on staff and research students, and less impact on undergraduate students (CABE, 2005). The students in general indicated that buildings could help motivate and inspire them in their work, as well as providing key facilities critical to their course and research (*ibid.*).

The UK university estate is very large (AUDE, 2015), with EMS for 2014/15 showing it as having 727 sites, and 15,404 buildings of which 61% are non-residential (HESA, 2016) (Table 5-1)[36]. As a consequence of its size, replacement of the university building stock takes some time to undertake (AUDE, 2015) meaning the UK university estate is of variable quality (Rawlinson and Brett, 2009). A poorly maintained university estate, with an uninspiring appearance and tired-looking façades, and which provides sub-standard accommodation with poor environmental performance, does not aid the attraction and recruitment of staff and students (d+b facades, 2010). Due to competition from other university institutions, "*it is becoming ever more important to mitigate the impact of the existing estate*" (Rawlinson and Brett, 2009). Competition became greater still when the UK Government ended the control in student numbers in September 2015, meaning UK university institutions can now set their own size and recruitment objectives (AUDE, 2015).

[36] The data presented in Table 5-1 is based on a total of 145 *recognised bodies*, made up of 120 from England, 8 from Wales, 15 from Scotland, and 2 from Northern Ireland; this equates to 87% of the UK's recognised bodies as of 9 June 2016. See Table 9-7 in Appendix H for the list of institutions.

The sector has responded to the increasing competition by continuing to spend significant amounts of capital on new buildings and major refurbishment projects[37]; expenditure on non-residential buildings steadily rose from 2003/04 to 2008/09, and after four years of fluctuating spend, the spend in 2013/14 was over £2.5billion, which is the highest annual spending on record (*ibid.*). However, the 2013/14 spend is attributed to just over a dozen university institutions spending over £40million, with four spending over £100million; meanwhile, capital spend fell in half of the institutions between 2008 and 2014, and by as much as 25% in a third of the institutions (*op. cit.*).

Table 5-1 UK recognised bodies' estates management statistics for 2014/15 by country (compiled from HESA, 2016)[38]

| Description | England | Wales | Scotland | Northern Ireland | Total |
|---|---|---|---|---|---|
| UK recognised bodies | 120 | 8 | 15 | 2 | 145 |
| Sites - total no. | 507 | 52 | 156 | 12 | 727 |
| Buildings - total no. | 12,600 | 1,103 | 1,393 | 308 | 15,404 |
| Non-residential buildings - total no. | 7,429 | 639 | 1,093 | 219 | 9,380 |
| Non-residential buildings - total % | 59 | 58 | 78 | 71 | 61 |
| Gross internal area (GIA) - total $m^2$ | 21839388 | 1507700 | 3113534 | 581018 | 27041640 |
| Non-residential GIA - total $m^2$ | 16621184 | 1130973 | 2629747 | 515755 | 20897659 |
| Non-residential GIA - total % | 76 | 75 | 84 | 89 | 77 |
| Energy consumption - total KWh | 5953232748 | 354344339 | 1049001805 | 139383391 | 7495962283 |
| Non-residential energy use - total KWh | 4781439754 | 270742776 | 931108259 | 122081605 | 6105372394 |
| Non-residential energy use - total % | 80 | 76 | 89 | 88 | 81 |
| Non-residential GIA DEC/EPC-rated A ($m^2$) | 149913 | 46093 | 24092 | 0 | 220097 |
| Non-residential GIA DEC/EPC-rated B ($m^2$) | 1397222 | 86137 | 217576 | 69001 | 1769936 |
| Non-residential GIA DEC/EPC-rated C ($m^2$) | 3915129 | 189362 | 178515 | 230339 | 4513345 |
| Non-residential GIA DEC/EPC-rated D ($m^2$) | 3512701 | 161621 | 282827 | 44218 | 4001367 |
| Non-residential GIA DEC/EPC-rated E ($m^2$) | 1896722 | 75327 | 399348 | 82718 | 2454116 |
| Non-residential GIA DEC/EPC-rated F ($m^2$) | 867014 | 32060 | 221901 | 45002 | 1165977 |
| Non-residential GIA DEC/EPC-rated G ($m^2$) | 1557979 | 46622 | 114368 | 6521 | 1725490 |

[37] AUDE (2015) state that due to the way the capital expenditure data is returned, it is not possible to separate out the university institutions spend on refurbishment, from that which is on estate expansion and new-build.

[38] Table 5-1 is compiled from the data submitted by 87% of the UK's 166 recognised bodies (GOV.UK, 2016b).

The non-residential stock continues to demonstrate the legacy of an ageing university estate, which saw a very large proportion of its property portfolio built in the 1960s (AUDE, 2008). Despite the share of non-residential buildings constructed from 1960-1979 slowly decreasing and those constructed from 1980-onwards slowly increasing, almost 80% of the UK university non-residential building stock as of 2013/14 was constructed prior to the year 2000, with around 10% constructed from 1980-1999 and over 30% constructed from 1960-1979 (AUDE, 2015) (Figure 5-1).

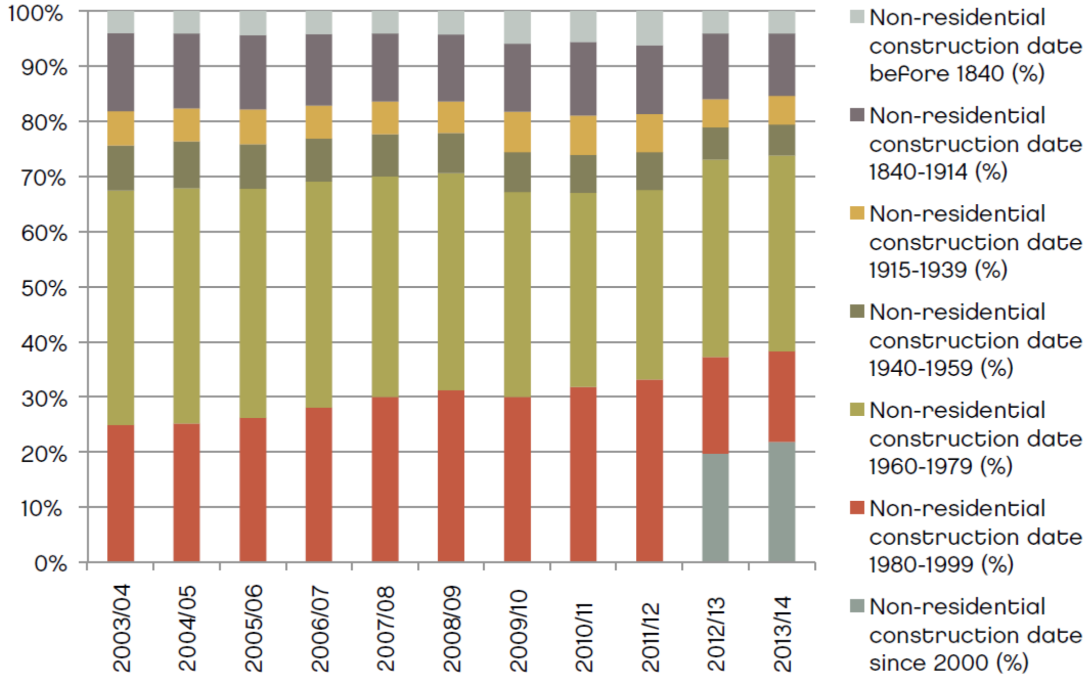


Figure 5-1 UK university estate age (reproduced with kind permission from AUDE, 2015: 43)

UK academic buildings built circa 1960s are typically single-glazed, lack insulation and suffer from uncontrolled solar gain, which results in poor thermal performance and an internal environment that is often cold in winter and hot and stuffy in summer (AUDE, 2008; d+b facades, 2010). Metal window frames, asbestos insulation, and asbestos containing materials were also widely used (AUDE, 2008). Deteriorating original façade materials, which result in water ingress and air infiltration, further impact on thermal performance, as well as carrying potential health and safety risks to building users in cases of severe façade erosion (d+b facades, 2010). In the UK, every HEI suffers from a backlog of investment in its existing estate. Due to the UK Government's under-investment in higher education, which ran until the late-1990s, the problem is particularly acute for institutions with a large proportion of 1960s and 1970s buildings (Wates Construction, 2013).

In addition to the 1960s legacy stock, and the early-1970s university buildings which have similar issues to the 1960s stock (AUDE, 2008), the sector faces another challenge. A "*significant amount of the estate is reaching a critical point in its life when it will require refurbishment. Buildings built in 1980 are now 35 years old and likely to require significant investment in the near future*" (AUDE, 2015). University buildings from the 1960s, 70s and 80s may have suited users at the time of construction; however, user requirements can change over time (AUDE, 2008). University building user requirements evolve for a variety of reasons, including: changes in teaching, research or administrative practices, and the volume of such practices; changes required to maintain an institutions' competitive stance in the 'market place'; and social and legislative change (*ibid.*). These, and other changes in user requirements, can result in buildings being less functionally suitable (*op. cit.*)[39].

In the face of competition from the UK and abroad, and to appeal to potential students, universities are overhauling their estates, with new-builds and renovations taking place through the whole of the UK university estate (Wates Construction, 2012). AUDE (2015) reported that functional suitability in the university sectors' non-residential estate has increased considerably from 2003/04 to 2013/14, as institutions have spent capital with a clear desire to make their estate more fit for purpose; the share of functionally unsuitable non-residential buildings, i.e. functional suitability Grade 4, is now at its lowest over the 10-year study period. Refurbishment is a cost-effective and environmentally friendly way to achieve the same objectives as building from scratch (Wates Construction, 2013). Seventeen

[39] The functional suitability of building space is defined by HESA (no date-a) according to a number of factors, including: environment, layout/plan, location, flexibility, servicing requirements, user perception, and general external environment. Each UK university institution reporting to the EMS measures their estates' proportion of GIA that is Grade 1 Excellent, Grade 2 Good, Grade 3 Fair, and Grade 4 Poor, with Grade 1 representing space that fully supports its current functions and Grade 4 deemed unsuitable for current use (*ibid.*).

percent of the research respondents in Wates Construction (2012)[40] identified 'refurbishment' as the second main driver behind their current/next construction projects, with the top driver being 'attracting students'. Similarly, in Wates Construction (2013)[41], 'buildings ageing/no longer fit for purpose' was identified as the second main factor driving estates budget allocations and planning, scoring an average rating of 7.2 out of 10, with the top factor being 'student numbers'. Moreover, the four key points relating to refurbishment that emerged from The Legacy of 1960s University Buildings (AUDE, 2008: 2) are:

- "*Academic buildings can often be refurbished more successfully than residential.*
- *While the financial case for refurbishment might look poor, with costs in some cases as high as 80% of new build, there are often significant other benefits from the refurbishment route, particularly environmental ones.*
- *High standards of environmental performance can be achieved on refurbishment projects, provided that objective is at the core of the design from the outset.*
- *Architectural excellence can still be achieved in refurbishment projects*".

### 5.2.2 Energy use in university buildings

The energy consumed by the non-residential estate equates to 81% of the university sectors' total energy consumption (HESA, 2016) (Table 5-1)[42]. Energy consumption in the higher education sector is driven by numerous factors, including: "*student and staff numbers, weather conditions, building characteristics and appliances, available fuels and fuel costs, as well as equipment deployed within the buildings for academic business*" (Altan, 2010: 7723). The increases in energy demand in HEIs over the past years are believed to be due to the vast estates' heating and lighting requirements, and the heavy use of computers and power-hungry research equipment (*ibid.*). Energy reduction is thus seen as a 'must' action that will

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[40] Wates Construction's (2012) research analysing the trends, challenges and objectives facing UK universities, comprised an independent survey of 52 university participants: estates directors, deputy directs, project and facilities managers, plus in-depth interviews with leading estates directors.

[41] Wates Construction (2013) research analysing the trends, challenges and objectives facing UK universities, comprised an independent survey of 42 senior estates officials (representing a quarter of the sector), plus five in-depth interviews with senior university officials and estates directors, and an expert on higher education policy

[42] The data presented in Table 5-1 is based on a total of 145 *recognised bodies*, made up of 120 from England, 8 from Wales, 15 from Scotland, and 2 from Northern Ireland; this equates to 87% of the UK's recognised bodies as of 9 June 2016. See Table 9-7 in Appendix H for the list of institutions.

produce many benefits for the HIE sector: financial, i.e. saving the institutions money; environmental, i.e. reducing demand for fossil fuels will reduce the release of associated emissions; and social, i.e. enhancing the institutions' corporate image (*op. cit.*). Energy efficiency in UK HEIs, as a result of changes in energy consumption patterns, is influenced by external influencing factors including taxation and regulatory frameworks, and internal influencing factors (Table 5-2).

Table 5-2 Factors influencing energy efficiency in HEIs (summarised from Altan, 2010)

| External influences | Internal influences |
|---|---|
| European Union Emissions Trading Scheme | Rising energy costs |
| Climate Change Levy | Corporate social responsibility |
| Part L of the Building Regulations for England and Wales | Statutory obligations |
| Display Energy Certificates | Economic competitiveness |
| Carbon Reduction Commitment | Concerns for the environment |
| | Access to capital |
| | Corporate image |

In relation to the predicted and operational energy performance of the estate, universities are defined as *social sector institutions* and their students as *members of the public*; thus, university buildings that are regularly visited by students are required to have a DEC, and where tenanted, are also required to have an EPC (EAUC, 2008)[43]. In terms of the energy performance of the UK universities' non-residential stock[44], 1.4% of the total GIA as of 2014/15 is A-rated, 11.2% is B-rated, 28.5% is C-rated, 25.2% is D-rated, 15.5% is E-rated, 7.4% is F-rated, and 10.9% is G-rated (HESA, 2016) [45]. The sectors' non-residential GIA DEC/EPC ratings by country and in total are presented in Figure 5-2 and Table 5-1.

[43] Non-dwellings are required to have an EPC on construction or modification, sale, or rent, to inform tenants about a building's predicted energy use (DCLG, 2012); and a DEC, to inform members of the public of the operational energy used by social sector buildings they visit (DCLG, 2015). These two forms of energy labels are explained in greater detail in Section 2.3.4.

[44] The data presented in Figure 5-2 and Table 5-1is based on a total of 145 *recognised bodies*, made up of 120 from England, 8 from Wales, 15 from Scotland, and 2 from Northern Ireland; this equates to 87% of the UK's recognised bodies as of 9 June 2016. See Table 9-7 in Appendix H for the list of institutions.

[45] For the non-residential GIA by DEC or EPC, the data is collected by the EMS predominantly as DECs, with EPC data collection applying to Scotland only (HESA, no date-b). Note: The Scottish institutions' non-residential GIA represents 12.6% of the university sectors' total non-residential GIA (as per the data presented in Table 5-1).

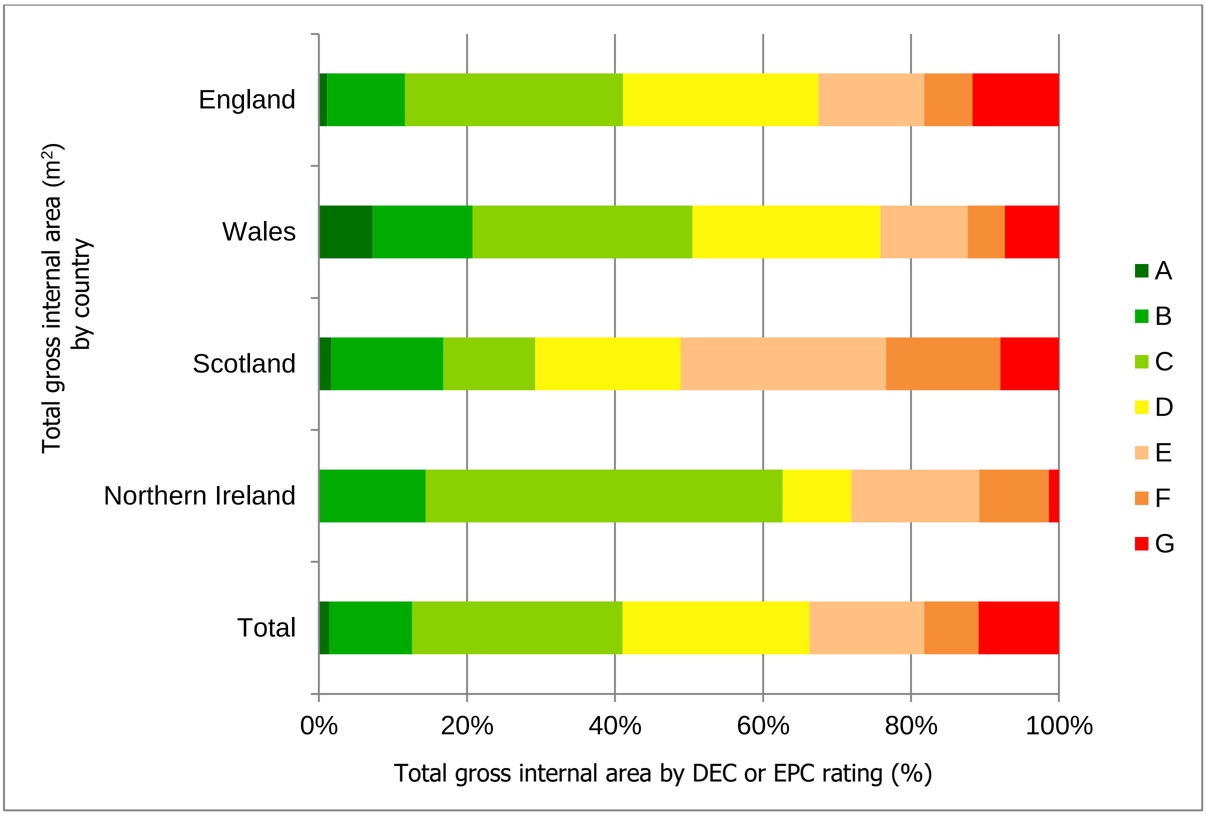



Figure 5-2 UK recognised bodies' non-residential GIA by energy label for 2014/15 (created from data obtained from HESA, 2016)

### 5.2.3 University building façade retrofit

"*Deciding whether to refurbish, redevelop or simply demolish buildings that no longer meet our needs and aspirations is a complex matter, and one that is particularly relevant to the university sector*" (AUDE, 2008: 1), with decisions regarding procuring new buildings or the major refurbishment of existing buildings on campus being some of the biggest to be made in the higher education sector (HEEPI et al., 2008). According to AUDE (2008), organisations such as BRE and the Health and Safety Executive have addressed a range of problems specific to 1960s and 1970s buildings (e.g. dealing with deleterious materials); however, little research has been undertaken regarding the question of whether to refurbish or replace such buildings in the university sector, prior to their research into the legacy of the ageing UK academic estate. AUDE's report focuses on 1960s buildings, which was a period of rapid expansion in the university sector; however, its principles are applicable to other university buildings, whether older or newer (*ibid.*).

Cost is a key influencing factor in university building retrofit decision-making. AUDE (2008) found the capital cost of refurbishing a university building could be up to 80% of the cost of an equivalent new-build, in which case, the building running costs are a critical factor for inclusion when conducting WLC analysis to compare the two options. WLC is considered particularly useful where the financial cost of refurbishment is close to that of demolition and replacement (*ibid.*). WLC can also support the business case for selecting more expensive, but more energy efficient services (Humblet et al., 2010). Furthermore, senior decision-makers in the university arena are advised not to focus on the immediate concerns of capital cost or design, but to evaluate options in relation to their impact on WLC, while also paying great attention to the designs' implementation, so benefits are actually achieved in practice (HEEPI et al, 2008). Two tools specifically developed to aid university institutions' retrofit decision-making are the Filter and the Matrix. "*The Filter is intended to assist Estates Directors, and others, to easily determine whether a project is likely to successfully support a refurbishment solution, from the Economic, Social, Vision and Environment perspectives. The Matrix is intended to be used by a project design team to enable various options to be assessed in terms of sustainability issues*" (AUDE, 2008: 2).

According to rainscreen over-cladding specialist, d+b facades (2010), academic institutions' Estates Departments have three options for addressing the ageing university building stock: leave and maintain, demolish and rebuild, or refurbish. The issues of rising energy costs and age-related structural deterioration are not addressed by leaving and maintaining the ageing stock; and while new-build positively contributes to meeting the aims of academic institutions, it carries high capital costs and is environmentally disadvantageous due to the embodied carbon released by demolition (ibid.). Refurbishing the envelope of ageing university buildings is however seen as offering the benefits of sustainable development: *economic* - the cost is typically 10-15% of a new-build, occupants can remain *in situ* avoiding decant costs, the existing façade's structural integrity is stabilised, and the building's useful life is extended by the new-build equivalent; *Environment* - the environmental impact is low due to embodied carbon being maintained and the building's performance is akin to that which can be obtained from a new-build; *Social* - the building's improved appearance, and internal and external quality, enables it to sit well in the competitive marketplace in which academic institutions operate (*op. cit.*). Chung and Rhee (2014) found that ageing university buildings constructed from envelope materials with low thermal performance have the potential for large improvements in energy efficiency. Window replacement and adding insulation to the envelope of such buildings was found to reduce energy use by 10-22%, while combining envelope thermal performance improvements with changing the behaviour of the building's occupants could reduce energy use by 18-29% (*ibid.*)

Work conducted to the façade of existing buildings is classified by four generic typologies: over-cladding, re-cladding, refurbishment, and retained façade (Richards, 2015), for which a university-related example for each typology is given as follows:

> **Over-cladding** Ingram Building, University of Kent, UK: This building's tired, dated and poorly performing exterior fabric was enclosed by adding cladding and windows, extending the façade's economic life by 50-60 years, while improving the building's energy efficiency and the building users' working conditions (University of Kent, 2016).
>
> **Re-cladding** Bartlett School of Architecture, University College London, UK: This retrofit project sees the building stripped back to its structural reinforced concrete frame and floor slab. The proposed design expands the available space for the school's functional needs via the addition of new floors and extensions, for which the building's structural strength and conservation area approval were key factors (O'Neill et al., 2015); the proposed new façade will be created from hand-cut brick (UCL, 2015). This retrofit project is estimated to cost around 80% of the cost of a full demolition and re-build, not including the costs associated with the significant demolition required to strip back the existing building to its structural frame and foundations (O'Neill et al., 2015).
>
> **Refurbishment** Calverley Building, Leeds Beckett University, UK: Modernisation of this 1970s teaching block, which saw the concrete façade cleaned and repaired, the

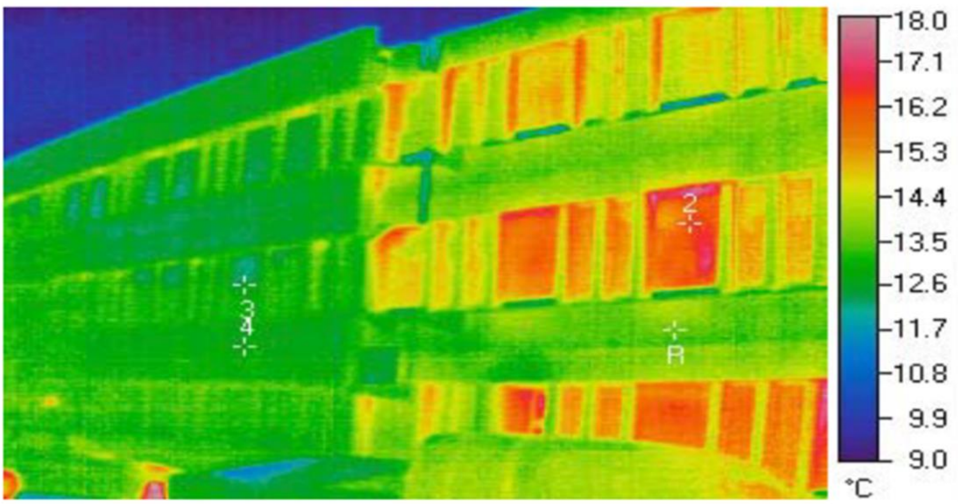
windows replaced, and internal work to upgrade plant and services, and create open-plan space, extended the building's life by 40-years (BAM Construct UK, 2016).

**Retained façade** University College Birmingham, UK: The Art Deco façade of a former print works is being retained as part of a campus redevelopment scheme, which is (at the time of writing) in close works with the LPA and conservation officers to ensure the modern design respects the area's architectural history (Jones, 2016).

This thesis chooses to focus on the façade retrofit typologies deemed as having the highest potential for improving a building's thermal performance and image, namely: *over-cladding* and *re-cladding*. Thermography is a tool that can be used to evaluate the success of thermal performance upgrades in building façade retrofit[46]. When Cottrell Building at Stirling University was over-clad, the university's Facilities Department commissioned thermographic surveying to assess any improvements in thermal performance as the work progressed (Thermal Innovations Limited, 2008). The over-cladding saw insulated cladding applied to the existing blockwork walls and the existing single-glazed windows replaced with double-glazing, with the aim of improving building aesthetics as well as thermal efficiency (*ibid.*). The cost of the over-cladding was around 7% that of a new-build and the occupants were able to remain *in situ* while the work was carried out (BPA Architecture, no date). The thermography showed the over-cladding had improved the building's thermal performance. Figure 5-3 shows a section of the building's façade that has been over-clad (left-hand side of image), while an adjacent section (right-hand side of image) is in its original state. The thermography showed the insulated cladding to be ~0.7°C colder than the existing blockwork; while a temperature difference (delta) of ~0.1°C was observed between the window and cladding on the over-clad section, and a delta of ~3.0°C between the window and blockwork on the existing façade (Thermal Innovations Limited, 2008). The Cottrell Building's façade retrofit reduced the building's heating requirement by around 80% (BPA

[46] See Appendix B for information on the use of thermography in façade retrofit and Table 9-4 of Appendix B for information on the key conditions required for thermography.

Architecture, no date). The greatest saving in heat loss is to be made by the new double-glazed windows, though only if they are kept closed; thermography conducted when the over-cladding was completed on the same elevation in Figure 5-3 counted 34 open windows that will reduce heat loss savings (*ibid.*).




| | Ref. | Point 2 | Point 3 | Point 4 |
|---|---|---|---|---|
| Emissivity | 0.98 | 0.98 | 0.98 | 0.98 |
| Max Temp °C | 13.3 | 16.4 | 12.6 | 12.7 |
| Delta Ref. °C | | 3.1 | -0.7 | -0.6 |

Figure 5-3 Thermography of Cottrell Building over-cladding as the work progressed (reproduced with kind permission from Thermal Innovations Limited, 2010b: 3)

### 5.2.4 Methods used to aid university building façade retrofit decision-making

The review of university building façade retrofit decision-making literature showed similarities to this thesis' review of decision-making in office building façade retrofit selection.

To fall within the boundaries of this thesis, the university building retrofit studies were required to feature over-cladding and/or re-cladding façade treatment, plus a description of how the façade retrofit was selected. Several studies described the façade treatment applied to existing university buildings, but gave no explanation of the decision-making leading to the façade selection, such as the following real-life cases of over-cladding: Northumberland Building at Northumbria University (CADDET, 1998; Pearsall and Wilshaw, 1996), Southbank University Student Centre (Bailey, no date; Divisare, no date), and Chapman Building at the University of Salford (CA Specialist Cladding Systems, 2012). Also, some studies featuring the façade treatment gave an explanation of the projects' retrofit decision-making, but did not mention the façade selection process, such as for the Strand Building at King's College London and Muirhead Tower at the University of Birmingham (AUDE, 2008).

Five case studies were found to meet this thesis' literature reviews requirements for studies of university building façade retrofit decision-making (Table 5-3). Three of the cases report façade selection that occurred in real-life[47]. Normative decision-making was demonstrated by the theoretical cases, who both utilised the payback period method, with one based on NPV.

The decision-making process for the real-life cases is discussed below, following which, the theoretical cases are discussed.

*Real-life cases of university building façade retrofit decision-making*

The real-life cases – REC A and REC B/C at the University of Amsterdam (AHMM, 2014), the Arts Tower at Sheffield University (Everett, 2013; HLM Architects et al., 2007; Mara, 2010), and G. E. Fogg Building at Queen Mary University (FBMA, no date-a; FBMA, no date-b) – showed numerous information sources being used in the façade retrofit selection process, relating chiefly to performance, aesthetics, collaboration, and cost.

The performance-related information included original architectural drawings from university archives, building condition surveys, building movement survey, ferroscan survey, concrete core samples, structural calculations, U-value calculations, air tightness testing, research into the occupants' use of the building with particular regards to window opening, and meteorological investigation. Modelling was used to confirm the energy demand reduction for the G. E. Fogg Building. IES-VE software was used to establish the correct balance between thermal performance, air leakage, and solar control for the Arts Tower, with consideration to initial cost, cost in service, and energy usage/costs. The Arts Tower structural analysis was carried out using the finite-element method and 3D modelling.

[47] This thesis defines 'real-life' case studies as involving a façade retrofit that has taken place, and thus describes decision-making methods and sources of information that have been used in practice in the AEC industry. The theoretical cases studies may use real-life building data, but the retrofit scenarios have not occurred in actuality.

With regards to aesthetics, the G. E. Fogg building architect worked closely with the building users when developing the façade, with detailed construction drawings prepared in response to the building's complex geometry. The REC A and REC B/C architect considered the ratio of solid façade to glazing treatment, the interplay between the building's three façades, and the building's relationship with its environment. Evolution in the REC A and REC B/C façade design was shown by the fact that one idea (fins) being tried and rejected, sparked the idea for highlighting in the window modules. The Arts Tower's ultimate appearance was initially governed by the building's listed façade, but aspects such as occupant safety, driven for example by the Building Regulations for England and Wales' current requirements for lower fixed window panes, led the original façade to be stripped and replaced.

The Arts Tower and the G. E. Fogg Building both described the involvement of different parties in the façade selection process. Due to its nature, the Arts Tower particularly involved close collaboration between project team members and regulatory bodies, including early engagement with conservation officers, plus input from multiple advisors. According to Everett (2013: 47) of Gifford, the Façade and Structural Engineering Consultants on the Arts Tower retrofit, "*such a project provides a template for future comparable heritage projects, albeit these will contain their own unique set of challenges*".

*Theoretical cases of university building façade retrofit decision-making*

The theoretical cases – the Main building at Bielefeld University (Ebbert, 2010) and an office building at Izmir Institute of Technology (Güçyeter and Günaydin, 2012) – used normative decision-making in the form of the payback period method, for the comparison of façade retrofit scenarios, with input information relating chiefly to performance and cost.

For the main building at Bielefeld University, energy demand calculations and life-cycle costs were used as a basis for four façade retrofit scenarios, which included the use of individual experience in relation to aspects that cannot be represented by hard facts, e.g. user comfort and future adaptability of a design. The four proposed solutions were compared to see how long they take to break even on costs, which showed the solution that was initially cheapest (ventilated over-cladding) failed to be so after 15-20 years, at which point two of the other solutions (modular re-cladding and 'atrium') exhibited better performance. This retrofit, if carried out in real-life, must be feasible to the building owner who rents it to the university, but to consider aesthetics in line the university's ambition to improve its public image to attract students and teaching staff (Ebbert, 2010).

For the office building at the Izmir Institute of Technology, the payback period method based on NPV is used to compare proposed over-cladding options whose energy performance has been evaluated in detail. "*Retrofit strategies demand decisive criteria based on insufficiencies determined via building performance audit and/or analysis of existing building*"; thus, a performance audit is used to record building aspects, such as orientation, comfort ranges, and occupancy; while performance monitoring is used to record such aspects as indoor temperature, electricity consumption, and $CO_2$ emissions (Güçyeter and Günaydin, 2012: 652).

Table 5-3 Examples of university building façade retrofit decision-making

| Source | Building name | Original build date | Recognised body | Façade typology[1] | | Decision-making methodology[2] | | | Decision-making context[3] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Name and country | Over-cladding | Re-cladding | Normative | Descriptive | Information sources | Real-life | Theoretical |
| AHMM, 2014 | REC A and REC B/C | 1964 | University of Amsterdam, The Netherlands | - | ✓ | - | - | ✓ | ✓ | - |
| Everett, 2013; HLM Architects et al., 2007; Mara, 2010 | Arts Tower | 1966 | Sheffield University, UK | - | ✓ | - | - | ✓ | ✓ | - |
| FBMA, no date-a; FBMA, no date-b | G. E. Fogg Building | 1970s | Queen Mary University, UK | ✓ | - | - | - | ✓ | ✓ | - |
| Ebbert, 2010 | Main building | 1976 | Bielefeld University, Germany | ✓ | ✓ | ✓ | - | ✓ | - | ✓ |
| Güçyeter and Günaydin, 2012 | Office building | 2007[4] | Izmir Institute of Technology, Turkey | ✓ | - | ✓ | - | ✓ | - | ✓ |

Notes:

1. The façade retrofit typologies are defined in Section 2.2.4.
2. The decision-making methodology presented in this table reflects the methods and information sources as reported in the cases, with no implications drawn from the data source.
3. This thesis defines 'real-life' case studies as involving a façade retrofit that has actually taken place; thus, the decision-making methods and sources of information have been used in practice in the AEC industry. The 'theoretical' cases studies may use data from 'real-life' buildings, but the reported retrofit scenarios have not occurred in actuality
4. This building was completed in 2007; however, it was designed in 1997, prior to Turkish building codes' mandating standards for insulation.

## 5.3 Research methods: Exemplifying case studies

### 5.3.1 Aim and objectives

The in-depth study assists in meeting the aim and objectives of this thesis through the conducting of exemplifying case studies that enable a deep exploration of multi-storey building façade retrofit decision-making in the UK AEC industry.

### 5.3.2 Data collection

*Exemplifying case study building typology*

Prior to conducting the deep exploration, an exemplifying case study building typology is identified. The exemplifying case, known also as the representative or typical case by Yin (2009) denotes a case that is "*chosen because it exemplifies a broader category of which it is a member*" (Bryman, 2012: 70). The findings from the state-of-the-art literature review (Chapter 2) are drawn on, to identify this 'broader category' or exemplifying case study building typology. The literature findings suggest the exemplifying case study building should:

- be office-type accommodation;
- be of multi-storey construction;
- have an original construction date between the 1960s and 1990s;
- have received a façade retrofit involving over-cladding and/or re-cladding;
- be located in the UK; and
- have stakeholders willing to be interviewed about the façade retrofit selection, especially the Client and Architect who play a significant role in construction projects.

*Exemplifying case study building recruitment*

A combined sampling strategy was used to recruit four exemplifying building case studies: an office and laboratory building; music facility; office and music building; and an arts and media building, from three UK higher education campuses. Of the four exemplifying case buildings, three are from recognised bodies, while the arts and media case building is from a listed body. This thesis defines its exemplifying case study buildings as *university buildings* by their association with a recognised body, as mentioned in Section 5.2.1. Due to the arts and media building exhibiting similarities to the typology of ageing university buildings, it is thus included in the definition of *university buildings* for the purposes of this research.

The evolution of the unit of analysis from office to university buildings was due to case study building availability. The purposive sampling used in the initial stages of the in-depth study revealed a lack of office buildings for case study; however, through the combined use of convenience and snowball sampling, an acceptable number of university building case studies were obtained. This evolution in building focus is seen as acceptably complementing the exploratory study's façade retrofit decision-making findings, as university buildings are similar to office buildings (Ebbert, 2010), the typology of ageing university buildings holds many similarities with office buildings from the same era (see Table 2-6 and Section 5.2.1), and the UK local government office estate boom in the 1960s-70s resulted in a legacy that requires urgent attention in the same vein as the UK university sector (AUDE, 2008).

In recruiting interviewees from the university retrofit projects, any participants were required to have knowledge on various aspects of the case study façade retrofit, to include, but not be limited to: cost, technical function, and aesthetics. Nine AEC industry members from the university façade retrofit project teams were invited to take part in the research, of which eight accepted the invitation to participate. The resulting eight UK AEC industry expert interviewees acted either in the role of *Client* for their respective case study company and were employed in the Estates Department of their respective case study company, or were enlisted as a consultant on one of the façade retrofit projects.

*Exemplifying case study data sources*

To enable data triangulation, as mentioned in Section 3.4.1, the exemplifying case studies' data was gathered from multiple sources: in-depth interviews with project team members involved in the façade retrofit selection, a documentary evidence review (see Appendix J for a list of documentary sources reviewed), and internal and external thermographic surveys of the retrofitted façades (Table 5-4). The in-depth interviews, as mentioned in Section 3.4.1, were each approximately one-hour in length and guided by an interview sheet, which served to open the dialogue on two specific topics: the building retrofit, and the selection of the building façade. Data gathered from case study C1's in-depth interviews and documentary evidence review was also further explored via email with the case study company's Client.

The AEC industry roles involved in the exemplifying case studies are also shown in Table 5-4, as is the reference applied to the exemplifying case studies' campus and building for ease of analysis and reporting. Certain details pertaining to the in-depth interviews, i.e. interview length, date conducted, and the reference assigned to each interviewee for ease of analysis, are provided in Table 9-3 of Appendix A. The interview and ethical information sheet can be seen in Appendix F. Note: any identifying references to the case study buildings/companies have been removed from these sheets.

Table 5-4 Exemplifying case studies: data collection

| Case Studies | | | Data Collection[1, 2] | | | | |
|---|---|---|---|---|---|---|---|
| | | | In-depth interview[3] | | | | |
| Building function | Campus reference | Building reference | Client[4, 5a] | Architect | Mechanical Engineer[5d] | Documentary evidence review | Thermography of the retrofitted façade |
| Office and laboratory | A | 1 | ✓ | - | - | ✓ | ✓ |
| Music | B | 1 | ✓ | ✓[5b] | - | ✓ | ✓ |
| Office and music | B | 2 | ✓ | ✓[5b] | ✓ | ✓ | ✓ |
| Arts and Media | C | 1 | ✓ | ✓[5c] | - | ✓ | ✓ |

Notes:

1. Further interview details, i.e. the length of interview, date conducted, and the reference assigned to each interviewee, are provided in Table 9-3 of Appendix A.

2. Data collection difficulties were experienced for case study A1. Access was refused to key documentary evidence, e.g. the ER and tender documents, and it was not possible to obtain an interview with the Architect.

3. The LPA plays a key regulatory function in construction projects, holding the power to issue or withhold necessary consents (Hughes and Murdoch, 2001). Due to the difficulty in obtaining planning input for the exploratory semi-structured interviews (n=3 invited, with zero response), it was decided the in-depth study planning input would be taken from each projects' planning application documents.

4. The term *Client* has been used for the interviewees whose roles represent the interests of the client within each case study project. These interviewees were each a member of their home institutions' Estates Department and for the retrofit projects played the following role: A1 - Client Co-ordinator, B1 - Client Project Manager, B2 - Client Project Manager, and C1 - Client Representative.

5. In-depth interview participants' organisation size described in line with European Commission (no date) business class guidelines: (a) local, large specialist enterprise; (b) local, small specialist enterprise, (c) national, small specialist enterprise, and (d) national, large interdisciplinary enterprise.

Thermographic surveys were conducted on the case study buildings to provide an indication of the success of the retrofitted façades. As the case study buildings' retrofit projects were completed prior to being recruited for use in this thesis, only post-retrofit thermography was conducted. For the surveys, external thermography was conducted on each building's total façade, while internal thermography encompassed the majority of each building's interior, excepting the area where access was not permitted. In preparation for the surveys, the buildings' details were reviewed by Matthew Fox using architect's drawings for each building. The surveys were conducted by Matthew Fox (using a FLIR T620bx infrared camera) and assisted by the author, who made notes against the internal floor plans, site plan, and elevation drawings. The surveys were conducted using a single image walkthrough-style of thermographic surveying, in accordance with BS EN 13187: 1999 (BSI, 1999). The surveys were conducted post-sunset so as to capture images at a point when a 10-degree Kelvin temperature difference existed between Temperature In and Temperature Out (UKTA, 2007) to aid the image resolution. For three of the exemplifying case study buildings, the external and internal surveys were conducted in the same session; for the office and laboratory building, a lack of building access resulted in the internal survey being delayed until the following 'cold season'. Details of the case study survey conditions are provided in Table 5-5 to Table 5-9. See also Appendix B for important notes regarding the case study thermography, plus Table 9-4 of Appendix B for further information on the key conditions required for thermography and the use of thermography in façade retrofit.

Table 5-5 Office and laboratory building external thermographic survey conditions (compiled from Fox and Garmston, 2015a; Sunrise-and-sunset.com, *passim*)

| Survey conditions | Details |
|---|---|
| Survey date | 19.03.14 |
| Sunset on the day of survey | 1828 |
| Survey start time | 1930 |
| Survey end time | 2030 |
| Survey temperature In (°C) | Above 20[1] |
| Survey temperature Out (°C) | About 6 |
| Survey weather conditions | Overcast sky, but no rain present during survey. |

Notes:

1. The internal temperature was assumed due to a lack of building access.

Table 5-6 Office and laboratory building internal thermographic survey conditions (compiled from Fox and Garmston, 2015a; Sunrise-and-sunset.com, *passim*)

| Survey conditions | Details |
|---|---|
| Survey date | 19.11.14 |
| Sunset on the day of survey | 1626 |
| Survey start time | 1800 |
| Survey end time | 2000 |
| Survey temperature In (°C) | Average 23 |
| Survey temperature Out (°C) | About 9 |
| Survey weather conditions | Overcast sky, but no rain present during survey. |

Table 5-7 Music facility thermographic survey conditions (compiled from Fox and Garmston, 2015b; Sunrise-and-sunset.com, *passim*)

| Survey conditions | Details |
|---|---|
| Survey date | 24.03.14 |
| Sunset on the day of survey | 1833 |
| Internal survey | Start/End time: 1920-2008[1] and 2023-2050 |
| External survey | Start time: 2011 / End time: 2020 |
| Survey temperature In (°C) | About 21 |
| Survey temperature Out (°C) | About 5 |
| Survey weather conditions | Overcast sky, with light rain. |

Notes:

1. A break in the light rain saw the internal survey paused so as to conduct the external survey.

Table 5-8 Office and music building thermographic survey conditions (compiled from Fox and Garmston, 2015b; Sunrise-and-sunset.com, *passim*)

| Survey conditions | Details |
|---|---|
| Survey date | 24.03.14 |
| Sunset on the day of survey | 1833 |
| Internal survey | Start time: 2125 / End time: 2320 |
| External survey | Start time: 2110 / End time: 2125 |
| Survey temperature In (°C) | About 21 |
| Survey temperature Out (°C) | About 5 |
| Survey weather conditions | Overcast sky, with light rain. |

Table 5-9 Arts and media building thermographic survey conditions (compiled from Fox and Garmston, 2015c; Sunrise-and-sunset.com, *passim*)

| Survey conditions | Details |
|---|---|
| Survey date | 17.11.14 |
| Sunset on the day of survey | 1632 |
| Internal survey | Start time: 1800 / End time: 2110 |
| External survey | Start time: 2110 / End time: 2130 |
| Survey temperature In (°C) | About 22 |
| Survey temperature Out (°C) | About 4 |
| Survey weather conditions | Mainly overcast, with some patches of clear sky. |

### 5.3.3 Data analysis

To produce research findings that facilitate comparison between the five façade retrofit case studies conducted for this thesis, the data collected for the exemplifying cases is analysed mainly according to the mixed methods approach adopted in Chapter 4. Thus, to prepare the exemplifying cases' in-depth interviews' raw data for analysis, the interview audio-recordings were listened to and relevant sections typed up. The qualitative data arising from the interviews and the documentary evidence review is evaluated thematically using the repetition technique, and descriptive analysis is used to graphically present the evolution of the façade elements for each case study. The majority of the thermography findings are analysed qualitatively, while quantitative analysis in the form of simple spot temperature analysis is used for the thermography findings identified as benefiting from closer analysis. Note: the thermography analysis was carried out by Matthew Fox and provided in note-form to the author, who then incorporated said analysis into this thesis.

The exemplifying case study data analysis differs from the exploratory case in one respect: that of the method used to record the evolution of the façade elements. The exploratory case study's façade evolution is recorded against the RIBA Plan of Work 2007, with its eleven work stages[48] grouped according to seven main project points identified by the exploratory case study company: *Initial concept design (A, B, C); Initial tenders received (end of C); Planning application and consent received (D); Technical design and product information (E, F); 2nd tenders received (G, H); Post-tender (J, K); and As-built (L).* This specific grouping did not however suit the exemplifying case studies' project progression and so a different grouping method was adopted. Thus, the exemplifying case studies' façade evolution is recorded according to the five groups used by the RIBA Plan of Work 2007 to organise its eleven work stages: *Preparation (A, B); Design (C, D, E); Pre-construction (F, G, H); Construction (J, K); and Use (L)* (RIBA, 2009). In adopting the RIBA's work stage grouping method, the façade evolution is easily comparable between the four exemplifying cases, though not so easily between the exploratory and exemplifying cases.

The exemplifying case studies are presented in the form of individual written reports (Section 5.4). These reports are presented as per the exploratory case; therefore, the justification of this presentation method can be seen in Section 4.3.3. Summaries of the case studies' façade retrofit details, and decision-making methods and information sources, are also presented in Table 9-5 and Table 9-6 of Appendix C respectively.

Note: For the purpose of gaining a rich insight into decision-making in façade retrofit, the exemplifying case study typology required the case buildings to have received a façade retrofit involving over-cladding or re-cladding. This thesis' definition of *façade* pertains only

[48] The Work Stages in the RIBA Plan of Work 2007 are briefly described in Section 4.2.2.

to the buildings' elevations; thus, any decision-making leading to the roof selection, normally treated as part of a deep-energy *envelope* retrofit, is excluded. However, where the building retrofit case studies do involve work to the roof, a brief description is included in the corresponding case study report, to provide a broad picture of the retrofit project.

## 5.4 Exemplifying case study reports

### 5.4.1 Office and laboratory building

This case study explores the decision-making process used to select a façade retrofit for a UK-based university office and laboratory building located in a maritime climate. This building provides office space for academic functions, laboratory space for practical-based work by students, plus teaching space. For ease of reporting, this case study shall hereafter also be known as 'case study A1'.

*The building pre-retrofit*

Case study A1 was constructed in 1962. Originally comprising three-stories, the building was 11.9 metres in height. It is adjoined by two other buildings, one that abuts its west elevation in a parallel manner and one that abuts its east elevation at right angles.

Case study A1 was constructed from an exposed RC frame. On the second storey of its south elevation, a bay projected out from the façade that spanned almost the whole length of the south elevation. The building featured single-glazed ribbon windows to the north and south elevations, which were timber framed to the south elevation's first and third stories, and steel framed to the second storey south elevation and to all of the north elevation's stories. The north elevation had uninsulated PCC panels to sill level. On the south elevation to sill level, there were uninsulated PCC panels on the first storey, uninsulated opaque panels on the second storey, and uninsulated red brick cladding on the third storey and part of the second storey, around the projecting bay. The west elevation also featured uninsulated red brick cladding, plus a small section of timber cladding on its third storey adjacent to the south elevation. To the east elevation, the first storey had been over-clad with white brick and the upper two storeys over-clad with aluminium rainscreen when the building abutting it at right angles was retrofitted in 1998. Pre-retrofit, its total useful floor area was 1729m$^2$.

Case study A1's façade materials were in a general poor condition, especially those on the south elevation, which takes the force of the weather, with the projecting bay particularly prone to water ingress. The windows to the whole building were nearing end-of-life. The concrete frame and the north elevation's PCC panels were however in good condition. With regards to internal comfort conditions, the building elevations reported their own particular problems. The north side of the building was reported as cold for the majority of the year (summer and winter); while the south side's internal conditions fluctuated between overly hot due to excessive solar gain in warmer weather, to unacceptably cold at other times. In pre-retrofit condition, case study A1 achieved a G (200) DEC rating.

*The retrofitted building*

Case study A1 was retrofitted in 2008-2009, in line with Approved Document L2B 2006, the RIBA Plan of Work 2007, and a traditional form of procurement, which was an unsupported form of contract, quality assured via annual updates by solicitors appointed by the home institution. The building was 36-years old at the point of retrofit.

Due to its cost, case study A1 was classed as a major project by the home institution and a project executive board was formed to steer the project. This board consisted of a Project Director, Plan Co-ordinator, Procurement, Financial Director, Project Manager, Cost Consultant, plus representatives from the home institution and from the University school occupying the case building. The role of Plan Co-ordinator, who is required to have construction knowledge, was played by the case study's interviewee, who also acted as Client Co-ordinator for case study A1. The Client Co-ordinator role is the hub between the home institution, the case building's occupants, other end-users of the case building, and the project team. The role of Client Co-ordinator is henceforth abbreviated to *Client* in this report.

This retrofit project had several aims. It aimed to achieve a new façade appearance that would enable the building to sit more comfortably in its surroundings on campus, a new-build and an extension to an existing building having been completed in close proximity to case study A1, shortly before the point of case study A1's retrofit. It also aimed to give an improved sense of identity to the University school housed in the building. The retrofit aimed to improve the building's thermal performance and its weathertightness, while minimising disruption to the internal spaces and retaining the building's general rhythmical expression. The retrofit also aimed to increase natural light entering the building from the north and south elevations, the building pre-retrofit having a deep footprint with narrow dark corridors. A further aim of the project was to provide an element of future proofing via the addition of a new storey to the building's existing roof, which resulted in a 38% increase in the building's total useful floor area. The extra space was not required by the building's occupants at the point of retrofit. Thus, at planning stage, the new storey was not designated an end user group, but was designed with flexible space that could be adapted to office, laboratory or teaching use. Due to the issue relating to a lack of natural light, the new storey had an open plan design.

In addition to case study A1's existing floors receiving a façade retrofit, preceded by a *Type 3 Asbestos Survey* - now known as a *Refurbishment/Pre-demolition Survey*, the building received a new roof of insulated single-ply membrane over a profiled metal deck as part of the new steel-framed storey. Plus, internal work saw compartments opened up and new spaces created through the use of metal stud partitioning, ceilings, floor coverings, and new mechanical and electrical installations. However, as this thesis focuses on façade retrofit, these roofing and internal works, and the process involved in their selection, are out with the scope of this case study report.

The building's main entrance is located in the east elevation, with the west elevation containing a secondary entrance. With its new fourth storey, the building is 15.1 metres in height. As per its current DEC (at the time of writing) the retrofitted building is shown as having a total useful floor area of 2384.3m$^2$.

Post-retrofit (Figure 5-4), case study A1 achieved a C (70) rating in its current DEC (at the time of writing) representing 12-months operational performance from October 2014 to October 2015. This DEC is an improvement on its previous post-retrofit ratings, which for the following DEC accounting periods were: 2013-2014, D (93); 2012-2013, D (92); 2011-2012, D (86); 2010-2011, F (130); and 2009-2010, F (136). Note: a total useful floor area of

1729m$^2$ is shown on the DEC representing case study A1s operational performance from 2008-2009; while an increased total useful floor area of 2428m$^2$ is shown on the DEC representing case study A1s operational performance from 2009-2010, following the addition of the new storey. Case study A1 also achieved a BREEAM Very Good rating.

Figure 5-4  Office and laboratory building post-retrofit

*The completed retrofitted building façade*

Case study A1 received specific façade treatment according to its four elevations.

*South elevation:* On the ground floor, the existing windows and panels were removed and replaced with double-glazed PPC aluminium frame curtain walling, with insulated coloured opaque glass panels to sill level, PPC aluminium architectural façade louvres at high-level and silver privacy film to the windows. The opaque glass panels were insulated with Class 1 PIR rigid board insulation, with Class 0 fibre cement board acting as the panel substrate. On the second storey, the existing windows and panels were removed and replaced with full storey-height double-glazed PPC aluminium frame curtain walling, with low-level inset adjustable clear glass louvre blades. On the third storey, the existing windows and brick cladding were removed, and replaced with full storey-height double-glazed PPC aluminium frame curtain walling, with low and high-level spandrel panels. The fourth storey was clad with full storey-height double-glazed PPC aluminium frame curtain walling, with low and high-level spandrel panels. The south elevation also featured buttresses rising from ground level to the top of the third storey, comprising RC foundations, RC transfer slab, and RC fins, to support the addition of a new storey to the existing roof. Solar shading, comprising of fixed position PPC aluminium louvres, was fitted between the RC fins on the second and third storeys, while solar shading for the new fourth storey was attached to the roof.

*North elevation:* On the ground floor, the existing windows and panels were removed and replaced with double-glazed PPC aluminium frame curtain walling, with insulated coloured opaque glass panels to sill level, PPC aluminium architectural façade louvres at high-level and silver privacy film to the windows. Also on the ground floor, were full storey-height PPC aluminium fixed louvre maintenance access panels (one panel to the east-end and two panels to the west-end of the elevation). On the second and third storeys, the existing windows and panels were removed and replaced with double-glazed PPC aluminium frame curtain walling, with insulated opaque coloured glass panels to sill level and PPC aluminium architectural façade louvres at high-level. The opaque glass panels to the lower three storeys were insulated with Class 1 PIR rigid board insulation, with Class 0 fibre cement board acting as a substrate for the panel. The fourth storey was clad with full storey-height double-glazed PPC aluminium frame curtain walling, with low and high-level spandrel panels.

*East elevation:* The ground floor was over-clad with new platinum white facing brick. The second and third storeys remained as per the previously retrofitted aluminium rainscreen cladding. The fourth storey was clad with full storey-height double-glazed PPC aluminium frame curtain walling, with low and high-level spandrel panels.

*West elevation:* The ground floor was over-clad with platinum white facing brick. The lower three storeys, except where the second storey abuts an adjoining building, were over-clad with basalt-based overlapped rainscreen.

*The façade selection process*

Case study A1 was initially considered for demolition. However, while its façade materials were in a general poor condition and its internal comfort conditions poor, the building's scale and rhythmical expression (in particular, its fenestration pattern) were considered as complementing its locale.

The retrofit project aimed to engage stakeholders from throughout the home institution (e.g. from marketing, various University schools, cleaning, and health and safety) who were represented by one person, the Principle Client, who attended meetings and presentations on their behalf, previous experience having shown that too many individuals voicing opinions can disrupt the course of a project. This engagement often highlights aspects, such as space, windows, and maintenance, and aimed to aid the development of the brief to full sign-off at RIBA Stage C[49]. Drawing on the engagement outcomes, the Client developed the brief for submission to the project executive board, after which point the business case was drawn up.

The cladding system was chosen over the course of RIBA Stages D/E. This home institution does not normally select suppliers pre-tender; however, for case study A1, a cladding supplier was selected pre-tender following a presentation by various cladding suppliers. The selected Cladding Supplier then worked with the Architect through RIBA Stages D and E to finalise the proposals, with the Architect keen to secure desired aesthetic detailing. Detailed drawings provided by the Cladding Supplier were used by the Architect as the project progressed. The Architect proposed that the south façade's projecting bay be retained and made prominent through the use of significant glazing, as a means of encouraging a connection between the users of the building and its locale. And in light of the appreciation of the rhythmical expression of case study A's existing façade, the new façade features a bay pattern repeated across the building, including windows sitting within the pattern of the existing concrete frame. Lessons had been learnt from work carried out to nearby buildings on campus, e.g. tannins had been found to leak out of oak, so timber cladding was avoided. Also, the colours of the opaque coloured glass panels and spandrel panels were chosen to

[49] At the time of writing, the latest version is the RIBA Plan of Work 2013 (RIBA, no date). However, at the point of participating in this research, the exemplifying case study interviewees were using the RIBA Plan of Work 2007; thus, all references to 'RIBA Stage/s' in the case study reports relate to the RIBA Plan of Work 2007.

match those used recently (at the time of case study A1's retrofit project) on an extension to a nearby existing building.

Buttresses rising from ground level to the top of the third storey on the south elevation, aligned with and tied into the existing structural frame, and comprising of RC foundations, RC transfer slab, and RC fins, enabled the addition of a new storey to the existing roof. The building occupants did not need the extra space at that current time, but life cycle costings had shown that an extra floor added value over and above the cost of the project. The façade retrofit utilises the space above the south elevation projecting bay by turning it into a walkway for maintenance access. The projecting bay was also utilised during the project, by enabling the south elevation third storey curtain walling to be erected prior to removal of the storey's existing façade, thus minimising disruption to the internal space. The new façade was designed to provide solutions for solar gain and natural ventilation. Solar shading was expressed as an important consideration at the planning stage, if overheating of the internal spaces on the south elevation were to be avoided. Solar shading is fitted between the south elevation's second and third storey RC fins, with the louvre blades doubling as handrail and edge protection for the maintenance walkway located between the external face of the rainscreen and the solar shading. Natural ventilation is utilised where possible via the use of architectural façade louvres, located above the windows to the first three storeys on the north elevation and to the first storey on the south elevation, which allow a supply of fresh air and the removal of exhaust air. The use of mechanical ventilation in the building is dictated by the cellurisation of the internal spaces. Privacy film was added to the ground floor north and south elevations. Case study A1's conditional planning permission stated that the LPA must approve the materials to be used on its external surfaces, prior to any development taking place; the reason being to ensure the materials used were in keeping with the area's character, as per the core strategy of the area's LDF. In Table 5-10, the façade evolution is recorded against the eleven stages of the RIBA Plan of Work 2007.

For ease of maintenance, the RC fins were specified to have a plain, undecorated surface. Additionally, the retrofit glass was specified to be self-cleaning to minimise the need for cleaning. When access for maintenance and cleaning is required, the new fourth storey's east and west elevations are designed to be accessed using a cherry picker, i.e. an elevated work platform. The north elevation on the fourth storey is accessed via a gantry, which was added to the design during RIBA Stage F/G, while its south elevation is accessed via the new maintenance walkway; the second and third storey solar shading louvres making cherry picker access difficult to the south elevation's fourth storey. The first three storeys' elevations are designed to be accessed from ground level, either from standing or ladder-use, or via cherry picker as appropriate to the storey height, as per standard practice pre-retrofit. The Cladding Supplier's warrantee was quite onerous in regards to aspects such as cleaning. The Client discussed the matter of warranties at length, weighing up the warrantee cost in comparison to its benefits; ultimately, a 12-month warranty was accepted, rather than an enhanced warrantee, in the knowledge that major problems could go through latent defects.

The new façade did not take a one system/one supplier approach. The Cladding Supplier was responsible for the curtain walling, windows and doors, while the south and north elevations' architectural façade louvres were supplied and installed by a sub-contractor independent of the Cladding Supplier.

The project experienced problems associated with the façade. There were delays to the window package from the Cladding Supplier, including problems with delivery timescales. The Cladding Supplier was not able to work off scaffolding when installing the façade materials, meaning that a flying carpet scissor lift had to be used instead; this meant the frequent deliveries made by vehicle to the area by the building's north elevation had to be carefully co-ordinated. There were also problems associated with the detailing, which resulted in a lot of leaks and a delay in hand-over of the completed building. The RC fins ended up being too close to the planned location of the windows, which were designed to sit behind the fins as a continuous waterproof barrier. The windows therefore had to be joined to the fins, which required new waterproofing details. These waterproofing details proved inadequate, and in some places, resulted in the cladding having to be taken off, and the ethylene propylene diene monomer (EDPM) rubber damp-proof course re-done, prior to re-installation of the cladding. The Principal Contractor (PC) accepted the project knowing the contract stated they must adopt the Cladding Supplier as their domestic sub-contractor, which effectively removed the home institution from their position of having nominated the Cladding Supplier. This meant the PC was technically liable for the delay in the window package and the problems with water ingress, though related discussions still arose between the PC and the Client. With hindsight, the Client felt that a D&B contract, which clearly passes the risk to the Contractor, may have been a preferable method of procurement.

Table 5-10 Office and laboratory building: evolution of the façade elements

| Building element | Façade element | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| **South elevation** | | | | | | |
| Ground floor | Curtain walling; opaque panels; façade louvres | | ✓ | ✓ | ✓ | ✓ |
| | Privacy film to the double-glazed windows | | ✓ | ✓ | ✓ | ✓ |
| 2$^{nd}$ storey | Curtain walling; glass louvres | | ✓ | ✓ | ✓ | ✓ |
| | PPC aluminium louvre sun shade | | ✓ | ✓ | ✓ | ✓ |
| 3$^{rd}$ storey | Curtain walling; glass louvres | | ✓ | | | |
| | Curtain walling; spandrel panels | | ✓ | ✓ | ✓ | ✓ |
| | PPC aluminium louvre sun shade | | ✓ | ✓ | ✓ | ✓ |
| 4$^{th}$ storey | Curtain walling; spandrel panels | | ✓ | ✓ | ✓ | ✓ |
| | PPC aluminium louvre sun shade | | ✓ | ✓ | ✓ | ✓ |
| 1$^{st}$ to 3$^{rd}$ stories | RC fins located in front of the windows | | ✓ | ✓ | | |
| 1$^{st}$ to 3$^{rd}$ stories | RC fins attached to the windows | | | | ✓ | ✓ |
| 1$^{st}$ to 3$^{rd}$ stories | New damp-proof details on RC fins and windows | | | | ✓ | ✓ |
| **North elevation** | | | | | | |
| Ground floor | Curtain walling; opaque panels; façade louvres | | ✓ | ✓ | ✓ | ✓ |
| | Privacy film to the double-glazed windows | | ✓ | ✓ | ✓ | ✓ |
| | PPC aluminium louvre maintenance panels | | ✓ | ✓ | ✓ | ✓ |
| 2$^{nd}$ and 3$^{rd}$ stories | Curtain walling; opaque panels; façade louvres | | ✓ | ✓ | ✓ | ✓ |
| 4$^{th}$ storey | Curtain walling; spandrel panels | | ✓ | ✓ | ✓ | ✓ |
| Roof | Window cleaning gantry | | | ✓ | ✓ | ✓ |
| **East elevation** | | | | | | |
| Ground floor | Platinum white facing brick | | ✓ | ✓ | ✓ | ✓ |
| 2$^{nd}$ and 3$^{rd}$ stories | Existing aluminium rainscreen - retained | ✓ | ✓ | ✓ | ✓ | ✓ |
| 4$^{th}$ storey | Curtain walling; spandrel panels | | ✓ | ✓ | ✓ | ✓ |
| **West elevation** | | | | | | |
| Ground floor | Platinum white facing brick | | ✓ | ✓ | ✓ | ✓ |
| 2$^{nd}$, 3$^{rd}$, 4$^{th}$ storeys | Basalt-based overlapped rainscreen | | ✓ | ✓ | ✓ | ✓ |

Notes: The numbered columns indicate the five main groups by which the eleven Work Stages of the RIBA Plan of Work 2007 are presented (RIBA, 2009): [1] Preparation (A, B); [2] Design (C, D, E); [3] Pre-construction (F, G, H); [4] Construction (J, K); and [5] Use (L). A tick indicates façade element presence in that evolutionary stage.

*The thermographic survey*

Summary: Overall, the results from the thermographic survey showed that despite holding few thermal anomalies, there were several significant anomalies (e.g. cold bridging), which might have contributed to an overall reduction in thermal performance.

Key findings: The external thermographic survey reveals possible heat loss sources. Potential cold bridging was observed at a corner on the second floor where the south and east elevations meet, and at floor level on the fourth storey; while the same panoramic image also appears to show warm junctions in the aluminium cladding panels near the upper part of the east elevation (Figure 5-5 – image 1). However, the low emissivity metal cladding makes it difficult to observe potential defects behind the east façade rainscreen, as much of the radiation received by the camera from this material would have been reflected from other sources. The internal survey identifies ventilation heat losses from open windows that would be contributing to a reduction in internal temperature (image 2 and image 3). Conductivity heat losses were identified at floor level on the second storey south elevation, in the location of the projecting bay (image 4), and in an internal wall perpendicular to the north façade (image 5). Differences in construction fabric were also observed during the internal survey: an unexpected warm patch was found that suggests the location of an old window that could have been filled with materials superior to those of the construction surrounding it (image 6); some windows and door frames appear very cold compared with other parts of the structure (image 7); and potential cold bridging was observed around the RC frame (image 8) (Fox, 2015b).

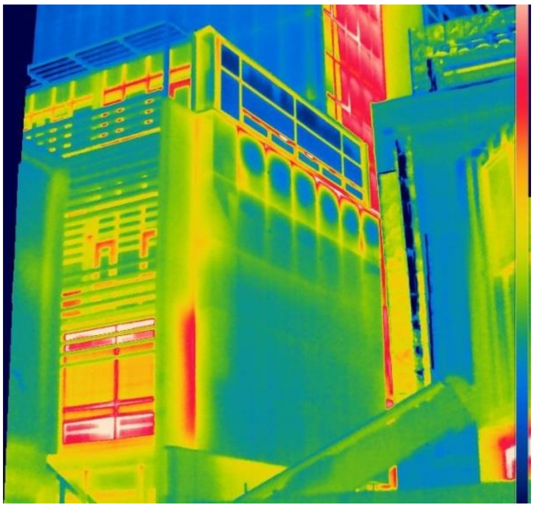


Figure 5-5 Office and laboratory building thermography - image 1

*(potential cold bridging at the corner of the building)*


Figure 5-5 Office and laboratory building thermography- image 2

*(ventilation heat loss from an open window)*

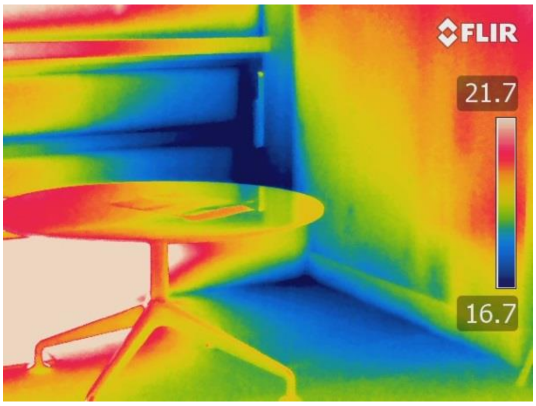



Figure 5-5 Office and laboratory building thermography - image 3

*(ventilation heat loss from an open window)*

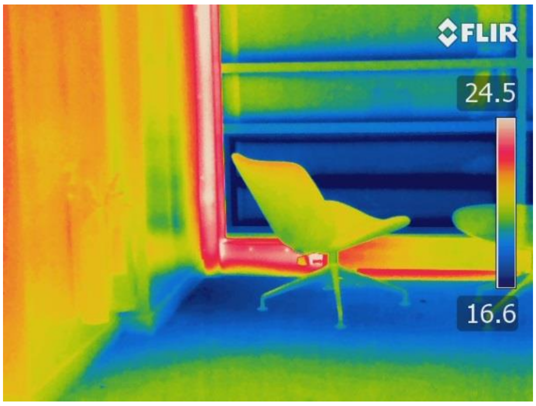



Figure 5-5 Office and laboratory building thermography – image 4

*(unexpected conductivity heat loss at floor level)*

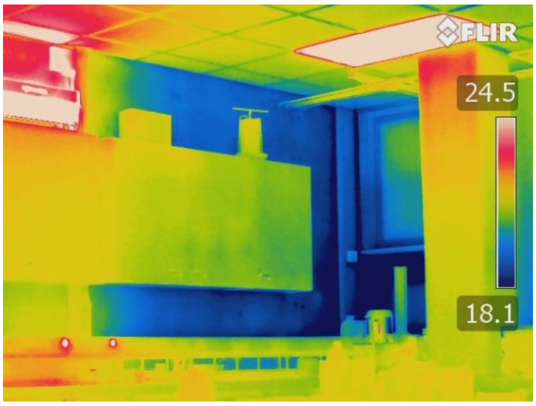



Figure 5-5 Office and laboratory building thermography - image 5

*(unexpected conductivity heat loss on an internal wall)*


Figure 5-5 Office and laboratory building thermography- image 6

*(unexpected warm patch)*


Figure 5-5  Office and laboratory building thermography – image 7

*(door frame appearing very cold compared with other parts of the structure)*

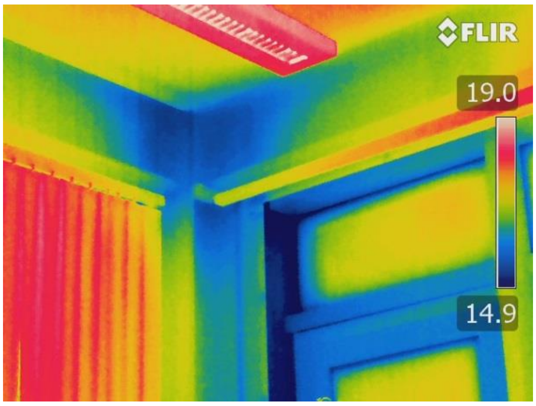



Figure 5-5  Office and laboratory building thermography - image 8

*(potential cold bridging observed around the RC frame)*

### 5.4.2 Music facility

This case study explores the decision-making process used to select a façade retrofit for a UK-based university music facility located in a maritime climate. This building provides space for students to rehearse music and to give performances, as well as flexible spaces that can be adapted for uses such as seminars/teaching, functions, and occasional dining. For ease of reporting, this case study shall hereafter also be known as 'case study B1'.

*The building pre-retrofit*

Case study B1 was constructed circa late-1950s/early-1960s, from an uninsulated reinforced PCC frame with exposed RC columns, uninsulated brick cavity wall infill panels, and RC slab floors with exposed concrete boot lintels. The building is 8.5 metres in height and contains two storeys. In the style of 'expressed concrete', the ground floor boot lintels were faced with PCC panels, and the first floor boot lintels faced with brick, with PCC panels directly above. The ground floor featured single-glazed windows in timber frames and single-glazed timber doors, while the first floor featured single-glazed aluminium windows in timber frames. Case study B1 has an oversailing first floor, which extends out beyond the ground floor by two to three metres on the south and west elevations, and along less than half the length of the south elevation and almost the whole length of the west elevation, with ten supporting columns in a colonnade effect. The approximate GIA was 815m$^2$ for the first floor and 730m$^2$ for the ground floor. In pre-retrofit condition, the walls featured various weaknesses: a lack of insulation, large and continuous thermal bridges, and poor airtightness; plus, other aspects in poor condition, such as rotten timber window frames. Case study B1 served as a dining block for nearby halls of residence, which were demolished in 2007. While not used in its dining block function for five-years prior to the retrofit, case study B1 was however in use until early-2010 as a rehearsal space for the university's music programme, and for social activities. In pre-retrofit condition, case study B1 achieved a G DEC rating.

*The retrofitted building*

Case study B1 was retrofitted in 2010, with work starting in May and ending in October. The retrofit project was conducted in line with Approved Document L2B 2006, the RIBA Plan of Work 2007, and a JCT D&B Contract - 2005 edition, Revision 2 - 2009. The building was circa 50-years old at the point of retrofit. The work was financed by a loan from the Higher Education Funding Council for England (HEFCE) Revolving Green Fund (RGF), a Salix grant for the cavity wall insulation, plus some funding from the home institution. The project was completed on budget and to programme. To engage with the building users and disseminate the retrofit project, the home institution took a multi-media approach including use of the home institution's website, leaflets, events, electronic newsletters, and social media.

This project had three primary objectives: firstly, to provide desired accommodation to a good standard of finish and acoustic quality; secondly, to upgrade the services; and thirdly, to improve the building's energy efficiency, acoustics, and appearance. University drivers for the case study B1 retrofit were for the improved energy efficiency of both the building, with a BREEAM Very Good rating desired, and of the campus. In appearance terms, the retrofit aimed to produce a building with a modern, clean, crisp look. In addition to case study B1 receiving a full façade retrofit, work was carried out to the roof as part of improving the building's energy efficiency. Internal works also saw improvements to the building's acoustics, a complete replacement of the mechanical and electrical services, and the creation of new music-related spaces. However, as this thesis focuses on façade retrofit, these other works and the process involved in their selection are out with the scope of this case study report. The building's main entrance is located in the south elevation. The building has a total useful floor area of 1530m$^2$.

Post-retrofit (Figure 5-6), case study B1 achieved a B (37) EPC rating. This predicted energy performance rating is mirrored by its operational performance, as case study B1 achieved a B (38) DEC rating in its current DEC (at the time of writing) for its 12-months of operational performance from October 2014 to October 2015. The previous two DEC ratings reveal similar operational performance, with case study B1 achieving a B (36) and a B (41) for its October 2012 to October 2013, and October 2013 to October 2014 DEC accounting periods respectively. Case study B1 also achieved its goal of a BREEAM Very Good rating.

Figure 5-6  Music facility post-retrofit

*The completed retrofitted building façade*

The walls to both stories were over-clad with a Class 0 insulated render system, comprising 100mm expanded polystyrene foam (EPS) and 4mm acrylic self colour render with feature panels. The façade retrofit also included blown insulation to the walls' cavity brick infill panels; thermally-broken double-glazed hollow fibre-reinforced polymer casement windows with a polyurethane satin finish; and thermally-broken double-glazed PPC aluminium doors.

*The façade selection process*

The Architect did a lot of space planning work in around 2007 for case study B1, before the project was put on hold for two-years. A *Type 3 Asbestos Survey*, now known as a *Refurbishment/Pre-demolition Survey*, was also conducted in 2007.

When the case study B1 retrofit project was re-started, its design period was nine-months. This period included three-months of feasibility work, mainly carried out in-house by the home institution, with some input from the Architects Practice that was later appointed to the project and who was the same Architect involved in the earlier space planning. This feasibility work confirmed that the budget allocated for the retrofit project was realistic. The feasibility work was carried out prior to the Client Project Manager, henceforth abbreviated to *Client* in this report[50], becoming involved in the project.

The brief and its targets were set at the outset of the project (RIBA Stage A). The project initially aimed to increase the building's insulation values by retrofitting the windows and roof. Insulating the walls was not in the initial scheme. The Architect however, evidenced the need for insulating the walls, both internally via cavity fill and externally, via the use of *Therm* building heat-transfer modelling software to demonstrate thermal bridging and dew points. The Client took on board the need for external wall insulation (EWI) and added it to the project, with this aspect of the retrofit entering the project at RIBA Stage C. Funding for the cavity wall insulation was then obtained via a Salix grant, whose application was initiated by the engineers and the home institution's Estates Department.

A further *Type 3 Asbestos Survey* was conducted in early-2010, and due to the asbestos risk, the Client stripped the building of asbestos and fixtures and fittings before handing it to the Contractor. A structural condition survey was also conducted in early-2010. The Contractor was appointed without going to tender, which saved time. The Architect was novated to the contract at RIBA Stage D and was nominated as Contractors Consultants for the Contractor.

It seemed natural to over-clad the building because of its shape. An insulated render system was specified because of the budget. The Client and Architect researched other types of façade treatment, such as panel and rainscreen cladding, but the Architect advised that the budget would not stretch to such forms of façade treatment. Also for budgetary reasons, polystyrene was chosen from the outset as the insulation element of the render system, as it is so much cheaper than PIR foam. Polystyrene burns quickly, so the specification stated that it must be sealed as part of the over-cladding process. The polystyrene thickness in the insulated render system was subject to debate: the ER stated 120mm, 75mm was suggested by the Contractor at Stage F, but ultimately 100mm EPS was applied. The cavity wall

[50] The term *Client Project Manager* was found by Hughes and Murdoch (2001) to be a synonym of various construction project roles representing the interests of the *Client*.

insulation brief gave instructions to fill where possible, as cavity wall fill can have filling issues with buildings featuring expressed concrete. The Mechanical Engineer created thermal models to aid the façade selection. The mechanical engineering consultancy also produced the BREEAM report.

Due to case study B1’s location between new-build student accommodation of red brick, with decorative cedar panels, and a Grade II listed circa-1700 red-brick mansion, the Client wanted the retrofit to achieve a modern crisp look, but with a subtlety of appearance to ensure it would contrast with and not dominate its surroundings. A crisp look with some colour is easily achieved with self colour render. The render system is thus finished with grey self colour render, though the grey was not as dark as the Architect wanted it to be, with colour feature panels. One particular of case study B1’s full planning permission was that samples of the materials to be used externally must be submitted to the LPA for approval prior to any development starting; the reason being to ensure the materials used conformed with the visual amenity of the surrounding area.

There were concerns about the render system being damaged at lower level when the retrofitted building came into use; however, the insulated render system was still applied down to plinth level. The Cladding Sub-Contractor was considered to be good. The chosen over-cladding will extend case study B1’s life by up to 30-years; however, no warranty was obtained for the render system used on case study B1.

The retrofitted windows are slightly smaller than the original so as to accommodate the over-cladding. The windows feature hollow fibre-glass frames, due to their superior acoustic properties. The retrofitted double-glazed windows were modelled using IES-VE energy analysis and performance modelling software. Triple glazing was looked at informally, but as the project was not working to an initiative that required such measures (such as the AECB CarbonLite Programme) it was never officially included in the specification. It was planned that windows, where not needed, would be blocked up using insulation. The proposed façade retrofit at pricing stage indicated one blocked window to the south elevation, two partially blocked windows to the west elevation, and four blocked windows to the east elevation. In the end, however, most of the windows were felt to be giving useful daylight and thus deemed to be needed, and ultimately just the one window on the south elevation was blocked up. Due to budgetary reasons, it was decided from the outset not to have brise soleil or shading. A section of the upper storey on the south and west façades overhangs the lower façade, thus naturally helping to reduce solar gain; plus, the retrofitted windows feature deep reveals to counteract solar gain. An initial aim was to have natural ventilation throughout, reliant on openable windows. This stance, however, proved less than ideal in terms of achieving a BREEAM Very Good rating, meaning that mechanical ventilation had to be introduced, to the detriment of the budget. In Table 5-11, the façade evolution is recorded against the eleven stages of the RIBA Plan of Work 2007.

Value engineering was not restricted to a particular RIBA Work Stage; it was fairly informal. The value engineering that took place related mainly to the fixtures and fittings, e.g. to the café kitchen, bar, and concert hall lighting. The Contractor did try to cheapen some areas, as expected from D&B contracting; in relation to the façade, this consisted of a lack of detailing. The Client provided a broad performance brief, which was met in terms of U-values. The Client wanted the building to better Part L of the Building Regulations for England and Wales' U-value and air tightness requirements, thus air tightness was set at 5.0 $m^3/(h.m^2)$ in the ER's design criteria.

Table 5-11 Music facility: evolution of the façade elements

| Building element | Façade element | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Façade retrofit | Review of potential cladding materials | | ✓ | | | |
| Cavity walls to all stories and elevations | Blown insulation | | | ✓ | ✓ | ✓ |
| External walls to all stories and elevations | Insulated render system (120mm EPS, render) | | ✓ | ✓ | | |
| | Insulated render system (75mm EPS, render) | | | ✓ | | |
| | Insulated render system (100mm EPS, render) | | | ✓ | ✓ | ✓ |
| Windows to all stories and elevations | Thermally-broken double-glazed; PPC Aluminium | | | ✓ | | |
| | Thermally-broken double-glazed; fibre-reinforced polymer with polyurethane satin finish | | | | ✓ | ✓ |
| Doors to first storey | Thermally-broken double-glazed; PPC Aluminium | | | ✓ | ✓ | ✓ |

Notes: The numbered columns indicate the five main groups by which the eleven Work Stages of the RIBA Plan of Work 2007 are presented (RIBA, 2009): [1] Preparation (A, B); [2] Design (C, D, E); [3] Pre-construction (F, G, H); [4] Construction (J, K); and [5] Use (L). A tick indicates façade element presence in that evolutionary stage.

*The thermographic survey*

Summary: The thermographic inspection on this building showed how the retrofit work had largely been successful. Whilst some areas of existing structure could be observed, and were not adequately dealt with (e.g. at the bottom of the external walls), the majority of this building had been thermally improved.

Key findings: Light rain was experienced during the survey, which meant that little could be learnt from the external thermography. However, despite the weather, signs of cold bridging were observed externally at the bottom of the wall on the south elevation, in the location of the original frame's reinforced PCC columns (Figure 5-7 – image 1). This observation appears to be reflected by the internal survey, where intervallic cold bridging was noticed at wall-base level, on the ground floor south elevation (image 2 and image 3). Potential cold bridging was also observed externally at the bottom of the wall on the east elevation, where the end-point of the insulated render system extends out beyond the line of the original wall (image 4). This observation appears to be reflected by the internal survey, where signs of cold bridging were noticed at floor level, on the ground floor east elevation (image 5). The internal survey, which was unaffected by the weather conditions, shows that some of the external doors and windows appear to have ventilation losses around the frames that would be contributing to a reduction in internal temperature (image 6 and image 7); while the windows and doors appear very cold compared to the rest of the construction materials, as shown by the panoramic image in image 8 (Fox, 2015b).

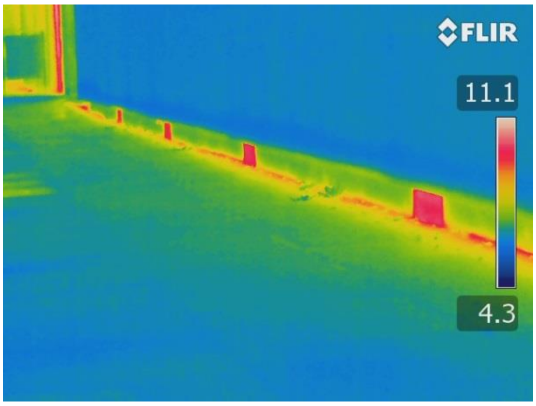



Figure 5-7 Music facility thermography - image 1
*(signs of cold bridging observed externally; assumed to be structural columns at the wall base.)*

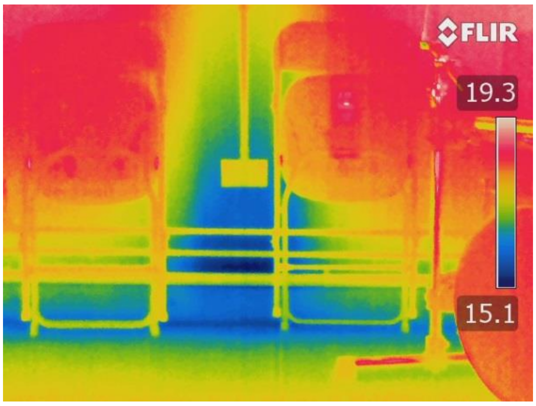



Figure 5-7 Music facility thermography - image 2
*(potential cold bridging observed internally at intervals at the wall base)*

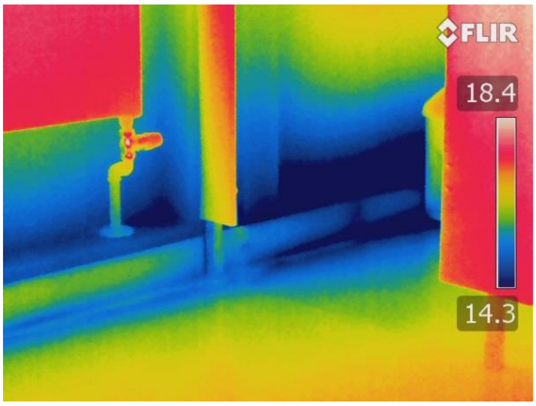



Figure 5-7 Music facility thermography - image 3
*(potential cold bridging observed internally at intervals at the wall base)*

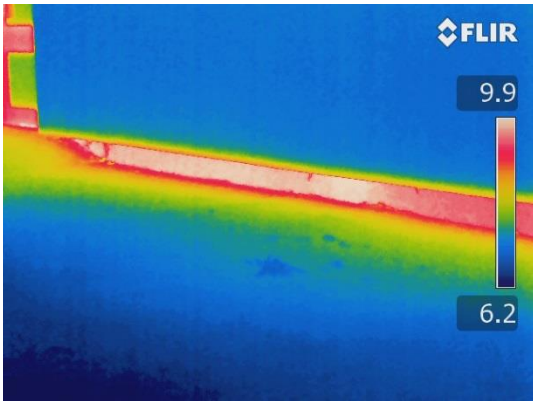



Figure 5-7 Music facility thermography - image 4
*(potential cold bridging observed externally at overhanging wall base)*

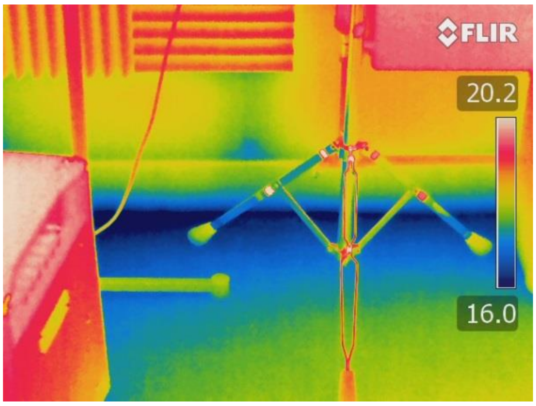



Figure 5-7 Music facility thermography - image 5

*(potential cold bridging observed internally at floor level)*

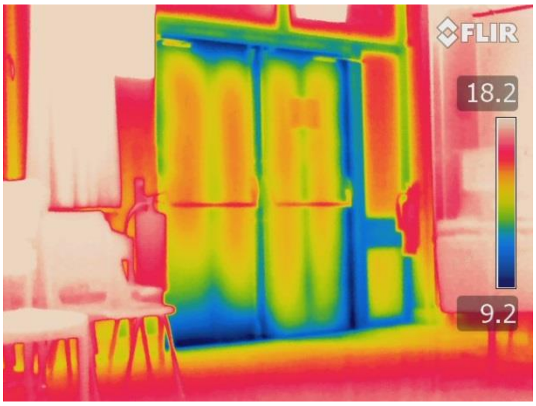



Figure 5-7 Music facility thermography - image 6

*(cold bridging and ventilation heat loss observed around an external door frame)*

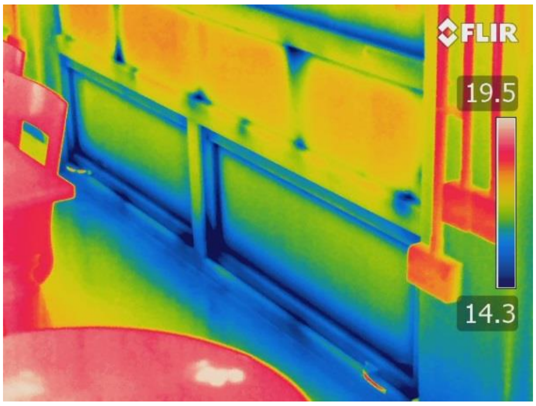



Figure 5-7 Music facility thermography - image 7

*(ventilation heat loss around a window frame)*

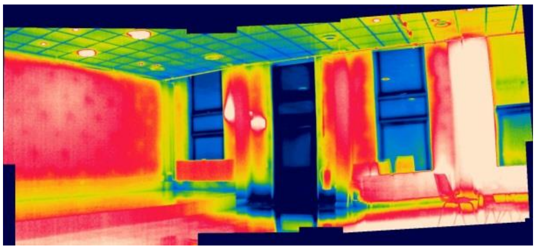


Figure 5-7 Music facility thermography - image 8

*(windows/door different in temperature to adjacent materials)*

### 5.4.3 Office and music building

This case study explores the decision-making process used to select a façade retrofit for a UK-based university office and music building located in a maritime climate. This building provides space for offices and library associated with the university's music provision, plus space for student music practice, other student activities (e.g. martial arts), and a student nightclub. Ancillary uses include a launderette, catering kitchen, restaurant, changing rooms for the open air swimming pool, and a shop. For ease of reporting, this case study shall hereafter also be known as 'case study B2'.

*The building pre-retrofit*

Case study B2 was constructed circa 1969-1970. Due to the natural topography of the building's location, case study B2 has a two-storey façade to south and west, and upper façades only to north and east, with the upper and lower storeys known as 'ground floor' and 'lower ground floor' respectively. The overall height of the building is 7.7 metres.

Defined as a 'hard to treat' building, case study B2 was constructed from uninsulated structural pre-cast concrete (PCC) panel walls and an internal structural steel frame. The concrete panels were unlined, though some rooms were lined at a later date, and each panel contained an element of glazing. The building featured fixed pane single-glazed steel ribbon windows, with some high level openable windows or glass louvres, plus single-glazed doors with some retrofitted timber-frames. The façade comprised over 60% glazing and the building suffered badly from solar gain. A right-of-way existed through the building on a 24-hour basis. In pre-retrofit condition, case study B2 achieved a G (177) DEC rating for its October 2011 to October 2012 DEC accounting period, which represents a full 12-months of operational performance prior to the retrofit starting. Case study B2 was one of the worst performing buildings on campus, and as such, was selected by the university for retrofit, to show what could be done and as a learning curve for the campus as a whole.

*The retrofitted building*

Case study B2 was retrofitted in 2013, with work commencing on site mid-May and finishing mid-October. The building was in full use during the retrofit. The project was scheduled for a 16-week programme to end mid-September, but delays resulted in the project being finished on a 'live' campus. The project was conducted in line with Approved Document L2B 2010, the RIBA Plan of Work 2007, and a traditional form of procurement. The building was circa 43-years old at the point of retrofit. The work was financed by two HEFCE RGF loans, plus funding from the home institution. After the first of the two funding bids received HEFCE approval, it was given to the Client Project Manager, henceforth abbreviated to *Client* in this report[51], for commencement of the works. It soon became obvious to the Client, however, that windows had been omitted from the first bid. The Client thus submitted a second funding bid for the window package, which also received HEFCE approval.

This retrofit project aimed to improve the case building's energy efficiency, by means of upgrading the thermal envelope, improving air tightness, and addressing solar gain, while also contributing to the university's carbon-reduction goal. In energy performance terms, by taking a 'hard to treat' building and making it better than average, it was aimed that the retrofit should result in case study B2 achieving a D EPC rating. In appearance terms, which were secondary to energy efficiency, but still important due to the building's visibility on campus, the building aimed to be clean, crisp, and colourful.

For the purpose of engaging with the building's users and disseminating the retrofit project, the home institution put together a stakeholder group that represented all the functions that used the building, to enable their input into the façade design. Engagement with the building's users and dissemination of the project was considered key to the retrofit's aim of improving the building's energy efficiency, since this aim involved encouraging behavioural change in the staff and student users in regards to energy consumption. Furthermore, where

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[51] The term *Client Project Manager* was found by Hughes and Murdoch (2001) to be a synonym of various construction project roles representing the interests of the *Client*

it would benefit their degree course, undergraduate students were offered opportunities to be involved in the retrofit via work-based learning and work-shadowing. Plus, disseminating the retrofit project as a case study for use during some of the university's courses was also a consideration.

In addition to a full façade retrofit, work was carried out to the roof as part of improving the building's energy efficiency. Internal works saw certain areas modified, such as the lower ground floor for the creation of music practice rooms, and work to the building services was carried out. However, as this thesis focuses on façade retrofit, these other works and the process involved in their selection are out with the scope of this case study report. The building's main entrance is located in the east elevation, while the west elevation contains the main entrance to the nightclub. The building has a total useful floor area of 2456.1m$^2$.

Post-retrofit (Figure 5-8), case study B2 exceeded its target predicted energy performance by achieving a C (59) EPC rating. Case study B2 then met (and proved) its target energy performance, by achieving a D (96) and a D (100) DEC rating for the two-years clear of the retrofit being completed. These two DEC ratings represent 12-months of operational performance during the building's December 2013 to December 2014, and December 2014 to December 2015 DEC accounting periods, with the latter rating representing the building's current DEC (at the time of writing).

Figure 5-8 Office and music building post-retrofit

*The completed retrofitted building façade*

The ground floor walls were over-clad with a Class 0 insulated render system. The general over-cladding comprised, from the building substrate outwards, of: 70mm flexible insulation batts to infill the concrete panels' recessed areas, fitted between the softwood framing for the subsequent particle board; 12mm cementitious particle board; steel support rails for the insulated render system; and the insulated render system. The render system comprised 150mm EPS insulation blocks, with the joints sealed with expanding foam, a reinforcing base coat of cement-free plaster with fully embedded fibreglass mesh, and a finishing coat of cement-free silicone resin render. Where existing windows were blocked up, the over-cladding in that area comprised from the window outwards, of: black self-adhesive film applied to the window pane, 60mm+50mm flexible insulation batts, and 12mm cementitious particle board, followed by the steel support rails and insulated render as above.

The ground floor façade retrofit also featured thermally-broken double-glazed solar control windows formed in bays to emulate the original ribbon windows. The bays comprised glass panes in a random insert pattern, alternated with green PPC aluminium mullions insulated with 35mm flexible insulation, and framed with grey PPC aluminium with projecting edges to minimise weathering. Also included in the ground floor façade retrofit, were: PPC heavy duty aluminium welded doors with double-glazing; a wooden-framed recessed upstand to the parapet roof, covered to front and top with PPC aluminium-capping, and rendered to the rear; a vertical-framed false beam bridging the main entrance; a glass canopy to the shop entrance on the east elevation; an insulated ground level upstand of painted marine WBP plywood, made using *water and boil proof* adhesive; and a protective foot barrier attached to the face of the insulated rendered wall adjacent to the nightclub entrance.

The lower ground floor walls' over-cladding comprised, from the building substrate outwards, of: 70mm flexible insulation batts to infill the concrete panels' recessed areas, fitted between the softwood framing for the subsequent particle board; 12mm cementitious particle board; and an external covering of insulated PPC aluminium spandrel panels, containing 35mm flexible insulation. The aluminium spandrel panels comprised either near full-storey height panels, with high-level inset double-glazed PPC aluminium windows or PPC aluminium louvres, or sill height panels, with thermally-broken double-glazed solar control PPC aluminium windows above. Also included in the lower ground floor façade retrofit were PPC heavy duty aluminium welded doors with double-glazing or in the case of plant room doors, fixed metal louvre panels; insulated PPC aluminium column surrounds, alternated between the panels/windows; and an insulated ground level upstand of painted marine WBP plywood. The lower ground floor façades are slightly recessed to give the ground floor an appearance of floating.

*The façade selection process*

After the HEFCE funding approval was received, the Client recruited a team of consultants to put the entire retrofit package together, which due to the ample time available for the works, was done on a traditional procurement basis. Budget was the main constraint driving façade decisions in the retrofit project for case study B2; none of the project design team was involved in the funding process.

RIBA Stages A, B and C featured a review of potential cladding materials, followed by an options appraisal of certain cladding solutions with a consideration to cost.

The Architect used professional in-house knowledge to come up with design options. The architect's practice selected different types of materials with knowledge of budgets, and then also looked outside the box. Lightweight cladding applications were generally considered more suitable, thus certain external cladding processes involving materials such as stone and brick were discounted from a construction aspect. The Mechanical Engineering Consultant became involved from RIBA Stage B onwards. The Mechanical Engineering Consultant delved into the building energy use with the building management system (BMS) managers, thus producing relatively accurate thermal load and heating information. At RIBA Stage D, the Mechanical Engineering Consultant demonstrated what happened in terms of the heating load, with the aim of producing a 25% improvement over Part L, for the Architect to hopefully take forward. Heat loss via infiltration (air permeability) was also considered by the Mechanical Engineering Consultant. The Structural Engineer played a part in the selection of the vertical façade element in terms of what can be added to the existing building based on dead and live loads. Various cladding types were initially proposed on aesthetic grounds for review at RIBA Stage C. Of these proposed cladding types, various options were then analysed in greater detail at RIBA Stage C, e.g. aluminium faced composite panel, standing seam sheet system, high pressure laminate panel system, and render system. The south and west façades were focused on for the options analysis, due to both being two-storey.

A stakeholder group was put together that represented all the functions that used the building. The Student Guild (SU) played a large part in this stakeholder group, though it was necessary to temper the students' perceptions, e.g. some perceived the mixed-use building as solely a night-club, and their transient nature, e.g. being users of the building for only the duration of their studies. Progress in the design process was disseminated to the stakeholder group. This dissemination took the form of an open presentation at RIBA Stage C by the Architects Practice selected to work on the retrofit design, with a static display of various potential cladding options set up in the early afternoon on the day of the presentation. The presentation highlighted the primary importance of energy efficiency to the project and the secondary, but still important, need for aesthetics. It stated how all the options reviewed at this stage were over budget, but that some were close to being within budget if value engineering was applied; it also stated that the options' development would take into account, and include elements of, stakeholder feedback in the most cost effective way. Stakeholder consultation was also facilitated via case study B2's Facebook page. While the students in general played a large part in the stakeholder group, only one student attended the open presentation; student engagement was much higher via the Facebook page. While appreciative of the stakeholders' input, the Client observed the difficulty of using such a stakeholder group, in that while someone may like something, there is generally always someone who does not. For example, a one-tone finish in green or other bright colours, or a mix of different bright colours, was rejected by the home institution's Directors as they were felt to give a primary or secondary school effect; while the majority of the student votes via Facebook expressed a preference for multi-colour slabs. The retrofit was ultimately felt to have experienced 'design by committee', where a final design, though acceptable to the majority, can tend to be a bit bland.

Taking on board stakeholder feedback, the proposed external appearance for case study B2 was developed to an extent that it could be presented to the LPA, along with an outline of the retrofit project, in terms of a planning application. The RIBA Stage D report was then developed, incorporating any LPA recommendations, to progress the project to the full planning application stage. As part of the LPA consultation process, approval for the proposed retrofit was sought and obtained from the Conservation Officer at a local branch of the Garden History Society, now part of The Gardens Trust. When case study B2 was granted full planning permission, the decision had no conditions applied in regards to LPA approval of external construction materials.

At RIBA Stage D, the proposed façade retrofit included insulated render and coloured fins to the ground floor, and over-cladding in a contrasting material and colour to the lower ground floor. At this stage, the design also included a green living wall to the south elevation and around the main entrance to the east elevation. Ultimately, the façade choice came down to a cost exercise, during which an all-in-one system/one supplier insulated render system was chosen for the ground floor façade. The existing concrete panels were found to be fairly true, indicating that case study B2 had not experienced much movement during its life. However, the Architect still selected engineered mechanical fixing for the render system, to adjust any truing if needed, via the use of metal rails. The alternative method for attaching the insulation was adhesive, which would have revealed any non-true faces, as the substrate, which in this case comprises EPS insulation blocks, is relied upon for its trueness prior to hand application of the render layers. The rail system was confirmed by the Mechanical Engineers, at RIBA Stage D, as suitably transferring any additional vertical load from the insulated render system into the existing structural concrete wall panels. Flexible insulation batts were specified to infill the recessed areas of the concrete panels. A stronger render system was specified, since case study B2 is located in a main pedestrian thoroughfare on campus and the 24-hour right-of-way through the case building was being replaced by a set of steps adjacent to the south façade and a path adjacent to the north façade. In the area of this new walk-way, special fixings were used where handrails were attached to the building, so as to prevent the insulation being crushed. The render system was applied by an approved contractor to ensure a warranty was obtained, for which the Client was pleased to obtain a really good warranty of 20-years. A single Sub-Contractor was in charge of applying the total façade retrofit components, so as to stand a better chance of achieving better air tightness in the finished façade. Flexible insulation batts were also specified to infill the recessed areas of the concrete panels on the lower ground floor, prior to the application of insulated spandrel panels and glazed units. For safety purposes, and to conceal the view of the roof plant and thus improve the building's appearance when viewed from an elevated position, the height of the low upstands on the parapet roof was increased as part of the façade retrofit.

The glazing did not go through the same iterative process. The Client wanted this aspect of the retrofit to reflect the style of the original ribbon windows, so new windows were formed in bays, with thermally-broken double-glazed panes alternated between insulated coloured PPC aluminium mullions, within a PPC aluminium frame. The new bays included low-level openable windows to aid natural ventilation, set alternately with double fixed panes. The new bays maintain the existing glazing height. The Services Engineer carried out a review on brise soleil, and as a result, solar control glass was initially specified at RIBA Stage D for the south and east façades. The application of solar control glazing focused on performance, with g-values tested through modelling, rather than on the supplier or the make of the glass. Ultimately, solar control glass was added to all of the retrofitted windows, as the cost difference was minimal and it made the glazing process easier. The window supplier was changed part way through the project due to budgetary reasons.

As part of the glazing scheme, ground floor windows were removed where it would not result in the increased use of electric lighting. The students suggested that windows were not required on the nightclub, but as this part of the building was used only twice-weekly as a nightclub, other users of the space needed to be considered. Overall, 8-9% of the original glazed area was filled in, which equated to a total of 35 windows, from the elevations as follows: west (n=7), south (n=4), north (n=11), and east (n=13). Rather than being removed, the filled in windows were blocked up externally, thus creating a monolithic façade with improved thermal performance. The blocking was conducted by coating the external face of the selected glazing units with black self-adhesive film, flexible insulation, and insulated render. The self-adhesive film was purely to obscure the insulation from the room users. The Contractor used black film without checking with the design team; the Architect would have used white or silver film to aid surface reflectancy of the insulated glazing units' interior face into the rooms. Four windows were left in their original single-glazed state; these windows, sequentially located on the ground floor west elevation, are positioned where case study B2 closely abuts a later addition to the building: an external plant room, and a spiral staircase serving the upper level of the plant room and the roof. These single glazed windows were left in their original state because of the expense of repositioning the service ductwork and the spiral staircase. Finally, retrofitted windows to the shop, located to a corner of the east façade, were masked with plain or patterned self-adhesive film to reduce solar gain.

Single-glazed external doors were originally specified by the Architect. Double-glazed external doors were then added to the RIBA Stage D estimate, at extra cost, by the consultancy in charge of Project Management and Cost Management. The Contractor, however, suggested double-glazed doors of better performance, but at the same price as the originally specified single-glazed units, which were ultimately used.

A draft lobby and external door were added to the east elevation, to close off a small recessed area that previously housed the discreet main entrance. Leading out from this area, a larger recessed area was bridged with a false beam (with no roof covering) to make the main entrance more focused. For aesthetic purposes, this false beam was originally specified with an inclined frame of circa six degrees, tapering inwardly from the beam down to the ground at both sides; however, this detail was substituted for a vertical frame during construction at RIBA Stage K. A glass canopy, over the entrance to the shop on the east elevation, was indicated on plan at RIBA Stage D and adjusted in its design in RIBA Stage K. On the west façade, some issues were experienced with mud-splash and with people who were waiting to enter the night-club putting their feet up on the wall; a protective foot barrier was thus attached to the insulated render system adjacent to the nightclub entrance at RIBA Stage L. In Table 5-12, the façade evolution is recorded against the eleven stages of the RIBA Plan of Work 2007.

Various activities resulted in sources of information to aid the façade selection process: a building survey was conducted, which included a walk-around of the building, and a review of plant efficiencies and system controls; a pre-retrofit thermographic survey was commissioned by Estates to highlight weaknesses in the building's original façade; meter readings were reviewed to help determine the building's energy performance and the level of current building use; structural load calculations; and thermal modelling was carried out. The thermal modelling was used for structural verification, to review the impact of energy efficiency measures and calculate fabric U-values, and to inform architectural decisions with regards to the arrangement and design of the windows (including solar gain). The Mechanical Engineering Consultant needed to know the heating load of the building to thus determine what the façade would do, with the model also used to test some areas for which retrofit was considered useful, i.e. testing a range of features, including different fabrics, with a view to stretching the budget as much as possible. The thermal model was built by an Approved Energy Assessor from within the home institution using IES 2012-2013 software and was then taken on by the mechanical engineers. The Mechanical Engineering Consultant was aware the budget was of keen importance. Window openings were also modelled, using a macro flow element in the software; the window opening (how they are hung) affects the air flow, plus the closest weather file location to the building was chosen. Added to these points, the Mechanical Engineering Consultant modelled the window opening according to his perception of how the building would be used. Mid-way during the retrofit, different departments moved in and others moved out, which will have impacted on the building use. This change in use, which happened after RIBA Stages C and D had occurred, had an effect on the glazing, as some windows could instead be blocked up. Such changes crept into the project along the way; the building was lightly used when it was first surveyed, but later became more heavily used, especially as it evolved into a nice refurbished building. These later changes were therefore naturally not included in the initial model/U-value calculations provided to the Architect; however, the model was kept up-to-date by the Mechanical Engineering Consultant, as they knew it would be used to show the final solutions for the EPC. Insulation levels/thicknesses were focused on. The Mechanical Engineering Consultant knew it was likely to be an insulated render system, so U-values via the insulation levels/thicknesses were focused upon. The U-value calculations carried out by the Mechanical Engineering Consultant were passed to the Architect who carried out more U-value calculations. The building was in full use during the retrofit; hence, work was programmed around the building's use and peak periods of occupancy, and to keep the main entrance in use, to thus minimise disrupting the student experience.

The case study company planned various activities to help assess the success of the retrofit project, these being: air tightness testing; EPC/DEC assessments; post-retrofit thermography; ongoing energy metering; ongoing user engagement; and occupancy evaluations. The 5.0 $m^3/(h.m^2)$ target for heat loss via infiltration and air permeability was achieved - the Contractor carried out the air tightness test, which achieved 5.2 $m^3/(h.m^2)$. The EPC/DEC ratings met and proved the energy performance targets in terms of both predicted and

Table 5-12  Office and music building: evolution of the façade elements

| Building element | Façade element | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Façade retrofit | Review of potential cladding materials | ✓ | | | | |
| Ground floor façades | Insulated render system (softwood frame, flexible insulation, cementitious particle board, rails, EPS, mesh, render) | | ✓ | ✓ | ✓ | ✓ |
| | PPC aluminium-cap parapet roof upstand | | ✓ | ✓ | ✓ | ✓ |
| Windows to ground floor façades | Thermally-broken double-glazing, PPC aluminium frames and insulated mullions | | ✓ | ✓ | ✓ | ✓ |
| | Solar control glazing to south and west | | ✓ | | | |
| | All elevations solar control glazed | | | ✓ | ✓ | ✓ |
| Blocked up windows to ground floor façades | Clear or silver self-adhesive film; flexible insulation batts; insulated render system | | ✓ | ✓ | | |
| | Black self-adhesive film; flexible insulation batts; insulated render system | | | | ✓ | ✓ |
| Ground floor east façade | Inclined frame at main entrance | | ✓ | ✓ | | |
| | Vertical frame at main entrance | | | | ✓ | ✓ |
| | Green living wall around main entrance | | ✓ | | | |
| | Glass canopy to shop entrance | | ✓ | ✓ | ✓ | ✓ |
| Ground floor south façade | Green living wall | | ✓ | | | |
| Ground floor west façade | Foot barrier attached to insulated render system adjacent to nightclub entrance | | | | | ✓ |
| Lower ground floor façades | Insulated PPC aluminium cladding (softwood frame, flexible insulation, cementitious particle board, flexible insulation, aluminium spandrel panels) | | ✓ | ✓ | ✓ | ✓ |
| | Thermally-broken double-glazed solar control PPC aluminium frame windows | | ✓ | ✓ | ✓ | ✓ |
| | PPC aluminium louvres | | ✓ | ✓ | ✓ | ✓ |
| | Insulated PPC aluminium column surrounds | | ✓ | ✓ | ✓ | ✓ |
| Doors to ground/lower ground floor façades | Single-glazed, PPC aluminium | | ✓ | | | |
| | Double-glazed, PPC aluminium (extra cost) | | ✓ | | | |
| | Double-glazed, PPC aluminium (at no extra cost) | | | ✓ | ✓ | ✓ |
| Ground level upstand to ground/lower ground floor façades | Insulated PPC aluminium | | ✓ | ✓ | | |
| | Insulated painted marine WBP plywood | | | | ✓ | ✓ |

Notes: The numbered columns indicate the five main groups by which the eleven Work Stages of the RIBA Plan of Work 2007 are presented (RIBA, 2009): [1] Preparation (A, B); [2] Design (C, D, E); [3] Pre-construction (F, G, H); [4] Construction (J, K); and [5] Use (L).  A tick indicates façade element presence in that evolutionary stage.

operational energy use. The Client-commissioned post-retrofit thermography did not highlight concerns in regards to cold bridging or areas of poor insulation. And finally, involving building occupants and users in the retrofit project proved very successful, in that it resulted in the project team's increased knowledge of how the building works and tremendous buy-in by the building's occupants and users to the proposed energy efficiency changes. The Client was very impressed by the stakeholder's overall input and planned a continuation of the user engagement for 12-months post-retrofit completion.

*The thermographic survey*

Note: This section of the thesis discusses the thermography conducted by Matthew Fox and the author, as opposed to the pre/post- retrofit thermography commissioned by the Client.

<u>Summary</u>: In general, the retrofit work on this building was viewed as being relatively successful. Despite showing signs of ventilation related defects, these were not significant and did not impair on the air permeability rating, which was achieved for this building.

<u>Key findings</u>: Due to the weather conditions during the survey (light rain), little could be learnt from the external thermographic survey. The rain did not diminish the conditions for internal thermography however, and the internal thermographic survey identifies a number of points of interest. Ventilation losses were observed that would be contributing to a reduction in internal temperature: from under the main entrance door (Figure 5-9 - image 1), where the new exterior door to the new draft lobby had been left open, leaving the original single-glazed timber-framed door as the main barrier to the outside; from an open window (image 2); and from under a pair of doors (image 3). A ground floor image shows further ventilation heat loss around the window and door frames, and cooler patches at the lower edges of the structural wall panels than the surrounding building fabric (image 4); while a corner at lower ground floor level appears to be exhibiting signs of cold bridging (image 5). With regards to reducing heat loss, an internal panoramic image demonstrates the thermal performance of two blocked up windows in a corner of the building (image 6) (Fox, 2015b).

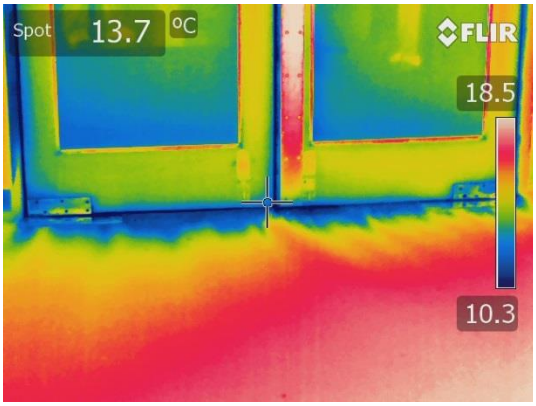



Figure 5-9 Office and music building thermography - image 1

*(ventilation loss under main entrance door)*

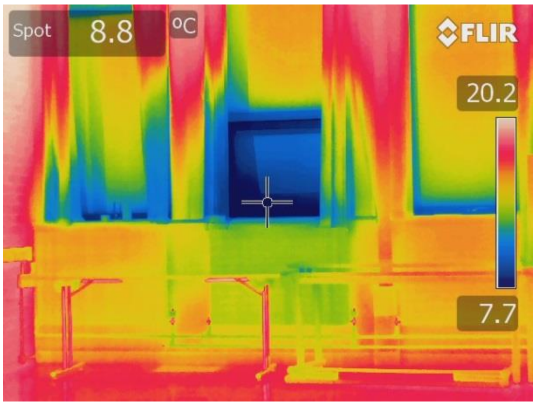



Figure 5-9 Office and music building thermography - image 2

*(ventilation loss from an open window)*

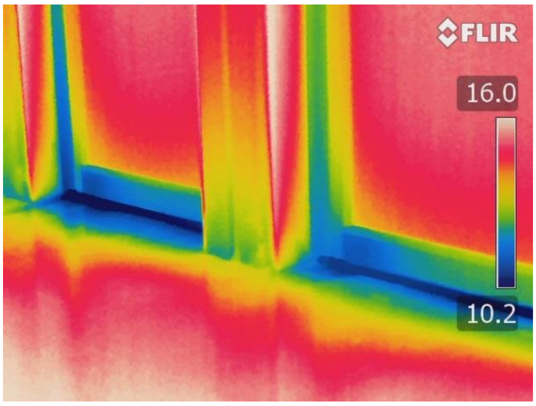



Figure 5-9 Office and music building thermography - image 3

*(ventilation loss under a pair of doors)*

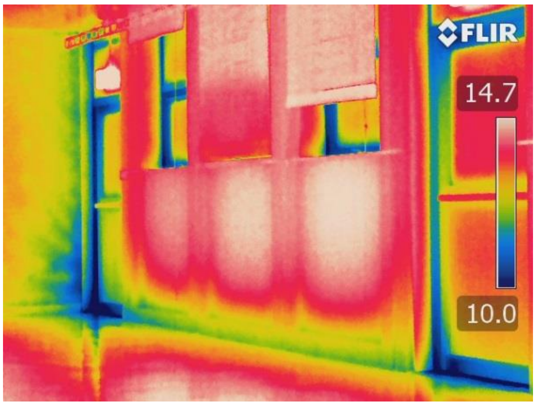



Figure 5-9 Office and music building thermography - image 4

*(ground floor building fabric temperature differences and ventilation heat loss around a doorframe)*

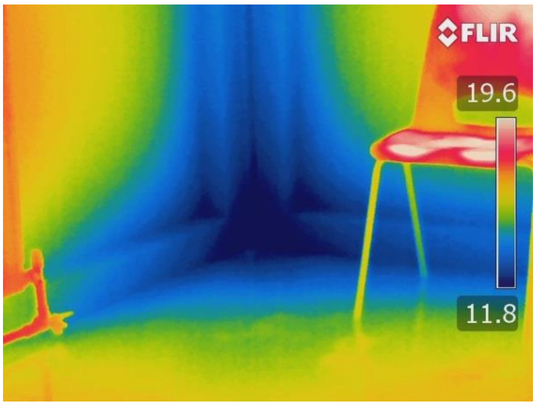



Figure 5-9 Office and music building thermography - image 5

*(lower ground floor level corner showing potential cold bridging)*

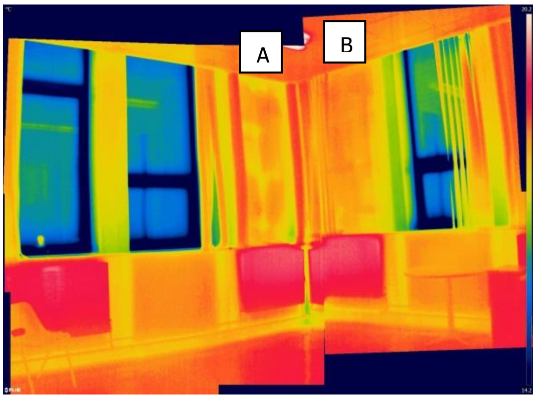



Figure 5-9 Office and music building thermography - image 6

*(thermal performance of two blocked up windows (A and B))*

### 5.4.4 Arts and media building

This case study explores the decision-making process used to select a façade retrofit for a UK-based university arts and media building located in a maritime climate. This building provides open-plan studios, computer labs, and office space for academic functions. For ease of reporting, this case study shall hereafter also be known as 'case study C1'.

*The building pre-retrofit*

Case study C1 was constructed in 1971, from an uninsulated exposed in-situ concrete frame, with exposed columns to the ground floor, and exposed protruding feature columns and exposed floor edges to the upper floors. Also included in the original construction, were: cavity infill panels of non-structural riven-faced dense concrete block; single-glazed ribbon windows with mill finish aluminium frames and glazing bars; inclined single-glazed aluminium windows, to the north and east elevations; single-glazed aluminium windows to the stairwell, with a later addition of single-skin blockwork to partially block up the stairwell windows; single-glazed timber doors; a small canopy to the south-east entrance; and a concrete canopy and columns to the north-west entrance. The building is 30.6 metres in height and contains seven-stories, of which three are more than 18 metres above ground level.

The building's original façade was in need of replacement. The exposed concrete frame was suffering from spalling, and corroded fixings and reinforcement. The blockwork cavity infill panels were suffering from corroded fixings, ledge angles, and lintels; and from open joints, and being out of alignment. The aluminium windows had become corroded and ill-fitting, and in some cases, were no longer openable or close-able. Rain penetrating the building was causing health and safety concerns in terms of slips and falls on wet floor surfaces, and electrical faults. Despite the extensive use of supplementary electric heating, case study C1 could not achieve the required comfort conditions; for example, the top floor could not achieve an internal temperature of 20°C, when the external temperature fell below 10°C. Previous retrofitting has seen the roof insulated and recovered in 2001.

In pre-retrofit condition, Case study C1 is shown as achieving a D (77) DEC rating, as per its December 2009 to December 2010 DEC accounting period, which represents a full 12-months of operational performance prior to the retrofit starting. However, this rating is not an exact representation of this building's operational energy performance. Case study C1 is one of 13 buildings, which are fed by a central boiler house and which do not have separate metering; individual operational energy use can therefore not be identified, and as a result, the buildings each receive the same DEC rating.

*The retrofitted building*

Case study C1 was retrofitted in 2011, with work commencing on site in the March and finishing in the October. The building was kept fully occupied and fully operational during the retrofit. The retrofit project was conducted in line with the RIBA Plan of Work 2007 and a JCT D&B Contract - 2005 edition. The building was 39-years old at the point of retrofit. The work was funded by a grant from a HEFCE fund allocation awarded to a party associated with the home institution, plus funding from the home institution.

The retrofit project had four objectives: to improve the building's appearance, to improve insulation and natural ventilation, to reduce its running costs, and to address ongoing issues with the condition of the existing building fabric. The over-clad areas of case study C1 were required to achieve a U-value of 0.27 $W/m^2K$. The retrofit was completed to budget and to programme. In addition to case study C1 receiving a full façade retrofit, other work was carried out, including upgrade work to the heating system, and to the stair core by the addition of new fire doors (preceded by a *Refurbishment/Pre-demolition Survey* to assess the presence and extent of asbestos containing materials in the $1^{st}$-$6^{th}$ floor stairwells). However, as this thesis focuses on façade retrofit, these other works and the process involved in their selection are out with the scope of this case study report. The building's main entrance is located in the south-east elevation, while the north-west elevation contains a secondary entrance. The building has a total useful floor area of $2503m^2$.

Post-retrofit (Figure 5-10), case study C1 is shown as achieving a C (58) rating in its current DEC (at the time of writing), which represents 12-months of operational performance from December 2014 to December 2015. However, this rating is not an exact representation of the building's seemingly improved operational performance. Case study C1 is one of 13 buildings, which are fed by a central boiler house and do not have separate metering; thus, reductions in operational energy use cannot be attributed to an individual building/s and the buildings each receive the same improved DEC rating.

Figure 5-10 Arts and media building post-retrofit

*The completed retrofitted building façade*

The six upper floors' walls were over-clad with a Class 0 insulated rainscreen system. The ventilated cladding system comprised, from the building substrate outwards, of: an aluminium alloy secret fix channel system, which was secured to the structure in the position of panel joints with resin anchors; 100mm thick semi-rigid resin bonded mineral wool slabs, fitted between the rails, and fixed to the existing structure with nylon fixings; and PPC 3mm 3103-H14 grade aluminium alloy rainscreen cassette panels, hooked onto locating pins within the secret fix channel system. Also included in the six upper floors' façade retrofit, were ribbon windows, individual windows, inclined glazing sections, and PPC aluminium parapet capping. The ribbon windows were set with alternating full and half-width windows, formed from thermally-broken double-glazing in composite timber frames faced externally with PPC aluminium, with clear solar control glazing to the south, west, and east elevations. The individual windows were formed from thermally-broken double-glazing in composite timber frames faced externally with PPC aluminium, with clear solar control glazing to the south, west, and east elevations. The inclined glazing sections were set with fixed lights, formed from PPC aluminium curtain walling with thermally-broken double-glazing. Where windows were blocked up, which included partial blocking to the stairwells, and the windows in a projecting bay, the interior-facing window void was filled with plasterboard and painted, while the exterior-facing void received the insulated cladding system.

To the ground floor, the blockwork cavity infill panels were injected with Class 0 blown glass mineral wool cavity wall insulation, and the panels' exterior face coated with two-coats of sand cement render, a finishing render coat, and masonry paint. The exposed concrete columns coated with masonry paint. Also included in the ground floor façade retrofit, were: thermally-broken double-glazed windows in composite timber frames faced externally with PPC aluminium, with clear solar control glazing to the south, west, and east elevations; and double-glazed PPC aluminium doors. A new porch entrance to the south-east elevation, comprising a free-standing wall and canopy set away from and parallel to the building, was formed from PPC aluminium rainscreen cladding with plywood backing, vertically inset narrow glazed panes, and single ply roofing. At the north-west elevation entrance, the existing canopy and side screens were over-clad with PPC aluminium, with PPC aluminium kickplates to the columns.

To all floors, PPC aluminium louvered ventilation panels were fitted to the toilet windows.

*The façade selection process*

Case study C1 was initially considered for demolition. However, when the Client Representative, henceforth abbreviated to *Client* in this report[52], made the business case for re-cladding versus demolition, the case building was seen as having several factors in its

[52] The term *Client Representative* was found by Hughes and Murdoch (2001) to be a synonym of various construction project roles representing the interests of the *Client.*

favour. The building's functionality, structural integrity, and location were good; the building, even in pre-retrofit condition, was liked by its users; and re-cladding was significantly cheaper than the cost of replacing the building. A structural survey was conducted to confirm the structural soundness of the original building. The survey showed visual spalling, but also showed the building did not require demolition. Prior to the work involved with the case study C1 retrofit, the ageing exposed concrete frame had received epoxy mortar-based repairs conducted in-house.

One of the deciding factors for the Client in the choice of façade was that the building had to be kept fully operational. The selected façade thus combined the application of the cladding with that of the windows, which meant the old windows could be removed after the new ones had been installed. The new windows were put in with an ethylene propylene diene monomer (EDPM) rubber membrane, and the cladding and window elements connected at the last minute. The building remained weather tight, with no disruption to the internal services, and thus, fully operational throughout the retrofit.

For the Architect, the façade selection process involved the preparation of drawings (very prescriptive design intent drawings, showing details such as joint locations); the ER, which were discussed between the Architect and the Client; and the specification. The Architect worked to the RIBA Plan of Work 2007 up to a point. The fee scope document, and the design stage activities and outcomes (general assumptions, sketch design, scheme design, tender information, detailed design development, and fabrication and site stage) were based on the RIBA Plan of Work 2007. The Architect did not aim to get novated to the Contractor; instead the Architect worked with the Contractor to ensure the Client got the required design. The Architect made decisions relating to material selection and design based on previous knowledge, and on knowing what works. The Architect expressed that they are dealing with very well informed clients and that the clients' needs are not just related to aesthetics; they have great interest in building performance, and from past experience, are often very concerned about the quality of windows. Through the use of brainstorming, discussing the building and its needs in great detail, and taking the sun's path into account, the Architect aimed to understand the Clients' main concerns.

The Architect kept the case building's location in mind for the consideration of such items as: the life of the fixings, with all fixings used in the retrofit being either aluminium or stainless steel, as ferrous fixings would have been prone to rusting; on which elevations to install solar control glass; and the decision not to use brise soleil, because of the likelihood of seagulls roosting on them, for which reason, the cladding panels were also specified as being free from bird perches. With regards to future access for cleaning, the façade is self-cleaning to a certain degree, since the ER specified the cladding panels should be self-cleaning, and aluminium was chosen because it stays looking good. The aluminium alloy grade (3103-H14) was selected as it is designed to remain flat and true in service, thus ensuring the panels' surface forms a true vertical plane. A secret fix channel system was chosen to enable individual panels to be easily removed, to permit periodic inspection of the original structure or the replacement of a panel. Fixings were also required to be free of vibrations, while the cladding was required to be free of noises that might occur as a result of thermal, structural, wind or air movement.

The façade materials did not change as the project progressed, but the colour did. The retrofit was part of a re-branding for the home institution, and as colour was seen as part of this rebranding, it thus influenced the final product. Colour is often part of re-branding, so the Architect is not always fully in control of this aspect of the design. The Client wanted a certain shade of blue and a specific logo to be incorporated into the design, and then the Architect chose an accompanying silver cladding because it is considered to be ageless and therefore does not date the building. The Architect also tried not to use too much colour, as this too can date a building. Ultimately, a basic palette of blue, silver, and dark grey was adopted for the new façade to the six upper floors. The local Parish Council and regional development agency (RDA) were involved in the approval of the proposed façade, with the RDA apparently wanting the façade to have a bolder patterned colour finish. When case study C1 was granted conditional planning permission, it stated LPA approval must be received regarding the size, position, and colour of the cladding panels, prior to any work commencing; the reason being in the interests of visual amenity.

Aesthetics were considered when selecting the glazing element. For the windows, timber was used for the internal portion of the frame, to give a 'friendly' feel, while aluminium was used for the external portion of the frame, to give a metallic, 'glitzy' appearance. Composite windows are also beneficial from a practical point of view, as the stronger timber element lends strength to the overall unit. In terms of size, the main portions of the windows were kept almost as per the existing windows. However, as part of the glazing scheme, a significant number of differing-sized windows were blocked up. The glazing to the two stairwells was partially, but significantly blocked up, with the new window sill height starting at the same height to which the single-skin blockwork had been added. The stairwell glazing removal involved the blocking up of 77 windows. A further six windows were blocked up in a rectangular projecting bay; case study C1 had three projecting bays, of which only one contained glazing.

Clear solar control glazing was used only to the south, west, and east elevations, so as not to interrupt the quality of the north light. The north light in the art studios was a unique aspect that required special consideration. The Architect selected clear solar control glazing, rather than tinted, due to the building's art use. Likewise, the inclined glazing, an important feature for enabling north-light to enter this purpose-built art building, was retained wherever possible. A feasibility study conducted by a contractor, different to the one ultimately appointed for the case study C1 retrofit, included a rainscreen cladding system that proposed cutting off the inclined glazing, which would have cut out the north light. As the loss of north light was not a suitable proposition for this art building, the proposed system was rejected. The retrofit project was then delayed due to a lack of funds. When the retrofit project re-started, this rejected feasibility study was used as a starting point.

The windows were fitted with trickle ventilators. The case building was circa 90% naturally ventilated. The toilets had mechanical ventilation (extract fan, plus louvres) and some rooms had mechanical ventilation installed on an ad-hoc basis. The opening lights in the ribbon windows operated on a tilt and turn basis. The tilt and turn mechanism was designed to be operated using a removal handle, with its spindle concealed behind a cover plate, which is then slotted into a square hole in the cover plate to operate the window. However, the building occupants found they could operate the window mechanism by slotting a screwdriver into the square hole in the cover plate. A variation to the D&B Contract was therefore required at RIBA Stage L for the installation of chrome blanking plates to the openable windows, as a security/safety measure to prevent tampering in the windows as-built. Blinds were accidentally omitted from the tender, so a separate tender was issued at a later date to cover their cost; the original blinds no longer fitted, as the window openings had slightly changed size with the over-cladding.

Because of the perceived risk of aluminium rainscreen becoming damaged at ground floor level, the blockwork infill panels to the ground floor were not over-clad. Instead, to give robustness, their wall cavities were insulated, and a sealing and decorative coat of sand cement render applied to the panels' exterior blockwork face. The rainscreen was however, used in one instance at ground floor level, where it formed the new porch to the south-east entrance. To protect against damage in this instance of rainscreen cladding, plywood backing was added to the panels as a variation at RIBA Stage K. Aluminium was also used as a cladding material to the existing canopy and columns on the north-west elevation, where as a protective measure kickplates were installed at low-level. In Table 5-13, the façade evolution is recorded against the eleven stages of the RIBA Plan of Work 2007.

The Architect had worked previously with the Cladding Supplier and was familiar in the ways of drawing the cladding design so that the supplier could make it. Despite being considered specialists in their role, the Architect could not name the Cladding Supplier during the tendering process, so as not to show favouritism, and a framework agreement was used to keep the tendering process open. The specification was however, written closely to fit the Cladding Supplier’s requirements; and as part of the design process, the Client visited examples of retrofit cladding projects conducted by the suggested Cladding Supplier. The new building envelope is required by the ER as achieving a design life of 60-years, while components of the whole works are required to achieve a service life of 30-years. The Architect also wrote into the original ER that a 20-year new-build equivalent warranty was required on completion, though the Client later agreed to a 12-year Construction Industry Council (CIC) Collateral Warranty for the contractor design. The Architect prompted the inclusion of a façade mock-up of the rainscreen system in the ER. The mock-up was full-size, one-storey high and 3-metres wide, and installed at ground level on the case study building, so the façade could be inspected from inside and outside. The main purpose of the mock-up was to demonstrate the appearance and colour of the cladding panels to the LPA, for approval as per the conditional planning permission. It was also a working model to allow the Client to explore the façade design, in advance of confirming acceptance of quality prior to full installation, and to allow pull-out tests to be carried out and then to refine the fixings. The mock-up was required to be fabricated and applied within four-weeks of the contract being awarded.

Various contractors submitted bids for the case study C1 retrofit, in which they proposed the use of separate sub-contractors for the façade elements, e.g. for the windows, and for the external wall covering. Integration of the façade elements was considered key by the appointed Architect to avoid the finished building leaking. The successful Contractor’s tender return described a one system/one supplier approach to the façade retrofit; it also stated how experienced their proposed Cladding Supplier was with this kind of façade retrofit and how their tried and tested façade system was over-engineered in terms of compliance with design guidelines. Due to the nature of case study C1s funding platform, it was important to the Client that a façade type was picked with no time risk. The successful Contractor submitted a compliant and an alternative tender, so the Client could see where the

Contractor was trying to save money before entering into a contract; and carried out the retrofit to their tender submission, as their specified façade system met the ER.

Professional expert knowledge from the Contractor and the Cladding Sub-Contractor aided in finalising the façade design, as the matter of bespoke detailing was discussed in detail, and also assisted the façade selection process, e.g. in knowing that 1960/1970s buildings can vary by +/- 45mm in the x, y, and z coordinates. Additional loads imposed by the cladding were designed and certified by the Consulting Engineer. U-value calculations conducted by the Consulting Engineer were used to determine the thickness of mineral wool to be applied to the building's external face. The Architect did not use thermal modelling, as it was assumed that the building's thermal capacitance was going to be improved anyway; the successful Contractor's tender return also stated the non-inclusion of thermal modelling and air testing, due to there being no requirement for such items in Approved Document L2B. The Cladding Sub-Contractor conducted a measured survey, and then returned with a setting-out engineer to conduct a geometric survey, which was to help show where the building was not true and to reveal any tolerances that might needed correcting by the façade application method. The Cladding Sub-Contractor did not make any decisions after the building was handed over to them during the retrofit; from this point, communication between the Architect and Cladding Sub-Contractor was for an exchange of information. The Contractor did however make a decision after this point, as the Architect and the Contractor developed the cladding joint design between them. The rainscreen cladding applied to case study C1 was a proven proprietary system and to obtain maximum benefit from such a system, its dimensions must be carefully tailored to suit the structure of the building. The panel size and joint positions were thus carefully considered from an aesthetic point of view, to maintain the building's horizontal and vertical emphasis. Prior to application of the façade retrofit, the Contractor carried out further concrete repairs to all four elevations in light of the structural survey's findings.

To aid the Client's need to keep the building operational during term time, the Cladding Sub-Contractor worked during the evenings and weekends to complete tasks such as slotting in new windows. No scaffolding was used during the retrofit; instead, the use of a mobile climbing wall platform system kept the site area very compact. Protective 'obscuring' film was applied to the existing windows prior to the works, to afford privacy to the occupants while the external access was erected around the building, but also protection in the face of accidental breakage of the glass. Further protection was provided by adding restrictors to the windows, to prevent the building occupants effectively entering a construction site. The building was thus kept fully occupied and fully operational during the retrofit, which was also one of the major benefits of using an over-cladding system. The building was well regarded by its users pre-retrofit, so the project team received very good cooperation from the users during the retrofit. Ninety percent of the work required to install the rainscreen cladding was conducted from the outside of the building. Overall, the feedback received indicated there were just a couple of issues relating to noise produced when drilling for fixings.

It is apparent to the Client that improved comfort conditions have been achieved in the retrofitted building. Prior to the retrofit, it was difficult for case study C1 to attain an internal building temperature of 15°C, whereas now, an internal temperature of 20°C is easily achieved. Furthermore, the building's heating optimiser need not be scheduled to come on so early in the day to attain suitable internal temperatures. It was calculated by the Client that case study C1 achieved a 77% reduction in heat loss through the new envelope.

Table 5-13 Arts and media building: evolution of the façade elements

| Building element | Façade element | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Walls to six upper floors | Insulated rainscreen system (rails; mineral wool slabs; PPC aluminium cassette panels) | ✓ | ✓ | ✓ | ✓ | ✓ |
| Windows (ribbon and individual) to all floors | Thermally-broken double-glazed, timber frame faced externally with PPC aluminium | | ✓ | ✓ | ✓ | ✓ |
| | Clear solar control glazing to the south, west and east elevations | | ✓ | ✓ | ✓ | ✓ |
| | Blanking plates to the openable windows | | | | | ✓ |
| Inclined glazing sections | Thermally-broken double-glazed PPC aluminium curtain walling | | ✓ | ✓ | ✓ | ✓ |
| Blocked up windows | Paint; plasterboard; insulated rainscreen | | ✓ | ✓ | ✓ | ✓ |
| Ground floor façades | Mineral wool cavity wall insulation | | ✓ | ✓ | ✓ | ✓ |
| | Sand cement render; finishing render; and masonry paint to the walls' exterior surface | | ✓ | ✓ | ✓ | ✓ |
| | Masonry paint to the columns | | ✓ | ✓ | ✓ | ✓ |
| | Double-glazed PPC aluminium doors | | ✓ | ✓ | ✓ | ✓ |
| Porch to main entrance | PPC aluminium rainscreen; glazed panes; single ply roofing | | ✓ | ✓ | ✓ | |
| | Plywood-backed PPC aluminium rainscreen; glazed panes; single ply roofing | | | | ✓ | ✓ |
| Canopy to secondary entrance | PPC aluminium cladding; low-level PPC aluminium kickplates | | ✓ | ✓ | ✓ | ✓ |
| Toilet windows all floors | PPC aluminium ventilation panels | | ✓ | ✓ | ✓ | ✓ |
| Façade to seventh floor | PPC aluminium parapet capping | | ✓ | ✓ | ✓ | ✓ |

Notes: The numbered columns indicate the five main groups by which the eleven Work Stages of the RIBA Plan of Work 2007 are presented (RIBA, 2009): [1] Preparation (A, B); [2] Design (C, D, E); [3] Pre-construction (F, G, H); [4] Construction (J, K); and [5] Use (L). A tick indicates façade element presence in that evolutionary stage.

*The thermographic survey*

Summary: On reflection, the thermographic survey showed how the retrofit work had been generally successful above the ground floor level, which was less successful. Nevertheless, there were areas of potential defect/poor performance, which were found during this survey.

Key findings: The external thermographic survey visually reported largely cool temperatures across the main body of the façade. This was likely due to the lower emissivity cladding reflecting the surrounding environment and sky. Yet an unexpected warm patch was noticed on the 6th floor north-west elevation (Figure 5-11 – image 1) (the cause of the warmer patch could not be conclusively characterised during this survey). A distinct difference in emissivity between the ground floor's rendered walls and the aluminium rainscreen was observed, and the rendered façade on the ground floor appeared warmer than the rest of the building (image 2). The internal survey highlighted regions where loft insulation did not reach to the edge of the structure (image 3); and where a new internal wall, not fitted up against the underside of the ceiling (the existing corrugated metal roof) had created gaps that were allowing heat to pass into an un-heated store room (image 4). Potential cold bridging was also observed around the building's existing frame (image 5) and where an internal wall was fitted perpendicular to a window sill (image 6). The internal survey also identifies a number of window-related ventilation heat losses that would have been contributing to a reduction in internal temperature: not fully closed window catches (image 7); window trickle vents (image 8); apparently poor window seals, such as where actuators have been fitted (image 9); and under a window sill, where the effect of an apparently poor seal is visible (image 10) (Fox, 2015b).

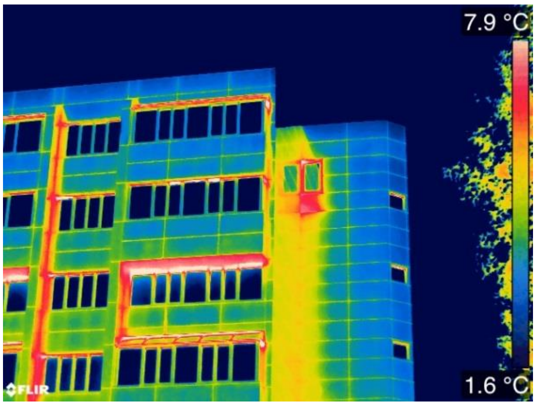



Figure 5-11 Arts and media building thermography - image 1
*(observed warmer patch on the 6th floor north-west elevation)*

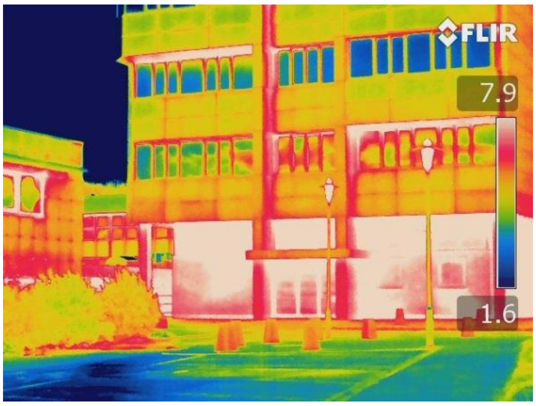



Figure 5-11 Arts and media building thermography - image 2
*(ground floor appearing warmer than the other floors)*

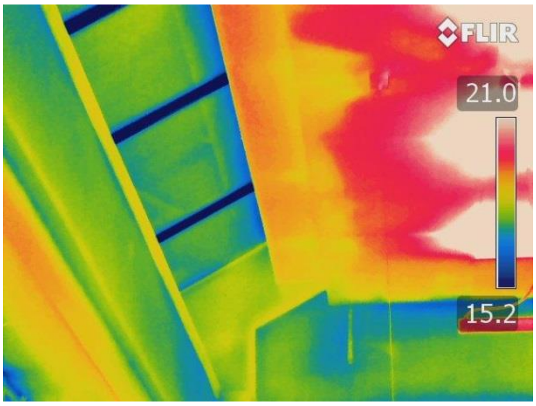



Figure 5-11 Arts and media building thermography - image 3

*(loft insulation not reaching to the edge of the structure)*

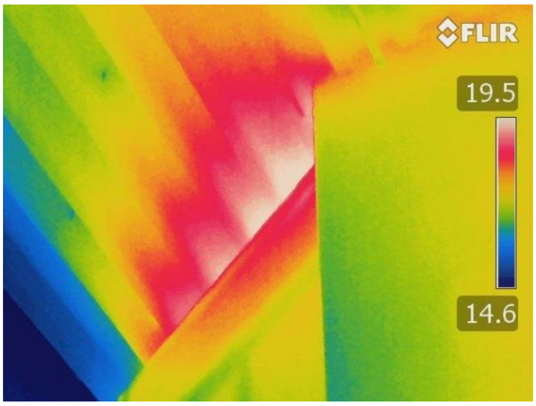



Figure 5-11 Arts and media building thermography - image 4

*(heat loss where an internal wall is not fitted to ceiling height)*

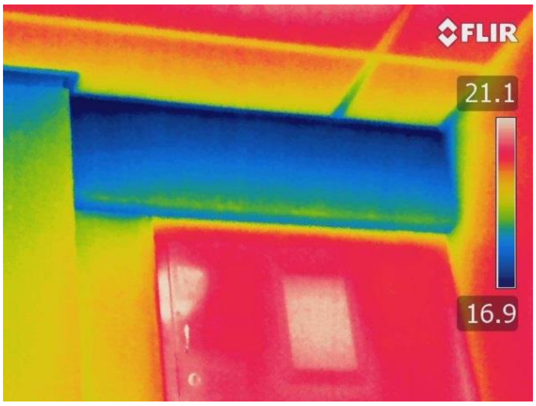



Figure 5-11 Arts and media building thermography - image 5

*(potential cold bridging around the building's existing frame)*

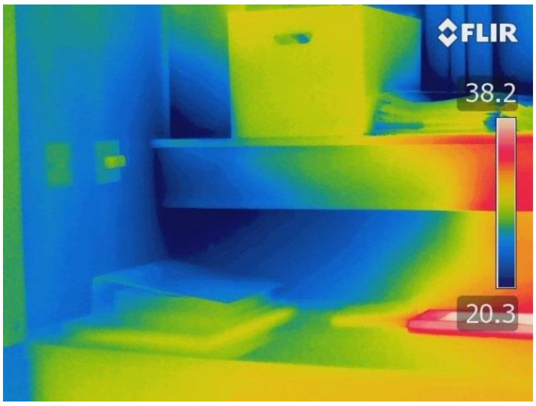



Figure 5-11 Arts and media building thermography - image 6

*(potential cold bridging at junction of interior wall and window sill)*

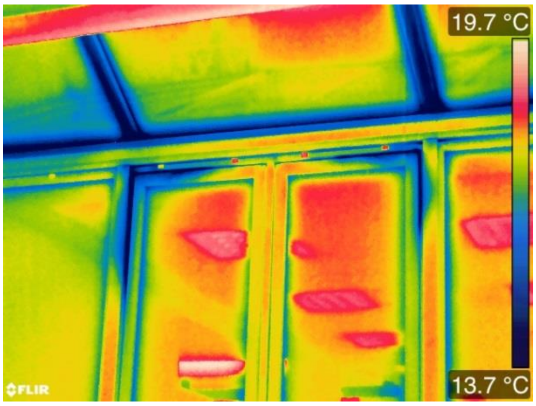



Figure 5-11 Arts and media building thermography - image 7

*(ventilation heat loss where window catches slightly open)*

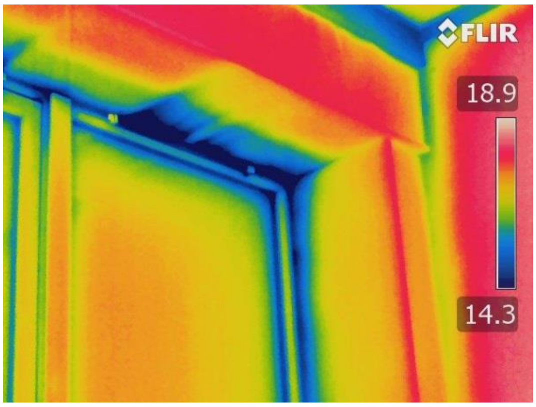



Figure 5-11 Arts and media building thermography - image 8

*(ventilation heat loss from window trickle vent)*

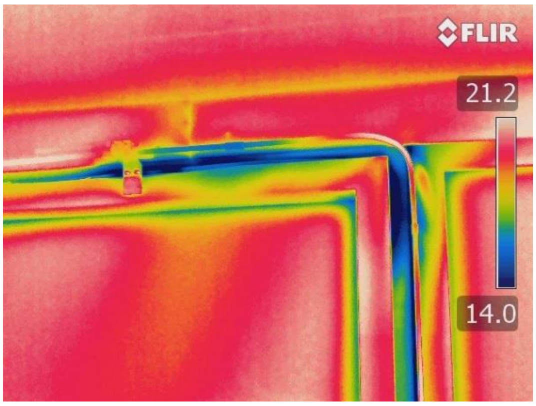



Figure 5-11 Arts and media building thermography - image 9

*(ventilation heat loss apparently from a poor window seal)*

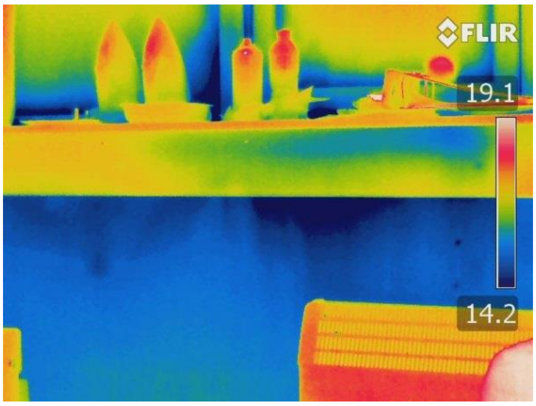



Figure 5-11 Arts and media building thermography - image 10

*(ventilation heat loss from under a window sill)*

## 5.5 Results

The retrofit projects gave a new lease of life to the exemplifying case study buildings. Case study A1 was targeted for potential demolition, before structural engineering work revealed a new storey could be added. Case study C1 was on the verge of being demolished; however, the poor state of its existing façade and the need for ongoing repairs, when compared to the building's functionality, structural integrity, and good location guided the business case for over-cladding versus demolition. Case study B1 was out of use prior to its retrofit, and case study B2 had light use prior to retrofit that became heavier as the project progressed. The exemplifying case buildings are of typologically-similar original construction dating from the late-1950s to 1971, with the buildings being on average 42-years old at the point of retrofit.

The exemplifying case studies' façade retrofit included three cases of over-cladding, and one that featured over-cladding and re-cladding. Of the solely over-clad buildings, two were comprised of insulated render and one of rainscreen cladding. Case study A1's over-cladding and re-cladding comprised of brick and rainscreen, and curtain walling and spandrel panels respectively. The new storey added to case study A1, increased the building's total useful floor area by 38% and brought an element of future-proofing to the campus; this additional space, which was not yet required but which enhanced the business case for retrofit, reflects the adaptability concept of flexibility (Arge, 2005).

The exemplifying case buildings' glazing is typical of its era, in that all the cases originally contained expansive areas of single glazing. Furthermore, three of the buildings – case study A1, B2, and C1 – originally featured ribbon windows, and wishing to remain faithful to this feature, ribbon-style windows were emulated in these case studies' façade retrofit using modern, energy efficient materials. To increase building energy efficiency, however, some of the retrofit work did involve the blocking up of windows, with case study B2 and C1 blocking up 35 and 83 windows respectively. Case study B1 planned to block up windows where not needed, with seven windows initially proposed to be blocked up; however, only a single window was blocked up in the end. Case study C1 has three storeys at a height of more than

18 metres above ground level; thus, its selected wall covering was required to be Class 0 rated for fire spread, for compliance with the safety requirements of Approved Document L2B. The insulated render system applied to case study B1 and B2 was also Class 0 rated for fire spread, despite these buildings being a height of 8.5 and 7.7 metres respectively. As part of their retrofitted façades, case study B2 and C1 made their main entrances more pronounced, potentially corresponding to the fact that *"most new university buildings now have a true entrance, rather than the low-key, 'back door' entrances common to many existing buildings. They psychology department at the University of Newcastle gained a striking entrance when a new lecture theatre was placed on pods over the existing entrance. The interior was also remodelled to open up the reception. As an added advantage of this design solution, the lecture theatre required no valuable campus footprint*" (Bone, 2004: 40).

The exemplifying case studies show the client, architect, and planner as playing key roles in the façade retrofit selection. The client interviewed for each exemplifying case was employed in the corresponding home institutions' Estates Department. The architects produced façade design ideas in response to the brief, with input from the client, advisors, and in some cases, the building occupiers and users. Various advisors, but chiefly the cladding suppliers, structural engineers, and mechanical engineers, played a supporting role in the façade decision process through the provision of information, e.g. specifications, cost and performance calculations. The contractors were found to sometimes make decisions prior to and during construction, though not always with architect approval, as in case study B2 where the contractor self-selected the film colour for the blocked up windows. Planning had final control over the proposed façade from an aesthetic point of view. The LPA placed conditions on three of the exemplifying cases, and had the power to delay or even stop work if the materials proposed for the buildings' exterior did not receive LPA approval. The exception was case study B2, which involved the LPA at the design stage and received full planning approval with no conditions relating to its external construction materials.

The exemplifying cases' façade evolution show the majority of façade decisions as occurring during *Design* and *Pre-construction*, while a small number of façade decisions were found across all of the other RIBA 2007 work stages, including in-use. The façade evolution also shows the façade selection process as having an iterative nature, with all four case studies experiencing change to certain façade elements over the course of the project. The changes were prompted by various reasons: cost, structural/construction error, safety concerns, and concerns about damage to the façade. Cost was the overall driver in the façade iterations, chiefly in relation to the project budget restricting the façade choice from the outset, but also in relation to the use of value engineering, and the use of higher specification but equal value elements, as certain projects progressed.

The exemplifying case study findings did not evidence the use of decision-making methods to choose one façade system from a number of alternatives or to produce a group of options from which the client could choose his preferred system. The façade selection process was however found to use numerous sources of project information. These sources have been categorised by this thesis and are thus presented in Table 5-14 according to the aspects of the façade selection process they are deemed to support (e.g. *performance*), the general nature of the data provided by the information source (e.g. *quantitative* meter readings), and whether their use chiefly relates to *mandatory* compliance with the Building Regulations for England and Wales' or the LPA (e.g. U-value calculations for compliance with Part L). The information used by the case studies was obtained from internal and external sources, with the external information obtained from personal (e.g. expert knowledge from case study C1's contractor) and impersonal sources (e.g. the Building Regulations for England and Wales'). Note: Table 5-14 shows the information sources used by the exploratory and exemplifying case studies, while the sources used by each case are presented in Table 9-6 of Appendix C.

Table 5-14 Information used in façade retrofit selection by the case studies

| | General nature of the information source | | |
|---|---|---|---|
| Façade selection process aspects | Quantitative | Quantitative and Qualitative | Qualitative |
| Project analysis and evaluation | - | Business plan<br>Feasibility study | - |
| Façade design | | | |
| *Cost* | Budget<br>Whole life cost analysis<br>Cladding options appraisal by cost | - | - |
| *Performance* | Measured survey<br>Building efficiencies and meter readings<br>Structural load calculations<br>U-value calculations<br>CWCT guidelines<br>Air tightness target<br>Dew point analysis<br>BREEAM assessment<br>Therm modelling (dew point; thermal bridging; insulation)<br>IES-VE modelling (double-glazing; window design)<br>Geometric survey<br>Heat loss via air permeability<br>Modelling (opening of windows; solar control glass)<br>Sun-path calculations | Space planning<br>Structural condition survey<br>Refurbishment/Pre-demolition survey<br>Building survey<br>Pre-retrofit thermography<br>Supplier specifications<br>Waterproofing details<br>Full-scale façade mock-up for C1 to confirm design and to do pull out tests | Detailed discussion<br>Cladding supplier presentations<br>Brainstorming<br>Experience used by architect, contractor, and sub-contractor<br>Knowledge of the building's local climate and setting<br>Triple glazing review<br>Brise soleil review<br>Review of cladding materials |
| *Aesthetics* | - | Full-scale façade mock-up for C1 to show the LPA for approval of materials | LPA consultation<br>Façade design input from Local Parish Council and RDA |
| *Collaboration* | - | - | LPA involved in the façade design stage<br>Stakeholder engagement |

Notes: Key to text colour: black = predominantly voluntary nature; red = predominantly mandatory nature

The exemplifying case studies' façade selection was chiefly influenced by aesthetics, thermal performance, and energy efficiency, with budget a key constraint for two of the buildings. The fact the rainscreen cladding used on case study C1 is a tried and tested system appears to have played a part in that client's decision-making process, as did the fact that the system allowed the building to remain fully operational during the retrofit. A summary of the retrofit project drivers and constraints is provided in Table 5-15. Success in the as-built façade was measured in various ways by the case study companies. Aesthetics were judged by the client. Thermal performance was judged by of the U-value calculations, and in some cases, by air tightness test results and post-retrofit thermography. Energy efficiency was judged by the DEC, and in some cases, by observed changes in building heating needs. The exemplifying case studies' pre- and post-retrofit DEC ratings are presented in Figure 5-12. Case study A1 was the only project to experience façade retrofit related problems, including delays, leaks, and changes to the method of working, as well as contractual and warrantee issues.

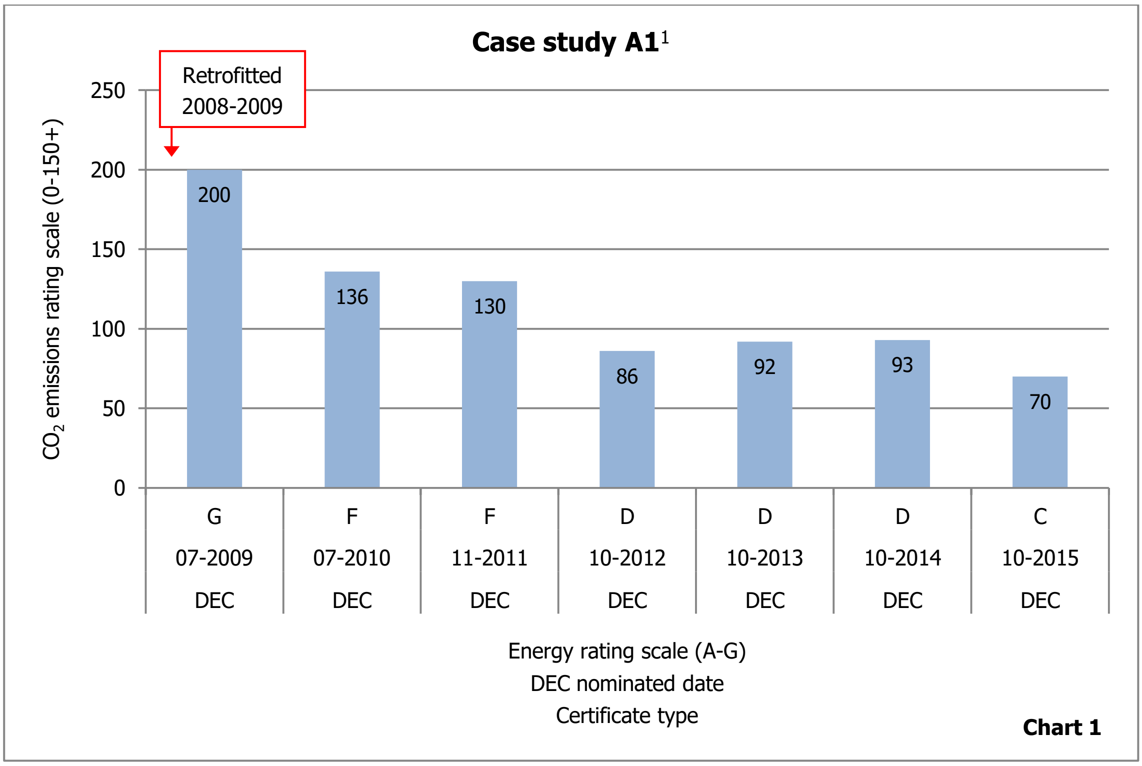
Table 5-15  Factors influencing the case study retrofit projects

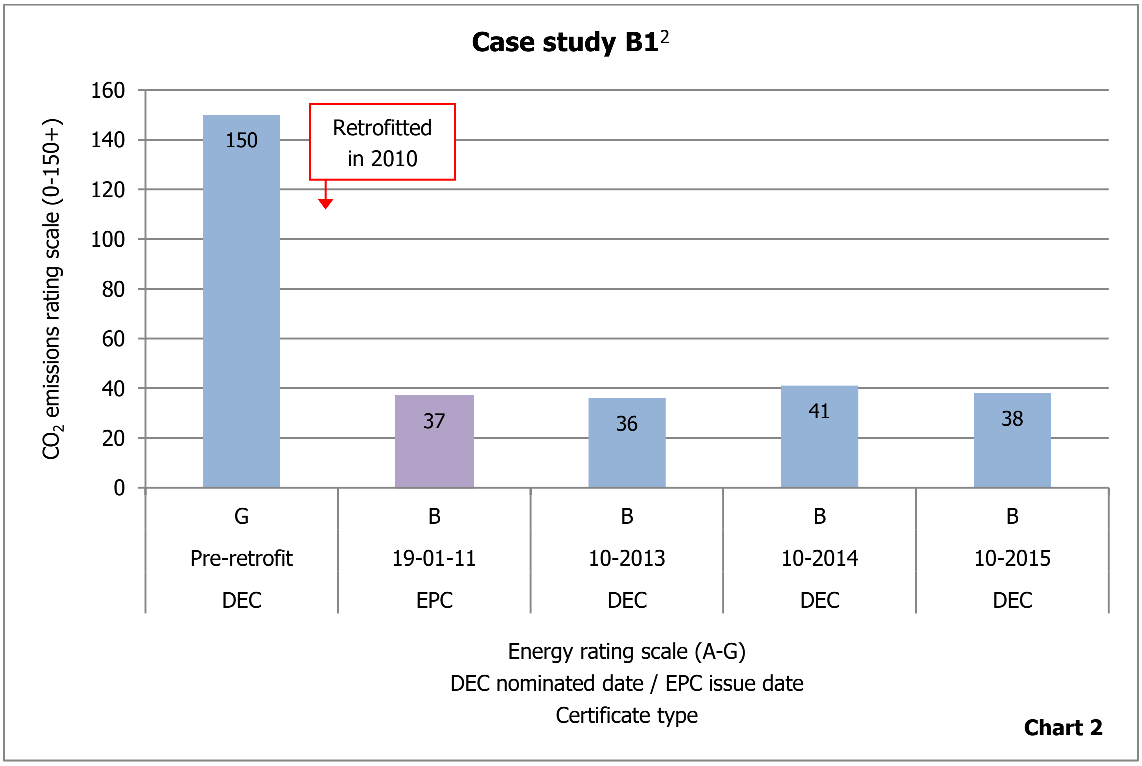
| | | Drivers | | | | | | | | | | | | Constraint |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Case name | Case reference | Improve aesthetics | Improve thermal performance[1] | Improve energy efficiency[2] | Improve weather tightness | Improve natural ventilation | Improve natural lighting | Improve acoustics | Attract tenants | Future proofing - new storey | Upgrade building services | Reduce running costs | Designing out ongoing fabric repairs | Budget |
| Commercial office | Exploratory | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | | | | ✓ |
| Office and laboratory | A1 | ✓ | ✓ | | | ✓ | ✓ | | | ✓ | | | | |
| Music | B1 | ✓ | | ✓ | | | | ✓ | | | ✓ | | | ✓ |
| Office and music | B2 | ✓ | ✓ | ✓ | | | | | | | | | | ✓ |
| Arts and media | C1 | ✓ | ✓ | | ✓ | ✓ | | | | | | ✓ | ✓ | |

Notes:

1. The thermal performance related drivers aim to improve air tightness (B2) and insulation (C1), and to address solar gain (Exploratory, A1, and B2).
2. The energy efficiency improvement for B1 and B2 aims to benefit the buildings and their campus.

Figure 5-12 Exemplifying case studies' energy efficiency ratings: Charts 1-4

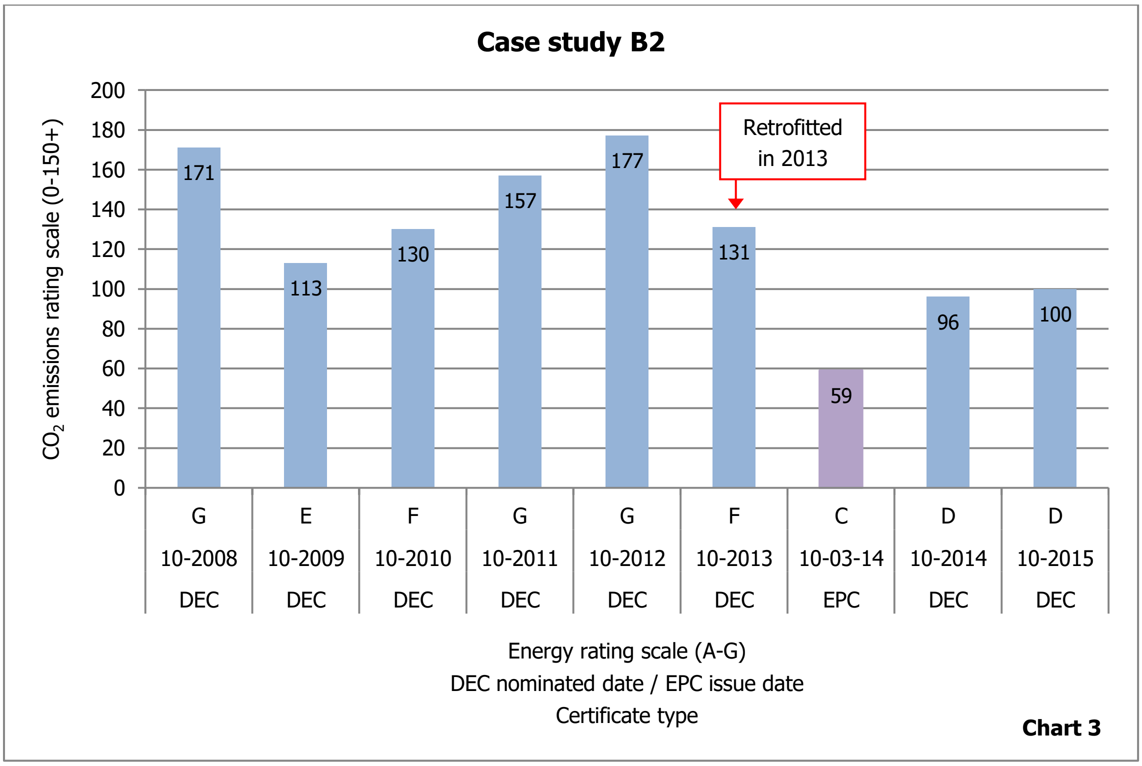


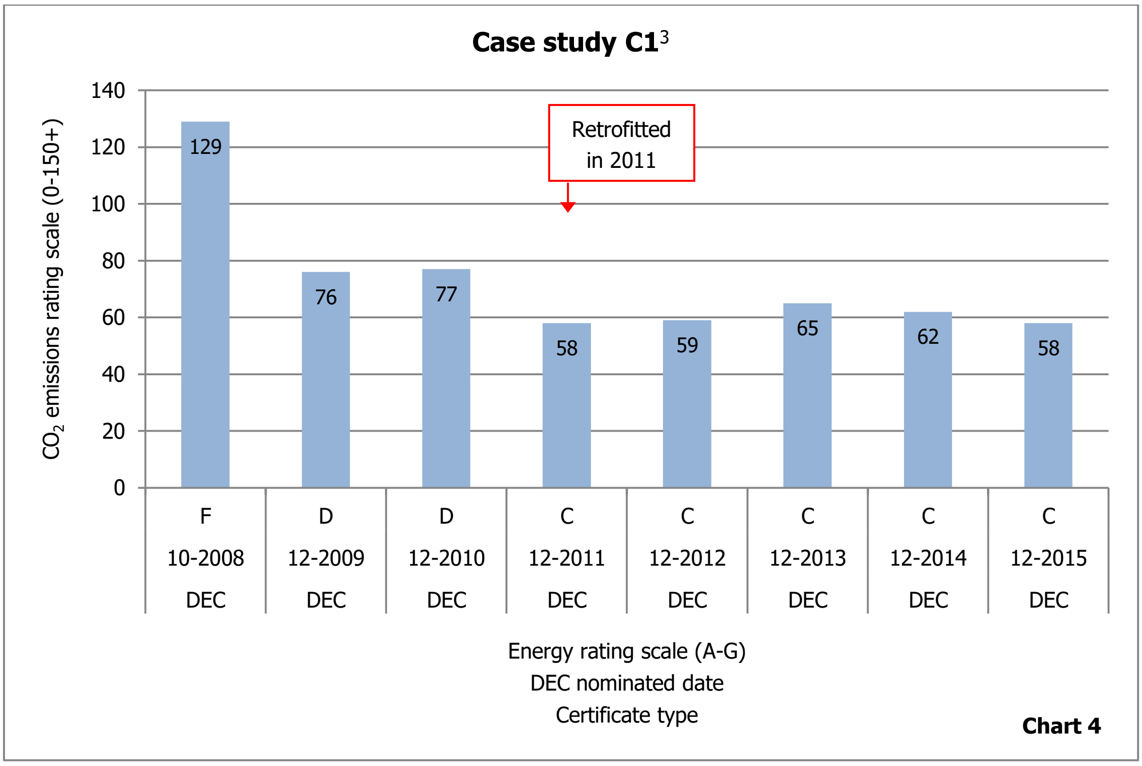




Notes:

1. A DEC with a 2008 nominated date does not exist for Case study A1.

2. Case study B1s pre-retrofit rating was taken from the documentary review and was unaccompanied by a numerical value. A notional value of 150 is assigned, given that a G rating equates to at least 150.




Notes for Figure 5-12, continued:

3. Case study C1 does not have an EPC because it is not tenanted.

## 5.6 Summary

This chapter presents an in-depth study of façade retrofit decision-making. Four exemplifying case studies, from a total of three UK higher education campuses, were conducted to deeply explore the decision-making process involved in façade retrofit selection. The exploration was enabled using in-depth interviews with a total of eight UK AEC industry experts involved in the façade selection process, a review of documentary evidence, and thermographic surveys of the completed retrofitted façades. The deep exploration was required to determine if the exploratory case study findings were representative of the UK AEC industry.

A specific literature review, conducted to set the context of university building façade retrofit, found that the UK university estate is large, and has a legacy of 1960s and 1970s buildings experiencing problems related to the building style typical of their era of construction. These buildings now typically feature ageing facades that exhibit poor thermal performance and poor weathertightness, and whose performance and aesthetics contribute negatively to the recruitment and retention of staff and students in an increasingly competitive market.

Façade retrofit is thus seen as an important consideration for many UK university institutions, in regards to improving the appearance, energy efficiency, thermal performance, and longevity of their building stock. Cost is a key influencing factor in university building retrofit. Other factors include improved performance and aesthetics, and where possible, keeping occupants *in situ* while improvement works are conducted. Decisions relating to university building retrofit are complex and are typically some of the biggest made in the HE sector.

This thesis considers over-cladding and re-cladding as having the highest potential to improve the performance and image of existing buildings, thus the in-depth study explores the decision-making used in such cases of façade retrofit. The literature revealed five cases of university building façade retrofit, containing a description of both the retrofitted façade and the decisions leading to the façade selection. These cases featured two incidences of over-cladding, two of re-cladding, and one where both façade types were discussed. Three of the cases were real-life. Normative decision-making was demonstrated by the theoretical cases, which utilised the payback period method, with one based on NPV.

The exemplifying case studies conducted for the in-depth study featured three cases of over-cladding, and one of over-cladding and re-cladding. Combining the exemplifying cases with the real-life cases of university façade retrofit in the literature, results in seven cases of real-life university building façade retrofit that did not show the use of structured (normative) decision-making methods to identify one optimum over-cladding/re-cladding system or a group of options from which the decision-maker could choose his/her preferred method. Informal (descriptive) decision-making methods were also not explicitly evidenced. However, the fact a façade system was selected and progressed to the as-built stage for each case, indicates the use of cognitive action by those involved in the façade selection, and as such, that some form of descriptive decision-making will have taken place. The use of descriptive decision-making, in the form of heuristics, is suggested by the exemplifying case study findings, with the contractor and sub-contractor on one project sharing expert 1960s-1970s buildings' knowledge with the project team, with one architect using lessons gained from other façades installed on campus to aid façade retrofit selection, and with another architect basing material choice and design on previous knowledge.

The real-life cases showed a widespread use of multiple sources of information in façade retrofit selection, with design-related sources relating to cost, performance, aesthetics, and collaboration, plus sources relating to the analysis and evaluation of the retrofit projects as a whole, namely business plans and feasibility studies. The majority of the information sources provided quantitative, or quantitative and qualitative data, for use in the façade selection process. The use of the majority of the information sources appears to be on a voluntary basis, with only a few being used to show mandatory compliance. The information used in the façade retrofit selection was obtained from internal and external sources, with external information stemming from both personal and impersonal sources.

To determine the representativeness of the exploratory and in-depth studies, to the UK AEC industry, the following chapter contains a cross case comparison that discusses the similarities and differences between the exploratory and exemplifying case study findings. The cross case comparison is then followed by this thesis' third main research step: a critical review of the research findings, which compares the findings from the state-of-the-art literature review, with that of the exploratory and in-depth studies.

# 6. Discussion

## 6.1 Introduction

The previous chapter presented an in-depth study of university building façade retrofit decision-making. A specific literature review of university building façade retrofit decision-making and four case studies of university building façade retrofit served to deepen this thesis' understanding of the decision-making methodology used in façade retrofit selection.

This chapter conducts a cross case comparison of this thesis' exploratory and exemplifying case studies, to determine their similarities and differences, and representativeness to the field of UK office building façade retrofit. As part of this analysis, the qualitative data arising from an in-depth interview from two of this thesis' case studies was reviewed using NVivo 11 (QSR International Pty Ltd., no date). NVivo is a qualitative data analysis software program that does not interpret data, but provides a single location for the storage of large amounts of data and aids data handling by enabling the application of consistent coding schemes (Bergin, 2011). There are concerns that data analysis software is a prescriptive approach that can introduce reluctance to change coding categories once developed, and the use of such software can distance a researcher from their data and thus impede or distort analysis (*ibid.*). For these reasons, all the qualitative data from this thesis' semi-structured and in-depth interviews is processed by the researcher using internal cognition and note taking, then two in-depth interviews are also reviewed using NVivo 11 for added depth of analysis.

The two interviewees selected for analysis in NVivo 11 are the client from the exploratory case study, who also acted as the architect (interviewee reference EXP1), and the architect from case study C1 (interviewee reference EXE8). These interviewees were selected because their respective case study buildings have similarities, plus key differences. The exploratory case study building and case study C1 were both originally completed in 1971, from an uninsulated in-situ concrete frame and infill panels with single-glazed ribbon windows. The cases were both retrofitted in 2011 with exterior wall insulation, cavity insulation, and double-glazing, with three key factors influencing the façade retrofit work for both cases being improved aesthetics, thermal performance, and weather tightness. The exploratory case building was sound, but structurally vacant (having been uninhabited for three-years), while case study C1 was a much loved building whose existing façade had become very unsound; budget was a key constraint for the exploratory case study building retrofit, while case study C1's key aim was to remain operational throughout the retrofit process.

This chapter also presents the third main research step used to implement this investigation: a critical review of the research findings, which draws on the state-of-the-art literature review, and exploratory and in-depth study findings, to critically examine the use of decision-making methodology for façade selection in real-life and theoretical office building retrofit.

## 6.2 Cross case comparison

This thesis' case study buildings all originate from a time when lightweight construction, poor insulation levels, and large areas of single-glazing lacking in external solar shading were typical in office building construction. Their original construction dates span from the late-1950s/early-1960s to 1971, meaning they represent the age of non-domestic buildings most commonly refurbished in the UK. Moreover, three of the exemplifying case buildings were constructed in the 1960s, and so also reflect the boom era in university construction with its resulting 'legacy' of significant numbers of ageing buildings. The case buildings averaged 41-years of age at the point of retrofit, which is slightly older than the estimated 30-year office retrofit cycle reported in the literature. The age at the point of retrofit ranged from 37-years for the commercial office, and 36 to 50 years of age for the university buildings. The details for all five case studies are summarised in Table 9-5.

The retrofit projects gave a new lease of life to all of this thesis' case study buildings, with two of the buildings ear-marked for demolition, two standing empty prior to retrofit, and one having only light use. Four of the case studies were fully over-clad, with three of these buildings receiving the cheapest form of over-cladding (insulated render) and the fourth receiving rainscreen cladding. One case was nearly fully over-clad, with new over-cladding and re-cladding used on three of its elevations, comprising of brick and rainscreen, and curtain walling and spandrel panels respectively, and existing rainscreen retained on one elevation. Due to its height, the building that was fully over-clad with rainscreen had to use façade materials that were Class 0 rated for fire spread to comply with Part B of the Building Regulations for England and Wales. The insulated render used on the three other fully-clad case buildings was also Class 0 rated, despite these buildings being significantly lower than the height specified by this mandatory requirement. All of the case study retrofit projects were influenced by a need to improve building aesthetics, with other key influencing factors including improvements to thermal performance and energy efficiency, and a reduction in solar gain (Table 5-15); these influencing factors relate to well-documented problems for 1960s-1970s office and university buildings. Budget was a key constraint for three of the case study projects. The case studies resulted in as-built façades that were on the whole successfully procured and installed, except for one university building that experienced multiple problems with its façade during installation. Additionally, two university buildings required in-use façade modifications.

The decision-making methodology used in the façade selection for this thesis' case studies showed strong similarities. The client, architect and planner played key roles in the façade selection process, with various advisors, including cladding suppliers, structural engineers, and mechanical engineers, providing information (e.g. U-value calculations, structural calculations) to help guide the façade selection process. The NVivo analysis supported the multidisciplinary nature of façade decision-making, with many of the same project team and regulatory body roles having involvement in the façade solutions designed by client EXP1 and architect EXE8. The NVivo analysis reinforced the iterative nature of façade decision-making, with decisions occurring throughout both projects, despite each building's façade having been decided at an early stage: the exploratory case study's insulated render for economic reasons and case study C1's rainscreen for protective reasons. A key difference between client EXP1 and architect EXE8's façade selection process is the iterative nature of the exploratory case included the value engineering of main façade elements, while case study C1's changes to the main façade were chiefly restricted to the choice of panel colour. A potentially beneficial difference is that case study C1 involved collaboration and thus iterative discussions between architect EXE8, the cladding supplier and contractor, at an early project stage; plus, other iterative scenarios were purposefully arranged by the architect, i.e. façade mock up for planning approval, and RDA and Parish Council approval. Cost was not a key constraint for case study C1; however, by taking a multidisciplinary, iterative decision-making approach from an early stage, this project potentially avoided the need for value engineering.

The case studies did not evidence any use of structured (normative) decision-making methods to identify one optimum over-cladding/re-cladding system or a group of options from which the decision-maker could make his final choice. The use of informal (descriptive) decision-making is suggested by each case resulting in an as-built façade, which indicates the use of some form of cognitive action on the part of the decision-makers. Descriptive decision-making, in the form of heuristics, is suggested by one architect using lessons gained from other façades on campus to aid façade selection, and by another architect basing material choice and design on previous knowledge.

Some similarities were observed in the case studies' façade selection process. Three of the case studies had basically made their façade choice from the outset. The exploratory case and case study B1 chose insulated render on grounds of cost, while the condition of C1's existing façade helped prompt the choice of rainscreen cladding. Case study A1 selected a cladding supplier pre-tender, who then worked closely with the architect to finalise the façade design; while case study C1's architect also worked closely with its project's cladding supplier, with whom they had collaborated on previous projects. Only case study B2's façade selection process was different in that it featured multiple occurrences of architect-led reviews of cladding options, and stakeholder involvement and dissemination in the design process; though ultimately, an insulated render system was chosen on grounds of cost and a lack of stakeholder consensus. Except for case study B2, the case studies did not evidence if various façade options were under consideration at any one point.

Numerous sources of information were used to aid the case studies' façade selection process (Table 5-14), though some dissimilarity was observed in regards to quantity, with the four university case studies shown as using a greater number of information sources than the commercial office (Table 9-6). The information sources used chiefly relate to certain aspects of the façade design process, namely cost, performance, aesthetics, and collaboration. The majority of the information used was quantitative in nature, though many sources of both a quantitative and qualitative, and qualitative nature were also used. The majority of the information sources appear to be used voluntarily, with only a few sources having an explicit mandatory nature, namely relating to showing compliance with the Building Regulations for England and Wales' Parts A, C, and L, and the LPA.

In regards to when the façade decisions were being made, the case studies' façade evolution showed a reasonably similar pattern, with the majority of façade decisions for the majority of the cases occurring during *Design* and *Pre-construction*, predominantly during RIBA Stages C, D, and E. Due to the different project points used when mapping the exploratory study's façade evolution, it is not possible to compare its façade decision timings on a like-for-like basis with the exemplifying cases; however, the majority of the exploratory case study's decisions were shown as occurring in RIBA Stages A-D.

The cross case comparison demonstrates the typologically similar nature of the five case studies conducted for this thesis and strongly suggests their representativeness of the ageing UK office and university building stock reported in the literature.

## 6.3 Critical review of the research findings

While normative decision theory ascribes that structured decision-making can help produce a well-reasoned course of action, only minimal incidences of normative decision-making chiefly in the form of the simple payback period were observed in this thesis' semi-structured interview and literature review findings. Furthermore, the real-life façade retrofit case studies conducted for this thesis resulted in successfully completed projects, which were chiefly unproblematic, without using normative decision-making methods.

It appears that normative decision-making may not suit the way in which façade retrofit decision-making is carried out in real-life:

- Real-life cases of façade retrofit use numerous sources of information relating to cost, performance, aesthetics, and collaboration in the façade selection process, while the models prepared for the incidences of normative decision-making described in this thesis appeared to only use information relating chiefly to performance and cost.
- Façade retrofit decisions are highly motivated by building aesthetics. This potentially intangible aspect can be derived from the cognitive processes of the architect in the early project stages where initial ideas can be based on past experience. This 'emotional' aspect of façade design may be difficult to define in a quantitative model.
- Architects appear to dislike the use of building performance simulation tools in general; thus, the use of building modelling, seemingly often used as a preparatory stage of normative decision-making, could be a barrier to the use of such decision methods, especially if the architects were expected to carry out this task.
- Architects play a key role in the façade decision-making process, especially in the generation of ideas in the early stages of a project. The architects' natural working style potentially sees them using cognition for the generation and comparison of ideas, which in effect sees them naturally conducting multi-criteria analysis.

It also appears that the use of information in façade retrofit decision-making may reduce or eradicate the need for normative decision-making. The process of façade retrofit decision-making appears to naturally incorporate numerous sources of information, of which many are of a quantitative nature. This use of information appears on the whole to be carried out voluntarily, with only a few sources explicitly used to show mandatory compliance. This seemingly naturally-occurring tendency to use multiple information sources to support façade retrofit decision-making may be a reason why normative methods are not widely used.

A further factor for the minimal use of normative decision-making may lie in the façades themselves, with the cladding for three of this thesis' case studies seemingly over-engineered. Class 0 rated façade systems were used on four of the case study buildings, when only one case warranted this level of specification as per the height requirements in the Building Regulations for England and Wales' Approved Document B2 – Fire Safety. The Class 0 rated insulated render system used 'unnecessarily' on the three cases is one of the cheapest forms of over-cladding; thus, the economic option was a highly specified option. This raises some thoughts: Does the use of such a system serve to remove some of a construction project's prototypical nature? Are such systems in effect a 'safer' option, from a construction project risk point of view? Does over-engineered cladding result in a decision-making process that has less need to assess all the alternatives?

Finally, collaboration is seen as key to the success of façade retrofit projects. For example, involving the LPA in the design process can result in planning approval with no conditions attached to the materials used on the exterior of a building. This highly important step – the approval of the façade aesthetics by planning – has the potential to make or break a project, and emphasises again the importance of aesthetics in the façade retrofit selection process.

### 6.4 Summary

This chapter presents a cross case comparison to compare the exploratory and exemplifying case study findings, to discuss any key similarities and differences, and to determine the case studies' representativeness as a whole to the UK AEC industry. The cross case comparison deemed the five case studies conducted by this thesis to be representative of the UK's ageing stock of office and university buildings, which being typical of the building styles for such buildings from the 1960s and 1970s, mean they lack insulation, have high infiltration, and poorly controlled solar gain. The key roles involved in façade retrofit decision-making, namely client, architect, and planner, were found across the literature, and the exploratory and exemplifying case studies. The points at which façade decisions occur in the retrofit project process was again reflective across the literature and exploratory and exemplifying case study findings, with façade decisions shown as having an iterative nature and occurring in the early project stages, predominantly in RIBA Stages C, D, and E.

The cross case comparison was followed by this thesis' third main research step: a critical review of the research findings, which evaluated the findings from this thesis' state-of-the-art literature, exploratory and in-depth studies to determine to what extent decision-making could be used to support façade retrofit decision-making. The critical review found that the current state of decision-making in the UK AEC industry, which has produced successfully completed projects on the part of this thesis' five façade retrofit case studies, is potentially aided by the decision process voluntarily incorporating numerous sources of information of a quantitative nature, which point may also serve to reduce or eradicate the need for normative decision-making. The critical review also suggests that normative decision-making may not suit the way in which façade retrofit is carried out in real-life, partly because of the heavy involvement of the architect in the façade selection process and the associated cognitive style of working. The use of over-engineered façade systems and a collaborative approach are also put forward as key factors for decision-making in a non-normative decision environment. The importance of aesthetics in façade selection was emphasised.

In the next chapter, recommendations are presented for use by UK AEC industry decision-makers in façade retrofit selection. The investigation's contributions to knowledge, the limitations of the research, and the possible direction of future research are also presented.

# 7. Conclusions and recommendations

## 7.1 Introduction

The findings from this thesis suggest that the process of façade retrofit selection functions naturally within the realm of the architectural profession and that normative decision-making may not suit the way in which façade retrofit selection is carried out in real-life. Therefore, while normative decision theory prescribes the use of structured methods in decision-making, this chapter instead presents recommendations for use by UK AEC decision-makers, for the purpose of enhancing current practice in building façade retrofit selection. The contributions to knowledge arising from this investigation, the limitations of the research, and the possible direction of future research are also here presented.

## 7.2 Conclusions

This research into non-domestic building façade retrofit decision-making adds to the discussion of how problems faced by the UK's poorly-performing ageing office building stock can be addressed, with façade retrofit capable of improving such aspects as building thermal performance, air infiltration, and solar gain, to name a few.

This research sought to explore façade retrofit selection in theory and in actuality, and thus involved an exploratory and in-depth study, featuring 30 UK AEC industry members, and 10 UK AEC experts in façade selection, combined with a state-of-the-art literature review of office building façade retrofit and a specific review of university building façade retrofit. The five case studies conducted by this thesis as part of its deep examination of UK façade retrofit selection are deemed representative of the UK's ageing stock of office and university buildings on grounds of their typologically similar existing building characteristics. Similarities also exist in this thesis' case studies in terms of the buildings' retrofit treatment, the factors influencing the retrofit treatment, and the decision-making methodology exhibited by key players in the retrofit project teams, for which the latter is on a par with the decision-making methodology revealed by this thesis' literature review and semi-structured interview findings.

This research findings show that façade retrofit decisions are important and have far-reaching consequences to a building and its occupants. Façade decisions are shown to be complex, with the UK AEC industry's prototypical projects and multi-disciplinary teams adding to the complexity of the decision-making arena. Where normative decision-making was reported as being used in façade retrofit decision-making, it was generally the simple payback period method, with one incidence of MCA. The façade retrofit selection process was found to utilise numerous sources of information, whose use is prompted by mandatory means or voluntarily used, and which are of a quantitative and/or qualitative nature.

Despite normative decision theory suggesting the use of structured decision-making methods to arrive at a well-reasoned course of action, this thesis does not proffer recommendations characteristic of normative decision-making. Instead, this thesis opts to support façade retrofit selection by making recommendations that reinforce current practice, namely, the utilisation of advisor-led information sources, collaborative working, and enhancing the energy efficiency resulting from a retrofit project via stakeholder engagement.

This thesis aimed to produce two contributions to the knowledge. The first, a state-of-the-art account of decision-making in façade retrofit selection in the UK architecture, engineering and construction industry, was achieved via the exploratory and in-depth studies, and literature reviews; while the second, recommendations for use by UK AEC decision-makers in the field of UK non-domestic building façade retrofit selection, was achieved following close examination of the research findings, including real-life façade retrofit cases conducted by this thesis and such cases in the literature. Moreover, as the literature review revealed that case studies of successful office retrofit are rare, this thesis' dissemination of five real-life façade retrofit case studies represents a further contribution to the knowledge.

## 7.3 Recommendations for practice

This thesis' recommendations for practice are solidly grounded on the combined findings from its exploratory and in-depth studies of façade retrofit selection.

The case studies conducted for this thesis' deep examination of decision-making in façade retrofit selection are deemed representative of the UK's ageing stock of office and university buildings. The case studies are chiefly considered representative on grounds of their typologically similar existing building characteristics, however, similarities also exist in terms of the buildings' retrofit treatment, the factors influencing the retrofit treatment, and the decision-making methodology exhibited by key players in the retrofit project teams.

The case study buildings original construction dates correspond with both the large cohorts of ageing office and university buildings resulting from boom periods of construction, and the age of non-domestic buildings most commonly refurbished in the UK. In pre-retrofit state, the case study buildings featured large expanses of poorly performing glazing, minimal insulation, and little or no solar shading, as is common to their era of construction, coupled with the effects of many decades of weathering. The façade treatment used on the case study buildings consisted of over-cladding (i.e. chiefly insulated render, with also rainscreen and brick) and re-cladding (i.e. curtain wall and spandrel panels). The key goal of the retrofit projects was to improve building aesthetics, with other important goals being to improve the buildings' thermal performance and energy efficiency, and reduce solar gain; the case study retrofit projects were on the whole successfully carried out, and all gave a new lease of life to the buildings concerned.

The case study projects' façade retrofit selection saw the client, architect and planner playing key decision-making roles, with various advisors providing information relating chiefly to cost, performance, aesthetics, and collaboration to help guide the façade selection process. The facade decision-making process can have an iterative nature from an early project stage and then onwards throughout the project. The majority of the sources of information used are quantitative and voluntary in nature; however, sources of a qualitative nature are also used, as are sources of a mandatory nature relating to building control and planning. With regards to this thesis' case studies' use of decision-making methodology, there was little evidence of informal (descriptive) methods and no evidence of structured (normative) methods. This decision-making methodology observed in this thesis' façade retrofit case studies is on a par with that revealed by this thesis' literature review and semi-structured interview findings.

Thus, recommendations for use by UK AEC decision-makers in the field of UK non-domestic building façade retrofit selection are developed from this thesis' complementary case study, semi-structured interview, and literature review findings. These recommendations are considered to complement certain aspects of façade retrofit selection in practice, as follows:

| | | Recommendations | | |
|---|---|---|---|---|
| Façade retrofit selection aspects complemented by the recommendations | | 1 | 2 | 3 |
| (i) | Aiding the façade retrofit decision-making process | ✓ | ✓ | ✓ |
| (ii) | Providing the right context for the achievement of good decisions | ✓ | ✓ | |
| (iii) | Aiding success in the completed retrofitted façade selection | ✓ | ✓ | ✓ |
| (iv) | Engaging building users in the changes associated with building retrofit | | ✓ | ✓ |

Recommendation 1: Utilise advisor-led information sources

*Façade retrofit selection aspect complemented: (i, ii, iii)*

Utilise the professional expertise of AEC industry advisors to guide the selection of a retrofit façade or elements of the façade. Advisor-led information sources range from the outcomes of a detailed discussion on a building's façade needs between the Architect's team, to the output of a calculation, e.g. U-values or heat transfer modelling conducted by the Mechanical Engineer. Façade specialists and suppliers are a key source of information, and the early involvement of such parties with the project architect may prove beneficial.

Recommendation 2: Maximise lines of communication

*Façade retrofit selection aspect complemented: (i, ii, iii, iv)*

Ensure good lines of communication and an ongoing dialogue throughout the project between AEC industry members involved in the façade decision-making process. Involving advisors (e.g. façade specialists and suppliers) and regulatory bodies (e.g. LPA, Building Control) from an early stage can help ensure a project meets the Client's needs with minimal delays and/or problems. Recording the decision-making process used for a façade retrofit project, including all the façade options considered, may aid the future refurbishment of the building concerned and that of buildings of a similar typology in an institutions' estate.

<u>Recommendation 3: Engage building stakeholders in the retrofit project</u>

*Façade retrofit selection aspect complemented: (i, iii, iv)*

Engaging building stakeholders can help improve the energy efficiency resulting from a retrofit project. This engagement may take the following forms: 1. To engender goodwill in building occupants, allow involvement in the design process and ensure noisy retrofit tasks are completed out-of-hours; 2. During the project, involve building users in proposed new energy efficient practices, and for university buildings, offer work shadowing/involvement opportunities for students on appropriate courses; and 3. When the project is finished, providing building users with operation and maintenance manuals in a user-friendly format, in advance of handover, increases time for familiarisation with any new systems. The use of different means (e.g. social media, static display, leaflets) for disseminating project proposals, etc. will ensure the most appropriate communication platform for each target audience.

## 7.4 Recommendations for future research

The research conducted for this thesis has some limitations, which may inform the direction of future research. Time limitations meant only five case studies were conducted based on buildings located in one country; thus, while the thesis draws on literature from a global field, it acknowledges a significant focus on UK building façade retrofit. Moreover, data drawn from such sources as the Building Regulations for England and Wales, and Pout et al. (1998) see the research focus aligning with England and Wales, and thence, England, in which the five case studies are located. In addition, as the retrofit projects were completed prior to sampling, only post-retrofit investigation, including post-retrofit thermography, was possible.

Future research could therefore see additional case studies conducted on completed façade retrofit projects, for comparison with the findings from this thesis.

If pre- *and* post-access can be gained to future façade retrofit projects, this could benefit additional case studies on two counts. Firstly, it could enable pre-retrofit thermography, which would provide information on the building's structural condition, which can be beneficial for: a) aiding retrofit project decision-makers in the façade retrofit selection; and b) comparing with post-retrofit survey findings to help ascertain success in the retrofitted façade. Secondly, it could enable the researcher to observe façade decisions in real-time, potentially involving ethnographic research, such as that used by Emmitt and Heaton (2003). Future research could ideally also involve obtaining additional case studies from countries other than England, pending the availability of buildings with a suitable typology.

The in-depth interviewing conducted for future case studies may benefit from an increased degree of structure. This thesis' guided interview approach involved a pre-prepared basic checklist to ensure specific topics were covered; however, the open nature of the data collection potentially limited some of the findings that could be drawn between the semi-structured and in-depth interview findings. The use of a standardised open-ended approach for future in-depth interviews may enable the collection of set (standardised) data, such as the decisions taken by specific construction industry functions in the façade retrofit project team or regulatory bodies involved in a retrofit project and the decision timings against the RIBA Plan of Work, while still allowing interviewees to talk freely about the projects' retrofit façade selection process and the interviewer the freedom to probe as necessary.

This thesis has suggested the importance of information sources in support of the façade selection process, which are categorised according to their predominantly mandatory, voluntary, quantitative and/or qualitative nature. However, the individual importance or optimum combination of such sources is unknown. Future research could thus involve the prioritisation and mapping of the information sources used in façade retrofit selection.

Finally, future research could involve further steps to validate the success achieved in façade retrofit selection. This thesis used post-retrofit thermography and certain data obtained from the documentary evidence review (e.g. pre- and post-retrofit DEC ratings) to aid discussion on the success of the selected retrofit façades. The case study companies were observed as considering other methods for assessing the retrofit project success (e.g. ongoing energy metering); however, these methods were aimed at validating the overall success of the retrofit project. Additional case studies could involve validation mechanisms that focus on the success of the selected façade; for example, post-retrofit interview/questionnaire surveys could be conducted with case study building occupants to determine their satisfaction with the retrofitted façade, ideally, if possible, for comparison with pre-retrofit surveys.

Depending on the focus of future case studies, e.g. should it be wished to compare the façade decision-making with the energy savings achieved, as a method of determining the success of the façade selection, it might be considered to exclude case study buildings that do not feature their own energy metering. In this thesis, case study C1 had shared energy metering, so its pre and post-retrofit DEC calculations could not be accurately compared. An example, where buildings have been excluded, is that of Chung and Rhee (2014) where only 11 of the 23 buildings on their target university campus in Seoul, South Korea, were selected for their study into the opportunities for energy conservation via university buildings' retrofit. The excluded buildings either shared gas and electricity meters with adjacent buildings or were already undergoing reconstruction for functional change (*ibid.*).

## 8. References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# 9. Appendices

| Appendix | Description |
|---|---|
| A | Exploratory semi-structured interview details<br>Exploratory case study interview details<br>Exemplifying case study interview details |
| B | The use of thermography in façade retrofit |
| C | Summary of the exploratory and exemplifying case studies' façade retrofit details, decision-making methods and information sources |
| D | Bulk-class definition |
| E | Summary of the PhD research dissemination activities |
| F | Ethical approval form<br><u>Exploratory study</u><br>Semi-structured interviews: ethical information and interview question sheets<br>Case study: ethical information and interview sheet<br><u>In-depth study</u><br>Ethical information and interview sheet |
| G | Exploratory case study protocol |
| H | Details of UK *recognised bodies* |
| I | Summarised responses to the semi-structured interview questions 4, 5, and 7-9 |
| J | Sources of documentary evidence |
| K | ARCOM 2012 conference paper |
| L | ARCOM 2013 conference paper |

# Appendix A

Table 9-1 Exploratory semi-structured interview details

| Interviewee reference | Interview date | Interview recording (minutes/seconds) | Interview format |
|---|---|---|---|
| SS1 | 05.04.12 | 23.25 | Face-to-face |
| SS2 | 10.04.12 | 21.44 | Face-to-face |
| SS3 | 10.04.12 | 41.49 | Face-to-face |
| SS4 | 12.04.12 | 17.34 | Face-to-face |
| SS5 | 12.04.12 | 20.23 | Face-to-face |
| SS6 | 13.04.12 | 41.28 | Face-to-face |
| SS7 | 13.04.12 | 19.01 | Face-to-face |
| SS8 | 16.04.12 | 11.12 | Telephone |
| SS9 | 17.04.12 | 27.36 | Telephone |
| SS10 | 18.04.12 | 54.35 | Face-to-face |
| SS11 | 18.04.12 | Circa 30 minutes, unrecorded | Face-to-face |
| SS12 | 19.04.12 | 42.15 | Face-to-face |
| SS13 | 20.04.12 | 55.24 | Telephone |
| SS14 | 26.04.12 | 21.51 | Face-to-face |
| SS15 | 01.05.12 | 37.47 | Face-to-face |
| SS16 | 09.05.12 | 17.48 | Face-to-face |
| SS17 | 09.05.12 | 36.02 | Face-to-face |
| SS18 | 09.05.12 | 51.04 | Face-to-face |
| SS19 | 17.05.12 | 18.31 | Face-to-face |
| SS20 | 19.06.12 | 26.56 | Face-to-face |
| SS21 | 22.06.12 | 54.29 | Face-to-face |
| SS22 | 25.06.12 | 28.03 | Face-to-face |
| SS23 | 02.07.12 | 59.44 | Face-to-face |
| SS24 | 19.07.12 | 15.59 | Telephone |
| SS25 | 10.08.12 | 47.55 | Face-to-face |
| SS26 | 10.10.12 | 24.33 | Face-to-face |
| SS27 | 16.10.12 | 52.47 | Face-to-face |
| SS28 | 15.11.12 | 22.50 | Face-to-face |
| SS29 | 15.11.12 | 57.42 | Face-to-face |
| SS30 | 22.01.13 | Circa 40 minutes, unrecorded | Face-to-face |

Table 9-2 Exploratory case study in-depth interview details

| Interviewee reference | AEC industry role | Interview date | Interview recording (minutes/seconds) | Interview format |
|---|---|---|---|---|
| EXP1.1[1, 2] | Client | 27.11.12 | 32.05 | Face-to-face |
| EXP1.12[1, 2] | Client | 29.11.12 | 29.13 | Face-to-face |
| EXP1.2[1] | Client | 04.04.13 | 70.35 | Face-to-face |
| EXP1.3[1] | Client | 12.04.13 | 35.45 | By telephone |
| EXP2 | Architect | 21.11.12 | 57.18 | Face-to-face |

Notes:

1. The Client, assigned interviewee prefix EXP1, was interviewed four times to achieve three finished interviews.

2. The Client's first interview was conducted in two parts, as the interviewee's work caused its postponement partway through, thus, part 1 (EXP1.1) and part 2 (EXP1.12) took place two-days apart.

Table 9-3 Exemplifying case study in-depth interview details

| Case study reference | Interviewee reference | AEC industry role | Interview date | Interview recording (minutes/ seconds) | Interview format |
|---|---|---|---|---|---|
| A1 | EXE1 | Client | 29.04.14 | 54.11 | Face-to-face |
| B1 | EXE2 | Client | 01.04.14 | 70.37 | Face-to-face |
| | EXE3 | Architect | 04.04.14 | 98.09 | Face-to-face |
| B2 | EXE4 | Client | 01.04.14 | 68.53 | Face-to-face |
| | EXE5 | Architect | 22.04.14 | 79.01 | Face-to-face |
| | EXE6 | Mechanical Engineer | 08.04.14 | 43.34 | Face-to-face |
| C1 | EXE7 | Client | 17.04.14 | 49.1 | Face-to-face |
| | EXE8 | Architect | 24.11.14 | 107.04 | Face-to-face |

# Appendix B

## The use of thermography in façade retrofit

Thermography is a powerful investigative tool, which has two main applications for buildings: 1) for assessing the condition of existing buildings; and 2) for inspecting the quality of new build/retrofitted existing buildings (Fox et al., 2014). With regards to existing buildings, thermography can be used to identify performance aspects, such as: ventilation losses; thermal bridging; moisture ingress; and structural defects (*ibid.*).

When used to assess façade performance as part of a façade retrofit project, thermography should ideally be conducted pre- and post-retrofit. Pre-retrofit thermography helps to identify structural details and building defects, thus providing an opportunity for redress via the retrofitted façade elements (Stockton, 2007). Post-retrofit thermography helps assess the quality of the façade installation, e.g. by identifying poorly installed doors and windows (Hayter et al., 2000), missing insulation (Stockton, 2007), and evaluating component mock-ups prior to installation (Colantonio, 2001).

In consideration of the defects to be assessed, i.e. different conditions are required if a moisture survey is to be conducted, a thermographer should generally try to meet certain climatic conditions (Table 9-4) when conducting a thermographic survey. When assessing the thermal images resulting from a survey, two methods of analysis exist: qualitative and quantitative. "*Qualitative analysis in thermography is the visual evaluation of colour patterns within a thermal image, which represent differences in measured radiation*" (ITC, 2006, in Fox et al., 2014: 299). "*Quantitative analysis adds to this by seeking to quantify thermal gradients for numerical analysis*" (Walker, 2004, in Fox et al., 2014: 299).

<u>Important notes relating to the exploratory and exemplifying case study thermography</u>:

The thermographic surveys that complemented this PhD investigation's case study data collection, and the thermographic images featured in the exploratory and exemplifying case study reports, are courtesy of Matthew Fox. Matthew Fox is a Level 2 Thermographer, whose own PhD centres on the use of thermal imaging as a tool for assessing housing in Cornwall in a bid to reduce fuel usage and fuel poverty (Fox, 2015a).

When viewing the case study thermographic survey images, it is important to note that while the images may show areas of cooler or warmer temperatures, it is always worth referring to the scale bar included in the relevant image, as the extent to which an observation causes a problem may be negligible. The surveys are not a substitute for a professional thermographic report. Any potential areas of heat loss shown in the case study reports' thermographic images are subject to interpretation by trained professionals, qualified thermographers, and should always be followed up with further inspection methods. The persons responsible for collating the data pertaining to these thermographic surveys and Plymouth University are not liable for the interpretation of the case study thermographic images by others.

Table 9-4 General climatic conditions for a thermographic survey (compiled from Fox, 2015a)

| General climatic conditions[1] | Reason |
|---|---|
| 10 degree Kelvin difference between Temperature In and Temperature Out | To aid image resolution. |
| Overcast sky, ideally day and night prior to the survey | To aid equalisation of the building's surface temperatures, by avoiding solar loading and very cold temperatures reflecting from a clear night sky. |
| Pre-sunrise | To lessen surface heat absorption from the previous day's sunshine. |
| Darkness | To avoid solar loading and to avoid reflections from the sun. |
| Non-rainy during the survey | To maximise the accuracy of the radiation transferred from the building's surfaces to the camera and to prevent evaporative cooling affecting the surface temperature readings. |
| Minimal wind speed | To prevent increased heat loss from the building's surfaces and more so, if the building's surfaces are damp. |

Notes:

1. Different conditions are required if a moisture survey is to be conducted, e.g. if the thermographer is aiming to detect roof moisture defects.

# Appendix C

Table 9-5 Case study façade retrofit details: summary

| Case study buildings | Commercial office<br>Exploratory case | Office and laboratory<br>Exemplifying case A1 | Music<br>Exemplifying case B1 | Office and music<br>Exemplifying case B2 | Arts and media<br>Exemplifying case C1 |
|---|---|---|---|---|---|
| Constructed (year) | 1971 | 1962 | Late-1950s/early-1960s | 1969-1970 | 1971 |
| Retrofitted (year) | 2011 | 2008-2009 | 2010 | 2013 | 2011 |
| Age at the point of retrofit (years) | 37 [1] | 36 | 50 | 43 | 39 |
| Building occupation during retrofit | Empty | Empty | Empty | Occupied | Occupied |
| Building description (pre-retrofit) | Uninsulated in-situ concrete frame and infill panels, single-glazing | Uninsulated RC frame, infill panels and cladding, single-glazing | Uninsulated PCC frame and infill panels, single-glazing | Uninsulated structural PCC panel walls, single-glazing | Uninsulated in-situ concrete frame and infill panels, single-glazing |
| Façade description (post-retrofit) | Exterior insulation system (render), cladding, cavity insulation, double-glazing | Curtain walling, insulated panels, rainscreen, solar shading, double-glazing | Exterior insulation system (render), cavity insulation, double-glazing | Exterior insulation system (render), insulated cladding, double-glazing | Exterior insulation system (rainscreen), cavity insulation, double-glazing |
| Building height (m) (post-retrofit) | 14.6 | 15.1 | 8.5 | 7.7 | 30.6 |
| Number of storeys (post-retrofit) | 5 | 4 | 2 | 2 | 7 |
| EPC rating (pre-retrofit)[2] | G 150 [4] | - | - | - | - |
| EPC rating (post-retrofit)[2] | B and C [5] | - | B 37 | C 59 | - |
| DEC rating (pre-retrofit) [3] | Not applicable | G 200 | G 150 [4] | G 177 | D 77 [6] |
| DEC rating (post-retrofit) [3] | Not applicable | C 70 | B 38 | D 100 | C 58 [6] |
| BREEAM rating (post-retrofit) | - | Very Good | Very Good | - | - |
| 'Wall' U-value ($W/m^2K$) (pre-retrofit) | 1.49 | - | - | - | - |
| 'Wall' U-value ($W/m^2K$) (post-retrofit) | 0.22 | - | - | - | - |
| Total useful floor area ($m^2$) (post-retrofit) | 3204 | 2384.3 | 1530 | 2456.1 | 2503 |

Notes for Table 9-5:

1. As it stood empty for 3-years, the building experienced structural vacancy (Remøy, 2010). It was technically 40-years old when the retrofit started; however, its age 'at the point of retrofit' is taken from the start of its vacant period, when the author considers the building as requiring retrofit.

2. The pre-retrofit EPC ratings are taken from certificates dated prior to retrofit and the post-retrofit ratings from certificates dated following retrofit completion.

3. The pre-retrofit DEC ratings are taken from certificates that reflect the building's energy performance for 12-months prior to the start of the retrofit, except for A1, where the earliest certificate obtained dates from the year its retrofit started. The post-retrofit ratings arise from each building's current DEC (at the time of writing).

4. These pre-retrofit EPC/DEC ratings were obtained from the documentary evidence review; the corresponding certificates were not viewed. No numerical rating accompanied the letter rating; therefore, the author applied a notional value of 150, this being the standard value accompanying the G rating on a DEC.

5. The exploratory case building holds multiple EPCs. Its upper four floors achieved a B EPC rating: 1st floor (46), 2nd floor (44), 3rd floor (44), and 4th floor (41); while the two retail outlets on the ground floor achieved a C EPC rating: outlet 1 (54) and outlet 2 (55).

6. Case study C1 is one of a number of buildings that run off a central boiler house, with no separate metering. These buildings thus receive a single DEC rating, making it difficult to judge each individual building's operational energy performance and any improvements in performance.

Table 9-6  Case study decision-making methods and information sources: summary

| **Case study buildings** | **Commercial office**<br>Exploratory case | **Office and laboratory**<br>Exemplifying case A1 | **Music**<br>Exemplifying case B1 | **Office and music**<br>Exemplifying case B2 | **Arts and media**<br>Exemplifying case C1 |
|---|---|---|---|---|---|
| Normative decision-making | - | - | - | - | - |
| Descriptive decision-making | - | Use of experience shown by architect | - | - | Use of experience shown by architect, contractor, and sub-contractor |
| Sources of information | Computer analysis to check location of dew points in the proposed insulated render system; U-value calculations | Business case; stakeholder engagement; lessons gained from other façades installed on campus; presentations by cladding suppliers<br>Life-cycle costings; new waterproofing details; BREEAM assessment<br>Detailed discussion, especially in relation to the cladding supplier's warrantee and then between the PC and Client in relation to delays and water ingress | Space planning; structural condition survey; Refurbishment/Pre-demolition Survey; feasibility work<br>Wall insulation evidenced by thermal modelling (Therm); thermal bridging and dew point location in the proposed insulated render system modelled (Therm); double glazing modelled (IES-VE); triple glazing looked at informally<br>U-value calculations; life cycle calculations; BREEAM assessment | Review of potential cladding materials; options appraisal of certain cladding solutions with consideration to cost<br>Stakeholder engagement; LPA involved in design stage; LPA consultation involved Gardens Trust<br>Structural calculations; building survey, including building efficiencies, meter readings, and heat loss via air permeability; pre-retrofit thermography; U-value calculations<br>Review on brise soleil; window design evidenced by thermal modelling (IES-VE); opening of windows, and solar control glass g-values tested via modelling | Business case; detailed discussions; brainstorming; supplier specifications; material choices and design also based on architect's previous knowledge and knowing what works<br>Measured survey; structural survey; geometric survey<br>U-value calculations; structural load calculations; sun-path calculations; knowledge of local climate and setting<br>Façade input from Local Parish Council and RDA<br>Full-scale rainscreen system mock-up; pull out tests for rainscreen fixings |

Notes: Decision-making Definitions can be found as follows - normative (Section 2.4.2), descriptive (Section 2.4.2), and sources of information (Section 2.4.3).

# Appendix D

The office building stock values listed in Chapter 2 result from the *Bulk class* categorisation described in Pout et al. (1998: 128), as shown below:

> "*Bulk class: This categorisation is used by the Valuation Office to distinguish four categories of commercial premises; retail, offices, factories and warehouses. In about 5% of cases, it results in the counter-intuitive entry of premises under different classes, e.g. one will find office premises associated with retail activity, retail premises associated with factories and so forth. …The bulk class 'offices' excludes national government offices, which are crown properties and hence exempt from rates. However, the bulk classes do cover about 70% of rateable premises in England and Wales*".

# Appendix E

Summary of PhD research dissemination activities:

| | Dissemination activity | Date | Publication | Thermography Report | Profile Article | Presentations | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Verbal | PowerPoint | Poster |
| 1 | EBG seminar: work-in-progress assignment | 02.05.2012 | | | | ✓ | ✓ | |
| 2 | University school research newsletter | Summer 2012 | | | ✓ | | | |
| 3 | 28th ARCOM conference, Edinburgh | 3-5 Sept 2012 | ✓ | | | ✓ | ✓ | |
| 4 | ARCOM Newsletter, Vol 29, Issue 2 | Sept 2012 | | | ✓ | | | |
| 5 | Research Booklet, EBG | 2012 | | | ✓ | | | |
| 6 | SWWIC Breakfast Meeting, Devon | 26.10.012 | | | | ✓ | ✓ | |
| 7 | EBG seminar: transfer assignment | 09.01.13 | | | | ✓ | ✓ | |
| 8 | WiTNet: email to student member | 13.03.13 | | | | | ✓ | |
| 9 | 2nd ISSR Sustainability Research Event, Plymouth | 29.04.13 | | | | | ✓ | ✓ |
| 10 | 29th ARCOM Conference, Reading | 2-4 Sept 2013 | ✓ | | | ✓ | ✓ | |
| 11 | Exploratory case study | 2013: various | | ✓ | | ✓ | ✓ | |
| 12 | 40th Celebration for Environmental Sciences, Plymouth | 13.09.13 | | | | | | ✓ |
| 13 | Guest lecture, UWE | 10.12.13 | | | | ✓ | ✓ | |
| 14 | Exemplifying case study A1 | July 2015 | | ✓ | | | | |
| 15 | Exemplifying case study B1 | 2013: various | | ✓ | | ✓ | ✓ | |
| 16 | Exemplifying case study B2 | 2013: various | | ✓ | | ✓ | ✓ | |
| 17 | Exemplifying case study C1 | 2013: various | | ✓ | | ✓ | ✓ | |
| 18 | Guest lecture, PU | 13.03.15 | | | | ✓ | ✓ | |

**Peer-reviewed conference papers:**

Garmston, H., Pan, W. and de Wilde, P. (2012) 'Decision-making in façade selection for multi-storey buildings'. In: Smith, S. D. (Ed) *Procs 28th Annual Association of Researchers in Construction Management Conference.* Edinburgh, 3-5 September. Association of Researchers in Construction Management, 357-367.

Garmston, H., Fox, M., Pan, W. and de Wilde, P. (2013) 'Multi-storey building retrofit with a focus on the façade selection process: a UK commercial office case study'. In: Smith, S. D. and Ahiaga-Dagbui, D.D. (Eds) *Procs 29th Annual Association Of Researchers In Construction Management Conference.* Reading, 2-4 September. Association of Researchers in Construction Management, 81-90.

**Posters:**

Garmston, H., de Wilde, P. and Pan, W. (2013) Balancing complexity in decision making for façade retrofit. Unpublished poster presentation *at 2nd Annual ISSR Sustainability Research Event*, 29 April 2013, Plymouth University, Plymouth.

Garmston, H., de Wilde, P. and Pan, W. (2013) Balancing complexity in decision making for façade retrofit. Unpublished poster presentation *at 40th Celebration for Environmental Sciences*, 13 September 2013, Plymouth University, Plymouth

# Appendix F

## Application for ethical approval

Ethical approval (FREC) form as submitted in 2012, since updated.

**UNIVERSITY OF PLYMOUTH**

**FACULTY OF ARTS**

**Faculty Research Ethics Committee (FREC)**
**APPLICATION FOR ETHICAL APPROVAL OF RESEARCH**

**ALL PARTS OF THIS FORM MUST BE COMPLETED IN FULL IN ORDER TO GAIN APPROVAL**

**Title of Research:** Balancing complexity in decision-making for façade retrofit

| | | | | |
|---|---|---|---|---|
| **1.** | **Nature of Approval Sought (please tick relevant box)** | | | |
| (a) | PROJECT*: | ✓ | (b) PROGRAMME*: | |
| | *If (a) then please indicate which category:* | | | |
| | • Funded Research Project | | | |
| | • MPhil/PhD Project | ✓ | | |
| | • Other (please specify): | | | |

**Note: In most cases, approval should be sought individually for each project. Programme approval is granted for research which comprises an ongoing set of studies or investigations utilising the same methods and methodology and where the precise number and timing of such studies cannot be specified in advance. Such approval is normally appropriate only for ongoing, and typically unfunded, scholarly research activity.*

**2. Investigators/Supervisors**

**Principal Investigator:**
Helen Garmston
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**Director of Studies:**
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The University of Hong Kong, Room 526, Haking Wong Building, Department of Civil Engineering, Pokfulam, Hong Kong

**Second Supervisor:**
Dr Pieter de Wilde
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Room 301, Roland Levinsky Building, Drake Circus, Plymouth, Devon, PL4 8AA

**Note: Principal Investigators are responsible for ensuring that all staff employed on projects (including research assistants, technicians and clerical staff) act in accordance with the University's ethical principles, the design of the research described in this proposal and any conditions attached to its approval.*

**3. Funding Body (if any), Amount of Funding (if any) and Duration of Project/Programme with Dates*:**

This research is funded by a three-year studentship from the Plymouth University Faculty of Arts, commencing October 2011 and due to end September 2014.

**Approval is granted for the duration of projects or for a maximum of three years in the case of programmes. Further approval is necessary for any extension of programmes.*

1 of 8

| 4. | **Aims and Objectives of Research Project/Programme:** |
|---|---|

**Research aim**

The aim of this research is to explore, and to suggest improvements, in decision-making practice for multi-storey building retrofit façade selection in the architecture, engineering and construction industry. This aim is driven by an overarching research question:

*To what extent does state-of-the-art decision-making methodology support façade selection for multi-storey building retrofit?*

**Research questions and hypotheses**

This research is being conducted in two phases. The first phase of this research is guided by one primary research question and six secondary research questions. The second phase is guided by a primary research question, plus two hypotheses and three secondary research questions (which are raised by the hypotheses), as shown below:

PHASE 1

Primary research question

What is the state-of-the-art in multi-storey building retrofit façade decision-making in the mainly-UK architecture, engineering and construction industry?

Secondary research questions

1. How are the façade types used in multi-storey building retrofit categorised, and how does façade selection relate to the building structure?
2. What decision-making methods are used when selecting façades for multi-storey building retrofit? And how is this compared to the decision-making methods used for new-build multi-storey building facade selection?
3. How does the type of decision-making method used in façade selection for multi-storey building retrofit affect the decision outcome?
4. Who makes façade decisions for multi-storey buildings?
5. When are façade decisions made during a multi-storey building project?
6. What problems (and solutions) exist in multi-storey building façade decision-making?

PHASE 2

Primary research question

How applicable is a complex* decision-making methodology for multi-storey building façade retrofit in the worldwide architecture, engineering and construction industry?

Hypotheses

$H_1$: A complex* decision-making methodology is less practicable over simple* methods when selecting retrofit façades on multi-storey buildings in 'x' countries**.

$H_2$: A complex* decision-making methodology does not bring commensurate levels of façade success* over simple* methods when selecting retrofit façades on multi-storey buildings in 'x' countries**.

| | |
|---|---|
| | * The terms 'complex', 'simple', and 'success' as used in the Phase Two primary research question and hypotheses will be defined from three of the Phase Two research activities: The findings from a critical review of literature will be used to form the basis of the survey questionnaire, which in turn, will be used to gain the architecture, engineering and construction industry experts' opinion as to what constitutes 'complex' and 'simple' in relation to decision-making methodologies, and what constitutes 'success' in façade selection. Subsequent in-depth open-ended interviews will then investigate the survey responses and add richness to the quantitative findings via the addition of qualitative interview responses.<br><br>** The hypotheses' will be tested using research findings from various countries, which at this present time, are not confirmed.<br><br><u>Secondary research questions</u><br>1. How do experts from the architecture, engineering and construction industry rate the usability of decision-making methods for multi-storey building façade retrofit?<br>2. What rating process can be used to delineate success in multi-storey building façade retrofit in the opinion of decision-makers from the architecture, engineering and construction industry?<br>3. How can success in multi-storey building façade retrofit decision-making be balanced against the complexity of the decision-making method/s used? |
| **5.** | **Brief Description of Research Methods and Procedures:**<br><br>PHASE 1<br><br>The first phase is qualitative in nature and involves semi-structured interviews and a case study, combined with a critical review of literature. The questions are designed using words like *how* or *what* to "convey an open and emerging" stance; they are also phenomenological in nature, being "broadly stated without specific reference to the existing literature" (Creswell, 2009: 130). This phenomenological research aims to both describe and explain events (Biggam, 2011), by analysing the interview and case study findings in relation to a critical review of current literature on decision-making, façade selection and multi-storey building retrofit.<br><br>The subject population will be obtained from the architecture, engineering and construction industry. Recruitment will be conducted by means of purposive sampling (Robson, 2011) whereby specific individuals (identified as the result of the literature review) are contacted and invited to participate in the research. The recruitment will also reflect an element of convenience sampling, as some interviewees will already be known to the interviewer; however, convenience sampling is an accepted method when "getting a feeling for the issues involved" is the chief aim of the exploratory study (Robson, 2011: 275). The number of semi-structured interviewees will target n=30 (Warren, 2002, in Bryman, 2012: 425; Adler and Adler, in Baker and Edwards, 2012: 9). One (or possibly two) exploratory case studies will be conducted so as to investigate the real-life phenomenon in depth, which, in addition to a review of the retrofit project information (e.g. tender documents, etc), will involve in-depth open-ended interviews with approximately n=4 interviewees in total (Yin, 2009). |

| | |
|---|---|
| | PHASE 2<br><br>The second phase is both qualitative and quantitative in nature. The qualitative research involves case studies and in-depth open-ended interviews, combined with an on-going critical review of literature. The quantitative research involves a survey design with self-administered questionnaires that will provide a numeric description of the subjects' opinions for quantitative testing of the hypotheses (Creswell, 2009: 146). The survey design will be given added depth by the succeeding in-depth open-ended interviews, which will be used to further explore the quantitative findings.<br><br>The subject population will be obtained from the architecture, engineering and construction industry. Recruitment will be conducted by means of purposive sampling (Robson, 2011) whereby specific individuals (identified as a result of the work conducted in Phase One) are contacted and invited to participate in the research. Three exemplifying case studies will be conducted, chosen because "they epitomize a broader category of cases" of which they are a member (Bryman, 2012: 70); and which, in addition to a review of the retrofit project information (e.g. tender documents, etc), will include self-administered questionnaires with approximately n=15 participants, followed by in-depth open-ended interviews with approximately n=15 participants from the case studies as a whole (Yin, 2009).<br><br>Sources:<br><br>Baker, S.E. and Edwards, R. (2012) How many qualitative interviews is enough? - Expert voices and early career reflections on sampling and cases in qualitative research. National Centre for Research Methods Review Paper. Available at: http://eprints.ncrm.ac.uk/2273/4/how_many_interviews.pdf (accessed: 04.12.12).<br><br>Biggam, J. (2011) Succeeding with your Master's Dissertation – A step-by-step handbook. 2nd edn. Berkshire: Open University Press.<br><br>Bryman, A. (2012) Social Research Methods. 4th edn. New York: Oxford University Press.<br><br>Creswell, J.W. (2009) Research Design – Qualitative, Quantitative, and Mixed Methods Approaches. 3rd edn. London: SAGE Publications, Inc.<br><br>Robson, C. (2011) Real World Research. 3rd edn. Chichester: John Wiley & Sons Ltd.<br><br>Yin, R.K. (2009) Case study research – design and methods. 4th edn. Thousand Oaks: SAGE Publications, Inc.<br><br>*Specify subject populations and recruitment method. Please indicate also any ethically sensitive aspects of the methods. Continue on attached sheets if required.* |
| **6.** | **Ethical Protocol:**<br>Please indicate how you will ensure this research conforms with each clause of the University of Plymouth's *Principles for Research Involving Human Participants.* Please attach a statement which addresses each of the ethical principles set out below. |
| (a) | Informed Consent:<br><br>Attaining informed consent is not a requirement for this project, as the subjects involved will be neither minors nor vulnerable adults; this project requires no access to persons for whom a 'gatekeeper' is required. |
| (b) | Openness and Honesty:<br><br>The participants will be fully informed as to the nature of the research project, both prior to acceptance to participate and at the point of participation. Materials conveying the purpose |

| | |
|---|---|
| | of the research, the withdrawal procedure, and contact details for communication with the PI and academic supervisors will be clear and legible in accordance with the requirements of the *Disability Discrimination Act 1995*.<br><br>*Note that deception is permissible only where it can be shown that all three conditions specified in Section 2 of the University of Plymouth's Ethical Principles have been made in full. Proposers are required to provide a detailed justification and to supply the names of two independent assessors whom the Sub-Committee can approach for advice.* |
| (c) | Right to Withdraw:<br><br>Participants will be informed of their right to withdraw prior to commencement of any research activity, e.g. face-to-face interview, survey questionnaire, etc.<br><br>Participants will also be informed that their participation in the research activity is voluntary and that they are free to withdraw either all or part of their responses up to a period of two-weeks after the data collection activity. Following this period, their responses will be combined with the general research findings for analysis. |
| (d) | Protection From Harm:<br><br>Protection from harm is not considered to be a direct requirement for this project, as the subjects involved will be neither minors nor vulnerable adults, and the research methods contain no activities that may be perceived 'dangerous' in the view of a reasonable person.<br><br>However, it is acknowledged that harm can be caused from activities such as indiscretion by the PI. Therefore, section (f) of this form: Confidentiality, details how the behaviour of the PI will serve to protect the participants' personal and/or commercial reputation from harm. |
| (e) | Debriefing:<br><br>The participants will receive an information sheet that details the research activity in which they have participated, and which also outlines the cooling-off period (two-weeks, as specified in Section (c) of this ethical application) and the contact details of the PI and the project supervisors, should the participant wish to ask for further information or to tender their withdrawal. |
| (f) | Confidentiality:<br><br>**Reporting of the research findings**<br><br>The PI proposes to report the PhD research findings via the following routes: conference papers, journal articles, and the PhD thesis. While anonymity is assured at all times in these methods of reporting, slightly differing levels of anonymity are proposed for Phase One and Phase Two of the research, as described below:<br><br><u>Phase One</u>: Complete anonymity, including the non-use of anonymous direct quotes, is promised to the participants of the exploratory study. The reason for this decision is that the PI considers that the key value of the Phase One findings lies in the combined opinions of the participants and not in the reproduction of any one individual comment.<br><br><u>Phase Two</u>: The participants of this phase will be identified experts in their field and because of this, each individual participant's responses are considered by the PI as being potentially key to the project findings. Permission shall therefore be requested of the Phase Two |

| | |
|---|---|
| | research participants for the PI to use direct quotes from their recorded opinions. This permission will be requested on the proviso that where direct quotes are used in reporting, that the anonymity of the participants will be assured through the use of generic AEC industry role pre-fixes, e.g.: Design Team #4, Engineer #2, Contractor #1, etc<br><br>**Storage of the data**<br><br>All data: Data from this research project will be stored for a minimum of 10-years, as per Plymouth University policy.<br><br>Electronic data: Any electronic documents confidential data pertaining to the subject population will only be stored and used on a password-protected computer. Individual files will be encrypted using suitable software that shreds the original file, leaving only the encrypted file; data stored on an external hard-drive, for transportation, will receive the same encryption treatment. A shredding software programme will be used when disposing of files that contain confidential information.<br><br>Hard copy data: Hard copy documents containing confidential data pertaining to the subject population will be stored in a locked cabinet, and when no longer needed, will be physically shredded.<br><br>Verbal communications: As with many industries, the architecture, engineering and construction industry can sometimes seem like a 'small place', with staff members crossing paths and exhibiting connections with persons from companies other than their own. The PI will thus ensure that no reference is made to persons having taken part in this project, when discussing this project's activities with other persons, to prevent the identity of participants becoming known to persons other than the participant and colleagues of the participant, e.g. those involved in arranging the liaison between participant and PI. This behaviour on the part of the PI strongly supports Section (d) of this ethical application. |
| (g) | Professional Bodies Whose Ethical Policies Apply to this Research:<br><br>The PI is an incorporated member of the Chartered Institute of Building (CIOB), which has its own code of conduct that demands its members to act at all times with integrity, and to discharge their duties with complete fidelity and probity (CIOB, 2008).<br><br>Source:<br>The Chartered Institute of Building (CIOB) (2008) Rules and regulations of professional competence and conduct. Ascot: CIOB [online]. Available at: http://www.ciob.org.uk/sites/ciob.org.uk/files/WEB-INF/files/documents/rules-regulations_July08.pdf (accessed: 19.11.11).<br><br>*Applicants **MAY** choose to write "not applicable" in the "Relevant Professional Bodies" section of the Ethical Application Form. However, if based on the information written in other sections of the form, FREC considers a particular professional code to be of relevance, then the Committee may make its consultation and adherence a condition of acceptance. The committee strongly recommends that prior to application, wherever possible, applicants consult an appropriate professional code of ethics regardless of whether or not they are members of that body (for example, Social Research Association . http://www.the-sra.org.uk/ethical.htm Market Research Society http://www.mrs.org.uk/standards/codeconduct.htmBritish Sociological Association http://www.britsoc.co.uk/equality/).* |

| **7.** | **Declaration*:** To the best of our knowledge and belief, this research conforms to the ethical principles laid down by the University of Plymouth and by the professional body specified in 6 (g). | | | |
|---|---|---|---|---|
| | | **Name** | **E-mail (s)** | **Date** |
| | Principal Investigator: | Helen Garmston | helen.garmston@plymouth.ac.uk | 13.12.12 |
| | Other Staff Investigators: | N/A | N/A | |
| | Director of Studies (only where Principal Investigator is a postgraduate student): | Dr Wei Pan | wpan@hku.hk | 13.12.12 |

*You will be notified by the Research Ethics Committee once your application is approved.

**Please Answer Either YES or NO to ALL Questions Below.**
**If you answer YES, please provide further details.**

**Do You Plan To Do:**

- Research involving vulnerable groups – for example, children and young people, those with a learning disability or cognitive impairment, or individuals in a dependent or unequal relationship

**Answer: No**

- Research involving sensitive topics – for example participants' sexual behaviour, their illegal or political behaviour, their experience of violence, their abuse or exploitation, their mental health, or their gender or ethnic status

**Answer: No**

- Research involving groups where permission of a gatekeeper is normally required for initial access to members – for example, ethnic or cultural groups, native peoples or indigenous communities

**Answer: No**

- Research involving deception or which is conducted without participants' full and informed consent at the time the study is carried out

**Answer: No**

- Research involving access to records of personal or confidential information, including genetic or other biological information, concerning identifiable individuals

**Answer: No**

- Research which would induce psychological stress, anxiety or humiliation or cause more than minimal pain

**Answer: No**

- Research involving intrusive interventions – for example, the administration of drugs or other substances, vigorous physical exercise, or techniques such as hypnotherapy. Participants would not encounter such interventions, which may cause them to reveal information which causes concern, in the course of their everyday life.

**Answer: No**

**Completed Forms should be forwarded BY E-MAIL to Sue Matheron (Susan.Matheron@plymouth.ac.uk) Senior Administrator, Research and Graduate Affairs, Faculty of Arts, Room 305, Roland Levinsky Building, Plymouth PL4 8AA**

## Exploratory study

Semi-structured interviews: Ethical information sheet

ENVIRONMENTAL BUILDING WITH PLYMOUTH UNIVERSITY

### Façade decision-making on multi-storey buildings

# ETHICAL INFORMATION SHEET

**Background**

This research is part of a PhD project funded by Plymouth University. It will be undertaken by Helen Garmston, under the supervision of Dr Wei Pan and Dr Pieter de Wilde, who are both academic Readers within the Plymouth University Environmental Building Group.

**Research Aims**

This project aims to review the decision-making processes in façade selection for multi-storey buildings, with the purpose of recommending best practice for the benefit of all stakeholders, e.g. constructors, clients, and occupants.

**Research Methods**

The data will be collected through the use of semi-structured interviews with a range of professionals involved in façade decision-making process on multi-storey buildings. The data will be qualitatively analysed to reveal any patterns and themes, which will be compared to current literature in the field.

**Informed Consent**

Participation in the study is voluntary. You have the right not to participate or to withdraw at any stage prior to attending the interview. Following participation, there will be a two-week cooling-off period, where you may ask for particular comments to be edited-out from the transcripts or recorded material.

**Confidentiality**

The results from this research will be treated confidentially. All published work will anonymise the data and will never identify its source. All data from this research will be stored securely for a period of 10 years, from the completion of the study, in accordance with the Plymouth University ethics policy.

**Feedback**

If you would like an update on the progress of this study, or if you have any questions about the research, please contact Helen Garmston (helen.garmston@plymouth.ac.uk), Dr Wei Pan (wei.pan@plymouth.ac.uk) or Dr Pieter de Wilde (Pieter.dewilde@plymouth.ac.uk).

**Thank you for your willingness to take part.**

## Exploratory study

Semi-structured interviews: Interview question sheet

ENVIRONMENTAL BUILDING WITH PLYMOUTH UNIVERSITY

### Façade decision-making on multi-storey buildings

This research is focused on the decision-making processes used in the selection of building façades. The interview questions are divided into two sections: the first asks about your role in construction, while the second asks about your involvement in façade decision-making.

Section one:

1. What is your role in the construction industry (e.g. Architect, Building Surveyor, Construction Management, Project Manager, Quantity Surveyor?)
2. Please describe the main business in which your company is involved (e.g. construction, design, supplier)
3. What type of buildings have you had experience with, in relation to:

    **Domestic** / **commercial** *(or please specify if other)*

    **Height** *(please specify in general, in metres)*

    **Number of storeys** *(please specify in general)*

    **Location: UK / Europe** *(or please specify if elsewhere)*

Section two:

4. What role have you played in the decision-making for façades?
5. Who else has influenced these façade decisions?
6. Can you tell me at what stage of the RIBA plan of work that these façade decisions were made?
7. Can you tell me more about how these façade decisions came about?
8. What do you see as the problems in façade decision-making?
9. How do you think these problems could be addressed?
10. Do you have any projects on which I may conduct a deeper analysis?

***Thank you very much for your time.***

## Exploratory study

Case study: Ethical information sheet

ENVIRONMENTAL
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### Case Study Investigation – Building Retrofit

# ETHICAL INFORMATION SHEET

**Background**
This research is part of a PhD project funded by Plymouth University. It will be undertaken by Helen Garmston, under the supervision of Dr Wei Pan and Dr Pieter de Wilde from the Plymouth University Environmental Building Group.

**Research Aims**
This project aims to investigate complexity in decision-making in retrofit façade selection for multi-storey buildings.

**Research Methods**
Findings from current literature in the field of façade retrofit decision-making for multi-storey buildings will be triangulated with data collected via semi-structured interviews and case study research.

**Informed Consent**
Participation in the study is voluntary. You have the right not to participate or to withdraw at any stage prior to attending the interview. Following participation, there will be a two-week cooling-off period, where you may ask for particular comments to be edited-out from the transcripts or recorded material.

**Confidentiality**
The results from this research will be treated confidentially. All published work will anonymise the data and will never identify its source. All data from this research will be stored securely for a period of 10 years, from the completion of the study, in accordance with the Plymouth University ethics policy.

**Feedback**
If you would like an update on the progress of this study, or if you have any questions about the research, please contact Helen Garmston (helen.garmston@plymouth.ac.uk), Dr Wei Pan (wei.pan@plymouth.ac.uk) or Dr Pieter de Wilde (Pieter.dewilde@plymouth.ac.uk).

**Thank you for your willingness to take part.**

**Exploratory study**

Case study: Interview sheet

ENVIRONMENTAL BUILDING WITH PLYMOUTH UNIVERSITY

## Case Study Investigation – Building Retrofit

This research interview is examining the decision-making processes involved in the retrofit of an office building, with a particular focus on the selection of the building's façade.

You are invited to take part in the interview because of your specific involvement with the project. The interview is guided by two topics (below) on which you are invited to speak freely. There are no right or wrong answers; this study is interested in your personal opinions and perspectives.

The interview is expected to take approximately one-hour. Permission to record the interview is kindly requested.

### The Topics:

- The building retrofit
- The selection of the building façade

***Thank you in advance for your participation.***

**In-depth study**

Exemplifying case studies: Ethical information sheet

ENVIRONMENTAL BUILDING WITH PLYMOUTH UNIVERSITY

## Case Study Investigation – Building Façade Retrofit

# ETHICAL INFORMATION SHEET

**Background**
This research is part of a PhD project funded by Plymouth University. It will be undertaken by Helen Garmston, under the supervision of Professor Pieter de Wilde from Plymouth University and Dr Wei Pan from the University of Hong Kong.

**Research Aims**
This project aims to investigate the decision-making processes involved in retrofit façade selection for multi-storey buildings.

**Research Methods**
Findings from current literature in the field of façade retrofit decision-making for multi-storey buildings will be triangulated with data collected via semi-structured interviews, and case studies (involving in-depth interviews, documentary evidence review, and thermography).

**How to withdraw from the case study**
Participation in the study is voluntary. You have the right not to participate or to withdraw at any stage. Following participation, there will be a two-week cooling-off period, where you may ask for particular comments to be edited-out from the transcripts or recorded material.

**Confidentiality**
The results from this research will be treated confidentially. All published work will anonymise the data and will never identify its source. All data from this research will be stored securely for a period of 10 years, from the completion of the study, in accordance with the Plymouth University ethics policy.

**Feedback**
If you would like an update on the progress of this study, or if you have any questions about the research, please contact Helen Garmston (helen.garmston@plymouth.ac.uk), Professor Pieter de Wilde (Pieter.dewilde@plymouth.ac.uk) or Dr Wei Pan (wpan@hku.hk).

**Thank you for your willingness to take part.**

**In-depth study**

Exemplifying case studies: Interview sheet

ENVIRONMENTAL BUILDING WITH PLYMOUTH UNIVERSITY

## Case Study Investigation – Building Façade Retrofit

This in-depth interview is examining the decision-making processes involved in the retrofit of a university campus building, with a particular focus on the selection of the building's façade. You are invited to take part in this interview because of your specific involvement with the project.

The interview is guided by two topics (below) on which you are invited to speak freely. There are no right or wrong answers; this study is interested in your personal opinions and perspectives.

The interview is expected to take approximately one-hour. Permission to record the interview is kindly requested.

### The Topics:

- The building retrofit
- The selection of the building façade

***Thank you in advance for your participation.***

## Appendix G

### Exploratory case study protocol

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# Exploratory case study protocol

Please note: To ensure the confidentiality of the case study participants, this protocol has been edited to remove the name and location of the case study building, and the names and contact details of the participants from the case study company. Further confidentiality-related edits have also been made.

**Helen Garmston** and Matthew Fox

Plymouth University

School of Architecture, Design and Environment

6th November 2012

## Contents

## Overview

This protocol describes the proposed plan for conducting an exploratory case study on the office building façade retrofit project.

This case study will track the retrofit process from start to finish and will focus on the decision-making processes involved in the selection of the building's new façade. The main aim of the case study is to discover how the building façade was selected, including such aspects as what decisions were made, when they were made, and by whom. To give added depth to the investigation, this case study has a secondary aim, which is to discover how the implemented façade performs thermally within the context of the building's envelope.

These case study aims will be guided by two research questions, which will be fulfilled using various data collection methods (see below in italics):

1. How was the building façade selected during the retrofit of the office building?
   *Data collection summary: in-depth open-ended interviews with key members of the building retrofit project team; review of secondary data; building survey.*

2. How does the implemented façade perform thermally within the context of the retrofitted office building's envelope?
   *Data collection summary: internal and external thermography; review of secondary data; building survey.*

This case study is to be conducted by Helen Garmston, in collaboration with Matthew Fox, and under the academic supervision of Dr Wei Pan and Dr Pieter de Wilde (for Helen Garmston), and Dr Pieter de Wilde and Professor Steve Goodhew (for Matthew Fox).

This protocol is to be approved by the academic supervisory team and key personnel at the case study company prior to starting the case study investigation. This protocol may be subject to change as the research progresses; however, approval will be sought by Helen Garmston prior to conducting any work that that deviates from the approved plan. This protocol has been designed to guide the investigators and in turn, serves to increase the reliability of this case study investigation (Yin, 2009).

## Field procedures

### Presentation of credentials

This investigation is part of the exploratory work of two Plymouth University PhD students. It has been initiated by Helen Garmston, who is investigating façade selection on multi-storey buildings, and who has requested assistance from fellow student Matthew Fox for the thermography element. For Helen, this work will assist the student in gaining knowledge of façade decision-making and process analysis, and will complement work already undertaken in the exploratory phase of her PhD. For Matthew, this work will assist in increasing his expertise in thermography.

Helen Garmston is a full-time PhD research student, funded by Plymouth University. Helen completed a Building Surveying degree at Plymouth University in 2010 and worked as a Research Assistant in their Environmental Building Group, prior to starting her PhD in October 2011. Matthew Fox is a full-time PhD research student, funded by a European Social Fund, Combined Universities of Cornwall (ESF-CUC) grant. Prior to this research position, Matthew worked as a qualified Architect for an Edinburgh-based practice specialising in energy efficient architecture.

### Case study building details and contact persons

The case study building is a five-storey office building located in the UK. It is owned and the top-floor occupied by the case study company, with other floors occupied by tenants of the case study company. The building was constructed in 1971 and retrofitted in 2011, with the case study company acting as both Client and Architect. The main contacts at the case study company for this investigation are the Managing Director and the PA to the Directors.

### Privacy Statement

In accordance with Plymouth University policy, all data collected during this case study will be treated with the utmost confidence and stored in a secure manner. Any use of data in reporting will be anonymous.

## Research design

### Literature review

To prepare for the case study investigation, Helen Garmston is conducting a literature review of: case study design; decision-making; and building and façade retrofit. Likewise, Matthew Fox is reviewing literature on: the use of thermography for building surveys and inspection, and pre and post building refurbishment investigations.

### Case study questions

1. How was the building façade selected during the retrofit of the office building?
   *Data collection summary: In-depth open-ended interviews with key members of the building retrofit project team; review of secondary data; building survey.*

2. How does the implemented façade perform thermally within the context of the retrofitted office building's envelope?
   *Data collection summary: Internal and external thermography; review of secondary data; building survey.*

**Data collection**

In-depth open-ended interviews

In-depth open-ended interviews with key members of the building retrofit project team will provide one of the most important sources of information for this case study. In-depth open-ended interviews will ask the interviewees to talk freely on a number of topics related to the project, with the aim of capturing the interviewees' opinion of events (Yin, 2009; Robson, 2011). Each interview is expected to last approx. one-hour and permission is kindly requested to record the interviews. The interviewees should have knowledge on aspects of the retrofit, to include, but not be limited to: cost, technical function, and aesthetics. The interviewees are:

The Client – who made the decisions on material choices and external cladding during the planning stage, and carried out value engineering to reach a build-cost that met with the UK Government's financial restrictions on SIPP borrowing.

The Lead Architect – involved in the retrofit project from the detail design stage and during construction.

The interviews will be conducted by Helen Garmston, in ideally November-December 2012.

Review of secondary information

It is expected that a review of files and plans pertaining to the project will provide useful information on the building retrofit. The review of secondary information will be conducted in ideally November-December 2012, by Helen Garmston (documents relating to the building retrofit in general, plus those specific to the façade selection, e.g. agendas, minutes of meetings, progress reports) and by Matthew Fox (documents relating to the building structure, fabric and building envelope U-values).

Building survey

An initial survey was conducted on the case study building on 20th June 2012, by Matthew Fox and Helen Garmston, to review the building details inside and out as preparation for the internal and external thermography. Access to the building and guidance during the visit was organised by the case study company

Thermography

Internal and external thermography will each be conducted once on the completed retrofit case study building. A snapshot style (steady state) thermographic survey will be conducted. External thermography will encompass the building's complete façade, while internal thermography will be conducted on Floor 4 only.

Ideal conditions for thermography generally exist when there has been a cloudy sky during the day and night (Hart, 1991). Conducting thermography late at night once temperatures have equalised is then of further benefit to the thermography (Walker, 2004). For internal thermography, a 10 degree Kelvin temperature difference is required between Temperature In and Temperature Out (UKTA, 2007).

Due to the requirement for key weather conditions, the thermography testing may need to be conducted at very short notice. It is hoped that following discussion with the case study company, with regards to building access and security arrangements, that bookings/cancellations can be made at short notice, e.g. 24 or 48 hours, to ensure that the optimum date/s for thermography are captured in autumn/winter 2012. The thermography will be conducted by Matthew Fox with assistance from Helen Garmston.

**Data analysis**

This case study is aiming for a convergence of evidence, whereby empirical findings from a wide array of information are triangulated to "understand a real-life phenomenon in depth" (Yin, 2009: 18). To evaluate these multiple sources of documentary information, this case study will adopt a mixed methods approach to analysis.

Qualitative analysis will be used to analyse the findings from the:

- open-ended interviews
- building survey
- review of secondary data
- (potentially) some of the thermography findings

Quantitative analysis will be used to analyse the thermography findings not chosen for qualitative analysis.

## Reporting procedures/outputs

1. Academic paper on the building retrofit, authored by HG, with thermography input by MF. The focus will be on the façade decision-making processes, supported by the thermography findings.

2. Stand-alone thermography report for the case study company, produced by MF.

Important note: The supervisory teams of both students will be consulted in relation to the preparation of the outputs shown above, and named on the outputs accordingly.

## References

Hart, J.M. (1991) A practical guide to infra-red thermography for building surveys. Building Research Establishment Report.

Robson, C. (2011) Real world research. 3rd edn. Chichester: John Wiley & Sons Ltd.

UKTA (2007) Building Thermography. Thermography Code of Practice - Number 1. UK Thermography Association.

Walker, H.J. (2004) Principles and practice. BINDT CM series infrared thermography – Volume 1. Northampton: BINDT.

Yin, R.K. (2009) Case study research – design and methods. 4th edn. Thousand Oaks: SAGE Publications, Inc.

# Appendix H

## Details of UK *recognised bodies*

Table 9-7 UK recognised bodies by country

| Recognised bodies by country | GOV.UK (2016b, last updated 09.06.16) | Thesis Table 5-1 (HESA, 2016) | Thesis Figure 5-2 (HESA, 2016) |
|---|---|---|---|
| **England** | | | |
| Anglia Ruskin University | ✓ | ✓ | ✓ |
| Anglo-European College of Chiropractic | ✓ | - | - |
| Archbishop of Canterbury, The | ✓ | - | - |
| Arden University | ✓ | - | - |
| Arts University Bournemouth | ✓ | ✓ | ✓ |
| Ashridge Business School | ✓ | - | - |
| Aston University | ✓ | ✓ | ✓ |
| Bath Spa University | ✓ | ✓ | ✓ |
| Birkbeck, University of London | ✓ | ✓ | ✓ |
| Birmingham City University | ✓ | ✓ | ✓ |
| Bishop Grossteste University | ✓ | ✓ | ✓ |
| Bournemouth University | ✓ | ✓ | ✓ |
| BPP University | ✓ | - | - |
| British School of Osteopathy, The | ✓ | - | - |
| Brunel University London | ✓ | ✓ | ✓ |
| Buckinghamshire New University | ✓ | ✓ | ✓ |
| Canterbury Christ Church University | ✓ | ✓ | ✓ |
| City University London | ✓ | ✓ | ✓ |
| Coventry University | ✓ | ✓ | ✓ |
| Cranfield University | ✓ | ✓ | ✓ |
| De Montfort University | ✓ | ✓ | ✓ |
| Durham University | ✓ | ✓ | ✓ |
| Edge Hill University | ✓ | ✓ | ✓ |
| Falmouth University | ✓ | ✓ | ✓ |
| Goldsmiths, University of London | ✓ | ✓ | ✓ |
| Grimsby Institute of Higher Education | ✓ | - | - |
| Guildhall School of Music and Drama | ✓ | ✓ | ✓ |
| Harper Adams University | ✓ | ✓ | ✓ |
| Heythrop College, University of London | ✓ | ✓ | ✓ |
| Hull College | ✓ | - | - |
| ifs University College | ✓ | - | - |
| Imperial College London | ✓ | ✓ | ✓ |
| Institute of Education, University of London | ✓ | - | - |
| Keele University | ✓ | ✓ | ✓ |
| King's College London | ✓ | ✓ | ✓ |
| Kingston University | ✓ | ✓ | ✓ |
| Lancaster University | ✓ | ✓ | ✓ |
| Leeds Beckett University | ✓ | ✓ | ✓ |
| Leeds Trinity University | ✓ | ✓ | ✓ |
| Liverpool Hope University | ✓ | ✓ | ✓ |
| Liverpool John Moores University | ✓ | ✓ | ✓ |

| Recognised bodies by country | GOV.UK (2016b, last updated 09.06.16) | Thesis Table 5-1 (HESA, 2016) | Thesis Figure 5-2 (HESA, 2016) |
|---|---|---|---|
| London Business School | ✓ | ✓ | ✓ |
| London Metropolitan University | ✓ | ✓ | ✓ |
| London School of Economics and Political Science, The | ✓ | ✓ | ✓ |
| London School of Hygiene and Tropical Medicine | ✓ | ✓ | ✓ |
| London South Bank University | ✓ | ✓ | ✓ |
| Loughborough University | ✓ | ✓ | ✓ |
| Manchester Metropolitan University | ✓ | ✓ | ✓ |
| Middlesex University | ✓ | ✓ | ✓ |
| New College Durham | ✓ | - | - |
| Newcastle College | ✓ | - | - |
| Newcastle University | ✓ | ✓ | ✓ |
| Newman University, Birmingham | ✓ | ✓ | ✓ |
| Northumbria University Newcastle | ✓ | ✓ | ✓ |
| Norwich University of the Arts | ✓ | ✓ | ✓ |
| Nottingham Trent University | ✓ | ✓ | ✓ |
| Open University, The | ✓ | ✓ | ✓ |
| Oxford Brookes University | ✓ | ✓ | ✓ |
| Plymouth University | ✓ | ✓ | ✓ |
| Queen Mary, University of London | ✓ | ✓ | ✓ |
| Regent's University London | ✓ | - | - |
| Royal Academy of Music | ✓ | ✓ | ✓ |
| Royal Agricultural University | ✓ | ✓ | ✓ |
| Royal Central School of Speech and Drama, University of London | ✓ | ✓ | ✓ |
| Royal College of Art | ✓ | ✓ | ✓ |
| Royal College of Music | ✓ | ✓ | ✓ |
| Royal College of Nursing | ✓ | - | - |
| Royal Holloway, University of London | ✓ | - | - |
| Royal Northern College of Music | ✓ | ✓ | ✓ |
| Royal Veterinary College, The | ✓ | ✓ | ✓ |
| School of Oriental and African Studies, University of London | ✓ | ✓ | ✓ |
| Sheffield Hallam University | ✓ | ✓ | ✓ |
| Southampton Solent University | ✓ | ✓ | ✓ |
| St George's, University of London | ✓ | ✓ | ✓ |
| St Mary's University, Twickenham | ✓ | ✓ | ✓ |
| Staffordshire University | ✓ | ✓ | ✓ |
| Teesside University | ✓ | ✓ | ✓ |
| Trinity Laban Conservatoire of Music and Dance | ✓ | ✓ | ✓ |
| University Campus Suffolk | ✓ | ✓ | ✓ |
| University College Birmingham | ✓ | ✓ | ✓ |
| University College London | ✓ | ✓ | ✓ |
| University College of Estate Management | ✓ | - | - |
| University for the Creative Arts | ✓ | ✓ | ✓ |
| University of Bath | ✓ | ✓ | ✓ |
| University of Bedfordshire | ✓ | ✓ | ✓ |
| University of Birmingham | ✓ | ✓ | ✓ |
| University of Bolton | ✓ | ✓ | ✓ |
| University of Bradford | ✓ | ✓ | ✓ |

| Recognised bodies by country | GOV.UK (2016b, last updated 09.06.16) | Thesis Table 5-1 (HESA, 2016) | Thesis Figure 5-2 (HESA, 2016) |
|---|---|---|---|
| University of Brighton | ✓ | ✓ | ✓ |
| University of Bristol | ✓ | ✓ | ✓ |
| University of Buckingham | ✓ | - | - |
| University of Cambridge | ✓ | ✓ | ✓ |
| University of Central Lancashire | ✓ | ✓ | ✓ |
| University of Chester | ✓ | ✓ | ✓ |
| University of Chichester | ✓ | ✓ | ✓ |
| University of Cumbria | ✓ | ✓ | ✓ |
| University of Derby | ✓ | ✓ | ✓ |
| University of East Anglia | ✓ | ✓ | ✓ |
| University of East London | ✓ | ✓ | ✓ |
| University of Essex | ✓ | ✓ | ✓ |
| University of Exeter | ✓ | ✓ | ✓ |
| University of Gloucestershire | ✓ | ✓ | ✓ |
| University of Greenwich | ✓ | ✓ | ✓ |
| University of Hertfordshire | ✓ | ✓ | ✓ |
| University of Huddersfield | ✓ | ✓ | ✓ |
| University of Hull | ✓ | ✓ | ✓ |
| University of Kent | ✓ | ✓ | ✓ |
| University of Law, The | ✓ | - | - |
| University of Leeds | ✓ | ✓ | ✓ |
| University of Leicester | ✓ | ✓ | ✓ |
| University of Lincoln | ✓ | ✓ | ✓ |
| University of Liverpool | ✓ | ✓ | ✓ |
| University of London | ✓ | ✓ | ✓ |
| University of Manchester | ✓ | ✓ | ✓ |
| University of Northampton, The | ✓ | ✓ | ✓ |
| University of Nottingham | ✓ | ✓ | ✓ |
| University of Oxford | ✓ | ✓ | ✓ |
| University of Portsmouth | ✓ | ✓ | ✓ |
| University of Reading | ✓ | ✓ | ✓ |
| University of Roehampton | ✓ | ✓ | ✓ |
| University of Salford | ✓ | ✓ | ✓ |
| University of Sheffield | ✓ | ✓ | ✓ |
| University of Southampton | ✓ | ✓ | ✓ |
| University of St Mark and St John, Plymouth | ✓ | ✓ | ✓ |
| University of Sunderland | ✓ | ✓ | ✓ |
| University of Surrey | ✓ | ✓ | ✓ |
| University of Sussex | ✓ | ✓ | ✓ |
| University of the Arts, London | ✓ | ✓ | ✓ |
| University of the West of England, Bristol | ✓ | ✓ | ✓ |
| University of Warwick | ✓ | ✓ | ✓ |
| University of West London | ✓ | ✓ | ✓ |
| University of Westminster | ✓ | ✓ | ✓ |
| University of Winchester, The | ✓ | ✓ | ✓ |
| University of Wolverhampton | ✓ | ✓ | ✓ |
| University of Worcester | ✓ | ✓ | ✓ |
| University of York | ✓ | ✓ | ✓ |
| Warwickshire College | ✓ | - | - |

| Recognised bodies by country | GOV.UK (2016b, last updated 09.06.16) | Thesis Table 5-1 (HESA, 2016) | Thesis Figure 5-2 (HESA, 2016) |
|---|---|---|---|
| Writtle College | ✓ | ✓ | ✓ |
| York St John University | ✓ | ✓ | ✓ |
| **Wales** | | | |
| Aberystwyth University | ✓ | ✓ | ✓ |
| Bangor University | ✓ | ✓ | ✓ |
| Cardiff Metropolitan University | ✓ | ✓ | ✓ |
| Cardiff University | ✓ | ✓ | ✓ |
| Glyndŵr University | ✓ | ✓ | ✓ |
| Swansea University | ✓ | ✓ | ✓ |
| University of South Wales | ✓ | ✓ | ✓ |
| University of Wales | ✓ | - | - |
| University of Wales Trinity Saint David | ✓ | ✓ | ✓ |
| **Scotland** | | | |
| Abertay University | ✓ | ✓ | ✓ |
| Edinburgh Napier University | ✓ | ✓ | ✓ |
| Glasgow Caledonian University | ✓ | ✓ | ✓ |
| Heriot-Watt University | ✓ | ✓ | ✓ |
| Queen Margaret University, Edinburgh | ✓ | ✓ | ✓ |
| Robert Gordon University, Aberdeen | ✓ | ✓ | ✓ |
| Royal Conservatoire of Scotland | ✓ | - | - |
| University of Aberdeen | ✓ | ✓ | ✓ |
| University of Dundee | ✓ | ✓ | ✓ |
| University of Edinburgh, The | ✓ | ✓ | ✓ |
| University of Glasgow | ✓ | ✓ | ✓ |
| University of St Andrews | ✓ | ✓ | ✓ |
| University of Stirling | ✓ | ✓ | ✓ |
| University of Strathclyde | ✓ | ✓ | ✓ |
| University of the Highlands and Islands | ✓ | ✓ | ✓ |
| University of the West of Scotland | ✓ | ✓ | ✓ |
| **Northern Ireland** | | | |
| Queen's University Belfast | ✓ | ✓ | ✓ |
| University of Ulster | ✓ | ✓ | ✓ |

# Appendix I

Table 9-8 Summarised responses to semi-structured interview questions 4, 5, and 7-9 (see Section 4.2.2 regarding responses to questions 1-3 and 6)

| Interviewee reference | Q4: What role have you played in the decision-making for façades? | Q5: Who else has influenced these façade decisions? | Q7: Can you tell me more about how these façade decisions came about? | Q8: What do you see as the problems in façade decision-making? | Q9: How do you think these problems could be addressed? |
|---|---|---|---|---|---|
| SS1 | Helping designers to make cladding decisions | Coalition of designers, including specialist cladding contractors | Determining cladding solution provider and securing transfer of design risk to specialist cladding contractor are key; also vital to the programme are cladding design, testing, and manufacture | Lack of choice in cladding providers, though most are excellent; small projects may only have access to bespoke solutions; cladding system performance testing is key | Entire design team to recognise significance of the façade to the success of a building; testing; prototyping; collaborative working as early as possible |
| SS2 | Designer/lead architect up to planning stage - discussing design options with colleagues; presenting options within the wider design team, including project manager, client, advisors | Façade mock-up discussed in combination with the client, contractor, and planner, to decide on façade design details | Façade selection is a team process; the architect makes most recommendations, with influence from others | Client not paying for a full consultant team pre-planning can lead to cost problems later in a project, often resulting in need for VE; D&B contracts may lead to loss of quality in façades | The Client to pay more fees initially to appoint a full consultant team at an early project stage, e.g. 40% of fees up to the planning stage, 40% up to tender, and 20% on site |
| SS3 | Cladding evaluation and selection for buildings within employers property portfolio | In-house project team, including building surveyors, energy manager, and financial manager, plus externally sourced project quantity surveyors | Cladding is a good answer to well maintained, but inefficient and unattractive old buildings | Priorities can differ in construction, e.g. energy efficiency, aesthetics, and construction quality can rank differently in importance according to industry function | Collaboration; procuring outside expertise if resources do not exist in-house for making an informed decision; paying fees up front to make the right decision, rewarded by payback |
| SS4 | Project Manager or Client's Representative – evaluating the required cladding performance against the cladding options and costs presented by the design team (architect, services) | The development appraisal examines the investment value, which impacts on façade choice; architects work with cladding contractors; planners decide what façade types are permitted | Determining how cladding options effect the net-floor area, e.g. façade systems opening inwardly for cleaning, plant requirements for externally cleaned and maintained façades | Façade problems changing over time, e.g. stick systems leaking from site applied mastic; deep mullions having glass in shade and heat; dirt build up in drained façades; nickel sulphide inclusion | Façade providers are addressing façade problems all the time |
| SS5 | Managing the design process, in terms of having involvement from the start, so as to advise the client by commenting on façade options from practical and aesthetic viewpoint | The whole design team, e.g. the façade engineer may suggest something the architect says cannot work for x reason; the façade design is a team effort as with other building elements | The Project Manager is usually involved quite early in a project, however, sometimes you come in later and then must review the scheme devised by the previous project manager | Costs too high due to architect ambition leading to VE, particularly if a building is large; seemingly suitable façades not wearing well and looking poor after just a few years | Façade design should involve a checklist; design workshops dedicated to the façade; and/or be treated as its own project, as the façade has such a great effect on the rest of the building |

| Interviewee reference | Q4: What role have you played in the decision-making for façades? | Q5: Who else has influenced these façade decisions? | Q7: Can you tell me more about how these façade decisions came about? | Q8: What do you see as the problems in façade decision-making? | Q9: How do you think these problems could be addressed? |
|---|---|---|---|---|---|
| SS6 | Not a great deal; façade decisions at pre-construction phase are generally led by architects, specifiers, and cladding experts, in liaison with planning and building control | Cladding and insulation manufacturers and installation teams; planning officers, urban developers, and English Heritage, depending on the area in which the building is located | Public consultation involving, e.g. the building users/tenants, nearby building occupants, local industry professionals, and the general public may impact on the façade decision | Environmental pressures are putting pressure on component manufacturers, and ultimately the client, who has to pay for the façade solution; aesthetics having to correspond with trends | Technology, leading to an evolution in façade products and material choices available, especially in regards to renewables |
| SS7 | Involvement after RIBA Stage D, by which point façade decisions have already been made by the architect in early project stages | Façade engineers, planners, structural engineers, suppliers | Cost is a key factor; structural stability; planning compliance, building control compliance; buildability; required design life | Façade solution cost to the client; acceptability of façade solution to planning, in terms of appearance in its surroundings | Talking, communicating, finding out the building's actual purpose and required design life |
| SS8 | A secondary role, trying to influence the insulation after the architect had already chosen the façade based on the building's form and function | The architect generally makes the façade choice; or in cases of D&B contracting, the contractor would procure the façade based on the performance brief | Façade choices, mainly driven by cost, are made by the architect; with computer analysis and simulation used to try and influence the material choices | Façade choice led by aesthetics rather than function; poor design details, e.g. seals, panel sizing; insufficiently supervised and/or poor quality installation | They are being addressed by tightening building regulations, which is leading to better insulation values and increased air tightness |
| SS9 | Promoting façade materials to the construction industry, e.g. on the grounds of aesthetics and eco-values, to encourage them to be specified by architects | Façade decisions are sometimes aesthetics driven; architects play a key role in façade decisions, while contractors try to influence to reduce cost; planners have final say in the façade decision | As a supplier of cladding materials, it is important to target architects and contractors to find out what work they are doing and to help guide the façade decision-making | Planning is the biggest problem architects and contractors face, as a new façade is generally required to suit the typical materials for the area in which the building project is located | It is understandable that planning serves to keep certain styles in certain areas, but it would be helpful if the length of time required for the planning process could be reduced |
| SS10 | Involvement in examining the potential operating cost savings to be derived by the use of a certain façade on buildings in employers property portfolio | Consultants, project managers; the business case; cost benefits analysis | - | Aesthetics, in the sense that building aesthetics is a driver for the covering up of 'ugly' concrete panel buildings which should perhaps instead be listed | Justifying the façade choice, for example, not just on grounds of energy cost savings, but also the safety resulting from stabilising a crumbling existing facade |
| SS11 | Compliance with building regulations | Quantity surveyors regarding the cost of the façade and planning officers regarding whether it is allowed to be done | Façade decisions generally equally driven by cost and planning; and guided by building regulations Part C and British Standards for wind-driven lift | Planners lacking knowledge of the durability of materials and an understanding of the building design purpose, which can lead façade designs to be rejected | Better training, including increasing understanding of the durability of materials and crucial craftsmanship skills, e.g. façade sealing, air leakage |
| SS12 | Involvement after the client has decided on the façade solution type, which while relating to VE does not aim for any massive changes that may cause delays | Ultimately the client, from the concept stage and the design period with the architect | The main driver is cost, as the whole build has to be cost effective, but the façade also has to look nice and the planners have to accept it | Maintenance, as to how easy it is to maintain, and buildability, regarding the detailing of joints where two or more façade types on a building have to meet up | Pay the necessary fees for good design work that produces buildings that stand the test of time |

| Interviewee reference | Q4: What role have you played in the decision-making for façades? | Q5: Who else has influenced these façade decisions? | Q7: Can you tell me more about how these façade decisions came about? | Q8: What do you see as the problems in façade decision-making? | Q9: How do you think these problems could be addressed? |
|---|---|---|---|---|---|
| SS13 | A key façade solution is offered [by the interviewee's company], thus there is no decision-making in the sense of what style of façade or façade materials are to be used | The [interviewee's] company's Managing Director and Pre-Contract Development Director discuss what is the best façade solution with potential clients | Tender requirements are put out, for which a façade solution is proposed together with the benefits of such a solution | Façade decision-making needs to be holistic, problems involve lack of thought as to how a cladding solution is going to be delivered; not including cladding specialist early enough in project | Involve cladding specialist early in project before detailed design works to determine the cladding solution, its delivery mode, that it meets performance standards, and that it is warrantable |
| SS14 | Minimal overall; had involvement in timber cladding on a commercial building | Client had ultimate cost sign off; planning involved at design stage in regards to aesthetics | Timber façade trying to fit in with look of surrounding area; cost versus aesthetics | Making sure the façade works – buildability; detailing for extreme weather, changes from heat/cold | Ventilation to prevent interstitial condensation |
| SS15 | Choosing materials - taking into account constraints such as the building's end-value (value per sq/ft) which impacts on façade budget, and façade performance in relation to UK weather | Client; professional client (develops buildings for profit), quantity surveyor; façade engineer when high specification facades are selected for use on a building | - | Constraints, rather than problems, exist in relation to cost and performance, e.g. preventing over-heating, use of intelligent façades | More use of façade specialists; more intelligent use of materials, not just intelligent façades, but also being aware of the interaction between materials |
| SS16 | Very little - façade decision-making is predominantly architect-led, with client making final decision; though in project manager role has involvement in creating the ER document | Consultants/advisors; planners have a big say through the planning process; consultation process | Façade selection influenced by Government funding, e.g. goal to meet certain BREEAM and Code for Sustainable Homes; U-values; $CO_2$ emission target exceeding building regulations | Approval by planning not really a problem, seen more as a challenge; ease of end-user's use/maintenance of the building needs to be taken into account | Making the façade fit for purpose; attaining warrantees and guarantees to ensure no latent defects; BREEAM credits for stakeholder end-user involvement in the project |
| SS17 | Involvement in cost-control role, producing feasibility estimate during feasibility stage, so if the budget is finite, the client has awareness while the architect comes up with the scheme | Planners – the scheme has got to be in keeping or acceptable if it is in a conservation area; buildability – location of site access, CDM-C, site staff; form of construction can dictate finish | Buildability and maintenance are key | Potential conflicts between cost, appearance, performance, ease of construction, maintenance (in no particular order); weighting on decision, e.g. long lasting cladding versus painted render | Collaboration |
| SS18 | Quantity surveying role, so cost-related; architect plays key role in specification of façade | Architect, structural engineers, contractor, influence on steel times and buildability, quality standards | Quantity surveyor can influence change, e.g. a 10% reduction is significant on a large building; feedback to architects using query sheets | Generally no problems exist, just design solutions - time factor, cost factor, maintenance, going back to structural engineering | 3D modelling – plan all buildings around it and you can predict wind movement; whole life cycle costing |

| Interviewee reference | Q4: What role have you played in the decision-making for façades? | Q5: Who else has influenced these façade decisions? | Q7: Can you tell me more about how these façade decisions came about? | Q8: What do you see as the problems in façade decision-making? | Q9: How do you think these problems could be addressed? |
|---|---|---|---|---|---|
| SS19 | English Heritage generally make decisions on Grade I buildings; some changes allowed on Grade II buildings; planning can help to persuade English Heritage | Architect; ideas from the development aspect of the property from the owners of the company | - | Maintenance; scheduled monuments, and Grade I and Grade II listed buildings; necessary building skills dying out/craftsman leaving profession | Training and apprenticeships to ensure availability of necessary building skills |
| SS20 | Virtually none; architects play key role in façade selection | Client; planners; cost always has a massive impact | Client aspiration is often compromised on grounds of cost; current trends are cedar cladding, glass, curved edges | Costs underestimated at outline design stage regarding structure - difficult to attach cladding to masonry; brick needs secondary fix for façade components; | Quantity surveying need better façade knowledge as to fixings and the work involved in fixing; too much dependency on Black Book; frame quicker for façades |
| SS21 | Not a massive part in façade and materials, main involvement is in detailing and technical delivery | - | Everyone in the design team involved in a project has an influence; architects have big influence; quantity surveyors produce costs | Clients not having budget to pay for capital cost; increased cost of core materials, e.g. copper; planning rules not transparent, pre-planning application required | More freedom in terms of the planning system; increased budget; offsite modular construction |
| SS22 | Involved in key client team (quantity surveyor, client's project manager), helping to develop the project and material palette for the building | Client; architect; planners; the facilities management role has the maintenance burden, however, only included if client makes team really inclusive | Cost versus performance; client sometimes puts aesthetics as top priority | Variety of systems and products leads to infinite choice and selection, it can be difficult to understand the options | Use people's experience as to what they are comfortable with; weights/parameters for decision-making; whole life cycle costs by project quantity surveyor |
| SS23 | Spatial input | Quantity surveyors, structural engineers | - | Not enough joined up thinking, professions involved in façade selection not understanding why materials have been chosen | Open and collaborative working |
| SS24 | Supply a wide range of façade materials directly to installers and main constructors specifying to architects | Main constructor, for purely cost-related purposes; client | Money dictating decisions | Specifications can be broken too easily, e.g. contracts awarded though having been under-priced by the main contractor | Don't know – JCT? |
| SS25 | Limited – it would be a conflict of interest for building control to design and approve; advising on the suitability of insulation | Building structure and materials have a big influence; consulting structural engineers; mechanical and electrical engineers (thermal models) contractors; programme | - | Decisions based on grounds of cost affecting the suitability of selected materials; lack of holistic thinking between the designer and structural engineer | Better co-ordination between the parties involved in the design; architects having more involvement from building control |

| Interviewee reference | Q4: What role have you played in the decision-making for façades? | Q5: Who else has influenced these façade decisions? | Q7: Can you tell me more about how these façade decisions came about? | Q8: What do you see as the problems in façade decision-making? | Q9: How do you think these problems could be addressed? |
|---|---|---|---|---|---|
| SS26 | Involved in design, engaging architect | Architect, who needs to keep budget and client expectations in mind; client; planners are not the key influence, but they have considerable influence | Façade designed to complement nearby properties and form an aesthetic link to satisfy planners; planning policy used to justify building size; sympathetic approach with the surroundings | Planners can be reticent to accept new technology; features added to a façade are often disproportionate as to what the building is worth in return | Architects and designers need to be more responsive to what the client wants, rather than creating a scheme with planning policy and planning preferences in mind |
| SS27 | Varies depending on which project stage involvement begins – if involved from the brief, the early involvement sees finances balanced with a bid the client likes; guiding architect on cost | Client; design team/architect; whoever is controlling the money, e.g. cost consultant (on the client side); planning officers giving advice on designs to avoid having to re-submit application | Steel frame is quick to erect and quick to clad; programme is key to what goes behind the façade; competing needs require justified priorities; liquidated and ascertained damages | Identifying what is important to those procuring the project; upgrades requested during project progression; multiple stakeholders | No real way to solve problems mentioned; parties come to a project with hang-ups from previous projects; politics sway decision-making; visible nature of façades make them emotive |
| SS28 | Costing out architects' ideas at feasibility stage, including looking at the construction of particularly different schemes, suggesting alternatives, rationalising structure if possible, keeping public funding in mind | Architect influences decisions about as much as the client; mechanical and electrical engineer involved to assess thermal performance and minimise thermal gain | - | Client not having the budget to afford what they want; climate limiting material choice and how materials are fixed, e.g. steel fixings need to be a certain grade in a marine environment; planning can be a problem in terms of what they let you do | Managing client aspirations (not just façade, may apply to every part of a building); suppliers to improve ease of finding information relating to product performance in exposed conditions; planning guides per town need to be easier to find |
| SS29 | Involved in early design stage, advising on cost, so a valued façade decision can be made, e.g. what cladding best suits building frame and achieves required U-values | Architect; planning/conservation officer (a project may have a client's appointed planning consultant); engineer in early feasibility regarding structure; client; external key stakeholders, e.g. local residents | At design team meetings, the design team present ideas that are then costed by the quantity surveyors for discussion at next meeting; reporting the difference between capital and whole life costs | Issues that have to be dealt with are planning/conservation; the use of the building; the required performance from the building; cost is not really considered a problem if you have a budget as it is known what can be afforded | To change building parameters, either more money can be put in to the budget or moved from another sector of the budget; the building system can be changed to take performance away from the façade |
| SS30 | Working to building regulations' required walls U-value guides façade material selection; also structural stability in relation to proposed cladding weight and inclusion of high impact layer at low level for damage limitation | Local authority planners; main contractors (when they get involved, their aim is to change things for cost efficiency purposes); quantity surveyors; consultants | While local authority planners may comment on a building scheme with poor thermal performance and poor aesthetics, it is the former that would trigger the need for work | Architect and local authority may research how to maintain a building's longevity, then the contractor changes elements for a more cost effective alternative, e.g. pull out tests may be omitted from a cheaper façade | Greater control by the specifier (architect, consultant – in conjunction with the architect, local authority); clerk of works to supervise work on site; system suppliers' guarantees |

# Appendix J

## Sources of documentary evidence reviewed for the thesis' case studies

Table 9-9 Documentary evidence reviewed for the thesis' case studies

| Source of documentary evidence | Exploratory case | Exemplifying case studies | | | |
|---|---|---|---|---|---|
| | | A1 | B1 | B2 | C1 |
| | Commercial office | Office and laboratory | Music | Office and music | Arts and media |
| *Relating to the completed retrofitted building* | | | | | |
| Post-retrofit building brochure | ✓ | - | ✓ | - | ✓ |
| Building details on case study company website | ✓ | ✓ | ✓ | ✓ | ✓ |
| Project details on architects practice website | ✓ | ✓ | - | ✓ | ✓ |
| Article/s in press | ✓ | - | ✓ | ✓ | ✓ |
| PowerPoint slides from building presentation | - | - | - | ✓ | ✓ |
| Post-retrofit BREEAM rating | - | ✓ | ✓ | - | - |
| Post-retrofit EPC | ✓ | - | ✓ | ✓ | - |
| Post-retrofit DEC | - | ✓ | ✓ | ✓ | ✓ |
| Post-retrofit building photos | ✓ | ✓ | ✓ | ✓ | ✓ |
| As built floor plan drawings | ✓ | ✓ | - | - | - |
| As built elevation drawings | ✓ | - | - | ✓ | ✓ |
| As built section drawings | ✓ | - | - | - | - |
| Operations and Maintenance manual | - | ✓ | - | - | ✓ |
| As built 'wall' U-values | ✓ | - | - | - | - |
| *Relating to the buildings' retrofit project* | | | | | |
| Article in press | ✓ | - | - | - | ✓ |
| Site plan | - | ✓ | ✓ | ✓ | ✓ |
| Proposed floor plan drawings | ✓ | ✓ | ✓ | ✓ | - |
| Proposed elevation drawings | ✓ | ✓ | ✓ | ✓ | ✓ |
| Proposed section drawings | ✓ | - | ✓ | ✓ | ✓ |
| Employer's Requirements | ✓ | - | ✓ | - | ✓ |
| Tender issue | ✓ | - | ✓ | ✓ | ✓ |
| Contractors proposals | ✓ | - | ✓ | - | - |
| Tender return | - | - | - | - | ✓ |
| Planning application documents | ✓ | ✓ | ✓ | ✓ | ✓ |
| Building Control documents | - | ✓ | - | - | ✓ |
| Risk assessment | - | ✓ | - | - | - |
| Cleaning and maintenance statement | - | ✓ | | - | - |
| Stage C report | - | - | - | ✓ | - |
| Stage D report | - | ✓ | - | ✓ | - |
| Cladding options estimates | - | - | - | ✓ | - |
| Stakeholder group feedback on cladding options | - | - | - | ✓ | - |
| Window specification | - | - | ✓ | - | - |
| Contractor's monthly report | - | - | - | - | ✓ |
| Time lapse video | - | - | - | - | ✓ |
| *Relating to the existing building* | | | | | |
| Pre-retrofit EPC | ✓ | - | - | - | - |
| Pre-retrofit DEC | - | ✓ | ✓ | ✓ | ✓ |
| Pre-retrofit building photos | ✓ | ✓ | ✓ | ✓ | ✓ |
| Existing floor plan drawings | - | - | - | - | ✓ |
| Existing section drawings | - | - | ✓ | ✓ | - |
| Existing elevation drawings | - | - | ✓ | ✓ | ✓ |
| Pre-retrofit thermographic survey | - | - | - | ✓ | - |
| Asbestos survey report | - | - | - | - | ✓ |
| Measured survey | - | - | - | - | ✓ |
| Existing 'wall' U-values | ✓ | - | - | - | - |

# Appendix K

### Bound-in publication – ARCOM 2012 conference paper

Garmston, H., Pan, W. and de Wilde, P. (2012) 'Decision-making in façade selection for multi-storey buildings'. In: Smith, S. D. (Ed) *Procs 28th Annual Association of Researchers in Construction Management Conference.* Edinburgh, 3-5 September. Association of Researchers in Construction Management, 357-367.

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# DECISION-MAKING IN FAÇADE SELECTION FOR MULTI-STOREY BUILDINGS

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The design and construction of multi-storey buildings faces a multitude of demands such as aesthetics, cost, energy efficiency, and occupier comfort; with façades on both new and re-used buildings playing a key role in helping to meet these demands. The process of façade selection is aided by a plethora of decision-making tools, yet façade decisions are often largely guided by cost and aesthetics. Poorly specified façades can potentially expose developers, owners and occupiers of multi-storey buildings to risks such as poor thermal comfort, glare, and increased operational costs. The aim of this paper is to explore the current state of façade decision-making, with the objectives of discovering who is making the decisions and when, and what problems are perceived and what potential solutions might exist. Literature pertaining to façades, multi-storey buildings and façade decision-making is reviewed. Experience of façade decision-making in today's construction industry in the UK is collected via semi-structured interviews with construction professionals. The findings show architects as leading the initial façade decisions, with clients and planners making the final decisions. Very few decision-making tools were revealed as being used: namely whole life cost analysis, life cycle cost analysis and simulation. Further research is proposed to define the roles participating in façade decision-making for multi-storey buildings.

Keywords: building façade, decision-making, multi-storey building.

## INTRODUCTION

This paper presents the initial findings of an exploratory study, conducted at the start of a larger research project that aims to provide decision support to the construction industry in the selection of façades for multi-storey buildings. The building façade is an outward facing component that has developed from being essentially protective, i.e. to shelter man from the elements, to playing also a key role in the architectural expression of buildings (Schittich 2006). In current building practice, façade selection appears to be largely driven by cost considerations and building aesthetics (Høseggen *et al.* 2008; Săparauskas *et al.* 2011). However, given the many demands on buildings, this approach can expose businesses and building occupants to risk. Buildings have to meet increasingly stringent requirements in terms of reducing carbon emissions, enabling high comfort and productivity of occupants, while also providing good return on investment; these requirements exist throughout the new and re-used life of a

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building. Meeting these requirements together is a complex task. People spend around 90% of their time indoors (BRE 2011) engaged in varying activities and in varying locales, meaning that buildings need to respond dynamically to changes in occupation and environmental load (Wigginton and Harris 2002). While façades exist on all buildings, this paper focuses only on multi-storey buildings, for which the term 'multi-storey' is used to denote any building containing two or more storeys above ground level. The focus on multi-storey buildings, as opposed to single storey buildings, is because of their increasing prominence due to the global trend towards urbanisation (Wang *et al.* 2012; Tang and Yiu 2010). Façade decision-making involves multiple participants, including: "client, design team, main contractor, specialist sub-contractors, and manufacturers" (Du and Ledbetter 2006: 1). Reaching a consensus in multidisciplinary teams can be very difficult (Šaparauskas *et al.* 2011), yet literature relating to façade decision-making appears to pertain more to building simulation (Høseggen *et al.* 2008; Stec *et al.* 2005) or multi-criteria analysis (Šaparauskas *et al.* 2011), as opposed to investigating the human element. Where it does focus on participants in decision-making in design and construction, much of its focus is on the architect (Emmitt and Heaton 2003; Luck and McDonnell 2005). This paper aims to help address this gap in the knowledge by providing an insight into façade decision-making in today's construction industry. The objectives of this paper are to:

1. Establish who makes façade decisions for multi-storey buildings, and when;
2. Identify the problems perceived with façade decision-making;
3. Explore the potential solutions to the problems in façade decision-making.

## BUILDING FAÇADES

The façade is an outward facing building component that has developed from being essentially protective, i.e. to shelter man from the elements, to playing also a key role in the architectural expression of buildings (Schittich 2006). It is further defined by BS6100-1:2004 (BSI 2004: 33) as being the exterior surface of a wall enclosing a building, which is usually non-loadbearing, and which can include a curtain wall, cladding or some other exterior finish. Façades often have protective or insulating cladding attached to them, with the cladding sector accounting for a substantial proportion of UK external wall construction (Doran and Anderson 2011: 1).

Buildings have to meet increasingly stringent requirements in terms of reducing carbon emissions, enabling high comfort and productivity of occupants, while also providing a good return on investment. Du and Ledbetter (2006: 1) succinctly describe the part that façades can play in helping to meet these requirements, showing clearly the multi-factorial contribution that just one element must make in helping to meet the overall demands placed on a building (Figure 1). These demands differ according to world view of an observer. From an occupiers view point, warmth and air quality are highly important (Humphreys 2005), as is user control (Stevens 2001). When architects, designers and builders consider the needs of building users at an early stage, it can lead to improved comfort, energy efficiency, and health and safety in buildings (Săparauskas *et al.* 2011). However, certain aspects of building performance can sometimes be reprioritised in the face of other drivers. The building client wants a good return on investment; therefore, as the façade can account for up to 25% (Layzell and Ledbetter 1998: 351) and sometimes even up to 40% of a total building's cost (Hall, 1997, in Wigginton and Harris 2002: 5), façade selection can often result in being cost-driven (Høseggen *et al.* 2008; Rosenfeld and Shohet 1999).

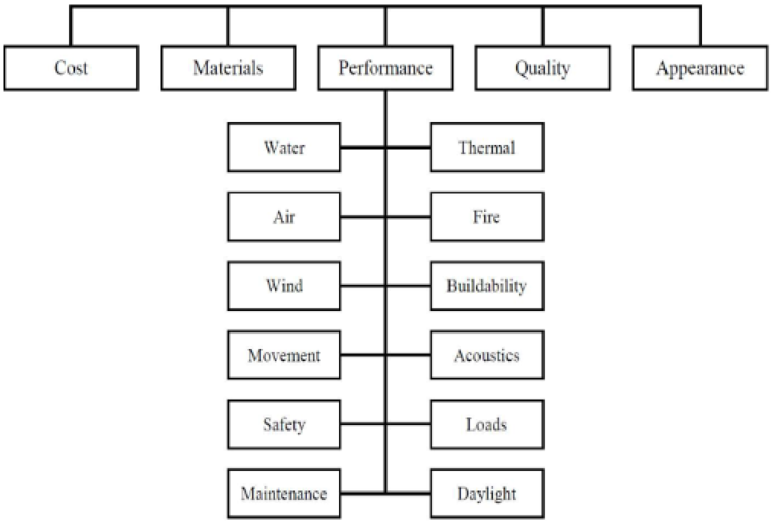


*Figure 1: The ingredients of cladding design (reproduced from Du and Ledbetter 2006: 1)*

## FAÇADES ON MULTI-STOREY BUILDINGS

Multi-storey buildings are required to meet certain statutory drivers, such as building regulations, of which many also apply to single-storey buildings. However, due to the potential height of multi-storey buildings, these statutory drivers often contain stricter elements solely for use on multi-storey buildings. For example, a proposed new dwelling building that is over 18m in height and located in England and Wales, may need to supplement the fire safety requirements of 'Approved Document (AD) B - Volume 1 - Dwellinghouses', with some of the guidance contained in 'AD B - Volume 2 - Buildings other than dwellinghouses'. Volume 2 states that "in a building with a storey 18m or more above ground level any insulation product, filler material (not including gaskets, sealants and similar) etc. used in the external wall construction should be of limited combustibility" (HM Government 2006: 94). The use of limited combustibility material is required "because of the increased risks associated with external flame spread on buildings of this size" and thus cladding must pass the testing criteria in British Standard 8414 in order to demonstrate compliance with AD B (Baker 2012). This requirement applies to façades on both new and re-used buildings, the latter of which is felt to be an under researched area, despite being a significant proportion of the European building stock (Zavadskas *et al.* 2008). Multi-storey buildings comprise thirteen per cent, and over one-third, of the existing building stock, in the old EU member states, and in the new Central and Eastern European member states, respectively; the majority of which has poor structural and thermal quality (Zavadskas *et al.* 2008). Furthermore, as "it is estimated that by 2050 two thirds of the UK's housing stock will be made up of dwellings built before 2006" (Business Link 2011), the refurbishment of existing high-rise (EST 2006) residential buildings is seen as a necessary part of improving the energy efficiency of the UK housing stock.

## BUILDING FAÇADE DECISION-MAKING

Numerous methods exist that can aid façade decision-making. These include multi-criteria analysis (Šaparauskas *et al.* 2011); building simulation (Høseggen *et al.* 2008; Stec *et al.* 2005); life cycle analysis (Radhi 2010); and bespoke façade selection software (Chartered Institution of Building Services Engineers (CIBSE) Façade Selector (CIBSE 2004); Environmental façade design tool (Robinson-Gayle and Tanno 2004)). Despite using such tools, decisions are shown in the literature as sometimes being 'disadvantageously' over-turned by human intervention in the final stage. This is demonstrated in Høseggen *et al.* (2008) where the most environmental façade option (derived using building energy simulation ESR-r) was not selected on grounds of cost; and in Rosenfeld and Shohet (1999: 510) when after conducting a building refurbishment exercise (using semi-automated selection), it was declared that "if the budget is really tight, the decision-makers may decide consciously to choose alternative #2, which requires the lowest initial investment despite its short life (5 years), poor service, high equivalent annual cost, and high uncertainty". Reaching a consensus in a multidisciplinary team is known to be very difficult (Šaparauskas *et al.* 2011). Where the literature focuses on the participants involved in decision-making in design and construction (as opposed to the decision-making aids) much of the research appears to focus on the architect, e.g. Emmitt and Heaton (2003) conducted an observational review of specifiers in the face of a new edition of Part L; while Luck and McDonnell (2005) investigated architect and user interactions. Research into the interaction that occurs between all participants involved in façade selection appears to be minimal, with perhaps the exception of Du and Ledbetter's (2006) research into decision-making in the cladding supply chain.

## METHODOLOGY

In order to produce robust results that are of benefit to the construction industry, this exploratory study is being used to discover the state of façade decision-making in today's construction industry in the UK (Davis 2006). The exploratory study uses semi-structured interviews, containing ten questions in two parts; the first part (questions 1-4) asks about the interviewees' role in construction, while the second part (questions 5-10) asks about the interviewees' experiences in façade decision-making. To determine when façade decisions are being made, one question asks at what stage of The Royal Institute of British Architects (RIBA) Outline Plan of Work the interviewees generally observed decisions as being made. The Outline Plan of Work is comprised of the following stages: A - Appraisal; B - Design Brief; C - Concept; D - Design Development; E - Technical Design; F - Product Information; G - Tender Documentation; H - Tender Action; J - Mobilisation; K - Construction to Practical Completion; and L - Post Practical Completion (RIBA 2009). Despite the varied construction roles being interviewed, the RIBA Outline Plan of Work was used, as it is "the most widely used model of building design" (Austin *et al.* 1999: 281).

Semi-structured interviews were adopted for the exploratory study, as it was deemed important to know the interviewees' opinions, as they could reveal aspects of the decision-making process that might benefit from further study (Bryman 2012). A semi-structured approach, also allowed the necessary "latitude to ask further questions in response to what are seen as significant replies" (Bryman 2012: 212). The interviews were mainly conducted face-to-face, but were also carried out as telephone interviews when this was more convenient for the interviewee. The interviews were recorded when permitted by the interviewee, or extensive notes taken, if recording was not permitted. All of the interview recordings were transcribed. The interview sample group was created with the purpose of capturing the opinions of construction professionals, who were deemed commonly involved in construction and thus, highly likely to be exposed to the intricacies of façade selection. The term 'construction professional' was used to denote that the interviewee was in receipt of some form of membership with one or more construction professional body, e.g. Chartered Institute of Building, Royal Institution of Chartered Surveyors. The construction professionals were categorised to ensure that all expected key areas concerning façade decision-making were captured. BS6100-1:2004 (BSI 2004: 74-75), which describes the persons involved in construction projects (user, operative, client, contractor, manufacturer, supplier, specifier, and consultant) was used to guide the interviewee categorization for this study. Further guidance was taken from Du and Ledbetter (2006: 1) who describe the participants in the cladding supply chain: "client, design team, main contractor, specialist sub-contractors, and manufacturers". The interviewees for this exploratory study are therefore grouped into six categories: client; design team; consultant; contractor; building control; and façade specialist and supplier. The method used to obtain the interviewees reflects purposive sampling (Robson 2011), as specific individuals were contacted and invited to participate in the study. The method also reflects an element of convenience, as some interviewees were already available to the researcher, while some further interviewees were proposed by interviewees taking part in the study. Convenience sampling is however, an acceptable method of sampling, when "getting a feeling for the issues involved" is the chief aim of the exploratory study (Robson 2011: 275), and this study's learnings should be of a suitable nature to guide the main study methodology for the larger study in question.

The semi-structured interviews, which were used to aid discovery in this exploratory study, resulted in a qualitative data set (Davis 2006), which was analysed by coding to a thematic framework. These findings were combined with the literature review to produce a rich picture of façade decision-making. The data set size is a limitation of this study. While theoretical saturation is stated in research methodology literature as being difficult to define (Bryman 2012; Robson 2011) it is however, unlikely that this sample group (itself split into six separate smaller groups) has reached saturation. Further exploratory work is proposed, ideally to the point that no new information is being added to the data set (Robson 2011), though as each building project is likely to be unique, the difficulty of this goal is recognised. A second limitation relates to the observations as to when façade decision-making occurs within the RIBA Outline Plan of Work. These observations are based on the interviewees' general building experience (so are not for specific buildings) and, therefore, while they can be considered as indicative, they cannot be used to draw definite conclusions as to the points at which decision-making might occur in a project. Future work could involve recording façade decisions for specific buildings throughout the project life. Despite its limitations, this study's findings are valid in their own right as they provide an insight into façade decision-making in today's construction industry, and thus, will aid in the generation of theory for the larger study in question (Davis 2006).

## RESULTS AND DISCUSSION

### Interviewee sample group information

Thirteen semi-structured interviews were conducted with personnel involved in façade selection, which were categorised by the following roles: client (2), design team (2), consultant (4), building control (1), contractor (2), and façade specialist and supplier

(2). Ten interviews were conducted face-to-face, while three were conducted by telephone. Eleven interviewees met this paper's definition of a 'construction professional'. The two interviewees within the 'façade specialist and supplier' category, which did not possess membership to a construction professional body, were however retained in this study's main data set, due to their clear role in the cladding supply chain (Du and Ledbetter 2006). The interviewees' experience related to buildings in the UK. The interviewees' general experience according to building type, height in metres (m) and number (no.) of storeys, is shown in Table 1.

*Table 1: Interview sample group experience: building type, height and number of storeys*

| Role | Position | Building type | Height (m) | Storeys (no.) |
|---|---|---|---|---|
| Client | Head of Estates Operations | C | ≤ 30 | 4-8 |
| Client | Energy and Environmental Manager | C | ≤ 30 | 4-8 |
| Design team | Chartered Architect | R | 5-8 | 2-3 |
| Design team | Senior Architectural Technologist | R&C | ≤ 100 | ≤ 23 |
| Consultant | Learning and Development Manager / Project Manager | C | ≥ 28 | ≥ 8 |
| Consultant | Chairman - Europe, Middle East and Africa | C | 75-100 | ≤ 26 |
| Consultant | Project Manager | R | ≤ 48 | 2-20 |
| Consultant | Regional Director | R&C | 9-12 | 3-4 |
| Building control | Principal Building Control Surveyor | R&C | ≤ 18 | 2-4 |
| Contractor | Director | R | 12 | 4 |
| Contractor | Senior Project Manager | R&C | ≤ 72 | 3-24 |
| Façade specialist and supplier | Senior Sales Executive | R&C | 4.8 | 2 |
| Façade specialist and supplier | Director of Business Development | R&C | 7-70 | 3-18 |

*Building type: R = residential; C = commercial (e.g. denoting one or more of the following: education, office, retail, health, stadia, hotels); R&C = residential and commercial.*

**How the façade decisions are being made and the influential roles**

When asked about how the decision-making was carried out, the interviewees made little mention of decision-making tools. Two interviewees: client (1), and façade specialist and supplier (1), mentioned whole life cost analysis, while one consultant mentioned life-cycle cost analysis in relation to the decisions made by owner-occupiers. Another consultant mentioned simulation software in relation to assessing façade designs with the purpose of trying to influence the client to increase the level of insulation. A few of the interviewees felt that the construction industry is changing and that the days when the architect was at the top are long gone. For some, the change was perceived to be a good thing, while for others, the reduction in project structure and in the quality of materials is considered to be a non-beneficial result of new methods of procurement, i.e. design and build. Despite comments about the changing industry, the interviewees still generally considered that architects were responsible for the initial façade decisions (reflecting the tendency for design and construction research to focus on the architect). Some interviewees (consultants, and façade specialists and suppliers) felt that they had no direct involvement in the façade decision-making, but tried to influence decisions where possible. The contractors try to make façade decisions at a later stage (post-tender), if possible, for the purpose of achieving cost and time reductions in the overall build. The client and the planning officer are seen as having the most say in façade decision-making, with the planning officer appearing to play a very 'commanding role', in which the interviewees opinion differed. Most of the interviewees expressed frustration at the time scales involved in the planning process, while two interviewees' responses were clearly divergent. One interviewee perceived that planners lack experience and knowledge in key areas such as material longevity, yet have inordinate power to block façade proposals made by experienced architects. Conversely, the other interviewee felt that planners should not act any differently to how they already do, as it was perceived to be correct that they work to preserve the integrity of a geographical area. The number of different roles participating in façade decision-making, in just this small sample alone, suggests that the 'traditional' project roles described in BS6100-1:2004 (BSI 2004: 74-75) should be amended to enable it to better reflect the complexity of today's construction industry.

**When the façade decisions are being made**

To investigate when façade decisions are generally being made, the interview sample group were asked to state, at which stages in the RIBA Outline Plan of Work, they had observed façade decisions taking place. These observations reflect the interviewees' general building experience and therefore, are only indicative in nature. Eleven interviewees responded with a total of 29 observations (Figure 2).

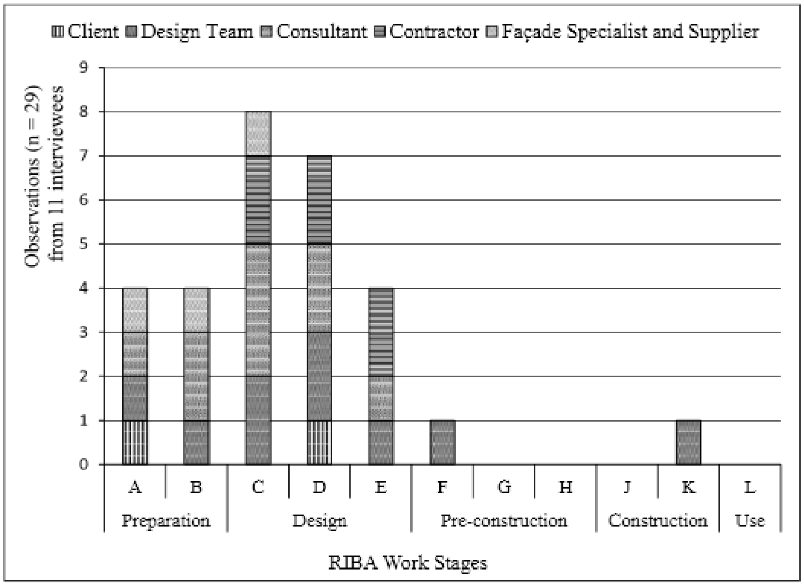


*Figure 2: RIBA Work Stages in which façade decisions were observed*

Two interviewees: building control (1), and façade specialist and supplier (1), were in roles that did not result in observing the RIBA Outline Plan of Work, and the fact that only 2 interviewees do not have exposure could be said to reinforce that it is "the most widely used model of building design" (Austin *et al.* 1999: 281). The results show that the majority of the observed façade decision-making occurs during the Preparation

(Stages A-B) and Design (Stages C-E) stages of a project. The design team and consultants observed decision-making at multiple stages, while the clients made unconnected observations, with one observing them in Stage A and one in Stage D. The façade specialist and supplier observed decision-making in the early project stage, reflecting their admission that they aim to influence decisions at an early stage to aid project success. The contractor observations slightly overlap the façade specialist and supplier, while their subsequent decisions hint at post-tender value engineering.

**Problems perceived in the façade decision-making and suggested solutions**

The problems that the interviewees perceived as occurring in façade decision-making are shown together with their suggested solutions, in Table 2 (listed alphabetically in order of 'Problem Theme'). Cost is a key factor in making good decisions, but not simply the total cost of procuring the façade. Other important cost factors include: paying adequate fees at an early stage in the design process to ensure that the right decision is made by the right people; and analysing the expected payback in terms of energy saving, but accepting that it might not 'win' the business case, in the face of less tangible gains, e.g. occupier satisfaction, maintaining the company brand. Collaborative working appears to be another way in which the perceived problems in façade decision-making can be improved. This collaboration can be among many roles and in varying combinations: architect and planner; lead architect with colleagues from the design team; client and consultant; or indeed, a whole project team of construction professionals collaborating at a project workshop dedicated to the façade.

*Table 2: Problems perceived in the façade decision-making and suggested solutions*

| Problem Theme | Perceived Problems | Suggested Solutions |
|---|---|---|
| Business case | Justifying the re-cladding of buildings; short-term view when making façade decisions | The driver is not always cost; benefits can come from other areas, such as managing the company brand, attracting customers and retaining staff; use whole life cost analysis |
| Energy Efficiency | The client needs the building as energy efficient as possible; increasingly stringent standards | A business case for refurbishment may see aesthetics as secondary to performance (though some architects may not think this way); evolution - embrace the changes |
| Fees | Making the wrong decision; having to value engineer at a later stage to reduce costs | Paying fees up-front so that the client gets the right advice and the right decision; paying for a full consultant team at the start, so that a quantity surveyor is involved from the outset |
| Planners | Façade material rejected for not being local enough; planning approval delayed due to other complications; planners lacking knowledge in material durability; planners lacking an understanding of the architects' design intent | Get the planner on-board early in the design stage; produce options; produce a mock-up of the façade for the planner to review; increase the number of project design workshops purely devoted to façades; create a project checklist of façade design issues; take time to consider the options; no one system will fit all projects; better training |
| Quality | Façade system must be well built; design and build procurement allows flexibility for the contractor to cut corners; material faults; led by aesthetics rather than function; installation standards; buildability; maintenance in-use | 25-year guarantee; collaboration to make a proper informed decision; pay for a full design team up-front so that full details are already produced when the job goes to tender; increase the number of project design workshops purely devoted to façades; Clerk of Works' role important to installation quality; craftsmanship - need to go back to grassroots |
| Specialist advice | Lack of choice in the façade specialists available | The specialists mentioned were all deemed of excellent quality, but where a job is small, may only provide off-the-shelf options |

## CONCLUSION

This paper has sought the opinions of different participants in the façade selection process, to explore and discover the current state of façade decision-making in today's construction industry in the UK. It has focused on façades on multi-storey buildings, due to the increasing prominence of multi-storey buildings as a result of the global trend towards urbanisation. The decision-making observations against the RIBA Outline Plan of Work indicate that certain participants might tend towards decision-making at different times in the project process. Architects are shown as leading the initial façade decisions; with consultants, and façade specialists and suppliers influencing these decisions where possible. Contractors are shown as attempting to make decisions at a later stage, post-tender, to potentially achieve cost and time reductions. The final façade decisions are made by the client, with planners giving ultimate approval. Very few decision-making tools were revealed as being used: namely whole life cost analysis, life cycle cost analysis and simulation. Further exploratory work is proposed to further define the roles participating in façade decision-making; and to investigate specific projects, with the aim of producing higher resolution as to what decisions are being made, and when.

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# Appendix L

### Bound-in publication – ARCOM 2013 conference paper

Garmston, H., Fox, M., Pan, W. and de Wilde, P. (2013) 'Multi-storey building retrofit with a focus on the façade selection process: a UK commercial office case study'. In: Smith, S. D. and Ahiaga-Dagbui, D.D. (Eds) *Procs 29th Annual Association Of Researchers In Construction Management Conference.* Reading, 2-4 September. Association of Researchers in Construction Management, 81-90.

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# 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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Garmston H, Fox M, Pan W and de Wilde P (2013) Multi-storey building retrofit with a focus on the façade selection process: : A UK commercial office case study *In*: Smith, S.D and Ahiaga-Dagbui, D.D (Eds) *Procs 29th Annual ARCOM Conference*, 2-4 September 2013, Reading, UK, Association of Researchers in Construction Management, 81-90.

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 (Femenias 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.

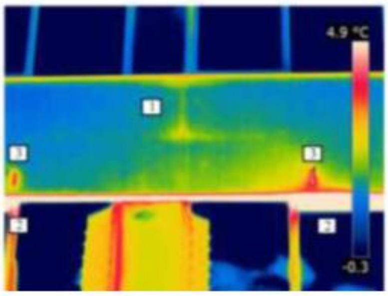


*Figure 1: Gaps between insulation boards [1], trickle vents [2] and cold bridging through the brise soleil brackets [3].*

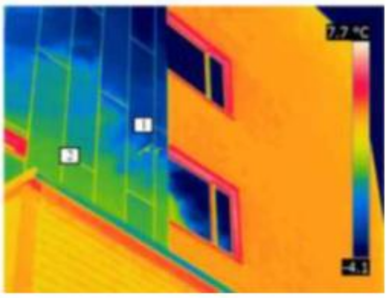


*Figure 2: Emissivity difference between render and cladding, note seagull [1] and cloud [2] reflecting off the cladding.*

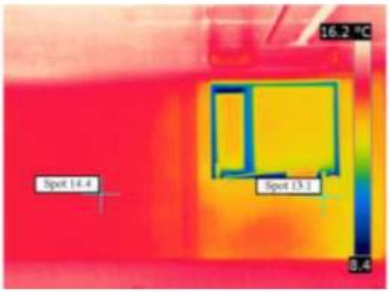


*Figure 3: Differences (°C) in construction build-up either side of column.*

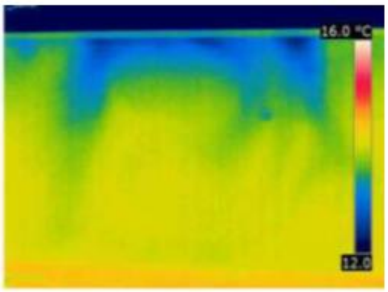


*Figure 4: An area of un-identified heat loss below a window frame.*

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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