An investigation of the tools and situated learning in non-domestic low carbon building design

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Abstract

This thesis investigated the enactment of low carbon policy aspirations by practitioners designing new non-domestic buildings during the 2010 transitional energy regulation change in England and Wales. The investigation called on social theories to examine how the low carbon policy model was adopted by designers in real-time project design. It analyses *what designers were doing as compared to what they were expected to be doing* by documenting the design process, the knowledge and the tools to embed performance.

The research was conducted by ethnographic methods that included non-participant observations, interviews and document analysis. Four architecture practices were recruited to analyse the conceptual and detailed design process in six non-domestic buildings for twelve to twenty-one months per case study. The architects were the main research participants and other design team members such as the mechanical engineers, the energy specialists and the BREEAM assessors were included. The study reveals how the compliance tools, guidance and standards (official tools) were incorporated in routine project design and the informal tools that designers used to embed low carbon performance throughout the design process.

The findings suggest that *the designers' enactment of the policy enters already formed design processes that reflect a multitude of concerns and precedents, a pre-existing social context*. The social context is likely to affect the evolution of the low carbon aspirations, the dissemination of knowledge and the use of tools in the process. The field data reveals the understanding performance cycles enacted by designers and the knowledge gaps likely to emerge in the process. The study identifies the designers' enactment of the policy aspirations and increases the understanding of the designers' adoption of official standards, tools and guidance during the real time design process.

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Abbreviations and acronyms

ARCH	architect
BB	Building Bulletin
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
BSRIA	Building Services Research Information Association
CABE	Commission for Architecture and the Built Environment
CIBSE	Chartered Institution of Building Services Engineers
CO_2	Carbon dioxide
DCLG	Department for Communities and Local Government
DECC	Department of Energy and Climate Change
DER	Design Emission Rate
ECEEE	European Council for an Energy Efficient Economy
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
FIT	Feed in tariffs
G-value	solar heat gain coefficient of glass (solar factor)
IES	Integrated Environmental Solutions
iSBEM	interface for the Simplified Building Energy Model
IT	Information Technology
KPI	Key Performance Indicators
$kgCO_2$	Kilograms of carbon dioxide
$kgCO_2/y$	Kilograms of carbon dioxide per year
kWh	kilowatt hours

kWh/y	kilowatt hours per year
m^2	square meter
ME	mechanical engineer
Mech Eng	mechanical engineer
NCM	National Calculation Methodology
NHBC	National House Building Council
Pa	Pascal
Part L	Approved Document Part L: Conservation of fuel and power in buildings
PV	photovoltaic
RHI	Renewable Heat Incentives
RIBA	Royal Institute of British Architects
RICS	Royal Institute of Chartered Surveyors
SAP	Standard Assessment Procedure
SBEM	Simplified Building Energy Model
TAS	Thermal Assessment Software
TER	Target Emission Rate
TM	Technical Memorandum
UK	United Kingdom
U-value	thermal transmittance
WG	Welsh Government

Glossary of terms

Affordances: According to Gibson (1977), affordances are the attributes of an environment that enable an agent to perform a variety of actions. It implies the noticing, perceiving and encoding of the properties of the environment by the agent within specific situations.

Appropriation: To make something external as if it was one's own, to take possession of. For the purposes of this investigation, appropriation refers to the process of designers' incorporation of tools in routine design process.

Aspiration: It refers to the informal design intentions in relation to performance targets outlined in the design process. They are likely to exceed the minimum regulatory targets but prone to be reconsidered as the design process develops. The thesis uses the term 'low carbon aspirations' to refer to the informal design intentions that exceed the minimum regulatory targets.

Building industry: refers to the activities of constructing, deconstructing, reconstructing, renovating, altering, demolishing, relocating, maintaining or repairing structures, buildings and infrastructure projects, including architecture and engineering endeavours. For the purposes of this investigation the term specifically refers to the practitioners involved in the design and construction of buildings.

Conceptual design: The conceptual design includes the briefing, early and conceptual design until planning application submission when the conceptual design is frozen, from RIBA A to D according to RIBA Plan of Work 2007.

Design process: It is the continuum of routines, tasks and procedures leading to the achievement of goals and requirements subject to constraints. This research has used the RIBA Plan of Work 2007 as a temporal reference to the design process.

Design team: The individuals involved in the design process who offer an input in the building design proposal. The design team includes the architects, mechanical engineers, BREEAM assessors, energy specialists and simulationists.

Designer: The person who works professionally in the design process as part of the design team. For the purposes of this investigation the designer is the architect who acts as building designer assisted by other design team members.

Detailed design: The detailed design comprises the activities developed after planning application submission, from detailed design to delivery or RIBA E to K as per RIBA Plan of

Work 2007 and the examination of knowledge dissemination and reflection once the project has been completed (RIBA L-M).

Ethnography: Ethnographic research enables an in-depth understanding of meaning and experience engendered in a social context (Silverman 2005; Gobo 2008; Bryman 2008; Hammersley and Atkinson 1995). It allows the exploration of 'the social issues and the behaviours that are not clearly understood' (Angrosino 2007) by considering the influence of the 'social context in the creation of meanings, attitudes and beliefs held by a group' (Schensul and Lecompte 1999a).

Explicit knowledge: The explicit knowledge is the knowledge that has been articulated, codified and stored in certain media. It can be readily transmitted to others. The explicit and tacit knowledge are complimentary and are not mutually exclusive (Ryle 1949; Polanyi 1966; Nonaka and Takeuchi 1995).

Formal: The formal refers to what has some structure engendered within specific groups. It is related to the notions of typification and routine. Typifications are interpretations that entail a common meaning (Berger and Luckmann 1997). The common typification of meanings and actions by the different actors within a group could lead to the emergence of the formal. The notion embeds some form of structure by an institution.

Informal: According to the Oxford dictionary (2012), informal is 'not done or made according to a prescribed form; not observing established procedures or rules'. In linguistics, this term refers to 'a structure suitable to everyday language rather than to official or formal contexts'. This investigation uses the notion of informal to refer to what is made within the social context, outside the mainstream of the official. The informal mirrors the connotation of 'dirt' by Douglas (1966): 'the patterns that emerge from the social context and do not fit into the official structures' which *do not match* the descriptions and expectations that outline how things *are supposed* to be and behave. Thus, the informal is a form of 'dirt' that arises from the existing social structures, preferences and habits in comparison to what it is expected or prescribed by the official.

Legitimation: Legitimation is the creation of new meanings that integrate various existing meanings, conferring them 'cognitive validity' and a new significance that is widely adopted by the members of the society. It implies the adoption of external elements as one's own (Berger and Luckmann 1967). For the purposes of this work, legitimation implies the wide incorporation and acceptance of a tool as part of the design process.

Official: According to the Oxford dictionary (2012), official is 'subservient to some purpose; derived from, authorised or supported by a government or organisation; hence (more widely) authoritative'. For the purposes of this investigation, the official refers to what it is derived from the government and organisations to facilitate low carbon design.

Policy makers: Individuals who are involved and possess the authority to define and formulate policies. For the purpose of this investigation, the term policy maker refers to the people who work at governmental level and who are responsible of the configuration and development of policies pertinent to buildings and built environment.

Routine: It is a regularly followed procedure; an established or prescribed way of doing something; a more or less mechanical or unvarying way of performing certain actions or duties. Routines are the repeated patterns that 'retain their meaningful character for the individual although the meanings involved become embedded in the general stock of knowledge' (Berger and Luckmann 1967).

Simulationist: The professional who holds the energy performance expertise and who uses the simulation tools, models and software to make energy performance appraisals.

Situated knowledge: It is the type of knowledge that is prompted by the problem-solving execution and in relation to the social, individual and physical contexts. This notion implies that knowledge is inseparable from context, activity, people, culture, and language (Lave and Wenger 1999). Situated knowledge is the individual's ability to respond effectively across situations rather than the accumulation of explicit knowledge per se.

Social context: The social context is the physical and social location where people interact and develop as part of the group. It comprises the beliefs, paradigms, motivations, attitudes, habits, repeated patterns of action that unfold during the interactions between individuals (Berger and Luckmann 1967).

Social theories: Social theories examine how the phenomena develop as a result of the experiences and perceptions of the individuals that are part of a group. Social construction entails the analysis of ideas, practices and beliefs as the result of the social interactions of the members of a group (Berger and Luckmann 1967).

Tacit knowledge: The tacit knowledge is acquired through practice and it could be disseminated by social interaction (Ryle 1949; Polanyi 1966; Nonaka and Takeuchi 1995). The tacit knowledge is a type of knowledge that is embodied in the abilities and skills that are not immediately transferable. The tacit knowledge is acquired as the result of experience and it is decoded through practice.

Tool: Dewey's definition of tools has been adopted in this investigation as it broadens the notion of 'means to ends' in the social context. According to Dewey, tools enable the consolidation of meanings and are means to consequences despite of their direct physical properties (Cochran 2010; Hickman 2009; 2011). Dewey's notion of tools is not limited by the physicality of the tools; it also includes linguistic symbols and concepts which are regarded as more flexible than physical tools 'since their symbolic function takes precedence over their material conditions'. Therefore, tools could be physical and conceptual.

Introduction

The United Kingdom is aiming for an 80 per cent reduction of carbon emissions by 2050, in alignment with Kyoto protocol commitments. For the building sector, the carbon reduction roadmap intends to mandate new buildings to be nearly zero carbon by 2020. The policy aspirations are to be delivered in three-year transitional periods to gradually enforce the reductions and enhance the building industry's understanding of increased targets. The first milestone was a 25 per cent reduction mandated in 2010. It is anticipated a further 44 per cent reduction by 2013 and nearly zero carbon buildings between 2016 and 2020.

Initially, Wales aspired to lead the decarbonisation pathway by enforcing higher interim transitional targets than the rest of the UK[1]. In 2007, the Welsh Government (WG), formerly known as Welsh Assembly Government (WAG), announced the aspiration of new homes to be zero carbon by 2011[2]. For the non-domestic sector, WG adopted in 2009 the Building Research Establishment Environmental Assessment Method (BREEAM), a building rating system to evaluate sustainability, as a planning condition. The Welsh planning policy stated that the new non-domestic buildings with an area equal or greater to 1000m^2 had to be certified as BREEAM Very Good and achieve a performance equivalent to Excellent on the issue Energy 1. These higher targets were meant to be facilitated by the devolution of Welsh regulations in 2012.

In order to achieve the policy reduction aspirations, official instruments have been made available to practitioners to comply with the energy performance requirements. The key statutory instruments vary across the four jurisdictions (England, Wales, Scotland and Northern Ireland) but for England and Wales[3] are the regulatory standard, Approved Document Part L and the National Calculation Methodology (NCM). The Approved Document Part L, Conservation of Fuel and Power outlines the minimum energy benchmarks. The European requirement for a NCM has been met by the Simplified Building Energy Model (SBEM) and there is proprietary software available for designers to determine

[1] The difficulties to achieve the carbon reduction targets were not fully anticipated; therefore, the initial targets were more ambitious than the ones likely to be enforced in the next interim transitions (2013 and 2016). At the time of writing this work, the 2013 target has not been fully clarified: the Welsh consultation for 2013 changes was conducted in autumn 2012 but the responses of the consultation have not been published. However, it should be emphasised that the focus of this work is how practitioners respond to changes in legislation and guidance regardless of the actual definition and targets.

[2] The Welsh aspiration for zero carbon homes by 2011 was announced in 2007; however, it was not realised. The current goal is to define the requirements of a 'nearly zero carbon' home, to be achieved by 2020 in alignment with the Energy Performance of Building Directive (EPBD) requirements.

[3] Wales is currently in the process of devolving the energy aspects of the building regulations, but this has yet to occur.

building energy performance. These instruments are intended to facilitate the regulation compliance. Supplementary material is available to the building designers about the energy performance such as trade literature, technical guidance and best practice guidelines.

The European Council for an Energy Efficient Economy (ECEEE 2009) estimates that the process of developing skills, knowledge and supply for technologies and products to achieve the mandated carbon targets may take ten to fifteen years. Research conducted in the context of transitional changes to zero carbon buildings suggest that the building industry will have to upscale techniques and gain the understanding of the practical implications of carbon reductions during the transitional periods towards zero carbon (Häkkinen and Belloni 2011; Hamza and Greenwood 2009; Osmani and O'Reilly 2009; Zero Carbon Hub 2010a).

Despite the official tools available for practitioners to understand and evaluate energy performance of the building designs, there are significant discrepancies between as-designed, as-built and in-use building performance, possibly due to the processes and cultures in the industry (Zero Carbon Hub, 2009). Research on the performance gap show that the expectations of building performance are not being realised despite the methods available to assess performance (Zero Carbon Hub 2010a; Sunnika-Blank and Gavin 2012; Bordass and Leaman 2005, 2012). There could be a mismatch between the policy intentions and the designer's enactment of the low carbon agenda. The disconnections between the policy and designers' levels could lead to unanticipated difficulties in realising the expected carbon reductions.

The challenges for, and the inertia in, the industry are often underestimated by policy makers and legislators. A key objective of this research has been to determine how practitioners cope with the regulatory changes in routine building design process. This work investigates the designers' enactment of the policy agenda by examining the real-time design process. This research analyses ***what designers are doing to design low carbon buildings as opposed to what they should be doing***. A socially-informed approach guided this investigation to consider the likely significance of the social context in the design of low carbon buildings. Social theories reveal the experience, meaning, attitudes and behaviours emerging from the ways that social groups act. According to social constructivist theories, design is a social process of negotiation of worldviews (Bucciarelli 1994; 2002) where the social context is likely to affect the knowledge and information exchange. Research undertaken in project environments has highlighted the importance of 'the informal' in the outcome of projects (Bresnen et alt 2003) and the need to understand tools in their context of use (Brown and Duguid 1994).

This work calls on social theories to reveal the designers' enactment of the policy intentions by exploring three main themes: the nature of the design process (social context), the tools and the knowledge for low carbon design. In order to analyse the tools in design, the theoretical propositions of this research compare the notions of ***official***[4] and ***informal*** and adopts Dewey's definition of ***tool***[5] (Cochran 2010; Hickman 2009; 2011). In relation to the analysis of knowledge in design, this work investigates the explicit and tacit knowledge invoked in design (Ryle 1949; Polanyi 1966; Nonaka and Takeuchi 1995) and it is informed by communities of practice and situated learning theories (Wenger 1998; Wenger et al 2002; Lave and Wenger 1999).

Ethnographic methods were used to conduct a case study comparison and explore how the designers were implementing the 2010 energy regulations in the real-time design of six non-domestic buildings located in England and Wales. Ethnography is a qualitative research method that enables the study of the meanings, knowledge and experience engendered in the social milieu of a group (Hammersley and Atkinson 1995; Silverman 2005; Bryman 2008). The locus of the ethnographic analysis is culture. It is used in anthropological, educational and medical studies to explore the problems that overlap policy and practice dimension (Hammersley 2006; Delamont 2012). This work was conducted as a case study comparison using non-participant observations, interviews and document analysis of the design process of six new non-domestic buildings. The data collection period comprised twelve to twenty-one months per case study.

Unlike previous work undertaken in this field, this research addresses the problem of designers' enactment of low carbon policy intentions by:

- Selecting routine projects as case studies without imposing the research agenda over the participants.
- Focusing on the design process of non-domestic buildings delivered by design and build procurement route by four large sustainable architecture practices
- Investigating the 2010 energy regulation transition when a 25 per cent reduction was enforced

[4] According to the Oxford English dictionary (2013), the *official* is 'subservient to some purpose; derived from, authorised or supported by a government or organisation; hence (more widely) authoritative'. The *informal* refers to what 'not done or made according to a prescribed form; not observing established procedures or rules'. In linguistics, this term refers to 'a structure suitable to everyday language rather than to official or formal contexts'.

[5] Dewey argues that *tools* are physical and conceptual items that are means to ends. The tools are not defined by their physicality but by 'their symbolic function takes precedence over their material conditions'.

- Conducting observational studies based on contemporary ethnographic methods to avoid out-of-context interviews, retrospective accounts and snapshots of the process.
- Observing practitioners while working, engaged in the problem-solving activities and designing for carbon reductions
- Comparing the case studies to identify commonalities and differences in the design processes
- Using a theoretical framework (intermediate theory) as a research tool
- Exploring how the social context affected the implementation of the 2010 regulatory changes, emphasising on the tools and knowledge deployed by designers

Research objectives and questions

The research objectives are:

- To identify the barriers experienced by designers working in low carbon non-domestic building

- To identify the models and routines that facilitate the understanding and the inclusion of low carbon performance in buildings during conceptual and detailed design

- To reveal the use of tools in routine project design

- To explore the social mechanisms that encourage the inclusion of low carbon considerations, their dissemination and learning across projects (social factors that enhance knowledge and learning)

The specific research questions that this investigation aims to answer are as follows:

- What are the challenges experienced by practitioners due to the transitional changes in energy regulations?

- How does designer's enactment in action compare to the assumptions held by the policy model?

- How do designers embed energy performance during design process?

    - How is knowledge invoked, created and disseminated in the design process in action?

    - How are the official tools used in the design process?

- What are the informal tools used by designers to assist the low carbon design process?

It should be noted that the research was developed between 2009 and 2013, including data collection and writing up. During this period, numerous changes that affected the policy instruments and the guidance available to designers were undergoing revision or coming to effect; some examples are:

- 2009 consultations for zero carbon definition
- 2009 consultation on Part L 2010
- 2012 consultations on Part L 2013
- process of devolution of Welsh regulations in 2012
- recast of the Energy Performance of Buildings Directive 2011
- definition of nearly zero carbon buildings
- proposals and changes in the conditions of financial incentives (Feed-in-tariffs, Renewable heat incentives and Green Deal)
- adoption of BREEAM 2008 as a planning condition for non-domestic buildings in Wales from 2009
- BREEAM 2011 version was published in summer 2011 superseding BREEAM 2008, used as planning condition in Wales
- RIBA Plan of Work (2007) underwent revision in 2012 for the publication of the 2013 version

Due to the quick rate of change in the field, it is necessary to clarify that the scope of this investigation is delineated by the 2010 changes in the energy regulations: Part L 2010 that came to effect in October 2010 and BREEAM 2008, the Welsh planning condition adopted in 2009. In relation to project timeline, the RIBA Plan of Work 2007 was used as a reference to describe the development of the design process.

This work analyses the designers' enactment and responses to changes. It enhances the understanding of how designers implement the official regulations, guidance and standards during convoluted periods of transitional policy changes, which is in essence a timeless phenomenon about policy intervention at designers' level and the adoption of performance-based process.

Thesis structure

The thesis comprises eight chapters: literature review (policy background, Chapters 1 and 2), research design (Chapter 3), data analysis and interpretation (Chapters 4, 5 and 6), recommendations and conclusions (Chapters 7 and 8). Figure i shows the thesis structure:

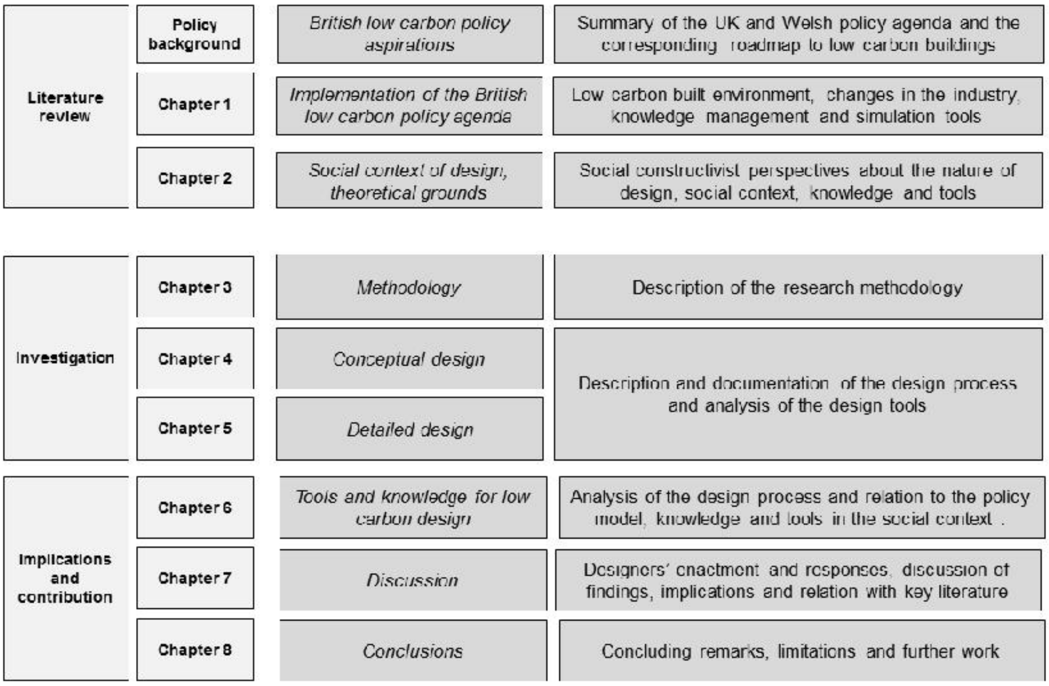

Figure i. Thesis structure

Background: British low carbon policy aspirations

This section summarises the policy aspirations and the roadmap for carbon reductions to 2020 towards nearly zero carbon buildings in the United Kingdom. There is a discussion about the Welsh aspirations that motivated the devolution of building regulations in 2012.

Chapter 1: Implementation of the British low carbon policy agenda

This chapter discusses the state-of-art research about low carbon buildings, implementation of changes in the buildings industry and simulation tools for performance design.

Chapter 2: The social context of design

It articulates the theoretical framework that guided the study of the design process, informed by social theories in relation to:

- *Nature of design process*: contrasting the rational view of the process with social perspectives that consider the design process as a negotiation, as a collective problem-solving process

- *Knowledge in the design process*: differences between information and knowledge, tacit and explicit knowledge, communities of practice views of situated learning and knowledge management in the building industry
- *Tools in the context of use*: human computer interaction and philosophy of technology perspectives related to the use of tools in practice

Chapter 3: Methodology

It presents the research design and explains the research protocols, the data collection methods, the fieldwork procedures, the data analysis and interpretation.

Chapter 4 and 5: Conceptual design process and Detailed design process

These chapters document the findings of the ethnographic phase that investigated the design process of six new non-domestic buildings designed by four sustainable architecture firms. It reports the fieldwork observations about the design processes. The findings were documented in relation to the Royal Institute of British Architects (RIBA) Plan of Work, inferring the low carbon problem-solving tasks executed in the case studies.

Chapter 6: Tools and knowledge for low carbon design

This chapter summarises the field data findings about the tools used by designers and the knowledge invoked in the low carbon design process. This chapter addresses:

- the understanding performance cycle enacted by the designers in the context of transitional changes in regulations
- the knowledge gaps that emerge in the design process

Chapter 7: Discussion

This chapter discusses the designers' enactment and responses to overcome the challenges to incorporate the policy agenda in real time routine design. It concludes by presenting the findings of the investigation, their implication and their relation with the prevailing literature.

Chapter 8: Conclusions

This chapter articulates the concluding remarks of the thesis, outlining the limitations and identifying further areas of work.

This thesis examines the design process adopted in six non-domestic buildings develop by four large architecture practices to reveal what designers are doing to enact the low carbon policy agenda. It examines in detail the design process in action, showing the influence of the social context and the interface between tools and knowledge in real-time design process.

Background

Low carbon policy aspirations in England and Wales

1. Policy aspirations[1]

Climate change and the depletion of energy sources have raised concerns about the suitability of growth models heavily dependent on non-renewable energy sources. There is a need to shift the intense patterns of consumption to more benign forms of development. The Kyoto Protocol set a precedent in engaging countries to decarbonise their economies and reduce their carbon emissions by 2050. In accordance to this goal, the European Union has legislative instruments to enforce carbon reductions across different sectors. The Energy Performance of Buildings Directive (EPBD) is the framework that defines the energy policies in the building stock (EPBD 2009). Each European Union member should set up their national policies and propose the instruments to achieve the overarching carbon reduction targets.

The United Kingdom, as EU member and signatory of Kyoto protocol aims to decrease 80 per cent of greenhouse gas emissions by 2050 compared to 1990 baseline level (Climate Change Act 2008; HM Government 2008; 2009). The White Energy Paper (DBIS 2003) was the first legally binding document outlining carbon reduction policies across different sectors of the economy, including the building sector which accounts for approximately 40 per cent of carbon emissions in the UK (HM Government 2009).

In England and Wales, the plan to decarbonise the building industry has been divided into three year interim transitional periods; defining the short term milestones for new buildings, existing stock and renewable energy for the built environment. The low carbon plan for new buildings aimed for 25 per cent reduction by 2010, 44 per cent by 2013 and nearly zero carbon buildings between 2016 and 2020 (CLG 2007a; 2007b; 2008a).

[1] As mentioned in the Introduction, during the research timeline numerous changes have occurred in relation to the low carbon policies. This discussion refers to the targets as outlined in the 2009 regulation consultation. The consultation for the changes in 2013 has not been included as the summary of responses has not been published at the time of writing this work. It should be remarked that the focus of this work is the designers' responses to regulatory changes regardless of the actual targets and definitions set by policy makers.

Wales is aspiring for higher interim milestones to 2020. In 2007, the Welsh Government (WG), formerly known as Welsh Assembly Government (WAG), announced the aspiration of new homes to be zero carbon by 2011[2]. The Code for Sustainable Homes and the Building Research Establishment Environmental Assessment Method (BREEAM) (BRE 2009) were adopted in 2009 as planning conditions for buildings in Wales on the Ministerial Interim Planning Policy Statement (Welsh Government 2009a; 2009b; 2009c). The devolution of Welsh regulations in 2012 was aiming to enable the Welsh Government to put forward the instruments to mandate specific Welsh policies and supporting mechanisms to realise the interim carbon reduction goals. The specific milestones for the new building sector are summarised in Table I.

	England targets	**Wales aspirations as proposed in 2010**
2010	25 per cent domestic and Non-domestic	31 per cent domestic and BREEAM very good non-domestic
2011	No milestone	Zero carbon homes
2013	44 per cent reduction	Up to 55 per cent reduction (Welsh devolution target)
2016	Zero carbon homes, schools, public buildings	Zero carbon homes, schools, public buildings
2018	Zero carbon non-domestic sector	Zero carbon non-domestic sector
2020	Zero carbon new buildings	Zero carbon new buildings
2050	Climate Change Act 80% Reduction CO2 (1990 levels)	Climate Change Act 80% Reduction CO2 (1990 levels)

Table I. Milestones for carbon reduction in the new building sector in the United Kingdom and Wales[3]

The low carbon policy in England and Wales is being delivered by a three-stranded framework for the achievement of carbon reductions, intending to articulate the regulatory system, financial incentives and educational mechanisms (Bell et al 2010; McAdam 2007). Figure ii. Below shows the main actors of the three-stranded low carbon policy framework composed by the regulatory system, educational and supporting schemes for the building industry and financial incentives. Each strand is related to a specific objective to facilitate the enactment of the low carbon policy aspirations: enforcement and compliance, industry awareness and market incentives. The regulatory system comprises the standards and policy instruments devised to enforce the low carbon performance levels (specific carbon reduction targets and mandated performance metrics i.e. 25 per cent reduction by 2010). The compliance tools in the regulatory system refer to the tools for compliance verification; for example, the national calculation methodology (NCM), discussed in Section 2. The financial system comprises the mechanisms to facilitate the market adoption of low zero

[2] Not delivered, current discussions attempt to define 'nearly zero carbon' homes.

[3] As per 2009 consultation to regulatory changes.

carbon technologies and encourage low carbon performance, outlined in Section 3. The educational and supporting system groups the initiatives to raise the industry awareness summarised in Section 4.

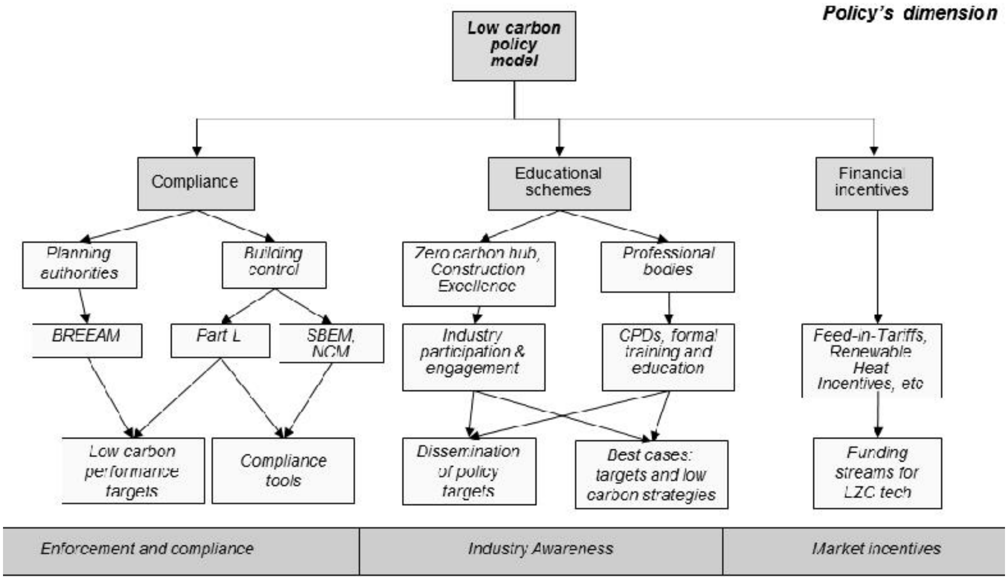

Figure ii. Three stranded low carbon policy model[4]

The following sections will outline the components of the policy model for low carbon reductions, with emphasis on the new non-domestic building sector which is pertinent to the scope of this investigation:

- Zero carbon definition and non-domestic approach
- Part L, the regulatory instrument
- BREEAM, the Welsh policy instrument
- Financial incentives
- Educational schemes

1.1. Zero carbon definition

The zero carbon definition for the residential sector comprises a hierarchy of energy efficiency, carbon compliance and allowable solutions (UK Green Building 2007; 2008; 2008b; CLG 2009a; 2009b; 2009c; 2009d; 2009e). A zero carbon house is one whose

[4] The organisations included in 'Education and supporting system' in the diagram are the ones that intent to connect the policy mechanisms and intentions to building industry practice; including professional bodies, universities, research centres, etc.

average carbon emissions during a year are equal or less than zero (CLG 2009f; 2009g). The energy efficiency involves an improvement in the performance of the dwelling in terms of fabric and construction such as insulation, airtightness and U-values. The carbon compliance is delivered by on site and direct connection to low and zero carbon technologies (HM Government 2010a; 2010b). The energy efficiency and carbon compliance measures should represent at least 70 per cent of total carbon reductions against 2006 standards (NHBC 2008, 2009; Zero Carbon Hub 2010b; 2010c). The allowable solutions are the supplementary strategies to offset any remaining CO2 emissions. The allowable solutions subsidise low and zero carbon technologies and financially support the renewable and low carbon technologies for heating generation as well as investments in low and zero carbon community heat. For calculation purposes, the energy in the building has been classed as regulated and unregulated. The regulated energy includes the energy used for lighting, ventilation, water and space heating. The unregulated energy comprises the energy that powers appliances, white and brown goods (television, radio, refrigerator) for the housing sector while for the non-domestic sector, items such as lifts and escalators (CLG 2008a; 2009h; 2009i; Craine 2009). The unregulated energy corresponds to those contributors that are not directly considered by the compliance tools for the energy calculation. If these unregulated energy elements were to be included in the definition of zero carbon, they were likely to be based on a percentage of the regulated energy derived from historical monitored data of similar building stock.

The non-domestic zero carbon definition process included a public consultation in 2009 whose summary of responses was published in December 2010 (CLG 2009g; 2009k; CLG 2010a; 2010b; 2010c). The responses supported the carbon reduction targets but there was opposition to the inclusion of non-regulated appliance energy use as part of carbon compliance as it was not estimated by building regulations calculation methodologies and it depends on the occupation (CLG 2010a; 2010b; 2010c). The respondents considered that the solutions should allow flexibility to the building professionals to choose the most convenient means to deliver zero carbon solutions in terms of energy efficiency, renewable energy and low carbon technologies (CLG 2010b).

1.2. Non-domestic aggregated approach

The diversity of the non-domestic building sector in terms of uses, build-ups and occupancy patterns and areas challenges the feasibility of a unified carbon reduction target (CLG 2007). Different non-residential building types are bound to have different characteristics that affect the energy performance. Therefore, an aggregated approach has been adopted to set up the carbon reductions for different non-domestic building types. Each non-domestic subsector would aim for different reduction targets that altogether achieve the required level of compliance allocated per transitional period in the non-domestic stock as a group (CLG 2009c; 2010b; 2010c; Target Zero 2010). The aggregated approach estimation was based on projections of the rate of construction of new buildings, known as the aggregate approach. AECOM and Davis Langdom (Archer 2012) analysed the aggregated approach and cost-effectiveness of a variety of zero carbon solutions to determine the appropriate energy performance levels for new and existing Welsh domestic and non-domestic sectors and their relation to EPBD recast. A regulatory impact assessment to lessen the regulatory burden was also undertaken to identify the feasible carbon savings in relation to costs, cumulative impact on future developments (including rural areas) and consumer benefits.

2. The regulatory framework

The Approved Document Part L, Conservation of Fuel and Power in Buildings is the legislative standard setting the compulsory performance of the building sector, in alignment to the EPBD (HM Government 2010c). Part L requirements are revised every three years to be articulated to the incremental carbon reduction targets by the policy agenda. In 2010, Part L required a 25 per cent carbon reduction in new buildings. As mentioned before, the Welsh Ministerial Interim Planning Policy Statement adopted BREEAM as a planning application condition for non-domestic buildings in Wales. Non-domestic buildings of 1000sqm or more were required to be certified to BREEAM 'Very Good' and from September 2010, this threshold was increased to 'Excellent' equivalent for the criterion Energy 1, Reduction of CO2 emissions (Welsh Government 2009a; 2009b; 2009c).

The Welsh Government has published policy statements and material to provide guidance to the building industry. Three Technical Advisory Notes (TAN) recommended the strategies and informed building practitioners and developers about the sustainable and energy matters: TAN 8 Renewable Energy (Welsh Government 2005), TAN 12 Design (Welsh Government 2009d) and TAN 22 Sustainable Buildings (Welsh Government 2010). Figure iii represents the Welsh policy roadmap for carbon emission reduction in new buildings. The interim milestones set were a 25 per cent reduction by 2010, between 40 and 55 per cent reduction by 2013 and zero carbon buildings between 2016 and 2018. This investigation is focused on the 25 per cent reduction enforced in 2010 where the policy gateways were BREEAM 2008[5] as a planning application condition and Part L 2010 for

[5] BREEAM is not a compulsory requirement but as a planning condition becomes a policy instrument for low carbon performance in new non-domestic buildings

building control. The planning condition required the achievement of 6 credits for the issue Energy 1. The planning application submission was likely to occur at the end of conceptual design phase. The building control instrument was Part L which required a 25 per cent improvement of the Target Emission Rate. The building control application was likely to be submitted during detailed design. BREEAM 2008 and Part L 2010 required as-designed and as-built submissions. More details about Part L 2010 and BREEAM 2008 are elaborated in the following sections.

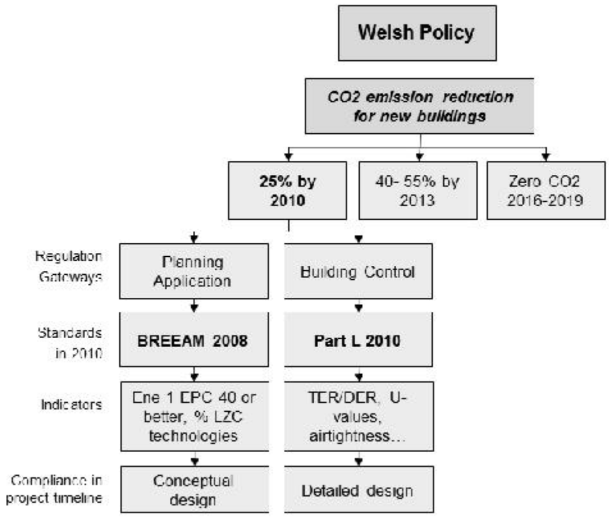

Figure iii. Landscape of the Welsh low carbon policy roadmap in 2010

2.1. Part L, the regulatory instrument

The Approved Document Part L, Conservation of Fuel and Power establishes the energy requirements in buildings. It addresses the energy for cooling, lighting and ventilation (HM Government 2010c). It is divided in four sections:

- Part L1A (new dwellings),
- Part L1B (existing dwellings),
- Part L 2A (new buildings other than dwellings); and,
- Part L 2B (existing buildings other than dwellings).

Part L comprises five criteria that include:

- carbon emissions improvement,
- energy efficient fabric,
- solar gain limit,
- building performance consistency with Building Emissions Rate (BER); and,

- efficient operation of the building.

The first three criteria are related to design while the last two are assessed after construction (as-built). In terms of evidence, there is a pre-construction submission of the estimated performance obtained through a method compliant with the National Calculation Method (NCM), a methodology aligned to EPBD recommendations. The Simplified Building Energy Model (SBEM) and iSBEM, its interface, are the official calculation tools provided to practitioners to produce the evidence and reports for compliance (CLG 2010d; 2010e; 2011; 2012; Johnson 2010). There are proprietary software aligned to the NCM for example Integrated Environmental Solutions (IES), Thermal Analysis Simulation software (TAS) and DesignBuilder. The calculation is based on design parameters and assumed scenarios of use. After the building's construction, there is a submission to update the model according to as-built documentation and results of site tests such as airtightness and ductwork leakage. The specific indicators and the minimum benchmark to comply with and the evidence to provide for compliance with Part L2A (new non-domestic buildings) are summarised in the following table:

ASPECT	INDICATOR	BENCHMARK	EVIDENCE
Energy improvement			
	KgCO2/m2	An aggregated approach determined by building type	National Calculation Methodology results-methods such as SBEM, iSBEM or simulation results from approved software
	% improvement TER	25 per cent.	Same as above
	EPC rate		EPC certificate, pre and post construction
Energy efficient fabric			
U-values	W/m2k	Dependant on building element s:	Specifications, NCM results
	Roof	0.25	Same as above
	Wall	0.35	Same as above
	Floor	0.25	Same as above
	Windows	2.2	Same as above
Building services efficiencies	Coefficient of performance	CIBSE and other technical guides	Same as above
Limiting solar gains			
Reducing solar gain		Part L's recommendations related to heat gain	Calculation reports from NCM or approved software
BB101 (only for educational buildings)	Compliance with 2 out of 3 criteria	120 Hrs <28C, Int -Ext average temp difference no more than 5C, Int air temp no more than 32C	
Building performance consistent with BER			
Thermal bridges and transmittance	Accredited details	Standard set of details from NBS	Checklist
	Bespoke	Calculating thermal bridges and adding safety factors to the calculation	Value increased by 0.02W/mK or 25%
	Unaccredited Generic values		0.04W/mk or 50%
	Air tightness	10 m3/hm2	Air permeability test. Tracking design & construction on large complex buildings.
Commissioning of systems	Ductwork leakage	CIBSE and other technical guidance	Test after construction
Energy efficient operation of building			
Building Log		Reference to technical guidance	Written documentation to facilities manager or users

Table ii: Part L2A requirements

Part L compliance is demonstrated by achieving a Building Emission Rate equal or greater than the Target Emission Rate. The Building Emission Rate (BER) is the total energy consumption of the building due to heating, cooling, water heating, lighting and services is estimated in kWh/m2.annum which is then calculated in terms of carbon emissions. The Target Emission Rate (TER) is obtained on the basis of a notional building with the same geometry, orientation and usage as the evaluated building and exposed to same weather conditions. The glazing area of the notional building corresponds to a percentage of the external walls and roof according to the building type. The notional building has standardised operation patterns for the building sector and standard assumptions for the fabric, glazing, and HVAC plant efficiencies (CLG 2010d; 2010e).

The energy demands of the spaces are calculated in relation to the activities. The cooling and heating demands are obtained from an energy balance model based on monthly average weather conditions and systems efficiencies. The input information includes the building geometry, weather data, occupancy profiles, building fabric which could be obtained from an internal database or set up manually, mechanical and lighting systems, low and zero carbon technologies. In addition, the EPBD recommends the labelling of buildings by an Energy Performance Certificate (EPC), a carbon index for buildings. The EPC can be obtained from the compliance calculation tool, the Building Regulation UK Part L (BRUKL) report.

According to (NBS 2010; Evans 2010), the key changes in Part L 2010 for new buildings are the requirement of a design stage calculation, commissioning plan, notional building updated to 2006 standards, the aggregated approach, revision of provisions for solar gain limits and guidance for low and zero carbon technologies.

2.2. BREEAM, the Welsh policy instrument

BREEAM is an environmental assessment method created in 1991 to evaluate the sustainability of the non-residential building stock (BRE 2009). It was the first building rating system to measure the impact of the building on the environment. It relates the impact of buildings to different aspects of sustainability, grouping such impact in the following categories:

- Management
- Health and Well-being

- Energy and CO_2 emissions
- Transportation
- Water
- Pollution
- Land Use and Ecology
- Innovation

BREEAM considers the different stages of the building life cycle such as design, construction, operation and demolition. It intends to be performance based and give an objective quantifiable measure of sustainability. However, some credits and categories are mostly qualitative or prescriptive, for example the issue Transportation 3, Cyclist facilities consist on the provision of a minimum number of bicycle racks in order to encourage a the building users to use bicycles to commute to the building. The system is revised periodically to align it to future regulatory changes, account for the changes in the industry and the emerging environmental concerns. In spite of BREEAM's voluntary nature, planning authorities and counties are adopting BREEAM as a planning condition.

There are different levels of BREEAM certification in relation to the credits achieved in the assessment: Unclassified (<30), Pass (≥30), Good (≥45), Very Good (≥55), Excellent (≥70) and Outstanding (≥ 85). Some levels require mandatory credits, i.e. the issue Energy 1 must achieve 6 credits if the building is aiming for Excellent rating. One of the key changes in BREEAM version 2008 compared to 2006 was the adoption of a two-stage certification process that required as-design and post-construction submissions to achieve the certification. In 2006 version, there was only an as-design submission and there was no need to submit post-construction evidence. In general terms, post-construction evidence is an update of the building documentation such as drawings and specifications, documentation of the changes that occurred during construction and for some criteria, provide photographic evidence demonstrating the adoption of strategies proposed in the design phase (BREEAM 2009).

BREEAM Energy category evaluates the aspects related to operational energy consumption through voluntary and mandatory issues. Table iii illustrates the mandatory credits to be achieved for BREEAM 'Excellent' rating, from which only CO2 Reduction was a compulsory planning condition requirement in the 2010 energy transition in Wales[6]:

ASPECT	INDICATOR	BENCHMARK	CREDITS AVAILABLE	EVIDENCE	MANDATORY CREDITS
Reduction CO2	EPC	40	15 (+2 exemplar credits for zero carbon)	EPC report, simulation results	6
Low and zero carbon technologies	% of energy used	10 20 30	1 2 3	LZC technologies report	Yes
Sub-metering of substantial energy uses	Use of meters	None	1	Technical drawing or documentation confirming use of meters or BMS and photographic evidence	Yes

Table iii: BREEAM mandatory energy credits for 'Excellent' rating

3. Financial incentives

The financial incentives sought to accelerate the implementation, development and dissemination of low carbon technologies, renewable heating and electricity. A number of programmes had been proposed for the new non-domestic sector such as the Low Carbon Programme, Feed-in Tariffs and Renewable Heat Incentives, to cite few programmes relevant to new non-domestic buildings (Rabinowitz and d'Este Hoare 2011). These programmes intended to increase the design and delivery of low carbon buildings and the growth of renewable energy use. The Low Carbon Building Programme provided grants to incorporate renewable energy generation in residential and public or charity buildings whereas the Renewable Heat Incentive and the Feed-in Tariffs provided grants to the generators and producers of renewable energy for electricity and heating.

The Low Carbon Building Programme comprised two phases from 2006 to 2010. This programme was sponsored by the Department of Energy & Climate Change. The phase 1 was administered by the Energy Saving Trust (EST) and the phase 2 by the Building Research Establishment (BRE).The second phase was focused on non-domestic buildings for non-profit purposes i.e. charities. This phase finished in May 2010. The programme funded up to 50 per cent of the capital cost of solar photovoltaics, solar thermal hot water, wind turbines, ground source heat pumps, automated wood pellet stoves, wood-fuelled boiler systems (Gardiner et al 2011).

The Feed-in Tariffs programme started on April 2010. It was a scheme where the generators of small scale renewable electricity are paid for the electricity that they generate. The

[6] In 2010, the planning policy in Wales required a minimum of BREEAM Very Good rating plus credits equivalent to Excellent for the issue Energy 1 (6 credits). Low zero carbon technologies and submetering were not compulsory credits to be achieved for planning application approval.

technologies included were solar photovoltaics, wind turbines, hydro-power, anaerobic digestion, micro-scale combined heat and power (micro-CHP) up to a 5MW capacity. Originally, two tariffs were accounted, the tariff due to kWh generated in the development and the exported tariff for the kWh transferred to the grid. The contract duration ranged from fifteen to twenty five years and the specific payment from 4.5p to 36.5p per kWh generated depending on the specific technology. The contract duration and fee per kWh was based on a '5-10 per cent investment return to install the technology' (Rabinowitz and d'Este Hoare 2011). In summer of 2011 the tariffs were revised and changes were applied in spring of 2012 (Ofgem 2012).

The Renewable Heat Incentives, launched in April 2011, provided financial support for the generation of heat from the following renewable energy sources: air and ground source heat pumps, biomass, solar thermal water heaters, combined heat and power plants fuelled from renewable sources, renewable biogas and bio-methane. It was funded by a levy on suppliers of fossil fuels for heat (DECC 2011; HM Government 2012). This programme was administered by Ofgem and the main objective was to encourage the switch from fossil fuels to renewable sources of heating. The sectors that were supported were industrial, commercial, public, non-profit organisations and communities.

4. Building industry awareness and engagement

The policy makers acknowledged the importance of engaging stakeholders and industry in the delivery of a low carbon built environment. Therefore, the educational and supporting schemes had been provided to assist the building industry in the carbon reduction pathway. These initiatives aimed to raise awareness, disseminate experience and supporting the industry in the design and delivery of low carbon buildings. The initiatives include educational activities, workshops, events and dissemination of the policy roadmap, regulation and best practice. The educational and supporting schemes include the Low and Zero Carbon Hub, continuous development programs by professional building industry bodies such as the Royal Institute of British Architects (RIBA), the Chartered Institute of Building and Services Engineers (CIBSE), the Chartered Institute of Architectural Technologists (CIAT), Royal Institution of Chartered Surveyors (RICS) and engagement events supported by the government, research centres, higher education institutes and universities.

In Wales, Constructing Excellence Wales and the Welsh Zero Carbon Hub act as links between the policy, industry and academic levels to disseminate best practice, the challenges and implications of future regulations in practice, the identification of gaps in

knowledge and skills and the identification of opportunities for building users' behavioural change. The lessons learned had been disseminated through demonstration programmes such as Exemplar where key sustainable performance indicators and targets have been highlighted. A web-based database called Script, the Sustainable Building Portal was developed as a repository of low carbon guidance, regulation, cost information, legislation and policy, materials and products, renewable energy sources, project team recommendation, research and development and; training and skills.
The Climate Change Commission in Wales (CCC Wales) is another initiative to develop four themes related to the aspirations of Wales to lead the decarbonisation pathway across different sectors of its economy. The specific work streams related to the built environment include residential new built, existing, non-domestic buildings, sustainable living, skills and training. In terms of the non-domestic strand, the core tasks include the investigation of performance discrepancies, gaps, mitigation actions, best practice documentation, identification of key performance indicators and best procurement practices (CCC Wales 2012).

The British policy efforts had been focused on defining the performance target and the zero carbon requirements while proposing instruments to facilitate the transition to nearly zero carbon buildings. As the deadlines approach, the feasibility of achieving the expected carbon reductions has been challenged. The barriers in achieving policy intentions are being identified as the building industry adapts to more demanding energy regulations, for example the lack of knowledge, the need to develop new skills, the redefinition of roles within the building process, the communication breakdowns, poor understanding of technologies and the division of the building process (Torcellini et al 2006; RICS 2008; Wang et al 2009; Jensen et al 2009; NBC 2008; 2009; Zero Carbon Hub 2010a; Bell et al 2010; HM Government 2010a).

It is unknown how the building industry is coping with the energy transitional changes at project level. One of the key objectives of this research is to identify how the building designers are enacting the policy aspirations and incorporating the legislation and the standards in routine project design in the light of regulatory changes, *what designers are doing as opposed to what they should be doing*. Such analysis could enable a better understanding of how the policy changes affect the design process so as to identify the designers' responses to enact the policy intentions.

Chapter 1

Implementation of the low carbon policy agenda in England and Wales

1.1. Introduction

This literature review discusses the challenges in the implementation of the energy policy agenda, with emphasis on England and Wales. The studies included in this review suggest that the British policy intentions may not be immediately incorporated by the building practitioners as anticipated by the policy makers. This review shows the difficulties that prior research have identified in relation to the incorporation of the regulatory requirements.

This chapter has been structured as follows:

- Low carbon building research
    - Challenges faced by the building industry for the adoption of the low carbon agenda for new buildings
    - Practitioners' perceptions of the low carbon agenda in England and Wales
- Implementing changes in the industry
- Models for low carbon processes
- Simulation tools for performance evaluation
- Discussion

1.2. Low carbon building research

1.2.1. Challenges due to the British low carbon agenda for new buildings

In studies about the adoption of the low carbon agenda for new buildings in England and Wales, the following critical issues have emerged:

- There are disconnections between the market demand and the regulatory drivers (Boardman 2004; Fisk 2008; Carmona et al. 2006; Mitchell and Woodman 2010; Strachan 2011; Meacham et al. 2005; Sexton and Barrett 2005; Lu and Sexton 2011)
- The targets and the modelling methods remain unclear to the building industry (Casals 2006; Ekins and Lees 2008; Kibert and Mirhadi 2012)
- The planning authorities and building control bodies are facing difficulties in enforcing the regulations (Faber Maunsell 2009; Zero Carbon Hub 2010a; 2010b; 2010c; NHBC 2008; 2009; Barrett et al 2008)
- The cultures of the industry hinder the adoption of the low carbon agenda (Sorrell 2003; Glass et al 2008)
- There is lack of stakeholders' demand for low carbon building performance (Cole et al 2010; Duffy 2008; Hill and Lorenz 2011; Markus 2001; Whyte and Gann 2001; Bakens et al 2005; Gunatilake and Liyanage 2010; Keirstead 2006; Lovell 2004; Sommerville et al 2011)

The lack of market demand for low carbon buildings is detrimental to the adoption of the low carbon policy agenda. Boardman (2004) claims that the market is unlikely to demand energy efficiency because of the lack of consumers' awareness and the consumers' apathy. He suggests that the policy dimension should provide feedback to consumers about carbon to encourage the demand. Fisk (2008) advocates for the integrated management systems, technologies and the vertical integration of markets to facilitate the focused intervention. On the study about urban planning codes, Carmona et al. (2006) discuss the difficulties in realising the policy agenda due to the lack of articulation between the market and standards. Although Carmona et al (2006) were focused on urban development; this intervention relied on a regulatory model and provision of standards, as the low carbon policy model does.

As a consequence of the limited consideration of the market demand, the policy model's expectations are based on optimistic assumptions to predict the carbon reductions. This has been addressed by Mitchell and Woodman (2010) who examined the impact of FIT realised through Ofgem as the economic regulator. They suggest that the policy model developed the incentives assuming that the energy goal would be trusted and valued by the stakeholders. However, the poor connection between the economic aspects and the different stakeholders' visions jeopardised the positive outcomes of the programme. The suitability of the policy ambitions are questioned by Strachan (2011). On his analysis of modelling scenarios for carbon reduction, he suggests that the prediction model is not coherent to the decision making rationale, modelling expertise, funding of core teams and the evolving uncertainties that emerge during the design and building processes.

The policy interventions should acknowledge the pre-existing conditions where the changes are to be implemented and anticipate the likely barriers to enactment. Studies conducted in relation to innovation and performance based regulations suggest that the interventions should seek for the integration of the policy intentions and market demands. Meacham et al. (2005) recommend the adoption of market-driven and risk-informed approaches over 'command and control models'. Meacham et al (2005, p. 101) advocate for a better understanding of 'the responsibility and accountability of all the actors to ensure that regulatory safeguards are established'. Sexton and Barrett (2005, p. 147) emphasise that the actors' demand could enable the investment return from performance building regulations otherwise 'building performance regulations might stay on the periphery of the innovation activity because it cannot meaningfully influence it'. On the other side, regulations could become problematic to the innovation processes which could be necessary for low carbon buildings. Meacham (2010) analyses the role of building regulations in relation to innovation and identifies the following challenges: lack of education, innovation outpacing readiness, lack of performance measures, poor feedback mechanisms and control, mismatches on performance expectations, lack of performance measures, inadequate application of available data and information. Lu and Sexton (2011, pp.1065) point out that 'command-and-control policies constrain innovation in so far as companies pursue minimum compliance over performance-based building codes'.

Another challenge suggested by the literature is the lack of clear targets and appropriate modelling methods. For example, Casals (2006) analyses the state of building regulations ruled by the EPBD and certification schemes to identify the difficulties to translate the EPBD to national regulations, with emphasis on the Spanish case. The study suggests that there are unclear indicators, unclear calculation methods and vague requirements for the implementation of renewable technologies. He advocates for a right indicator and building energy tools aligned to model it. Ekins and Lees (2008) discuss the need of setting up clearly the EU directives and the pathway for their implementation and enforcement. They highlight that the UK industry is unlikely to react promptly to energy efficiency as a requirement for the building stock. Although the focus of the paper is on existing building stock in the light of EBPD and Energy services directive, the implementation and underlying application is similar to the one for the building stock outlined in the Background Chapter. Kibert and Mirhadi (2012) discuss the need to define and clarify the targets (low energy, low carbon and net zero energy buildings) for policy formulation and implementation.

In terms of barriers related to the planning authorities and building control level, Faber Maunsell (2009) conducted a study with 15 Welsh local authorities and a response rate of 16 per cent. It was found that 59% of the respondents confirmed that there was no formal process to implement low and zero carbon policies. Only three planning authorities confirmed doing limited post construction reviews. The Zero Carbon Hub (2010) argues that the control processes based on objective performance information are fundamental to achieve the expected outcomes. It is suggested that rigorous and effective design and construction processes that include measurement and testing should be implemented. The National House-Building Council (NHBC) (2008; 2009) discusses the impacts of low carbon policies for the stakeholders involved in the new residential sector. Local planning authorities, building control and site inspectors were included in the study that identified the different scenarios for the transitions to zero carbon homes in 2020. Barrett et al (2008) raise attention to 'the need of a coordinated system of planning, building control and other policy instruments to monitor and give feedback on real performance, the inclusion of demand and supply and the consideration of social and economic aspects of the decarbonisation'.

The cultures and methods in the buildings industry could be barriers towards low carbon buildings. Sorrell (2003) suggests that aspects such the arrangements in the industry, the linearity and fragmentation of the process, the pressures for cost-competitive tendering jeopardise the achievement of the low carbon aspirations. He claims that the academic literature tend to ignore such barriers when suggesting best practice models. He recommends that the UK building industry ought to change to achieve a better product quality and productivity. He concludes that the reform agenda for sustainability is not considered to be comprehensive. By discussing the industry challenges in terms of products, techniques, skills and innovations for low carbon transition, Glass et al (2008) group the barriers and enablers as political, social economic and technological. The barriers are grouped as political, economic and technological. The policy related barriers are argued to be the stick based approach and restrictive legislative settings for manufacture. The economic barriers are the lack of support by investors, energy costs; social: skills shortage, needs of skills development, lack of know-how. The technological barriers are slow rate of change in the building stock, poor client knowledge base, poor specification writing, lack of data and evidence.

Previous studies have reported the lack of interest in low carbon buildings by stakeholders, building practitioners and users. Cole et al (2010) highlight the need of to reconsider the industry drivers to emphasise on the building quality as a social and ethical challenge. They advocate for performance based policy instead of reactionary approaches to foster building quality and good practices. The new professionalism required to design and deliver low carbon buildings has also been discussed by Duffy (2008), Hill and Lorenz (2011), Markus (2001), Whyte and Gann (2001) who advocate for the ownership of the buildings designed and delivered by the industry practitioners, emphasising on the need of reconsidering professional practice. Bakens et al (2005) highlight the need to engage stakeholders in the uptake of performance based building regulations. They recommend that market incentives should be included, knowledge should be managed and the fragmentation of the process should be addressed through collaboration and communication. Gunatilake and Liyanage (2010) recommend addressing the need of all the stakeholders. They suggest that the policy level should provide guidance at project level. However, the study is limited to a literature review, therefore the suggestions are general in scope.

The lack of stakeholders' engagement has been studied in the domestic sector. It has been pointed that the lack of integration of the users is problematic to achieve the expected reductions. Keirstead (2006) recommends considering the technologies for low carbon and their cost in combination with cultural and behavioural factors which are likely to affect energy use and conservation measures. Lovell (2004) suggests that there is a gap between the technical and social aspects which could be overcome by disseminating the sustainability discourses. Sommerville et al (2011) point that the low carbon performance is not part of the decision criteria for buyers.

1.2.2. Practitioners' perceptions about the British low carbon agenda

A number of studies have been conducted to investigate the views of practitioners regarding the implications of policy changes to practice in the context of regulatory changes. These studies were qualitative and have obtained data from small scale surveys and interviews. They sought to obtain the perceptions of practitioners regarding the transitional changes to nearly zero carbon buildings by 2020. In alignment to the studies discussed in the previous section, the practitioners perceived the following barriers:

- Unclear definition of low carbon targets (Fisher and Guy 2009; Isiadinso et al 2011)
- Inappropriate working methods (Hamza and Greenwood 2009; Zero Carbon Hub 2010a; NHBC 2010)
- Poor knowledge to achieve the low carbon policy intentions and the absence of market demand (Osmani and O'Reilly 2009; Williams and Adair 2007; Jensen et al 2009)

Building practitioners perceived that the definition of low carbon targets is unclear. For example, Fischer and Guy (2009) conduct a small number of interviews with designers inferring that some of the challenges include the lack of understanding about the building codes, poor information dissemination concerning changes and updates of regulations and the convoluted and rapid changes of performance targets. They suggest that the architects are facing emerging roles in their profession, fragmented design tasks and less control over the process creating conflicts. Nonetheless, the sampling criteria of the study are not clear, making difficult the interpretation of results. Isiadinso et al (2011) carried a small scale survey and interviews to determine the perceptions and understanding of low carbon buildings by design practitioners. Despite the study was undertaken after the UK consultations to the building industry to define low and zero carbon standards, the participants expressed their concerns about the lack of clarity in the carbon targets.

The working methods and the cultures in the industry are deemed as barriers against low carbon buildings. Hamza and Greenwood (2009) analyse the perceptions of building practitioners working on non-domestic buildings procured by design and built route. The research is based on semi-structured interviews. The findings suggest that regulations might result in changes of tendering practices, documentation and procurement and emerging roles of practitioners. The article identified the need of further research to capture practitioners' experience that could be fed back to the regulatory system and enhance best practice. The UK's Zero Carbon Hub (2010a) points the difficulty for designers and constructors to design efficiently and making a robust predictions, the need of clear performance parameters, confidence factors, measurement, testing and auditing. It is suggested that low carbon achievement is jeopardised by the division between design and construction, lack of coordination between different individuals involved in the process and the poor or lack of engagement of the industry in the life-cycle of the products. It is claimed that '…the performance issues are much more concerned with the processes and cultures within the industry than with the model that is used to predict carbon emissions' (Ibid p. 41). This report also shows that the lack of feedback on energy and carbon performance is detrimental as it 'reinforces existing performance norms, characterised by little capacity or enthusiasm to verify energy performance, rather than develop an understanding of what it takes to produce low carbon housing… Diffusion of understanding can only take place if coupled with improvement in the design and construction process and informed by feedback' (Ibid p.20). This suggests that the fragmentation in the process could become a hindrance to low carbon buildings. It is pointed out that in a typical process, the master planning, concept and detailed design phases are separate and often undertaken by different organisations so coordination is required to achieve the performance standard besides the cost target. It can be inferred from this report that the carbon reduction achievement requires to address the process. The report by NHBC (2010) suggests that the practitioners' skills should complement their knowledge in relation to new design approaches, new materials and technologies, systems build/offsite manufacture. These skills are likely to be gained under problem-solving execution. This aspect will be furthered discussed in section 1.3., which presents how the working methods and cultures in the building industry could react slowly to changes posed by the policy level.

Some studies have identified the poor knowledge and understanding of the implications of the policy requirements at practice level. Osmani and O'Reilly (2009) suggest that the building industry practitioners are unsure about the reliability of solutions and lack of confidence in low zero carbon technologies. Williams and Adair (2007) point out that there is a poor consideration of sustainability measures, discrepancies between real and perceived costs and inadequate expertise and power. Five case studies of residential developments were analysed using in-depth interviews and document analysis. The participants felt that there was a lack of knowledge, expertise, information and awareness. The regulations and policies were not perceived to be stringent enough. Stakeholders expressed that they were unable to seek best practice in sustainability because policies and regulations allow for less sustainable options. The lack of awareness by users might be problematic too. Williams and Adair (2007) found that practitioners perceived that lack of interest in low carbon performance by the end users discouraged the building practitioners to propose low carbon buildings. Similarly, Jensen et al (2009) find that builders perceived that the clients were indifferent to low carbon buildings which discouraged the delivery of better performing buildings.

Other studies undertaken in the context of low carbon transitional changes include Butler (2007) who discusses the concept of zero carbon; Tuohy (2009) who discusses low carbon building regulations; Tweed and McLeod (2008) who analyse the Passivhaus standard as a Welsh instrument for zero carbon homes ; Jones et al (2008) present case studies on zero carbon houses; Wang et al (2009) analyse a case study of a zero carbon house in the UK, Bailey and Ryall (2011) discuss the challenges of the Code for Sustainable homes for developers in Wales, Monahan and Powell (2011) examine the application of new energy systems application and implication to regulation compliance and Baiche et al (2006) explore the achievement of standards on site. These studies are some examples of investigations focused on the domestic sector. They do not examine the enactment of low carbon from a process perspective; their scope does not include the examination of the adoption of the policy requirements by the building industry practitioners.

The studies included in this section have unveiled the perceptions and experience of the industry in relation to the British low carbon policy agenda. Despite the policy model enforces the transitional reductions to increase the industry's knowledge and experience, the building industry is struggling to implement the low carbon requirements. The propositions of this literature suggest that the policy model might not be immediately adopted in the process and that there may be process-barriers impeding the enactment by designers. The adoption of the policy agenda has not been investigated from a process perspective. It can be noticed that little has been done to explore in the detail how the policy agenda is affecting the process during the energy regulation transitions. A characteristic of the studies reviewed in this section is their tendency to adopt 'snapshot' approaches. In other words they describe the situation without revealing the reasons in detail. Even when participants' opinions and accounts are obtained to reflect about possible reasons or to infer them, that approach is prone to difficulties. Emmitt (2001, p. 400) suggest that practitioners' accounts might describe the ways they would like to be seen instead of the ways they act. In addition, retrospective accounts are problematic in that practitioners' memory and ability to accurately report the process may be poor (Emmitt 2001, p.400).

An in-depth analysis of the process in action is likely to unveil the hindrances against the design of low carbon buildings. A socially-led approach is deemed suitable to explore the real-time responses and attitudes in the context of action, 'behaviour and experience in its full complexity' (Pidgeon 1996 p. 80), as further elaborated in Chapter 3, Research methodology.

1.3. Implementing changes in the industry

Prior studies have identified the nature of the industry and the challenges in implementing. Some of these studies are not focused on low carbon practices but they are relevant because they show the industry's reaction to transitions. This literature suggests that the building industry is prone to respond slowly to changes and even resist them. It can be inferred that the industry may react slower to the policy agenda than to the market demand. This confirms the earlier discussion in section 1.2.1 which pointed out the limitations of a regulatory-based approach and showed the need to address the market to accelerate the uptake of the low carbon agenda. The studies included in this section suggest that the existing cultures of practice and the fragmentation of the building process are detrimental to the implementation of changes. Changes towards low carbon buildings require addressing the process so to consider the entire building life cycle of the buildings. The design and delivery phases should be connected and coordinated to generate the performance results expected during operation.

The cultures of the industry are likely to undermine the opportunities for communication and collaboration. Latham (1994) criticises the contract tendering procedures, especially Design and Build procurement for being the least favourable route for innovation and quality since its aim is cost reduction. He advocates for the coordination of project information, the engagement of the client and the improvement of training methods. He suggests that 'a greater inter disciplinary approach is necessary, without losing the expertise of individual professions' (Ibid p.72). Egan (1998) discusses the endemic fragmentation of the UK building industry. Building projects are carried out as 'a series of sequential and largely separate operations undertaken by individual designers, constructors and suppliers who have no stake in the long term success of the product and no commitment to it. Changing this culture is fundamental to increasing efficiency and quality in construction' (Ibid, Chapter 2, point 17). The report recommends the need of an integrated process that 'utilises the full construction team, bringing the skills of all the participants to bear on delivering value to the client' (Ibid, Chapter 3, point 37). Eguchi et al. (2010) argues that the collaboration among design team members is fundament to articulate the common understanding and achieve innovation.. Kleinsmann and Valkenburg (2008) identify the barriers and enablers for the co-design process in the industry to determine how actors negotiate the differences. Organisational levels are separated in three levels: actor, company and project level. It is suggested that barriers and enablers are located in different levels and their interfaces. Baiden et al (2006) analyse the degree of integration of construction managers in the process of best practice cases. The procurement approach should be articulated to team practices and seek for integration. It is claimed that the sector must change organisational and behavioural barriers for further improvement. The effective integration of teams for effective project delivery is problematic and it could be detrimental to the outcome of the process.

The issue of fragmentation has also been explored by identifying the problems arising in different stages of the process. For instance, the briefing activity is argued to be challenging. In Kamara et al (2001) briefing practices are analysed in relation to concurrent engineering, identifying that current practices are not adequate. They suggest a methodology that aligns briefing and concurrent engineering framework. Yu et al (2007) identify problems in setting the building requirements on the briefing. It is argued that briefing is a live process so the time when the brief is fixed should be explicit. They recommend having a fixed brief before detailed design. They also propose a method to identify and represent client's requirements in the briefing process. Austin et al (1999) investigate the design process as a cycle of compromises that leads to time and cost penalties. They proposed a design planning technique, focused on detailed design process. During detailed design, Cattell et al. (2008) analyse the bidding model and Laryea (2011) analyse the quality of tendering documentation. These examples show the fragmentation of the process that emerges in different phases.

The fragmentation of the industry could produce problems for the dissemination of the knowledge required to design and deliver low carbon buildings. Gangemi et al (2000) discussed the knowledge gaps in the industry, suggesting that the architect alone does not possess the skills required for the design of sustainable buildings. They advocate the role of the environmental consultants. They use two British consultancy companies to illustrate the management of complex projects and the implications for architectural practice. McDermott et al (2011) claim that despite the building context should be a knowledge sharing environment where all the stakeholders develop their skills, the lack of trust between supply chain/team members leads to a breakdown of information flows and uncertainty between project partners. This article is not focused on low carbon processes yet it is relevant in the context of this research, as the findings related to trust and collaborative working are applicable on any building process. Zika-Viktorsson et al (2003) explore the psychological and social aspects of project work, showing how the work environment could enhance the individual experience, team processes, and the development of projects and the fostering of personal skills. Cacciatori and Jacobides (2005) suggest that the specialisation of the industry has created boundaries leading to knowledge gaps in the industry. Trebilcock (2009) stresses that practitioners require basic knowledge and awareness of common aspects where architecture and engineering overlap.

A number of studies undertaken in contexts other than the UK suggest that the building industry is characterised by its conflictive and divided nature. Elsewhere, the industry seems to face similar challenges to the UK while moving towards low carbon buildings because they require performance-driven processes. In order to overcome the fragmentation, Cheung et al (2009) recommend building up a continuum from conceptual design to pragmatic application. Chan et al (2006) advocate that partnering is important for the performance of projects to enhance communication, eliminate misunderstanding and increase efficiencies. However, while partnership is helpful in the process, it is argued that partnership might not be able to solve all the problems (Ibid). Cheung et al (2011) discuss the links between individual attitudes and organisational cultures and the potential outcomes on the buildings.

On a review of detailed design in Sweden, Eriksson and Westerberg (2011) suggest that the procurement factors such as trust and partnership affect the project performance. While Augenbroe et al (2004) propose a procedural methodology to structure the project development as a sequence of dialogues and workflow to lessen the difficulties in communication between building practitioners.

1.4. Models for low carbon process[1]

Low carbon and building industry research aiming for a performance-driven process increasingly acknowledges the need of an integrated process to overcome the fragmentation and the poor ownership of the product by the building industry, as outlined in the previous section. Thus, best practice models have been proposed to structure the process and learn from best cases. For example, the Technology Strategy Board (TSB) is supporting initiatives that monitor the performance of buildings such as the Building Performance Evaluation programme to undertake design, construction and operational reviews of the building performance. Other programmes for the non-domestic sector had been launched to obtain in-use performance data, such as the RIBA CIBSE Carbon Buzz and Carbon Trust's 'Low carbon buildings'. These initiatives compare the expected 'as-designed' estimation to in-use performance, identify the discrepancies and possible disconnections between different phases of the building lifecycle (as-designed, as-built and in-use). These initiatives propose best practice; recommend team communication, early briefing set up and an integrated design and construction processes.

One of the models of performance-driven process is Softlandings which has been adopted by BREEAM 2011 to address sustainable management of buildings[2]. Softlandings is based on BSRIA Usable Buildings (2010), Way and Bordass (2005). Soflandings promotes the post occupancy evaluation and performance indicators for 'designing for manageability'. It recommends the work of designers and constructors to continue during handover and for the first three years of occupation. The Softlandings process is divided into five steps that comprise design, construction, hand-over and first years of operation:

1. Inception and briefing, to enhance the dialogue between the designer, constructor and client

[1] It should be noted that most of the references reviewed in this section were published towards the end of the data collection period of this research except for the design review by CABE and Softlandings.

[2] The inclusion of Softlandings in the BREEAM 2011 version (July 2011) seemingly seeks to foster its wide dissemination within the building industry. BREEAM 2011 uses Soflandings as a reference on issues related to the Management category. Nevertheless, this research has studied projects certified by BREEAM 2008.

2. Design development and review, for project teams to define the building operation and targets according to similar projects from the manager and occupiers' perspectives

3. Pre-handover, for operators to understand the building and systems before occupation

4. Initial aftercare, including surveys to liaise the clients, the design and building teams in analysing the performance of the building during operation

5. Extended aftercare and post occupancy evaluation, relating results from following the operation from one to three years to learn about design aspirations and actual building operation.

Softlandings encourages the involvement of the design and construction teams beyond practical completion to help in the fine tuning of the building and its systems and facilitate the occupants' understanding of the building and its controls (BSRIA 2009, Buckley et al 2010).

Other examples of best practice are:

- Carbon Buzz is a RIBA CIBSE initiative to track the performance of the buildings in use and compare predicted as-design and actual in-use performance (Kimpian and Chisholm 2011)

- Key Performance Indicators (KPI) is construction best practice programme by Constructing Excellence to include the recommendations of Latham (1994) and Egan (1998) to enhance the performance of the construction sector in a variety of areas, including energy as a sustainability aspect

- The design review from the Commission for Architecture and Built Environment (CABE) which aims to foster the discussion between stakeholders and the inclusion of users in the design of buildings to clarify their needs and expectations as outlined in CABE (2006; 2009). The review comprises ten criteria for the design of buildings; one of them is sustainable design.

Low carbon guidelines are available to the building industry practitioners. For example, the Carbon Trust has published information to assist in low carbon building design and closing the performance gap (2011). RIBA[3] has published similar material to support designers in

[3] RIBA material for low carbon design has been published as part of the Climate Change toolkit, available at: http://www.architecture.com/FindOutAbout/Sustainabilityandclimatechange/ClimateChange/Toolkits.aspx

the incorporation of low carbon considerations. The information comprises exemplar cases, best practice, guidance, low carbon standards and assessment methods and low zero carbon technologies. A Green overlay on the RIBA Plan of Work was published to facilitate the incorporation of sustainability criteria in the design and delivery processes (Gething 2011). Cinquemani and Prior (2010) compile a guide to achieving higher BREEAM and Code for Sustainable Homes ratings mapped onto the RIBA Outline Plan of Work. This guideline suggests when to consider the BREEAM credits in relation to the project development timeline.

However, it is necessary to be cautious when recommending prescriptive models for practitioners' application during the design and delivery process. Szulanski (1996) considers that the best practice could be hard to follow. He studied eight companies, recording 271 observations of 122 best practice transfers. He suggests that the barriers related to knowledge are the 'lack of absorptive capacity, casual ambiguity and arduous relationship between source and the recipient'. He argues that motivational factors are not the only cause of the poor adoption of best practice which suggests that there could be process-based barriers that hinder the adoption of these models. Macmillan et al (2002) investigate the conceptual design stage, comparing process maps, conducting interviews and a case study analysis to propose a framework for concept stage development. Although the initial testing was received positively by research participants, it was rejected due to 'the focus on the gates between activities and the issues within each activity'. It is uncertain whether these best practice models are being implemented during design in-action to guide the process. One question that should be asked, therefore, is how these models and official tools (simulation, standards, best practice advice) are being used during the real-time building process.

1.5. Simulation tools for performance evaluation

This section outlines the academic research about simulation tools for the design with emphasis on the interface between tool and user in the context of design which is the scope of this investigation. This section has been divided into the following sub-sections:

- Simulation tools: from researchers to designers
- Attempts to consider the user: procedural and user-centred debates
- Simulation tools in their context of use
- Simulation tools for energy regulation compliance

The first three sub-sections addressed the trajectories of research concerning simulation tool development while the last sub-section summarises some research undertaken in relation to regulation compliance matters.

1.5.1. Simulation tools: from researchers to designers

The first attempts to move from research environments to architecture and engineering contexts sought to increase the 'tool power' by augmenting the capabilities or by creating user-friendly tools. These approaches seemingly positioned the tool within the ideal design process. The predominant interpretation of the process was based on rational models[4] that represented design problem-solving as a linear sequence of tasks. Therefore, it seemingly fails to consider the simulation tools in their context of use. This could be explained by the incipient development of the fields of design cognition and the predominant info-processing model of mind influenced by the artificial intelligence field. This model tends to consider that reasoning is a rule-checking exercise so action could be translated to prescribed rules. Thus, designers are consider as rational knowledge agents that follow predictive linear patterns while designing.

On this strand of simulation research the tool developers tended to hold a rational view of the design process. Some examples include Haglund (1985) who attempts to develop user-friendly tools, Crawford (1985) who discusses how to integrate of the simulation tool in the building design environment from a procedural perspective, Derickson and Holtz (1985) who develop a simplified simulation tool for designer's use. These researchers propose design tools following a rational model of the design process.

In the 1990's publications tend to define simulation as a mathematical and deterministic problem. The incorporation of simulation tools in the design process is advocated to rationalise the problem-solving and to move towards evidence-based design decision-making. For instance, Pols (1991) discusses the issue of building modelling on an analogy between buildings and machines. Logan (1993) outlines the limitation of simulation software highlighting the need to augment the simulation tool capabilities and power. Mahdavi et al (1993) suggests a normative approach for simulation use and Amor et al (1993) adopt a prescriptive approach to guide the use of tools. Amor and Hosking (1995) argue that the advances of the field should move towards positioning the simulation tools in what was perceived to be the optimal simulation environment. Nonetheless such assumptions about

[4] Rational models of design are discussed in detail in Chapter 2, Section 2.2.

the design process seemed to have ignore the social context as they were mostly based on laboratory-based research than observation of design practice.

1.5.2. Tools and the user: procedural and user-centred debates

The next strand of simulation research showed some attempts to consider the user and the context of use by including debates about procedural aspects and user-centred notions. For example, Clarke et al (1989) present the Intelligent Front End (IFE) project which consists on the design of software that helps the user in the problem description phase and analysis of the overall performance of buildings. Despite the claims to have included user-centred ideas, the publication is focused on the capabilities of the tool rather than the interface between the tool and the user. Such focus may be explained by the early phase of development of the research project.

This research strand seeks to move simulation from the research environments to the desing settings. Therefore, there is and increasing recognition of the user-tool interaction. Augenbroe and Winkelmann (1991) draw attention to the need of defining the role of simulation in design. They suggest that it is necessary to examine how the simulation tools fit in the design process and its data flows. They advocate for the use of energy design support software for integrated design, looking at the tool in its context of use. This publication addresses the tools and data flows. Clarke and MacRandal (1993) also address the user-centred aspects of tool use. They present some cases of best practice to demonstrate how simulation tools could facilitate the design work. Nevertheless, due to the scope of the study, the cases are based on theoretical representations of the process but not in observations of design in action.

Clarke et al. (1995) acknowledge that tools are decoupled from the design process and thus suggest an integrated data model that mix different design tools. This research was based on the COMBINE project, a European research effort that sought to produce a unique model and protocols for data exchange between different professionals in the building design and delivery process. Soebarto and Degelman (1995) consider aspects of capability, modelling, energy simulation procedures and output while presenting an energy simulation tool whose audience are the building designers. Papamichael et al. (1997, p. 98) highlight the importance of understanding how computer-based simulations 'fit within the building design process to meet the need of building decision-makers' in order to achieve the integration of simulation and the improvement of designs. They present the example of Building Design Advisor, a tool developed to help the design decision-making. The authors criticised the tendency to develop the simulation tools in research environments that are detached from the context of use. However, it is unclear how Building Design Advisor is used by designers. The tool is argued to be 'intended primarily for the academic use, both as research tool and teaching aid, to a lesser degree it is intended for professional use…'.

Mahdavi and Suter (1998) address the integration of simulation as a matter of creating the simulation environments within the design process. They mention that there is a 'relationship between [simulation] tools characteristics and their underlying –explicitly stated or implicitly present- assumptions regarding the nature of the design process that they are expected to support' (Ibid p. 189). They introduce a simulation tool for lighting assessment to support architecture design which is claimed to consider the nature of the design process.

Hand and Crawley (1997) include aspects related to human-computer interaction when discussing matters about training of novice simulation tool users. The focus of the study is the learning curve of inexperienced simulationists but not the relation tool-user in the design process. It does not attempt to portrait the challenges of simulation deployment in relation to the 'two-way communication' between the tool and the user. The tool requires knowledge to input data and analyse the results. While the tool helps to study phenomena, the user should have the background knowledge and expertise to set up the simulation scenario and interpret the results.

de Wilde and van der Voorden (2004) discuss the role of simulation in building design decisions. Two design processes are analysed to identify how simulation tools supported the selection of energy saving building components. The findings suggest that the decisions are based on the use of components in earlier projects or in reference projects. They point out that there is 'virtually no selection of energy saving based on equivalent comparison of the performance of design variants' (Ibid p. 751). It is observed that building simulation tools are used when conceptual design phase has finished 'to verify expectations or optimise but not to support the selection process' (Ibid p. 751). They suggest that further research should include 'the impact of social issues (social interaction, group behaviour, and politics) on design decision making' based on 'real time observations rather than retrospective analysis of the process' (Ibid p. 756).

Macdonald et al (2005) present how the simulation tools could be transferred from research environments to the industry to overcome the gap between academic simulation and their practical use by designers. Mahdavi (1999) suggest that one of the failures of simulation tools is the poor understanding about how performance cycles occur during design. He proposes a new system, SEMPER which is claimed to be part of the 'overall architecture of the simulation-based design support environment' (Ibid p. 428). While this publication does not address the integration of SEMPER in practice, it acknowledges that the problem of integration may not be merely computational power.

The simulation research has progressively moved to considering the challenges of tool incorporation switching the focus from *increasing the tool power* to *empowering the user*. Struck and Hensen (2007) suggest that guidance is unlikely to be used in early design process. Bunker et al. (2011) propose a design tool that enables the knowledge capture of previous design lessons in a database of rules of thumb connected to simulation tools. Nevertheless, it is not clear how the context of use and the user have informed the investigation. It is unclear if and how the potential users are involved in the development of the tool. Bazjanac (2011) discusses about the input quality and the availability of simulation results for decision making. He presents the conceptual design process of a small one story commercial office to highlight how the simulationist may make decisions based on arbitrary modelling data which brings attention to the need of expertise. Bleil de Souza (2012) also addresses the matter of simulation to the service of designers, comparing the design-thinking and problem-solving paradigms of the simulationist and the designer as separate communities. She points that the 'there are fundamental differences in knowledge and praxis' between the design and the simulation groups (Ibid p. 113). She suggests that the solutions for integrating of simulation in design are to be provided by the building designers themselves. Therefore, it could be inferred that the analysis of the design in action is an analytical resource to place the tools in action (during problem-solving) and in interaction (use of simulation tool in relation to the wider design team and stakeholders)

In summary, the research included in this section acknowledge to different degrees that the user interacts with the tool so the dynamics between tool and user should be considered when proposing simulation tools as design aids in the process. The tool-centric approaches that regard performance evaluation as an abstract deterministic task overlooks the nature of design problem-solving and the 'human-tool juncture' highlighted by the field of human-computer interaction[5].

[5] Human-computer interaction is a field that withdraws from computer science and behavioural studies to address the interaction between tools that embed knowledge and their users. A more detailed discussion about this field is elaborated in chapter 2.

1.5.3. Simulation tools in the context of use

It is noteworthy that simulations tools for building design have been mainly created by simulation researchers based on abstraction that represent the design process as a rational problem-solving activity. In order to achieve the integration of simulation tools while designing, normative approaches have proposed to instruct the user how to use the simulation tool within the process. However, research studies are increasingly recognising the necessity of user-centred views to inform the simulation tools and their incorporation in the context of use. These studies acknowledge that there may difficulties in the use of the simulation tools by designers. For example, Augenbroe (1992) suggests that implementing tools is about structuring the process. Hensen and Augenbroe (2004) point out that simulation is unlikely to be used in routine practice despite academic literature recommend its use. Macdonald et al (2005) suggest a gap between academic simulation and their practical use by designers. Clarke et al (2008 p. 4608) argue that ‘the use of simulation and modelling techniques has been well documented; however, their use is not widespread in the UK’. de Wilde et al (2002) point out that the design process is unpredictable and intuitive and therefore, simulation might not be used for decision-making. It is important to consider the context of problem-solving and decision making to understand the input of simulation in the process.. Augenbroe (2003) points out that ‘designers and the design process are moving targets’ (Ibid p. 4) and argues that designers ultimately look for ‘the rapid and timely invocation of the most adequate simulation function (rather than simulation tool) in a given design context’ (Ibid p.12).

Studies have recognised that the use of simulation tools in the process cannot be taken for granted. Mahdavi (1998) argues that the incorporation of tools may be obstructed by practices embedded in the design and construction processes. He points that the repeated patterns in the process could possibly become a barrier in the adoption of technologies, as ‘behavioural patterns could result in unreflected (quasi-automated) and in a sense, irrational routine’ (Ibid p.208). This argument is relevant in that it acknowledges the relationship between tool use and existing process; although the claim of irrationality could be argued. The irrationality could be the result of the social processes engendered in the local milieu where the simulation tool is adopted. However, the unexpected use of tools could be a reflection of the latent affordances[6] perceived by the users but unanticipated by the tool

[6] Affordance is the property of an object or an environment that enables the individual to perform an action, discover new action possibilities and enact new actions (Gibson 1977). Affordances are not only a result of the physical capabilities but also the actors’ goals, plans and past experiences (Norman 1988). Affordances refer to how the object is ‘interacted with’.

developer. Another important argument developed by Mahdavi (1998) is 'the dialectic between process and tool' which may determine the 'emergence and survival of tools… the degree of their dissemination and application' (Ibid p.210). This publication interprets the location of tools in their context of use as a 'co-evolutionary cycle of process and tool dialectic' and 'the complex relations between process evolution and tool development' (Ibid p.211). New technologies have the potential to make manifest the existing structures and process. Therefore beyond their role as design aids for computational support and decision-making, information technologies 'could augment the capacity of knowledge transfer and information flow and qualitatively enhance the design and construction processes' (Ibid p.211).

Other examples of research considering the interface between the user and the simulation tool include Mahdavi (2011), Hopfe (2009) and Attia et al. (2011). Mahdavi (2011) discusses the human dimension of building performance simulation. He advocates the simulation research community and tool developers to consider the users of simulation tools because that will prompt insights about how tools could be improved in terms of interfaces, data processing and visualisation features, integration and interoperability. This could also inform training programs for the use of tools and the proposal of tools to assist designers. Hopfe (2009) conducts an online survey among seven expert simulation tool users to obtain their opinions about the reliability of results, support of decision process, guidance through the design process and sensitivity parameters. Attia et al. (2011) conduct two surveys to identify the needs and preferences of architects and engineers regarding building simulation tools in five topics:

1. 'Usability and information management of interface,
2. Integration of intelligent design knowledge-base
3. Accuracy of tools and ability to simulate detailed and complex building components
4. Interoperability of building modelling
5. Integration of tools in building design process

Attia et al (2011) suggest a 'wide gap between architects and engineers as simulation tool users' (Ibid p. 165). Such gap is explained by the 'historical development of both professions…' (Ibid p. 165). It is highlighted that architects and engineers work on 'mono-disciplinary environments' so 'the tool functionality transcends the knowledge and skills base of only one discipline' (Ibid p. 165). The study points out the need to bridge the gap between architecture and engineering fields. The advantages of simulation tool use are highlighted suggesting that they could become ‘a platform to support the collaboration between architects and engineers’ (Ibid p. 168).

In summary, this section has discussed simulation literature that have considered the user while analysing the role of simulation in the design process. However, it could be noticed that there is lack of observational studies of designers in action to analyse the use of tools by designers.

1.5.4. Simulation tools for energy regulation compliance

This section summarises the research about the simulation tools for energy regulation compliance. The studies addressed the following aspects:

- the evaluation of the simulation tools by researchers (Simm et al 2011; Waseem et al 2009; Murphy 2009; Gupta and Chandiwala 2009; Nam Lim 2009)
- the role of the simulation tools in compliance (Ren et al 2007; Bambardekar and Poerschke 2009; Brahme et al 2009; Marsh 2005; Matipa et al 2010; Raslan and Davies 2012)

The simulation tools have been evaluated by researchers to compare the results of different compliance instruments. For instance, Simm et al (2011) develop a study of IES using differential analysis and Montecarlo statistical analysis to compare the variability of the results of different models and the accuracy of the predictions. Their analysis is based on 2006 building regulations. Waseem et al. (2009) analyse an office in Scotland using SBEM for conceptual design and IES. Murphy (2009) explores the SAP methodology, comparing the results of BREDEM and dynamic modelling. Gupta and Chandiwala (2009) develop a user-friendly SAP software in Excel to assist the design of zero carbon dwellings. Nam Lim (2009) addresses the UK scheme of certification of proprietary software that is used as a compliance tool. Discrepancies and variations are found in the results by software.

Concerning the role of simulation for compliance, Ren et al (2007) use case studies to illustrate the use of simulation to inform the design of a domestic building and a commercial building and suggest strategies for compliance. Bambardekar and Poerschke (2009) report on performance parameters related to architectural elements recommending how to assist architects in translating the design to simulation analysis. Brahme et al (2009) study how the tools used in detailed design could help to understand the impact of various building components. Marsh (2005) discusses the use of simulation tools for regulatory compliance.

He argues that in general terms, building designers do not use intensive simulation analysis. As regulations set the acceptable ranges of performance, policy makers should be able to forecast the implications of different compliance parameters. The use of simulation for compliance implies the validation of the design in relation to regulation benchmarks. Matipa et al (2010) explore the energy performance certificates and identify the tools available for design decisions in the construction process, based on a small online survey. 81% of respondents perceived the inadequacy of the existing tools for decision making. Part L, the Code for Sustainable Homes and BREEAM were some of the tools recognised by the respondents. Raslan and Davies (2012) conducted a survey and in-depth interviews about the National Calculation Methodology (NCM) as a methodology for compliance. The results suggest that the compliance tools may be limited in terms of usability, technical capability and reliability.

Despite simulation is claimed to be a critical part of performance-driven processes and evidence-based design, the research has rarely been undertaken from the users' perspective to show the role of simulation to inform routine building design. There is a tendency to recommend procedural approaches that advise the designers how to use the tools. However, little is known about how the simulation tools are part of the design in action. Simulation research tends to overlook user-centred design theories and human-computer interaction propositions. Some simulation research tend to adopt a misleadingly narrow focus on its subject matter ignoring the impact of the social and organisational context where simulation tools are used.

In general terms, the simulation research has been rarely developed with a focus on the affordances of tools and the variegated user-tool relationship. The limited consideration to the context of use has led to the development of simulation tools that have not been fully grounded on the design process in action. The main weakness of such approach is that it overlooks the likely influence of the social context in the use of simulation tools. On Suchman's (1987) seminal study about artificial intelligence developments, she questions the notion of human-machine interaction, arguing that the use of the technologies is not only a cognitive process but also interactional and circumstantial (Ibid p.47). Little has been done to examine the use of tools in the design in action. This investigation proposes the analysis of tools in the social context of design, departing from a user's perspective.

1.6. Discussion

In summary, this chapter has included the following themes:

- Low carbon building research
    - Challenges posed by the energy agenda
    - Practitioners' perceptions about the low carbon policy agenda
- The implementation of changes in the building industry, identifying the potential implications for designers' uptake
- Models for low carbon process
- Simulation tools for performance

As discussed in the background chapter, the policy roadmap for enactment is based on a rational model composed of three strands:

- Regulations (standards and tools)
- Educational schemes (regulation updates, low carbon information and best practice dissemination)
- Financial incentives (encouraging the adoption of low and zero carbon technologies)

The regulatory instrument for buildings in England and Wales is Part L which sets the minimum performance standards by design teams (criteria 1-3) and delivery teams (criteria 4 and 5). BREEAM, a voluntary system to assess the environmental impact of buildings, has been adopted as a planning condition for buildings over 1000 m2 in Wales. BREEAM is used as the policy instrument to encourage low carbon buildings. Although BREEAM does not have a regulatory status as Part L and it is intrinsically voluntary, it has become a policy gateway for new non-domestic buildings. Financial incentives, such as Feed in Tariffs (FIT) and Renewable Heat Incentives (RHI), seek to foster the use of low and zero carbon technologies by reducing their payback periods. Educational schemes are meant to disseminate updates and low carbon information. The timeline of transitional regulatory changes aims to accelerate the practitioner's learning curve in tandem with the incremental carbon reductions.

The policy model assumes that the low carbon targets enforced by regulations will result in the immediate implementation of low carbon design and delivery processes. It presupposes that if the practitioners are aware of the reduction targets, they will immediately embed the standards in the buildings and use the compliance tools to assist in the process. However, it is unknown if the policy instruments (standards, compliance tools and low carbon information) are adopted in the process as expected. The incorporation of the official compliance tools in the design process remains unknown.

The policy model is based on an optimistic prediction about the enactment that does not acknowledge the challenges of implementing changes in the industry discussed in previous sections. It does not take into account pre-existing barriers suggested by the literature:

- the disconnection between market and policy drivers
- the lack of clear target
- the slow response of the building industry to new regulatory requirements
- the existing cultures in the industry and the fragmented nature of the building process
- the absence of performance-based process
- the need to develop skills and knowledge for the design and delivery of low carbon buildings
- the limited use of simulation tools to inform the design and delivery processes

The shift to performance-driven processes required by the low carbon agenda could take longer than anticipated. As targets towards zero carbon in 2020 approach, early findings of the growing literature in the low carbon field warn about the possible failure of the policy model (section 1.2). A staggering body of knowledge has identified the complexities in implementing the low carbon agenda and serious discrepancies between predicted and actual performance which could be the result of problems in the process (sections 1.2 and 1.3).

The roadmap to low carbon buildings may be more complex than setting the mandatory target, spreading legislation updates across professions and disseminating low carbon information. The enactment of the policy aspirations entails the understanding of the requirements and the application of informed strategies during the relevant instances of the process. This could be assisted by adequate knowledge and supported by tools to assess the low carbon target. Ultimately, moving towards low carbon buildings implies a shift to performance-driven processes. Thus, this research investigates the design process in action to reveal how designers are enacting the regulatory changes. The investigation focused on the knowledge and the tools used by designers to embed energy performance.

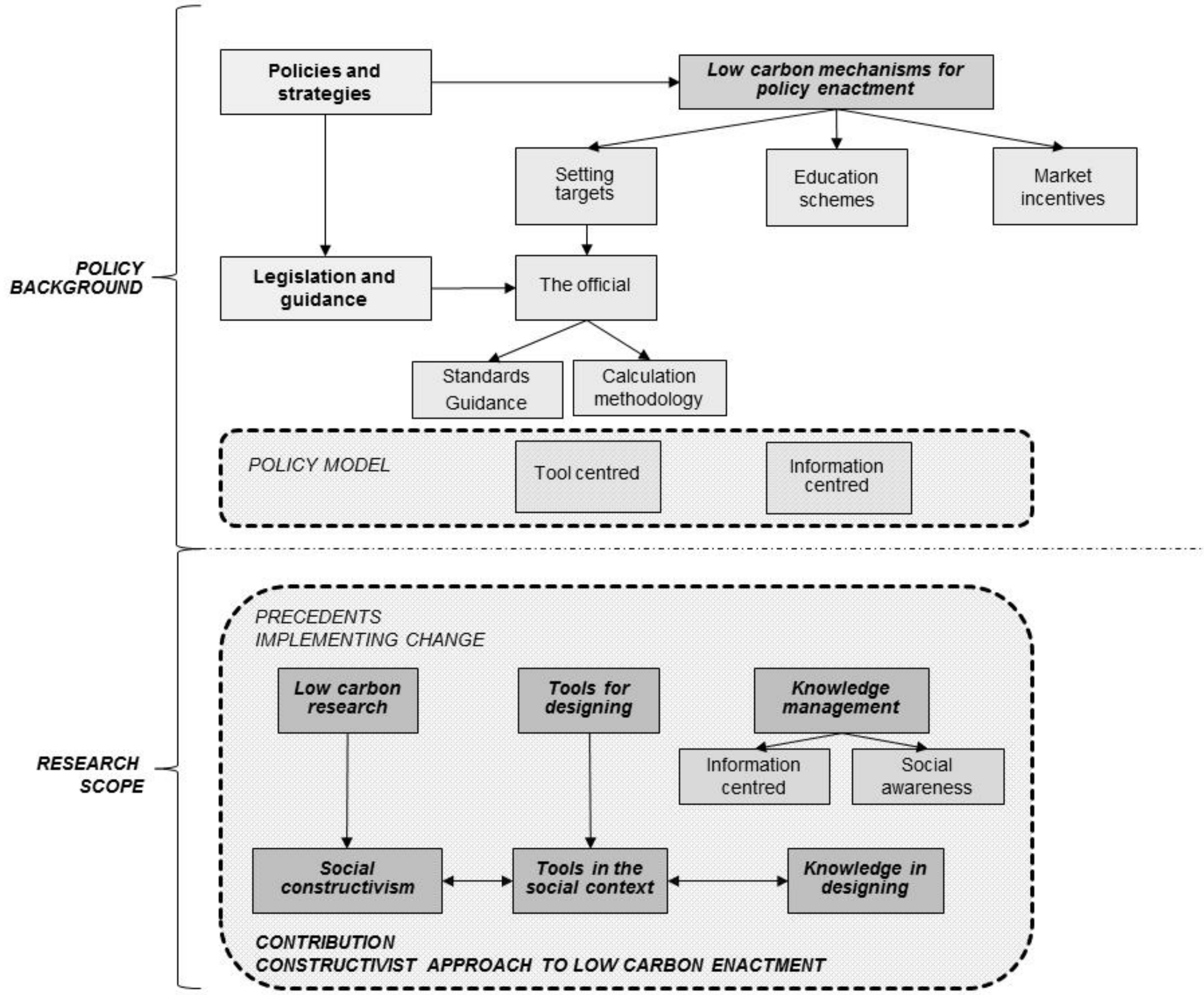

Figure 1.1. Research scope in relation to the British low carbon policy model for new buildings

Figure 1.1. illustrates the relationship between the policy model and the research scope. On the top of the figure, there is a representation of the policy model with the three strands: compliance (targets and standards), educational schemes and market incentives. This investigation examines the compliance model which includes the standards, the guidance and the calculation methodology. The policy model follows a rational view about compliance which results in tool-centred and info-centred approaches. This investigation questions the rational assumptions of the policy model by adopting a social perspective to the analysis of designers' enactment. On the bottom of the figure, there is a representation of the research

scope, outlining the two major themes of this investigation: the tools and the knowledge for design.

In summary, the research uses a socially oriented approach to analyse the designer's enactment of the policy intentions. It evaluates the assumptions of the policy dimension about the enactment of regulatory changes. It seeks to develop a bottom-up understanding of how the policy model is implemented by designers in routine projects. The research objectives are:

- To identify the barriers experienced by designers working in low carbon non-domestic buildings
- To identify the models and routines that facilitate the understanding and the inclusion of low carbon performance considerations in buildings during conceptual and detailed design
- To reveal the use of tools in routine project design
- To explore the social mechanisms that encourage the inclusion of low carbon considerations, their dissemination and learning across projects (social factors that enhance knowledge and learning)

Chapter 2
The social context of design

2.1. Introduction

As outlined in the previous chapter, the low built environment research has identified challenges in enacting the low carbon policy model despite the variety of mechanisms and tools available to practitioners to facilitate the achievement of low carbon aspirations. In this chapter, the theoretical foundations of this research are discussed to present the framework that guided this investigation. This review includes a breath of material focusing on the research themes: nature of the design process, knowledge and tools in design.

This research calls on social theory to analyse the enactment of the policy aspirations during the design process. Social theories examine how the phenomena develop as a result of the experiences and perceptions of the individuals that are part a group. Social construction entails the analysis of ideas, practices and understandings as the result of the social interactions of the members of a group.

The themes discussed in this literature chapter are:

- *nature of the design process*: discussion and comparison between rational views and social perspectives to the study and interpretation of the design process.
- *knowledge:* differences between explicit and tacit knowledge, knowledge management dissemination in the building industry, social perspectives for the management of knowledge
- *tools*: definition of tool according to human-computer interaction and philosophy of technology theories, the human-tool juncture, tools in architectural and engineering design

These literature discuss the design problem-solving and process (nature of the design process); communities of practice and knowledge management in the building industry (knowledge); and, philosophy of technology and human-computer interaction (tools). The rational literature about these topics has been included to be compared with the postulates based on the social theories.

The policy model is based on rational perspectives that low carbon requirements are immediately adopted by designers as a cognitive goal-seeker agent. However, the social theories suggest that the social context may affect the process of knowledge creation, the knowledge flows and the tool use. The propositions of this study are:

- design is a process of social construction where tacit and experiential knowledge are created during the problem-solving activities; and,
- the tools are used in relation to the social context.

This review does not negate rational perspectives about the design process. Rather, it uses social theories to analyse the design process beyond the rational notion of design as a deterministic cognitive process. Studies addressing the performance gap Zero Carbon Hub (2010a), Sunikka-Blank and Gavin (2012), Bordass and Leaman (2005, 2012) and monitored data collected by initiatives as RIBA/CIBSE CarbonBuzz and the Building Performance Evaluation Programme sponsored by the Technology Strategy Board suggest that the expected building performance is not being delivered despite the improvement in the performance assessment methods. The policy model for low carbon enactment is based on a rational perspective about the nature of the design. It is prone to be info-centred and tool-oriented. While regulations and compliance tools set the minimum benchmarks, it remains unknown how designers are coping with the changes. This work aims to explore the design process to reveal the designers' enactment of policy intentions in the context of regulatory changes.

As a result of the analysis of propositions about the nature of the design process in terms of problem solving, knowledge and tools, it is possible to conclude that the policy model is based on the following contestable rational premises:

- the official tools and standards are immediately incorporated in the design process
- the educational schemes for regulation update and low carbon information could immediately increase the knowledge and understanding required for low carbon design

This chapter concludes by articulating the theoretical framework, informed by social theories, so as to question the policy assumptions about designers' enactment.

2.2. The nature of the design process

2.2.1. Rational views

The rational perspectives of the design process argue that individuals' decisions are bounded by the information available, their cognitive skills and the limited time for decision making as suggested by Simon (1996). Rational decision making involves the identification of alternatives, the analysis of their consequences and the comparison between those consequences to select the preferred alternative.

Simon (1996) considers that design as a problem-solving activity that could be structured as a set of tasks comprising problem generation, recognition, identification of constraints and resolution where 'bounded rationality appears to produce better outcomes' (Ibid p. 38). Despite Simon (1996) considers that the professional's role is compatible with bounded rationality for problems with clear-cut and limited goals, Simon (1996) acknowledges that 'the role of the professional comes under questioning' for ill-defined problems (Ibid p. 150).

Rational problem-solving requires an integrated analysis of the process and the problem to enable the correct predictions. The rational perspective suggests that the logic of design implies a goal-seeking system to find optimised alternatives based on a means-ends analysis. The process is represented by the design 'inner and outer environment', the alternatives of action and their criteria. According to Simon (1996), the selection of the best alternative is determined by an utility function: 'the optimisation problem is to find an admissible set of values of the command variables, compatible with the constraints that maximise the utility function for the given values of the environmental parameters' (Ibid p.116).

The rational model has contributed to the development of protocols for analysing the design process, being the basis of methodologies to study design problems and conceptualise the design tasks and processes. Eastman's studies were related to Simon's rational view as the basis to structure a science of design, design cognition. Eastman (1970) used the rational model to theorise about information processing required for problem-solving of ill-defined problems and suggests how the computers could be used in design work. This was related to the early developments of artificial intelligence. On an empirical study of the redesign of a room, Eastman (1970) conceptualises that information could be regarded as a retrieval process. As a result, Eastman (1970) created a protocol for design process analysis to study ill defined problems and identify the process of information retrieval and search aspects during problem-solving (Ibid p.25-28). The identification of the specification and retrieval process in design tasks could inform the description of the design process for future applications on design aids (Ibid p. 31-33). A possible limitation is that it was a laboratory-based analysis of the problem-solving process of a single participant. Yet, it is valuable as an early attempt to structure the design process.

While the rational view has informed the analytical framework for conceptualising the process, considering design as a systematic linear process had led to narrow views that do not represent the nature of design. The rational model has informed the protocols for design cognition and process analysis. Eastman (2001, p.147-198) suggests that the rational model has help to identify what designers do but it has been less successful in identifying how they do it. In other words, the rational model may be limited when representing routine design practice.

There is a difference between using the rational model as a structural description and as a procedural prescription. As a structural description, it provides simplified representations of the process but as procedural prescription, it could result in the misleading notion of design as a purely reasoning process. Goldsmith brings attention to the postulate that design cognition as a science is undergoing development and that rigorous design methodologies that are informed by algorithms do not necessary result in better design quality (Goldsmith 2001 p. 199-212).

Cross (2001) conceptualises design as a process that interrelates problem formulation and solution generation. He argues that the process needs a flexible structure that enables deviant actions and opportunism as inputs towards the solution. Akin (2001 p.105-124) points out that the architectural solutions are proposed in relation to the circumstances that determined the problem, which was termed 'situated persuasiveness'. Eastman (2001 p.147-198) suggests that designers are bound to develop the process informally. He refers specifically to architects arguing that architects are unlikely to follow a deterministic process despite there are some general patterns of problem analysis and design development.. In his comparison of the design methodology and the outcomes of the design process, Kroes (2002) concludes that the design methodology seeks to improve the process while the methodology of science is normative, arguing that the design process is cannot be mapped as a procedural nor prescriptive pattern of action.

The rational views that separate few parameters of reality to convert them into ideal models or normative explanations are likely to result in non-rational attitudes towards the phenomenon when analysed in the broad scope because action implies a spectrum richer than motor routine completion (Winograd and Flores 1987 p.128). The risk of the rational view is that attempts to describe design as the addition of well-defined steps oversimplify and overlook sequences of operations with a rich set of meanings. Assuming that there is a clear and explicit structure could be misleading when describing the process to be understood.

Dorst and Dijkhuis (1995) compare the rational model of design (Simon 1996) to the socially informed model by Schön (1983) while examining the process applied in industrial design. The investigation was a protocol study that analysed the process leading to content-based decisions. The aim was to compare how the rational and the reflection-in-action model relate process and content during design decision making. While Simon's rational model enabled to record acts, goals, context and topics; Schön's model of reflection in action combined content and process as a coherent reasoning related to specification and problem-solving criteria. Dorst and Dijkhuis (1995 p.274) conclude that 'describing design as rational is apt in situations where the problem is fairly clear-cut, as reflection in action works well for conceptual stage where there are no standard strategies'. The rational model was found suitable to structure the problem-solving process for well-defined situations due to its 'clarity and rigour'.

The rational model reduces the process to a continuum of functional tasks mapped in relation to information needs and deliverables to enhance the decision-making logic. Rigid rational perspectives could lead to conceptualisations that do not represent nor capture the nature of the process and tend to prescribe structures that might not fit the process. A rational view may not be the suitable frame of reference for the analysis of ill-problems such as those solved in building environments.

2.2.2. Design as a social process

Without underestimating the contribution of the rational model to the science of design cognition, a social interpretation may be more suitable to understand the design in action. Alternative views to the purely rational model have acknowledged that the design process has an ill-defined nature where the problem is understood and solved as potential solutions are envisaged. The design process has been described as a process of reflection (Schön 1983), where the designer is engaged in a 'conversation' with the problem so as to find its solution. The problem-solving is not linear but rather undefined, what Lloyd and Deasley (1998 p.101) call 'the dust and rubbish, bits and pieces'. Thus, the rational methodologies might not be able to represent 'the rather messier actuality of work' (Lloyd and Deasley 1998 p.108). Design problems are multidimensional and highly interactive (Lawson 197 p. 58). Lawson et al (2003) consider that there is not enough evidence that the models that outline the design process describe what actually occurs during design development. When referring to organisational models that map the process, Lawson et al (2003) claim that process maps and procedures are limited descriptions of activities. Their study suggests that there is ‘a common failure and reluctance to use process maps’ which is shown by ‘the frequently observed gap between intentions and practices’ (Ibid p.338). According to Lawson et al (2003), maps are a simple’ guidance through the main critical stages of the project’ (Ibid p. 139).

In his analysis of design thinking, Rowe (1987 p.34) maintains that the process has an ‘episodic structure’ due to the ill-defined nature of design problems. In his seminal work, Schön (1983 p.241) compares the design process to a conversation between the designer and the problem: ‘surfacing, criticizing, restructuring and testing of intuitive understandings of experienced phenomena’

The design problems could be considered as multifaceted entities that evolve and change dynamically due to the synergy between the components (Schön 1990 p.16-17). The problem-solving process requires the integration of a complex set of parameters to attain an acceptable solution. As a consequence, the official structures that assume the linearity of the process could interrupt the natural process of reflection-in-action if ideally mapped procedures (prescriptions) are forced within the workflow (Schön 1990). A similar point is made by Suchman (1987 p. 21-46) when she argues how models and plans cannot impose how people act. Reasoning in design settings could hardly be linear because problems generally involve a subset of contesting issues and feedback loops (Rowe 1987 p.56). Lawson (2005 p.387) suggests that ‘in architecture the solutions and problems map onto each other in messy ways that so far we have been unable to describe formally’.

Design can be viewed as a social process of negotiation. Bucciarelli (1994) compares the design process to the negotiation of worldviews in the context of team work. Such negotiation embodies the notion of a social construction where controversies arising are settled during the problem-solving. Bucciarelli (1994) also acknowledges that prescriptive formal structures may hinder the negotiation and create tensions in the team. Hence, he advocates for reflexivity in acting, reacting and negotiating during design. He also recommends to ‘remain sensitive to the full breadth of social context and historical setting’ (Ibid p.20). Cross (1982; 1999) highlights that common, shared understanding cannot be assumed in collaborative work. Besides being a technical process and a cognitive activity, design is a social process. Coyne (2005) argues design involves the solution to wicked problems so it is necessary to consider the social practices that influence the design process.

This literature questions the purely rational models that prescribe the process and reduce it to a rule-checking continuum governed by the logics of optimisation. The rational model offers rigour to the science of design but it excludes the social context that could affect the process. As this investigation explores and compares the design in action for low carbon design, the analysis draws attention to the design as a process of reflection and negotiation. The problem-solving is based on the understanding of the solution gained as a result of the designers' collective engagement and participation in the social context of the process. Therefore, this research adopts the 'reflection in action' (Schön 1983) and the 'worldview negotiation' (Bucciarelli 1994) models to analyse the nature of the design process.

2.3. Social perspectives

Social theories argue that the reality is constructed in relation to the social context. Reality is influenced by the environment where it is embedded and it is subject to interpretation in relation to the social context. The social context is the physical and social location where people interact and develop as part of the group. It comprises the beliefs, paradigms, motivations, attitudes, habits, repeated patterns of action that unfold during the interactions between individuals. The social context is what (Berger and Luckmann 1967 p. 16) calls 'social location' and (Suchman 1987; Brown and Duguid 1994; Lave and Wenger 1999) name 'situatedness'. The social theories are focused on 'the relationship between human thought and the social context within which it arises' (Berger and Luckmann 1967, p. 16).

Berger and Luckmann (1967 p.147-204) consider that the society is the product of objective and subjective realities. As an objective reality, it is the result of institutionalisation and legitimation while as a subjective reality it is the product of the internalization of reality, social structure and identity. The individuals who are part of a social group create common frames of reference and meanings due to their daily interactions which result in typifications, habitualized actions, institutionalisation and legitimation.

Typifications are interpretations that entail a common meaning. Habitualized actions are repeated patterns that 'have retained their meaningful character for the individual although the meanings involved become embedded as routines in his general stock of knowledge' (Berger and Luckmann 1967 p.71). 'Institutionalisation occurs whenever there is a reciprocal typification of habitualized actions by types of actors' (Ibid p.71). Legitimation is the creation of new meanings that integrate various existing meanings, conferring them 'cognitive validity' and a new significance that is widely adopted by the members of the society.

Berger and Luckmann (1967 p.87) argue that the 'potential actors of institutionalised actions must be systematically acquainted with the meanings'. Thus, this investigation proposes to consider the notions of ***official*** and ***informal***. In such way, the notions of institutionalisation and legitimation could be reapproached. According to the Oxford English dictionary (2013) these are the definitions of the terms official and informal:

Official: 'subservient to some purpose; derived from, authorised or supported by a government or organisation; hence (more widely) authoritative'.

Informal: 'not done or made according to a prescribed form; not observing established procedures or rules'. In linguistics, this term refers to 'a structure suitable to everyday language rather than to official or formal contexts'.

In other words, the official refers to what it is derived from the government and organisations for the purpose of facilitate low carbon design. The informal is defined as what is made within the social context, outside the mainstream of the official. For the purposes of this investigation, the informal mirrors the connotation of 'dirt' by Douglas (1966). Douglas (1966, p.3) defines dirt as the patterns that do not fit into the official structures. The concept of dirt refers to aspects that do not match the descriptions and expectations that outline how things are supposed to be and behave (Ibid p. 30-41). Thus, the informal is a form of "dirt" that arises from the existing social structures, preferences and habits in comparison to what it is expected or prescribed by the official. It is important to consider the dynamics between the official and the informal because there could be some degree of friction between them which is likely to arise within the social context.

In the context of low carbon design, social perspectives are relevant to reveal the adoption and enactment of the policy model in practice. If design teams are considered as social groups where typifications, habitualised actions, institutionalisation and legitimation occur, imposing new requirements may demand the designers to reconfigure the process and reformulate the relationships to achieve the policy aspirations. New frames of reference could potentially emerge to react to the changes proposed by the policy agenda. The introduction of the 'official' as an external element could interfere with the existing structures rooted in routine design practice. The literature reviewed in Chapter 1 show that some of the difficulties in the adoption the low carbon policy agenda arise from the cultures in the building industry. Thus, this investigation is focused on the relations between the official and the informal that are engendered in the social context of the design process.

2.3.1. Social theories applied to low carbon design

This investigation considers low carbon design as a process of social construction where shared repertoires and goals are negotiated in the social context. By using social theories as the theoretical framework to investigate the design process, the researcher seeks to unveil the influence of the social context in the implementation of the low carbon policies.

As identified in the literature review in Chapter 1, the policy model has three strands for the implementation of low carbon policy intentions: the regulations, market incentives and educational schemes. The regulatory strand is related to the provision of standards and tools for compliance and the education schemes aim to disseminate information, regulations updates and best practice recommendations. The enactment is prone to rely on info-centred and tool-oriented approaches that reduce the design process to a cognitive logical optimisation endeavour. According to that model, the designers are considered to be rational agents that immediately incorporate the policy model into the design process. This research questions the info-centred and tool-centred based interventions that intend to produce change toward performance-based processes. Instead of assuming the immediate adoption of the policy model by designers, this research investigates the adoption of the policy model in relation to the social context and during routine design process. There is a narrow focus on knowledge and tools invoked in the problem-solving process to question the info-centred and tool-centred approaches advocated by the rational models.

2.4. Knowledge from a social perspective

The rational models applied to knowledge management tend to overemphasise on the capture of explicit information while ignoring the value of experiential knowledge. The policy model tends to be focused on the dissemination of information updates as part of educational schemes. Without underestimating the value of these initiatives, they overemphasise on the explicit information as design input, neglecting that tacit knowledge is needed to solve ill-defined problems. The designers 'develop new connections between applied science and reflection in action… practitioners need to reflect on their own tacit theories of phenomena of practice' (Schön 1990 p.321). Berger and Luckman (1967, p.28) argue that 'knowledge is socially distributed' and that 'depending on the social span of relevance of certain type of knowledge and its complexity and importance in a particular collectivity, the knowledge may have to be reaffirmed through symbolic objects and or symbolic actions. In other words, physical objects and actions may be called upon as mnemotechnic aids'. This argument highlights the significance of the social context in the process of knowledge creation. It also suggests that the knowledge flows could be facilitated by physical objects (tools) and actions (patterns of behaviour) in relation to the social context.

This section elaborates the concept of knowledge from a social perspective, comparing the notions of 'information' and 'knowledge'. It articulates the concept of knowledge in the context of communities of practice to highlight the forms of knowledge creation and dissemination within groups.

2.4.1. Information and knowledge

The discussion about information and knowledge refers to the notions of human mind to clarify the differences and relations between those terms. Ryle (1949 p.27-33) argues that information is related to 'know-that' aspects while 'know-how' implies understanding and therefore a higher level form of knowledge. Ryle (1949 p. 46) claims that the application of know-how 'is a disposition, but not a single track disposition like a reflex or a habit. Its exercises are observances of rules or canons or the application of criteria, but they are not tandem operations of theoretically avowing maxims and then putting them into practice'. He insists that 'Learning how or improving in ability is not like learning that or acquiring information. Truths can be imparted, procedures can only be inculcated, and while inculcation is a gradual process, imparting is relatively sudden (Ryle 1949 p.59). Polanyi (1966) defines tacit knowledge as the type of knowledge that people possess but cannot be immediately articulated. He argues that we know more than we can tell. The tacit knowledge is acquired through practice and it could be disseminated by social interaction. The tacit knowledge is a type of knowledge that is embodied in the abilities and skills that are not immediately transferable. The tacit knowledge is acquired as the result of experience and it is decoded through practice. The explicit knowledge is the knowledge that has been 'articulated, codified and stored in certain media. It can be readily transmitted to others. The explicit and tacit knowledge are complimentary and are not mutually exclusive.

Nonaka and Takeuchi (1995) develop a discussion about how information and knowledge are interwoven in a conversion process that spans by the means of:

1. Socialisation between different knowledge agents (conversion of tacit to tacit); i.e. conversations to exchange experience

2. Combination (conversion of explicit to explicit); i.e. the use of a formulae to solve a specific mathematical exercise

3. Externalisation (conversion of tacit to explicit); i.e. the formulation of a principle to explain a phenomena that has not been articulated before
4. Internalisation (conversion of explicit to tacit) i.e. the application of a medical principles from a medical book to the diagnose of a disease and the proposal of a treatment

It is important to clarify that there is no clear boundary between tacit and explicit knowledge. These knowledge dimensions overlap in the problem-solving. A typical example is the knowledge and skills necessary for driving. Learner drivers need to learn how to manoeuvre the car, read the road conditions, spot hazards and react while driving. The development of driving skills is not only a matter of being acquainted with the driving recommendations, codes and regulations. It also requires the ability of the new driver to apply those principles in real driving conditions. As the driver gains experience, the underlying principles that guide his driving become part of the driving routine. Thus, they do not need to be explicitly articulated or constantly reminded.

On the analysis of the work of the American philosopher John Dewey, Hickman (2009) suggests that Dewey's definition of understanding (know-how) and skills refers to 'the result of experimental activity that sharpens vague experiences and brings them to a useful conclusion' (Ibid p. 199). Understanding entails the ability 'to perform various functions, such as getting additional data about some problems that we want to solve. It would serve as a key that opens the door to lots of new ideas and new data' (Ibid p.199). According to Dewey, 'genuine or robust learning involves much more than getting control of the usage of nominal concepts. It involves a scientific understanding of situations' (Hickman 2009 p.196). According to Jung (2010, p.155), Dewey suggests that 'a mere contemplative understanding of knowledge and/or consciousness does not suffice, because they must be intrinsically related to action'. Johnson (2010, p.132) suggests that Dewey's definition of knowledge embeds the notion of 'Thought as embodied cognition… The meaning of a situation grows as we mark more differences, similarities, changes and relations: that is, as we are able to make finer discriminations within the ongoing flow of experience. Cognitive processing does not occur merely in a linear direction from core to shell structures' (Ibid, p. 135).

In design cognition research, Lawson (2004a p.453) points out that 'designers seem to rely heavily on knowledge that is not so much theoretical or semantic but more experiential or 'episodic'. He suggests that designers seek information in a way that is not limited to mere information retrieval 'Knowledge of information sources is not explicit but held in minds rather than recorded in an organised manner and it is accumulated through practice rather than through instruction' (Ibid p. 453). Bucciarelli (1994, p.143-149) refers to the 'ecology of design' as the complex and multidimensional features of the design environment that confines and shapes the ways people interact between them and within the process. The fuzzy and unclear design process make difficult for designers to articulate, archive and retrieve knowledge (Lawson 2004b). A vast amount of design knowledge might not get translated to explicit knowledge.

Dreyfus (1999 p. xi) argues that the symbolic information-processing model of human thought is 'atomistic' and unrelated to the involvement in the ongoing activity'. He suggests that '… common-sense knowledge [for problem-solving] was not really about how to represent knowledge; rather, the everyday commonsense background understanding that allow us to experience what is currently relevant as we deal with things and people is a kind of know-how'. The common-sense background may be similar to the social context that creates the reference to enable low carbon design. Information should be linked to social context of use to identify how people understand and make sense of such information (Brown and Duguid, 1994 p.129). Brown and Duguid (2000 p. 5) suggest that 'attending too closely to information overlooks the social context that helps people understand what that information might mean and why it matters'. According to Brown and Duguid (2000 p.72), incidental learning is essential to powerful learning environments. Embodied, inarticulate skill and judgement are the result of experience (Ibid p.80); therefore, 'learning requires more than just information. It requires the ability to engage in the practice in question' (Ibid p. 128). While Winograd and Flores (1987, p.74-75) claim that 'knowledge is always the result of interpretation which depends on the entire previous experience of the interpreter and on situatedness'. These literature suggest that the info-centred models for problem-solving are prone to overlook the judgement of the knowledge agent, the embodied knowledge and skills that enable to understand, judge and apply the information. Such notion could be applicable to design environments as design essentially involves the solution of ill-defined problems.

The problem with information-centred models for knowledge management is their tendency to ignore the social context and the human dimension of knowledge applied in practice. The postulates of this literature suggest that the knowledge required to design low carbon buildings is not limited to written documentation or information inscribed the form of standard, regulation updates or best practice recommendations. Such information needs to be assessed by the designer in relation to the problem-solving activities where understanding, knowledge and skills are exercised. The focus on information and knowledge capture placed by the rational info-centric approaches to knowledge management and learning are questioned by this investigation. This research seeks to reveal how the designers are using the information available for low carbon design. This approach requires the use knowledge theories that account for the role of the social context in the knowledge creation, flows and dissemination in practice such as Communities of Practice theory.

2.4.2. Knowledge in communities of practice

Community of practice is a social theory of learning that argues that knowledge is the competence gained through social participation in an enterprise (Wenger 1998; Burton and Tusting 2005). A community of practice is a group of people who share common interests in a domain. The social interaction between the members of the group contributes to the construction of common meanings, shared repertoires and identity. The skills obtained by working together, sharing information and experiences enable the members of the community to learn from each other and collectively. It is noteworthy that communities of practice are groups that could span the organisational boundaries such as hierarchies and job charts (Wenger 1998, p. 49). The boundaries that bring together a community could be the subtle demarcation of a tacit social structure in relation to the knowledge resources (Wenger et al 2002 p. 149).

The key postulate of the Communities of Practice theory is that knowledge is socially created and enhanced by members of the community and their interactions. Wenger (1998 p. 47) claims that ‘people are vehicles for information, resources, ideas and feedback to others’. Lave and Wenger (1999 p. 93) point that learning is a social process that occurs when being engaged in practice and that ‘[knowing] is located in relations among practitioners, their practice, the artifacts of that practice and the social organisation…’ (Ibid p. 122). Their argument suggests that the process of learning is the result of the engagement in the community (the social context), which they call ‘situated learning’. Situated learning is argued to be the result of a cognitive process and a social practice.

In design cognition, Communities of Practice principles are aligned to the concept of reflection in action by Schön (1983) and Bucciarelli’s postulate of negotiation of worldviews (Bucciarelli 1994) as discussed in the section about the nature of the design process. Schön (1983 p.242) claims that ‘organisations are repositories of cumulatively built-up knowledge’. Such claim could include the communities of practice as a social organisation. Thus, the Community of Practice theory fits into these descriptions that compare design to a social process.

For this design process investigation, the Communities of Practice perspective draws attention to the role of the social context in problem-solving environments such as design. It focuses on how the interactions between the members enable the creation and dissemination of knowledge and facilitates the problem-solving activities.

2.4.3. Knowledge management and dissemination

In terms of knowledge dissemination and management in building the industry, there is a variety of perspectives which range from rational approaches focused on information capture to the views addressing the relationship between tacit and explicit knowledge. In general terms, this literature recognises the difficulties in capturing knowledge and transfer the experience gained on the projects and the human dimension of knowledge. The procedural aspects of knowledge exchange and creation are recognised to be supported by the social context. Attention has been drawn to the limitations of the rational perspectives that follow an info-centred knowledge model. The literature in this section has been group in the following themes:

- Tacit and explicit knowledge conversion (Richard et al 2001; Woo et al 2004; Heising et al 2010; Bertola and Texeira 2003; Froese 2010; Demaid and Quintas 2005; Egbu and Carillo 2005)
- Development of knowledge management tools and strategies (Kamara et al 2002a; 2002b; Dave and Koskela 2009; Tang et al 2010; Kwan et al 2006)
- Social aspects that affect the knowledge creation (Carrillo 2005; Olomolalyle and Egbu 2006; Suresh and Egbu 2006; Suresh et al 2008; Graham and Thomas 2008; Bresnen et al 2003; Senaratne and Sexton 2008; Jackson and Koblas 2008; Olivera 2000; Tryggestad et al 2010; Berente et al 2010; Stokes and Dainty 2011; Bresnen and Harty 2010; Sage et al 2010; Styhre and Gluch 2010; Schweber and Harty 2010; Carlile 2002)
- Problems with information-centred knowledge views (Felmand and March 1981; Vaughan 1999; Pan and Scarborough 1999; Henderson 1991; Busby 1998; Lawson 2004b; Cook and Brown 1999; Rowlison and McDermott 1999; Brown and Duiguid 2000)

The literature recognises the challenges in the knowledge conversion process due to the tacit and explicit components. The knowledge intensive industries such as the building industry lose opportunities of learning due to the difficulties to capture the knowledge created in problem-solving. Richard et al. (2001) discuss the difficulties to convert tacit into explicit knowledge which prevents the acquisition and dissemination of knowledge within organisations. Knowledge exchange protocols are suggested to improve the conversion process. Woo et al. (2004) develop a theoretical discussion about the tacit and experiential knowledge in the building industry and introduce a software to assist the reuse of these types of knowledge and facilitate the communication between experts and enhance the knowledge transfer. Heising et al. (2010) identify the knowledge and information needs of engineering. Bertola and Texeira (2003) report a phenomenological study of thirty case studies of product development and business innovation. They suggest that the knowledge cannot be isolated from practice and problem-solving activities. The knowledge management structure should be informed by the design activities embedded in the practice. Froese (2010) advocates to couple the technical and management processes to improve the information and communication technologies in the building industry. He considers that changes should integrate the project management, the information, the tools and the procedures of the process. Demaid and Quintas (2005) use two case studies, one of them in the UK to explore the knowledge management processes in the building industry highlighting that enactment of the process in action is unlikely to follow best practice advice by academic and management research. They also suggest that policy changes are leading to unexpected responses by practitioners and particularly when sustainability issues are required. They acknowledge that the creation of knowledge is difficult especially when the capture is to be done by formal documents and procedures as 'formally represented systems clearly require a great deal of situated knowledge to make them work in specific national context…' (Ibid p. 605). Demaid and Quintas (2005) suggest that knowledge management initiatives in the industry should be informed by the sustainability and risk fields in terms of rules and socio-economic behaviours.

Other knowledge management studies have addressed the problem of knowledge loss by creating formal systems and tool to enable and facilitate knowledge flows. In relation to knowledge capture tools, Kamara et al. (2002a; 2002b) propose a cross-sectorial learning in the virtual enterprise research (CLEVER) project framework, with focus on the organisational and cultural dimensions of knowledge management. It suggests that the tool-centred approach should move towards people centred strategies. Dave and Koskela (2009) propose a web 2.0 internet forum to systematise the discussion of ideas and feedback to contribute to knowledge management. Tang et al. (2010) compare the building industry to the aerospace and automobile industries and suggest ways to learn from other industries in terms of information storage and retrieval strategies and comparing methods of knowledge management. Kwan et al. (2006) explore the managing process and knowledge sharing across organisations through a case study to establish the characteristics of the managerial structure to include key processes for the organisational learning.

Other studies that propose tools and strategies for knowledge management include Carrillo (2005) suggests how to record lessons learned for future retrieval. Olomolalyle and Egbu (2006) discuss the interfaces between knowledge sharing initiatives and human resources management. Suresh and Egbu (2006) propose to implement knowledge capture initiatives to improve small and medium scale enterprises in the UK. Suresh et al. (2008) argue that knowledge management initiatives involve complex management practice. They advise to include methods, leadership, strategic alignment, technology, people and culture. Graham and Thomas (2008) remark that CPD activities are not well linked to the knowledge need in practice and that the databases are rarely used. They recommend to promote dialogue and dissemination programmes to benefit from collective experiences.

The literature has considered the relevance of the social aspects in the creation of knowledge. Bresnen et al (2003 p.158) argue that the social influences ‘the nature of knowledge and learning and the impact they have upon attempts to codify and commodify knowledge’. Bresnen et al (2003 p.158) highlight that there is ‘very little detailed analysis available of the social mechanisms that support knowledge sharing, especially across projects and the communities that they link together’ and identify the need to know ‘what part social processes play in the creation and diffusion of knowledge and learning and how these social processes relate to the use of technology and other mechanisms specifically intended to capture and transfer knowledge and learning from projects’ (Ibid p.159). Senaratne and Sexton (2008 p.1303) argue that ‘problem-solving is increasingly recognized as a knowledge creation trigger’ and they propose a method to enhance the knowledge conversion process in the building industry. They suggest that knowledge should be managed both from the social and technical systems. In the analysis of knowledge creation, Jackson and Klobas (2008) warn that systems that do not respect the social context are doomed to failure. Olivera (2000) investigates the characteristics of organisation’s memory systems and identifies a variety of social systems that are part of the knowledge systems such as social networks, intranet, electronic bulletin boards and knowledge centres. He suggests that social networks have unique features that other memory systems lack. They enable different types of experiential knowledge and help to identify the location of knowledge in other systems and link dispersed knowledge (Ibid p. 287).

Examples of studies that have addressed the social component of knowledge creation are Tryggestad et al. (2010) who suggest that the practitioners struggle to reuse old knowledge in new practice, Berente et al. (2010) who discuss the tools for knowledge management in the social context, Stokes and Dainty (2011) who address the knowledge co-production in construction research, (Sage et al. 2010) who analyse knowledge tools in construction management, (Styhre and Gluch 2010) who explore boundary objects, stocks and flows of knowledge and (Carlile 2002) who discusses knowledge flows in boundary organisations and the mediating role that material artefacts and social processes in aligning the collective interests; to cite few.

Another strand of knowledge research highlights the problems with info-centred knowledge approaches due to their tendency to underestimate the influence of the social context. Feldmand and March (1981 p.24) suggests that 'masses of information are not useful, except in a symbolic sense'. Vaughan (1999) criticises the formal procedures prescribed by organisation since the may affect the natural processes of reflection and knowledge creation. She warns that information technologies give the 'illusion of completeness, masking the incompleteness of all information'. Pan and Scarborough (1999) suggest that the formal knowledge management procedures in organisations can interfere with the knowledge-production process, constraining knowledge dissemination and flows. Henderson (1991) claims that coordination and conflict take place as the components of the social organisation of collective cognition and the locus for practice situated and practice-generated knowledge. Busby (1998) questions the way in which design organisations attempt to create a tractable environment because that may interfere with feedback and learning processes. Lawson (2004b) suggests that despite the use of sophisticated information systems, there may be little transfer of knowledge in organisations working in similar type of projects overtime. Cook and Brown (1999) argue that there is a need to address the non-transferrable or situated dimension of knowledge and knowing and enhance the knowledge creation within the organisations. These examples emphasise on the collective creation of knowledge and the relationship between individual knowledge and organisational learning.

As shown by this review, there is an extensive body of literature in the field of knowledge management that has adopted a social perspective to discuss knowledge flows and creation in the building industry. This investigation builds up on those precedents to study the knowledge creation and knowledge flows in the design process in action as a result of the regulatory requirements.

It is important to identify effective mechanisms for learning and disseminating low carbon knowledge that withdraw from the methods and working practices preferred by the designers. Any initiative to foster the knowledge dissemination should consider the flows that occur in the design process. Therefore, initiatives for the dissemination of low carbon information and regulation albeit educational, might not be immediately translated by designers into the knowledge to embed energy performance while designing.

In summary, these literature draw attention to the influence of the social context in the knowledge creation and knowledge flows. The postulates in this section contest the rational models focused on the capture and retrieval of explicit information. The use of low carbon information and the transference of knowledge for design are examined by looking at the following aspects:

- *the knowledge creation and flows in the design process*
- *the influence of the social context in the dissemination of knowledge*
- *the ways that knowledge management systems are being used during the design process*

2.5. Tools: a social exploration

This section presents postulates conceived in the fields of philosophy of technology and human-computer interaction. These fields analyse the interaction between humans and machines. Philosophy of technology theorises about the social effects of technology in everyday life and vice versa. The field of human-computer interaction studies the interface between humans and machines that embed knowledge. The postulates discussed in this section use a variety of terms to refer to what this investigation calls 'tools'. Some of the terms are 'instrument', 'object', 'artefact', 'technology' and 'device'. In spite of the different terms used, they all embody the notion of 'means to an end' and 'external element'. Another commonality between the references in this section is that they raise attention to the challenges of incorporating tools in the context of use. The references presented in this section highlight that tools could be external elements that require a process of incorporation in the existing social context.

The examination of tools in the social context seeks to increase the understanding about the use of tools and their contribution to implement the low carbon aspirations during project design. As suggested by the 'Simulation tools' section 1.5 in Chapter 1, the tool-centric approaches might neglect the human dimension in the use of tools. These references, as well as those included in this sections contest the validity of the rational assumptions that presuppose the immediate application of 'external elements' (the official) by the designers in the process.

Firstly, the definition of 'tool' is outlined to clarify the notion adopted in this investigation. Then, a discussion is elaborated to raise attention to the human-tool juncture and the potential challenges of incorporating tools in their social context. Finally, research about the use of tools as aids for designers is summarised.

2.5.1. Definition of tool

Dewey's definition of tools has been adopted in this investigation as it broadens the notion of 'means to ends' in the social context. According to Dewey (Cochran 2010; Hickman 2009; 2011), tools help to configure meanings; they are means to consequences in a broad sense that is not limited to their physicality. Dewey's notion of the term tool includes linguistic symbols and concepts whose purposes could precede their material conditions (physicality), for example, expert advice could be a means to solve a problem. Therefore, the term 'tool' embodies the broad concept of means to end; whether the tool is physical or conceptual.

2.5.2. Human-tool juncture

The perspectives presented below criticise the tool-centric approaches that reduce human action (and problem-solving) to a deterministic model where the tools fit into the process regardless of the features of the social context where the tools are to be incorporated. In her study of an artificial intelligence application, Suchman (1987 p.20-47) uses the analogy of what plans are to human action to illustrate the potential role of technologies and computers. She argues that 'the communicative significance of a linguistic expression is always contingent on the circumstances of its use' (Ibid p. 41). As linguistic representations, plans are efficient formulations of situated actions that need to be interpreted under the specific circumstances of use (Ibid p. 46-48). Her argument highlights that maps, as external elements, do not determine action; it is absurd to believe that maps can control a travellers' movement (Ibid p. 46). This argument is likely to be applicable for tools in the context of design. When Suchman mentions 'the unique circumstances and unarticulated practices of situated activities', she is referring to the social context.

Winogrand and Flores (1987 p.6) claim that 'the significance of a new invention lies in how it fits into and changes its network… [what produces] new domains of possibilities of the network of human interactions'. They advocate for the consideration of the social context where technologies are to be incorporated and recommend 'a holistic view of the network of technologies and activities into which it fits' (Ibid p. 6). Winograd and Flores (1987 p.8, p. 179) advocate the need to understand the complexities of design thinking to avoid erroneous interpretations about the role of computers in the context of human practice. In his seminal work about designers, Lawson (1997 p. 72) reinforces this view and argues that 'designers need to have some feel for meaning behind the numbers rather than precise methods to calculate them… strategic decision rather than careful calculation'. Lawson's argument questions the role of tools within the design process suggesting that designers' goal is not necessarily accuracy but understanding. Understanding could be gained without invoking calculation tools.

Borgman (2004 p.114-136) explores the limitations of conventional ways of thinking about technology if the social context is disregarded. Hodder (2012) uses Gibson's concept of affordances to refer to the potential of an object to enable particular actions. Hodder suggests that although the affordances are latent, their realisation requires the ***association of objects and situatedness'*** (Ibid p.52).

Ihde (2004 p. 130) argues that '***an object 'is' what it is in relation to its embedded cultural matrix***…' and he points out at the ambiguity in the 'human-technology juncture: 'Our actions are embedded in the multiple ways we interact with and presuppose our technologies, yet this multiplicity remains perceptually and praxically ambiguous' (Ibid p.68). Ihde (2004 p.140) argues there are <u>two flawed assumptions about tools</u>:

1. they are merely instrumental and therefore neutral; and,
2. they are completely determinative and therefore uncontrollable.

He claims that both positions ignore the relativity of the relations ***human-technology*** and ***culture-technology***. While technologies provide a 'framework for action'; they are defined by existing use-patterns intentions and preferences (Ibid p.140). (Ihde 2004 p. 139) uses the term 'double ambiguity' to refer to the 'trajectories of development' in relation to the 'instrumental intentionalities' of objects. The trajectories of development are the ways how the user uses the tool and the instrumental intentionalities are the expected uses anticipated by the tool developer. The double ambiguity 'introduces a certain indeterminacy to all human-technological directions' (Ibid p. 139). As a consequence, tool developers' intentions play only a small part in the subsequent history of the artefact'. The history of technology shows that technologies are part of 'a multiplicity of uses, few of which were intended at the outset'. 'There are only things in contexts and contexts are multiple…' (Ibid p. 69). (Ihde 2004 p.70) points out that 'a technological object becomes what it 'is' through its uses. This is not to say that the technical properties of objects are irrelevant, but it is to say that such properties in use become part of the human-technology relativity' (Ibid p.70).

Ihde (2004 p.139) advocates to understand technology in the context of use to reveal the double ambiguity: 'by placing technology within a cultural context, the two dimensions of the essential structural ambiguity of technology may be reapproached', the trajectories of development and the instrumental intentionalities. He suggests that 'the positioning of technologies as belonging to a continuum of relations and links their essential artefactual properties within human praxis…' (Ibid p. 112)

The human-tool juncture discussed by Ihde (2004) has been addressed in the user-the field of human-computer interaction and in user-centred design. For instance, Brown and Duguid (1994 p.19) suggest that 'different communities use objects differently', Suchman (1987) refers to 'unique circumstances and situated practices', Berger and Luckmann (1967, p.112) highlight the 'common frames of reference' and Bucciarelli (1994 p.24) advocates to examine the tools in 'the several dimensions spanning the social fabric of a community'. Cetina (1997) has addressed the tools as objects for the social production of knowledge. These precedents bring attention to the consideration of the relationship user-tool in action.

2.5.3. Tools according to Human-computer interaction studies

In human-computer interaction field, the instrumental genesis model presented by Rabardel (2003) is a theoretical framework to analyse the incorporation and roles of tools. This model employs a system view that recognises that artefacts and users interact in the wider social context. Therefore, the use of artefacts is relative to the cultural and social dimensions. Studies that have applied the instrumental genesis perspective are Tuikka and Kuutti (2000) who consider that the artefacts can adopt different roles in praxis; Crilly (2010) addresses the non-technical and culturally accepted understandings using a motor car example; Pfaffenberger (1992) suggests that the technological processes and artefacts can be subject of multiple interpretations; Masino and Zamarian (2003) raise attention to the tailoring of artefacts, Kaptelinin (2003) highlights the difference between design for use and design in use.

In a variety of fields, there is a growing recognition that tools could be deployed in numerous ways when invoked in action and in interaction, in relation to the task, to the context of use and to the users. Pascal (2003 p. 714) suggests that the design of artefacts [should be looked] as a mutual learning process between users and designers of artefacts, Visser (2009) suggests that the social context influence the artefacts' impact on people's activities. Kroes (2002) argues that artefacts are deployed in relation to the object word negotiation so there are differences between the community of designers and the community of users. However, though he advocates for a process oriented and normative design methodology. Lave and Wenger (1999 p.101) argue that 'understanding the technology of practice is more than learning to use tools; it is a way to connect with the history of the practice and to participate more directly in its cultural life'.

2.5.4. Tools in architectural and engineering design

In architectural and engineering research, some precedents have addressed the use of tools from a social perspective that acknowledges the human-tool juncture. For instance, Bucciarelli (2002) suggest that artefacts facilitate the communication, negotiation, learning and living the language. Baxter and Berente (2010) discuss the IT artefacts and point out that new tools are introduced to old systems and routines, leading to new configurations of practice. Tweed (2001) addresses the context when discussing the introduction of CAAD in design practice. He points out that one of the main shortcomings of design research is the stereotypical and totalising view of the end-user that defines a single type of designers, which neglects to consider the beliefs, norms, values and history of end-users that fall outside the ideal type (Ibid p.624). Tweed (2001) suggests that the lack of context to understand the use of CAAD may result in misleading conceptions about the role of CAAD as a design tool. Coyne et al (2002) discuss the role of devices and their affordances in relation to the context. He uses the 'evolutionary metaphor' to highlight the dynamic nature of devices. He suggests that the 'complex ecology of devices' includes notions of derivation, improvement, survival, suitability to purpose, adaptation, inheritance of features, and recombination. Perry and Sanderson (1998 p.286) argue that 'design work is not a linear process but a situation in which joint, coordinated learning and work practices evolve and in which the artefact help to mediate and organise communication'. They acknowledge that 'the informal means enable rich and varied communication and that the technology is unlikely to improve this directly'. Jagodizinski et al (2000) criticise some new technologies because traditional approach to incorporate change based on technology might overfocus on technical and informational aspects while overlookin the social systems. Gabriel and Maher (2002) recommend that tools for collaboration shall be informed by the understanding of the how collaborative work develops, the resources and challenges deployed by the people engaged in collaboration.

In his discussion about 3D CAD software, Harty (2008 p.1026) points out that the tool developers 'endow the technological artefacts they produce with certain assumptions and constraints based on their visions of intended users and these scripts of use allow certain ways of using and prohibit others. Importantly, these scripts represent not only attempts of developers to satisfy user requirements, but also the developers' own expectations and associations.' He brings attention to the fact that 'technologies could not be brought into the project without bringing with them the displaced or delegated intentions of their developers, in terms of imagined users and desired ways of using' (Ibid p. 1036). Chastain et al (2002 p.239) suggest that the 'tool makers hold an image of practice which is articulated in the assumptions made about the kinds of affordances needed', so when a new technology is to be adopted 'a dysfunctional relationship can develop between the tools and the task' (Ibid p.239). They argue that 'while rule based expert systems may appear attractive for capturing design knowledge due to their modularity, they are, in fact, highly personalised, arbitrary expressions of knowledge and operational practices' (Ibid p. 242). Chastain et al (2002 p.242) argue that 'although some rule-based systems are successful at what they were intended to do, they must often be accepted as 'black boxes, which are difficult if not impossible to evolve, modify and adapt by anyone other than their authors'.

This section has discussed literature that have analysed the use of tools in architecture and engineering settings. However, the focus of these studies has been mainly representation support (CAD, drawing) rather than energy assessment analysis or performance-based design.

2.5.5. Tools in low carbon design

The idea of 'ready-made' tools has been contested by this literature. It is argued that the user defines the roles of the tools. That correlates to the concept of affordances by (Gibson 1979), the double ambiguity by Ihde (2004), the borderline issues by Brown and Duguid (1994), the unique circumstances and situatedness by Suchman (1987). The notions of mutability and object-in-use suggest that the tools are likely to be recast and used for purposes beyond those anticipated by tool developers. Tools for low carbon design are in this sense no different to any other tools and could be similarly affected by social context.

The propositions of this literature highlight the possible problems in the immediate incorporation of tools as anticipated. The literature bring attention on some of the shortcomings of the rational predictions about the use, role and contribution of the official tools to assist low carbon design; and ultimately, realise the policy agenda. It is necessary to understand the social context of design and observe whether the 'official' is part of the process and how it becomes part of it. Equally, the consideration of the 'informal' enables to identify the 'frames of reference', 'situated practices and circumstances' and 'shared repertoires' engendered in the social context which tend to be less explicit to those who are not part of the community. As any external structure, the official compliance tools could become prescriptions imposed in the design process. Therefore, the official might interfere with the design process by instigating conflicts on existing structures.

Thus, a socially-led approach is employed to analyse how the tools are used and incorporated in the design process. For the purpose of this investigation, tools are not limited to 'official' or 'external structures'. The Dewey's notion adopted in this study comprises physical and conceptual tools, official and informal.

Therefore, the following aspects will be investigated in relation to tools:

- *The official and informal tools in the design process and their relationship to social context*
- *The human-tool juncture in low carbon design*
- *The trajectories of the use of tools and their links to knowledge for low carbon design*

2.6. The theoretical framework

According to the rational view, the design process is a sequence of problem-solving steps. The rational model tends to systematise and compartmentalise the design rigidly. The designer is reduced to a passive receptor of information in relation to knowledge. In relation to tools, the potential and perceived affordances of tools are not considered in the context of use. The info-centred and tool-centred approaches fit well in the rational model because the actions are regimentalised and prescribed linearly in an ideal albeit theoretical process. Implementing change and enabling interventions are reduced to technical challenges. According to this model, the external elements proposed to foster change are assumed to be immediately adopted in the process by designers. However, the social literature discussed in this chapter suggests that the social context is likely to affect the process and thus, the enactment of policy intentions.

The literature included in this review has been illustrated in Figure 2.1. The central discussion has comprised the nature of the design process, the knowledge and the tools for design (grey boxes). While the central discussion is focused on the social perspectives about those topics, the rational views have also been addressed to compared them and characterise the assumptions of the policy model (supporting references in white dotted boxes).

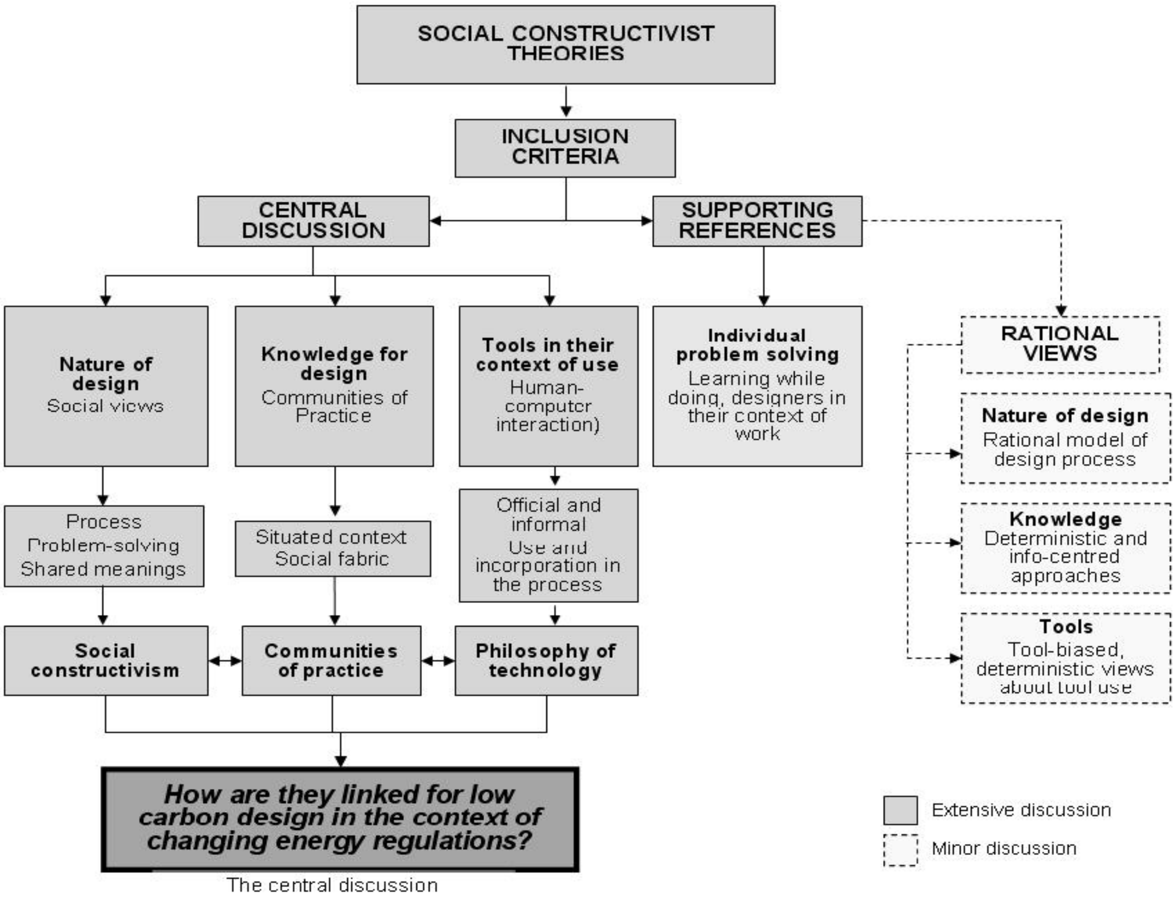

Figure 2.1. Themes addressed in the literature review

The comparison of the rational and the social literature suggests the following propositions concerning the nature of the design process, knowledge and tools:

	Rational perspectives	Social perspectives
Design process	Linear problem-solving seeking optimisation	Negotiation and learning while doing
Knowledge	Explicit, know-that Designers as passive receptors of information (info-centred bias)	Tacit, know-how and know-why Knowledge creation in the social context by reflection and dialogue
Tools	Technical challenge Power of the tool instead of empowering the user Focus on the output of the tool	Double ambiguity, need of incorporation in the existing social context Not just a problem-solving aid but also an element that mediates the design process and is part of the social context

Table 2.1. Comparison between the rational and social perspectives about the design process, knowledge and tools

The challenge of reducing the carbon emissions is unlikely to be limited to the definition of targets, the dissemination of legislation and information updates. The enforcement of a compliance target via standards and tools may not be sufficient to realise the policy aspirations. The new requirements may entail the restructure of the process which could become a hindrance towards the enactment of the policy agenda. As highlighted by the literature about implementing change in the building industry (chapter 1), the building industry may experience difficulties in incorporating performance-driven processes and reconfigure it so low carbon buildings move from demonstration to mainstream. The designers need to understand the requirements and have the skills and competences to make sense of the low carbon information and use the tools during the relevant problem-solving instances in the process. The knowledge flows and the use of tools are likely to be affected by the social context that underpins the process.

The main proposition of this investigation is that ***design is a social process of negotiation where the relationships between design team members enable the problem-solving activities, supporting the knowledge flows and facilitated by the use of tools***. The designers invoke different forms of knowledge and tools along the process, which might not fit the rigid descriptions of rational models. The design process is likely to be assisted by informal structures that emerged from the social context and facilitate the knowledge creation and performance understanding. This investigation relates the dialectic nature of the design process; the knowledge created; and, the tools invoked while designing. The synergies between learn about/learn to be, know that/know how, computer/people, database/community are to be articulated on this investigation to contribute to the critical debate about the policy agenda and its realisation in the design process. The observation of practitioners in action and the analysis of design process needs to:

- Identify what practitioners are doing as opposed to what they should be doing.
- Reveal the creation of knowledge, knowledge in action and its management in the context of low carbon design.
- Analyse the appropriation of the official, the use of the informal and the social context as part of the low carbon design process. The notion of appropriation implies the trajectory of the official tools from being adopted as an instrument prescribed by the policy model until it becomes part of the process.

The propositions summarised in the table 2.2. were obtained from the literature. The left column refers to the assumptions based on the rational perspectives. The social perspectives are the basis of the theoretical framework that guided the research. These propositions are not hypothesis to be tested but early postulates to create a generative model for research development and investigate how the low carbon policies are affecting the design process.

	Rational model assumptions	Social theories propositions
Nature of the design process	Embedding performance requires the access to low carbon information and the use of calculation tools to verify targets and achieve compliance.	Design is a negotiation of worldviews. Designers learn by doing.
Policy model for enactment	The official tools such as standards, compliance tools and models are adopted in the process and foster the implementation of performance-driven processes.	The official might contribute to low carbon buildings although as an external element, it could become a prescription. The informal (dirt) is part of the process. The social context (situatedness) of the design process might affect the enactment of the policy agenda.
Knowledge	Info-centred models contribute to the transference and dissemination of information to assist low carbon design. Therefore, databases and knowledge management tools for knowledge capture could facilitate the process.	Knowledge is socially created and distributed. Design knowledge could be constrained by knowledge management approaches that focus on the capture of explicit information.
Tools	Designers use simulation tools to as aids to predict the performance and assist the problem-solving and decision making. The tools fit in the process if following best practice recommendations.	The design process could be assisted by informal structures emerging from the social context. The tools for low carbon design could present the 'human-tool' juncture therefore it is necessary to understand tools in their social context.

Table 2.2. Assumptions of the rational model of policy enactment and propositions related to the key themes of this investigation

2.7. Research objectives and questions

As outlined in Chapter 1, the research objectives addressed by this research are:

- To identify the barriers experienced by designers working in low carbon non-domestic building
- To identify the models and routines that facilitate the understanding and the inclusion of low carbon performance in buildings during conceptual and detailed design
- To reveal the use of tools, in the broad, Dewey's sense, in routine project design
- To explore the social mechanisms that encourage the inclusion of low carbon considerations, their dissemination and learning across projects (social factors that enhance knowledge and learning)

The following research questions were explored in this investigation, based on the conceptual framework obtained in this review, illustrated in Table 2.2. (right column):

- What are the challenges experienced by practitioners due to the transitional changes in energy regulations?
- How does designer's enactment in action compare to the assumptions held by the policy model?

- How do designers embed energy performance during the design process?
    - What are the informal tools used by designers to assist the low carbon design process?
    - How is knowledge invoked, created and disseminated in the design process in action?
    - How are the official tools used in the design process?

In summary, this design process investigation analysed how designers embedded energy performance during real-time design development during the transitional energy regulation change in 2010 when Part L required a 25 per cent reduction of carbon emission in new buildings. Its propositions are:

- Design is a dialectic process. This notion recognises that the low carbon aspirations are constructed in relation to the meanings and frames of reference emerging from the social context.
- The policy model and its instruments are external structures that need to be incorporated by designers into existing patterns. Thus, there is a distinction between 'the official' and 'the informal'.
- The knowledge flows and the use of tools to embed energy performance are affected by the social context of design

The following chapter, Research methodology, will explain in detail the research design and the methods used for the data collection and analysis.

Chapter 3
Research methodology

3.1. Introduction

As discussed in chapter 1, a vast majority of studies about the implementation of low carbon policies by practitioners in the context of transitional changes have adopted ‘snapshot approaches’ such as surveys, questionnaires, interviews and focus groups. These literature, discussed in Chapter 1, have addressed the practitioners’ perceptions about the increasingly demanding energy regulations; however, little is known about how the designers incorporate the policy agenda in the design process in action. This work builds upon the research precedents that have explored the practitioners’ dimension so as to investigate in-depth how the designers are enacting the design process for new non-domestic buildings in the 2010 energy regulation transition. In order to explore what designers are doing to incorporate the policy agenda and why they hold particular attitudes and behaviours, this investigation has adopted ethnographic methods. This chapter presents the research design, the data collection, the data analysis and the limitations of this investigation.

3.2. Research design

Ethnographic research enables an in-depth understanding of meaning and experience engendered in a social context (Silverman 2005; Gobo 2008; Bryman 2008; Hammersley and Atkinson 1995). It allows the exploration of ‘the social issues and the behaviours that are not clearly understood’ (Angrosino 2007 p.26) by considering the influence of the social context in the creation of meanings, attitudes and beliefs held by a group (Lecompte and Schensul 1999 p.58). Pidgeon (1996, p.80) suggests that ethnography helps to study the ‘meaning of experience and behaviour in context and in its full complexity… grounded of concepts in data rather than their imposition in terms of a priori theory’. Berger and Luckmann (1967, p.34-35) suggest that ‘the phenomenological analysis enables to unveil different layers and structures of meaning’. O’Reilly (2004 p.10) argues that ethnography is valuable to discover what people do in specific settings and circumstances.

According to Hammersley and Atkinson (1995), ethnographic research describes in detail how action and meaning develops in a specific setting. It allows the rich analysis of the development of the processes and phenomena in their context of occurrence. Hammersley and Atkinson (1995) argue that ethnography is characterised by:

- its focus on the exploration of a social phenomena
- the small number of case studies that are investigated
- the interpretation of meanings and attitudes
- the immersion of the researcher in the environment where the social phenomena occurs

The contemporary ethnographic methods have been widely used in educational and medical research to investigate the problems that overlap between practice and policy dimensions. Contemporary ethnography is valuable as it could inform the recommendations for interventions withdrawing from the situated social context of practitioners (Delamont 2012; Hammersley 1992). Contemporary ethnographic methods are informed by theoretical grounds that guide the investigation and the theoretical enquiry. Therefore, they are not simply descriptive accounts of observations recorded in the field.

In design research, ethnography has been used as methodological approach to study practitioners in design and construction; for example, Bucciarelli 1984; 1998; Lloyd and Deasley 1998; Baird et al 2000; Ball and Ormerod 2000; Button 2000; Cross and Clayburn 1995; Gorse and Emmitt 2007, to cite few. In the ethnographic study about migrant construction workers, Pink et al (2010 p. 658) argue that 'ethnographic research can make visible informal (or unofficial) worlds of action, interactions and ways of knowing that can easily slip under the industry (or official) horizons of notice'.

Ethnography was selected as the suitable method to explore the meanings and behaviours in relation to the incorporation of the policy intentions, the use of tools and knowing in practice. The study examines the conceptual and the detailed design process of six non-domestic buildings developed by four sustainable architecture firms displaying different levels of commitment to designing energy-efficient or low carbon buildings. The study used ethnographic methods to compare how the designers embed performance in the design in-action.

Figure 3.1. shows that the research scope and the theoretical grounds used in the investigation. The low carbon design process is examined using a socially-led approach that explores the tools and knowledge in design. Those topics were selected as it was identified from the review in Chapter 1 that the policy model follows a rational view that emphasises on tool-centred and information-centred support for designers' enactment.

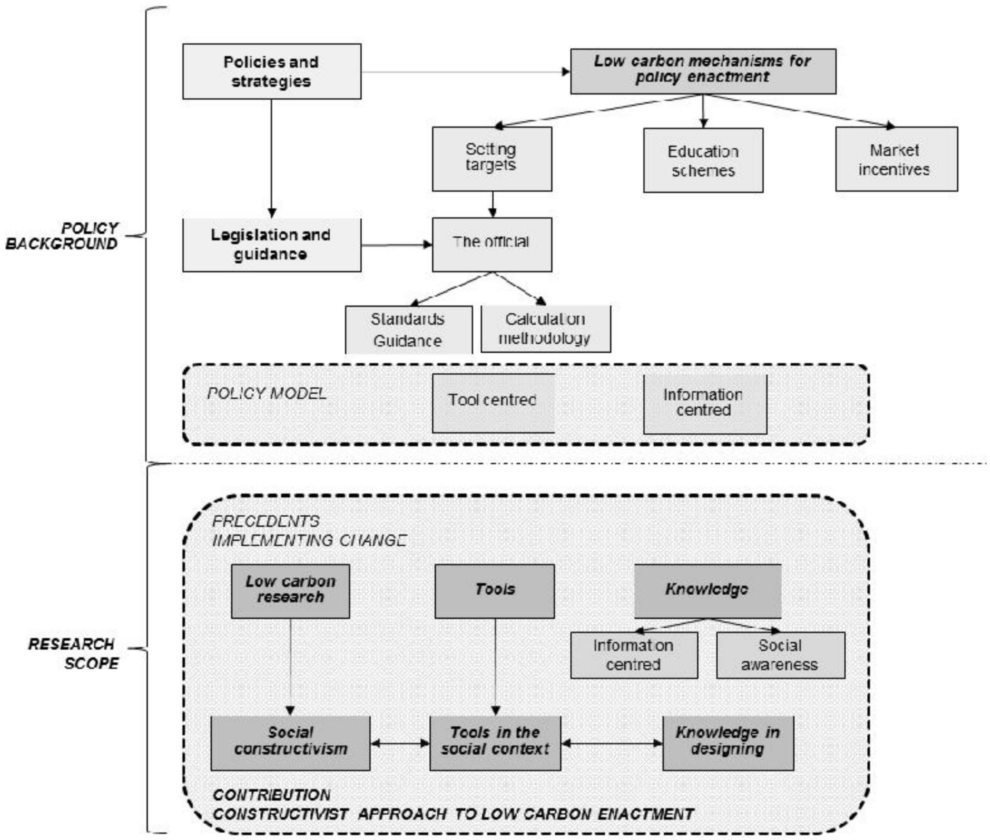

Figure 3.1. Research scope

This investigation was designed as a comparative case study to identify the commonalities and differences in the ways the designers incorporate the low carbon policy requirements. The case study could answer how and why questions by a detailed analysis of the context (Eisenhardt 1989; Stake 1995; Yin 2003). Case studies are suitable 'when the investigator has little control over events and when the focus is on a contemporary phenomenon with some real-life context' (Yin 2003, p.1). Case study research is especially relevant 'when the boundaries between the phenomenon and the context are not clearly evident' (Ibid p. 13).

Building upon the principles of qualitative research (Denzin and Lincoln 1998; 2008; O'Leary 2004; Seale 2004; Silverman 2006; Creswell 1998), purposeful sampling was done based on communities of practice criteria (Wenger et al 2002 p. 65-112) to create an in-depth picture of the phenomena. A thematical analysis was adopted to analyse the field data. A qualitative software package, Atlas t.i. (2010) was used to assist with the coding and analysis of information and facilitate the identification of themes, classification of codes and saturation of categories and concepts that enlightened the emerging discussion and analysis of findings. The research was guided by the qualitative research flux suggested by (Wolcott 1994): description, analysis and interpretation.

3.2.1. Sampling criteria of the case studies

The study was interested in how the new low carbon agenda was affecting the design process. Therefore, the sample gravitated towards firms with an explicit interest in delivering sustainable projects. The recruitment process was guided by the recommendations of key informants with knowledge about the Welsh building industry as well as a web-based search of firms and practitioners working in Wales with experience in sustainable projects. Eight architecture firms were contacted and potential participants were interviewed to explain the study and to be recruited in the research.

Four large architectural firms were selected based on their interest in participating in the study and a theoretical sampling withdrawing from communities of practice principles. The architecture firms that participated had experience in sustainable design demonstrated by the green certifications awarded to their projects (PassivHaus, BREEAM) and recognitions to the company (RIBA, AJ100, CIBSE, FX). The architecture firms were large in size and had several studios in the UK and overseas (Table 3.1.). Under the umbrella of 'sustainable architectural firms', firms with different expertise profiles were recruited to enable observations about the designers' work, the knowledge and the tools to embed energy performance during conceptual and detailed design phases. Four cases were deemed acceptable to withdraw research conclusions as the nature of the research method calls for a small number of cases (Emmitt and Gorse 2007 p.86-92).

The following table summarizes the profile of the firms included in the study:

	Profile of the company	Locations	Awards
1	Architecture firm with in-house expertise in engineering, sustainability, lighting, acoustics	10 studios in UK and 5 internationally	Sustainable Designer/consultant of the year, sustainable building of the year, several RIBA awards, CIBSE Building performance awards
2	Architecture firm with in-house expertise in landscape, urban design, interior and environmental design	7 studios in UK and 2 internationally	CEW 2010 Project of the year, awards and shortlistings, nominations for sustainable architect, champion of the year
3	Architectural firm with in-house expertise in town planning, urban design and interior design	3 studios in UK and 1 internationally	Shortlisted FX awards, BCSE
4	Architectural firm with in-house expertise in urban, landscape, interior design and conservation work	5 studios in UK and 1 internationally	Shortlisted and winner of AJ 100 awards, Building awards

Table 3.1. Profiles of the architecture firms that participated in the investigation

In terms of theoretical sampling, the architecture firms represented a different type of community of practice, according to criteria obtained from Wenger et al (2002 p. 65-112):

- The firm's identity in relation to sustainable and low carbon design
- The in-house expertise
- The type of learning organisation

The firm's identity in relation to sustainable and low carbon design refers to the emphasis that the firm poses on the sustainable experience and credentials as a specific feature to attract the market, identified on a web-based search. This relates to the attitudes and likely motivations that could be held by the designers in relation to sustainability and low carbon performance. The categories are:

- *Strong* for firms with a long-term sustainable experience, variety of awards and recognition, publicity on the website of projects with emphasis on the sustainability credentials

- *Medium* for firms with some sustainability experience, a growing number of sustainable projects which are advertising other types of expertise apart from sustainable design i.e. renovation, urban planning. These firms are positioning their experience as a sustainable architecture studio.

The in-house expertise indicates the presence of a dedicated energy or environmental specialist in the architecture firm. This relates to the firm identity in relation to sustainable design (how the firm portraits itself to the market), the expertise and the knowledge that is likely to circulate in the firm.

The type of learning organisation denotes the existing arrangements in the company to nurture and disseminate the knowledge that circulates among employees. There are two categories:

- *Strong* refers to the firms where there is an extensive experience and identity in relation to sustainable and low carbon design and the knowledge management approaches encourage social practices and a diversity of methods to disseminate information i.e. seminars, notice boards.
- *Medium* implies that the firm is implementing methods to disseminate knowledge and there is a lesser degree of dissemination of information related to low carbon and sustainable design.

The categories to which the firms belonged to was ascertained the preliminary recruiting interviews and a desk-based investigation of the companies' profile (Table 3.2.).

Architectural firm	Identity as sustainable firm	In-house expertise	Learning organisation
1	strong	Yes	Strong
2	strong	Yes	Strong
3	strong	No	Medium
4	medium	No	Medium

Table 3.2. Characteristics of the architectural firms recruited in the investigation

This design process investigation studies the conceptual and detailed design phases. The delivery and construction phases are outside the scope. However, the aspects related to delivery, construction and operation have been considered in that they overlap to the design process. The main research participants were the architects. Other design team members were included to depict the dynamics and richness of the process.

3.2.2. Features of the case studies and architectural teams

In order to investigate the knowledge and tools to embed performance in the social context, the study analysed the whole design process from conceptual to detailed design per architecture firm recruited.

The Royal Institute of British Architects (RIBA) Plan of Work was used as a reference to document and compare the observations across case studies. RIBA Plan of Work is a model used in the UK to organise the building delivery process from early design to practical completion (RIBA 2007) . The RIBA Plan of Work[1] was used mainly because it is a recognised model despite of its limitations and potential inaccuracy when compared with real-time activities. A number of studies have criticised the RIBA Plan of Work because of the artificial division between the stages in the design and delivery process (Mackinder and Marvin 1982; Lawson et al 2003; Schon 1983; Beadle 2008). The difficulty of mapping the process could be explained due to the variety and multiplicity of overlapping and non-linear tasks and loops necessary for problem-solving. The researcher acknowledges the limitations and challenges of using the RIBA Plan of Work as a model of the design process. Nonetheless, the RIBA Plan of Work was used as a starting point to describe the process. Further details about the definition of conceptual and detailed design phase are included in Section 3.2.4, Field data documentation and project timeline.

The project schedule in the cases 1 and 2 allowed the observation of the conceptual and detailed phases. In the architecture firms 3 and 4 there were no suitable projects available to study the conceptual and detailed phases during the research data collection timeline. Therefore, it was decided to include two projects in each of these firms; one for conceptual phase and another for detailed phase

The cases 3A and 4A were analysed in conceptual design phase (RIBA Stage A-D) and the cases 3B and 4B were focused on the detailed design phase (RIBA Stage E-K). By doing so, the conceptual and detailed design phases were studied in the architecture firms 3 and 4. All the case studies were procured by Design and Build route which is a contractual arrangement where 'one organisation takes the sole responsibility, on lump sum fixed price basis, for the bespoke design and construction of a client's project' (Masterman 2002 p.67). In the case studies, the design and build procurement method consisted on 'design-bid-build'. The design team was led by the architects during conceptual design (pre-planning application). After the appointment of the contractor during delivery, the design team was novated[2] as a contractor's consultant.

In terms of architects' involvement in the design process, three scenarios were analysed to include a wide spectrum of the low carbon design processes:

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[1] This work used the 2007 version of the RIBA Plan of Work. The 2013 version of the RIBA Plan of Work went to consultation by the end of the writing period of this investigation.

[2] Novated design team is the one that works as part of the consultant team, under the leadership of the contractor during the delivery phase. In novated design and built, 'once the contractor has been appointed the novated team carry out the detailed design as the contractors' consultant'. (Masterman 2002, p.83)

1. Same architecture team working on conceptual and detailed design. These teams were part of the delivery team when the buildings were built (cases 1 and 2)

2. One architecture team working on conceptual phase and another team on the detailed phase. Both teams were based on the same architecture firm. Two scenarios were examined:

2.1. The first architecture team worked on conceptual and detailed design (RIBA A to G/H). When the contractor was involved, another architecture team worked on the detailed design as part of the delivery team. (cases 3A and 3B)

2.2. The first architecture team worked on conceptual design until planning application (RIBA A to D) and then a second architecture team worked on detailed design (from RIBA E). The second architecture team was part of the delivery team. (cases 4A and 4B).

RIBA	A	B	C	D	E	F	G	H	K
	Conceptual design				Detailed design				
Case 1									
Case 2									
Case 3A*									
Case 3B*									
Case 4A*									
Case 4B*									

**Cases 3A and 4A were not studied in detailed design. Cases 3B and 4B were not studied in conceptual design*

Design work undertaken from conceptual design by the conceptual architecture team
Design work undertaken by an architect team different from the conceptual design team
Stages that were not studied in the investigation*

Table 3.3. Architectural team arrangements in the case studies

The following table summarises the team composition and the architects' input in the process in each of the case studies:

Cases	Partnership Arch and design team members	Type of project	Location	BREEAM	Phases studied
1	ME, acoustics and lighting consultant in-house	Educational	South Wales	Excellent	Conceptual and detailed design
2	No partnership with consultants	Educational	England	Excellent (outstanding)	Conceptual and detailed design
3A	Previous work with ME and sustainability consultants	Educational	South Wales	Outstanding	Conceptual design
3B	No partnership with consultants	Educational	England	Excellent	Detailed design
4A	Previous work with ME and sustainability consultants	Educational	South Wales	Excellent (outstanding)	Conceptual design
4B	Previous work with ME and sustainability consultants	Health care and housing	South Wales	Excellent	Detailed design

Table 3.4. Summary of the case studies

The unit of analysis is the design process which is the ‘case study’. The projects studied were developed in sites located in Wales (cases 1, 3A, 4A and 4B) and England (cases 2 and 3B). The case studies were BREEAM certified. Non-domestic buildings were selected to explore the architect’s work, relationship and knowledge exchange mechanisms with the wider design team members: mechanical engineers, BREEAM assessors, and energy and sustainability consultants. The case studies were educational buildings except for case 4B which was a health care facility and housing development. The performance targets of the case studies are summarised in Figure 3.2., tables 3.5. and 3.6.

Case 1. Ebbw Vale, 9411m2 EPC 31, BREEAM Excellent

Case 2. London, 6000m2 EPC 40, BREEAM Excellent

Case 3A. Bridgend, 14500m2 EPC 7, BREEAM Outstanding

Case 3B. Somerset, 9440m2 EPC 40, BREEAM Very Good

Case 4A. Llanelli, 3500m2 EPC 17, BREEAM Outstanding

Case 4B. South Wales, 9570m2 EPC 28, BREEAM Excellent

Figure 3.2. Case studies

Case study	1	2	3a	3b	4a	4b
Roof	0.15	0.18	0.18	0.15	0.15	0.10
Walls	0.15	0.26	0.26	0.18	0.16	0.16
Glazing	1.20	1.60	1.60	1.60	1.60	1.50
Floors		0.32	0.19	0.21		0.12
Airtightness	3	1	3	5	5	5
EPC	31	40	19	40	40	28
% LZC tech	10	20	30	15	15	10

Table 3.5. Targets per case study

BREEAM credits	1	2	3a	3b	4a	4b
Management	90	17.00	19.00	18.00	12.00	9.00
Health and wellbeing	76.47	11.00	11.00	13.00	12.00	8.00
Energy	52	16.00	19.00	14.00	14.00	15.00
Transport	66.67	6.00	6.00	6.00	4.00	9.00
Water	87.5	6.00	6.00	7.00	5.00	5.00
Materials	60	11.00	5.00	4.00	7.00	6.00
Waste	85.71	6.00	5.00	3.00	4.00	3.00
Land use and ecology	91.67	11.00	11.00	7.00	3.00	5.00
Pollution	66.67	11.00	5.00	4.00	8.00	4.00
Innovation		3.00	2.00	4.00	4.00	2.00
Total	71.85	81.70	89.00	64.00	73.00	66.00
Rating	Excellent	Excellent	Outstanding	V Good	Excellent	V Good

Table 3.6. BREEAM credits per case study

3.2.3. Length of ethnographic study

The ethnography study was conducted for twelve to twenty one months per case study. It comprised an average of seventy five hours per architecture firm distributed in eighteen to twenty five visits per firm. The visits were scheduled every two to three weeks, with a minimum monthly visit. The researcher maintained contact with the research participants by email or by phone to remain updated about the development of the case studies. In average, there were two research visits every week to collect information related to the case studies during the data collection period. The length of the observation and the variety of situations observed during the design process (shadowing of work and team meetings) reduced the possibility of affecting the behaviour of the research participants during the study.

Figure 3.3. shows the ethnographic immersion timeline, including the period required for entry and leaving the field. During the entry phase, the research gained access to the architecture firm, carried exploratory interviews to make research arrangements for access and obtain the initial information about the case studies. During the immersion period, the data collection methods were non-participant observation (shadowing of work and attendance to design team meetings), interviews and document analysis. In the final phase when the researcher left the

field, the researcher remained in contact with the participants to be updated about the development of the case study and collect additional information required for the analysis. The periods used to entry and leaving the field did not include non-participant observation.

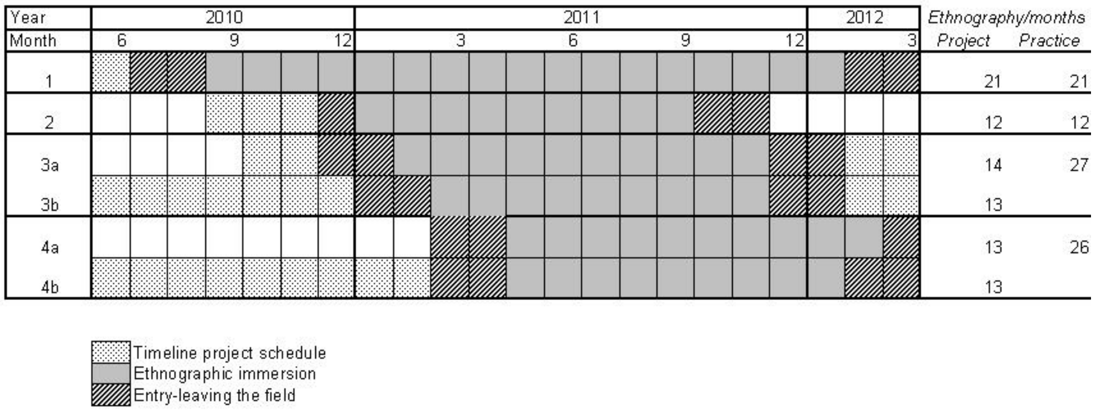


Figure 3.3. Timeline of project development and ethnographic immersion per case study

3.2.4. Field data documentation and project timeline

For the purposes of this investigation, the design process was divided in relation to planning application submission. The conceptual design includes RIBA A to D while the detailed design starts on RIBA E after planning submission. This division was done to examine the two policy gateways: BREEAM for planning application (conceptual design) and Part L for building control (detailed design).

The conceptual design (figure 3.4.) included briefing, early and conceptual design until planning application submission when the conceptual design is frozen, from RIBA A to D.

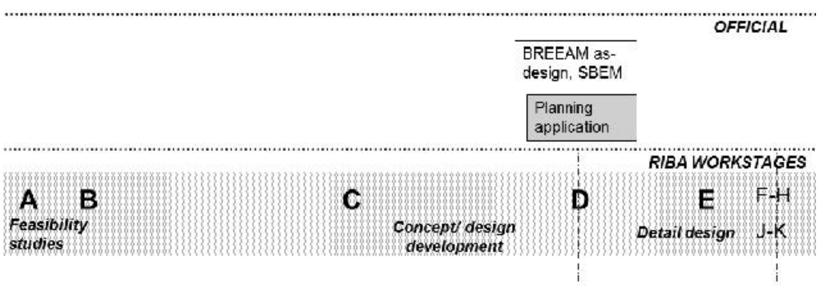


Figure 3.4. Conceptual design

The detailed design (figure 3.5.) comprised the activities developed after planning application submission, from detailed design to delivery or RIBA E to K and the examination of knowledge dissemination and reflection once the project has been completed (RIBA L-M).

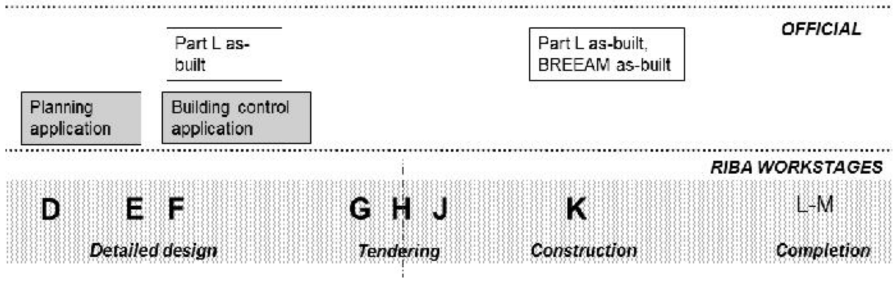


Figure 3.5. Detailed design

The RIBA Plan of Work is a descriptive tool to document and compare the field data in relation to the project development timeline. However, the author acknowledges that the RIBA Plan of Work, as a process model, is a limited abstraction that simplifies a non-linear iterative process. Therefore, another analytical tool, the low carbon problem-solving framework was obtained from the data analysis as a means to highlight the commonalities and differences observed in the enactment of the process. The low carbon problem-solving framework is further elaborated in Section 3.4.2.

By the end of 2012, there was a consultation to implement a RIBA Plan of Work to supersede the 2007 version. At the time of completion of this investigation, the RIBA Plan of Work 2013 had not been published. The consultation for the RIBA Plan of Work 2013 proposed seven Work Stages. The RIBA Plan of Work 2007 used to report the findings of this investigation and the 2013 version, according to the consultation document (RIBA 2013) overlap as follows:

RIBA Plan of Work 2007	RIBA Plan of Work 2013	Division of the design process for the purposes of this investigation
A-B C D/E	Preparation Concept design Developed design	Conceptual design (Chapter 4)
E-H H J-K	Technical design Specialist design Construction (offsite and onsite)	Detailed design (Chapter 5)
L	Use and aftercare.	Outside the scope of this work

Table 3.7. Overlap between RIBA Plan of Work 2007 and the 2013 version

3.3. Data collection methods

The ‘entry the field’ phase included semi-structured interviews to obtain the perceptions of the research participants about the low carbon policies and the design process. Table 3.8. outlines the topics that were covered in these early interviews:

Key topics	Aims	Prompting themes
Low carbon policies	Discover the ways practitioners keep updated and adopt official requirements (information centred)	Part L, Voluntary schemes BREEAM, Calculation methods (SBEM, Simulation), Financial incentives, Educational mechanisms,
Design process	Understand how practice takes place compared to ideal models (process-centred) and intended process to adopt low carbon policies	RIBA plan of work, procurement issues, impact of regulations at practitioners' dimension, company databases
	Identify the social context of design (people-oriented, culture of practice)	Meetings, informal discussion, consultation to peers, dissemination of experience, tools for low carbon design, emerging practices

Table 3.8. Topics covered in the preliminary interviews

The discussion of the low carbon policies and the design process with the research participants enabled a preliminary understanding of the context of practice and the design process. It also facilitated a thematic analysis of the data to be collected in the immersion phase. The preliminary findings obtained from the interviews undertaken in the 'entry the field' phase informed the data collection protocols for the non-participant observation and the document analysis undertaken in the immersion stage.

The data obtained in these early interviews facilitated the conceptualisation about how the designers were incorporating the policy intentions in the design process. This sought to reveal the designers' perceptions about how the effect of the increasingly demanding energy regulations in the process. The interviews were recorded and transcribed verbatim. Notes and memos about impressions and insights from interviews were also taken to inform the understanding of the social context.

The data were analysed on Atlas t.i. using a thematic coding approach to reveal the nuances of the process, designers' problem-solving activities and responses to embed performance. The analysis was guided by a preliminary thematic analysis of the key topics prompted on the interviews. The data was codified to compare different data extracts. The interrogation of the data enabled the identification of connections and disparities between the perceptions and accounts of the research participants. The data was analysed in terms of groundness and density. The groundness indicates the number of associated data extracts and density refers to the number of links to the same type of objects (Atlas t.i. 2010). These indicators assessed the theoretical saturation to identify the themes for further exploration. The transcriptions were indexed with theoretical notes informed by the literature review and the theoretical framework. This procedure helped to generate enquiries for an in-depth exploration during the immersion phase.

Semi-structure and opportunistic interviews, non-participant observation and document analysis were deployed for data collection during the immersion phase. The semi-structured interviews helped to discuss and clarify the design development with the design team members. The retrospective accounts were avoided due to the difficulties associated to poor memory and reflection as raised by Emmitt (2001, p.400). While the focus of the investigation was the architects' work, the research also included other members of the design team such as mechanical engineers, BREEAM assessors, energy and sustainability consultants. The non-participant observation included the shadowing of architects' work and attending design and delivery team meetings. The document analysis was primarily focused on the project documentation. It included the written material produced during the process such as sketches, technical notes, reports, minutes of meetings and interim documentation. In terms of the official documentation, the databases and intranet from architectural firms and official guidance and standards consulted by architects were analysed.

The main data sources of this research were:

- Designers (self accounts, opinions, observation of their work)
- Design and delivery team meetings
- Project documentation (reports, sketches, drawings, BREEAM documents, simulation reports)
- Routines of work (working practices, artefacts and tools deployed in the process)
- Formal system (company intranet, notice boards, simulation tools, guidance, standards, regulations)
- Informal routines and informal tools to adopt the low carbon agenda (rules of thumb, in-house tools, conversations, interdisciplinary feedback)

The immersion started in case study 1 which acted as a pilot case to inform the data collection protocols, data management, analysis, interpretation and reporting procedures. The management and analysis of the data guided by the main research questions, the theoretical framework (Chapter 2) and the emerging field findings (relations between the official and the informal, the social context, design as a negotiation process).

The following sections explain in more detail the features of the different data collection methods.

3.3.1. Non-participant observation

The design in action was studied with a focus on the architects' work by non-participant observations that included shadowing of work and attendance to design team meetings. Field notes and memos were taken to describe the current progress of the design, the people observed and the tasks performed. During the observation of design and delivery team meetings, notes were taken to record the incidents that unfolded in the meetings. The researcher attended twenty seven meetings, approximately seven meetings per case study except for cases 3A and 3B where access to meetings was limited. In case studies 3A and 3B, interviews with the architects were arranged to discuss the topics emerging in the meetings. The non-participant observation was informed by prior studies about communication in the building industry (Emmitt and Gorse 2007; Brookes et al 2006; Dainty et al 2006; Gorse and Emmitt 2007) and observation of team work (Cross and Cross 1995; Cross and Dorst 1996; Angrosino 2007).

3.3.2. Interviews

The architects and the design team members (mechanical engineers, the BREEAM assessors and the energy specialists) were interviewed to discuss the design development in the case studies. The interviews were guided by the recommendations of Kvale (1996); Silvermann (2006 p.109-152); Bryman (2008) to prompt the discussion and obtain the perceptions of the interviewees in a range of topics related to the project development. The interviews were semi-structured in nature and were conducted on RIBA C-D (energy aspirations, project requirements, design strategy, reuse of knowledge from past experience, networking), RIBA D (planning application, BREEAM certification, energy evaluation, partnering between architects and mechanical engineers), RIBA E-F (detailed design and Part L compliance, views about delivery), RIBA J (delivery, views about contractor, dissemination of knowledge, partnering with contractors and suppliers). The topics included the project targets, opinions about simulation and compliance requirements, working relationship with the design team members, the client and the contractor, tools used for calculating the energy performance, statutory requirements.

Table 3.9. summarises the number of semi-structured interviews conducted per case study. These interviews do not include the opportunistic interviews conducted during the non-participant observations.

Case study	Number of semi-structured interviews per case study	Number of interviews per architecture firm
1	15	15
2	12	12
3A	5	11
3B	6	
4A	6	13
4B	7	

Table 3.9. Semi-structured interviews conducted in the case studies

There were also opportunistic interviews conducted during the non-participant observation (during shadowing of work and design and delivery team meetings).

3.3.3. Document analysis

The project documentation was analysed and compared to the fieldwork observations and the interview data. The documentation analysis included the official project documentation (drawings, technical specifications and reports) and informal documents (sketches, diagrams, notes and other written material produced in the process). The informal documents were obtained during the shadowing of work and non-participant observation in meetings.

The document analysis was informed by the recommendations of (Atkinson 1992; Hammersley 1992; Coffey and Atkinson 1996 p. 54-107; LeCompte and Schensul 1999; Wolcott 2001; Silverman 2006) in relation to contextualisation of the documentation produced by the participants. These literature draws attention to the nature of the documents produced in the field: 'Documents need to be as situated products' (Prior 2003 p.26). There are dynamics between the production, consumption and content of documents (Ibid p. 26). Therefore, the ethnographic documents were analysed in the light of the data collected by other methods and based on the understanding gained in the field about the participants and their working methods.

The analysis of the field data was done by organising the information of the case studies on matrix and digital files with the folders:

- Interviews (semi-structured and opportunistic interviews)

- Intranet and database (project summary information, snapshots of the databases and intranet system)
- Non-participant observation (notes about shadowing of work)
- Project documentation (plans, reports, simulation results, BREEAM documents)
- Website information (architecture firm profile, project information)
- Emails (communication with designers, updates of the case study development)
- Meeting notes (agenda, minutes and notes of observed meetings)
- Pictures (non-participant observation and fieldwork visits)
- Case study summary information

In cases 3B and 4B, the researcher did not observed the conceptual design. The architects were interviewed to understand the project development. In these cases the conceptual design was not included because the data was obtained from retrospective accounts and official written documentation. These methods were unlikely to capture the richness of real-time observations.

3.4. Field data analysis and interpretation

3.4.1. Analytic models for data analysis and interpretation

The data analysis used a thematic coding approach informed by the theoretical framework presented in chapter 2 and the emerging research findings. Codes were used to categorise the data in relation to prompting themes related to research questions. Axial coding was used to examine different dimensions of the data, selective codes to identify the main themes to conceptualise about the phenomena and open coding for the discovery of unexpected aspects in the field. The researcher used techniques such as mind maps, networks and diagrams (Buzan and Buzan 2006; Checkland 1999; Checkland and Scholes 2001; Conway 2001) to visualise the findings emerging from a variety of ethnographic sources (interviews, documents, field notes, memos). The emerging concepts generated a continuum for the reinterrogation of the data and the examination of the evidence. The ethnography was conducted in a series of loops to interrogate the data and achieve the theoretical saturation. The layers of analysis used to examine the data were:

- *Knowledge and tools in design, differentiating the notions of official and informal*
- *Low carbon problem-solving framework*

Figure 3.6. illustrates the layers of analysis used to interrogate the data. The data collection started by identifying the tools and knowledge in terms of official and informal. Then, the data collected was articulated as tools for calculation and mediation that contributed to the low carbon problem-solving tasks. Finally, the description of the process enabled to infer about the performance understanding cycles and the knowledge flows and creation that occur in the design process in action.

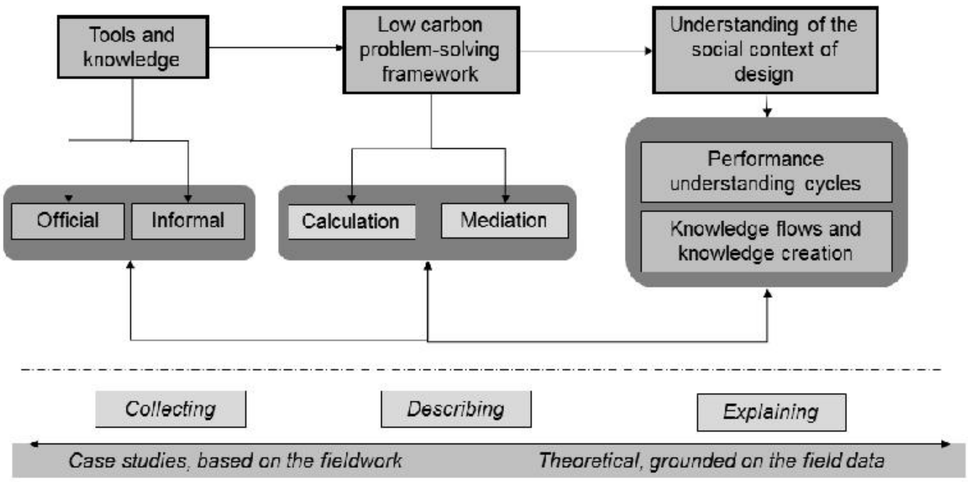


Figure 3.6. Layers of data analysis

The analysis of the knowledge and tools in design enabled the identification of the official and informal tools and knowledge invoked by the designers to understand and assess the energy performance. The notion of tool uses the broad Dewey's concept where tools are not defined by their physicality (elaborated in Chapter 2, Section 2.5.1). Accordingly, a tool could be a physical or a conceptual device; for example, a routine or expert advice given to solve a problem. Thus, the tools to embed performance include the ones that contribute to the performance calculation (compliance) and those that mediate the performance dialogue and the construction of the energy aspirations.

The notion of tool adopted in this study also makes a distinction between the official and the informal as outlined in Section 2.3 in Chapter 2. The official refers to what it is derived from the government and organisations for the purpose of facilitate low carbon design. The informal is defined as what made within the social context, outside the mainstream of the official. The official tools are the instruments to assist the design process and to comply with the regulatory targets, for example simulation software and Part L. In contrast, informal tools correspond to instruments that rely in the social context such as conversations, in-house tools, rules of thumb, conversations and internal checklists. These informal tools were part of routine design. Given their informal nature, they were unlikely to leave any evidence on project documentation or deliverables. The informal was identified through the observation of the process and reflection on the tasks, activities and roles during design.

The analysis of the official and informal tools led to a better understanding of the performance appraisal cycle beyond the use of calculation tools. It becomes an analytical device to infer about the knowledge flows and knowledge creation in the design process.

3.4.2. Low carbon problem-solving framework

This layer of analysis articulates the tasks undertaken by designers in the process. It maps the interface between knowledge and tools in the process and reveals what the designers are doing in real time design process. The low carbon problem-solving framework helps to describe the processes and highlights the commonalities and differences found in the case studies.

The *low carbon problem-solving framework* helps to document the development of the process, the use of official and informal tools over time and illustrate the dynamic relations and the changes that occur in relation to the social context during the design process (Figure 3.7). T*he low carbon problem-solving framework* is a model to document the tasks to embed energy performance observed in the case studies, obtained by a thematic coding approach of the field data. The *low carbon problem-solving framework* is a representation of the interface between tools and knowledge in the social context of the design process. The field data comparison suggested six key tasks that contributed to the function of embedding performance.

In the conceptual design (RIBA A-D, planning application, BREEAM):

1. *Outlining the aspirations*

2. *Understanding the energy aspirations*

3. *Calculating the energy performance*

In the detailed design (from RIBA E, building control, Part L):

4. *Transposing the design intentions*

5. *Following the design intentions*

6. *Learning from the process*

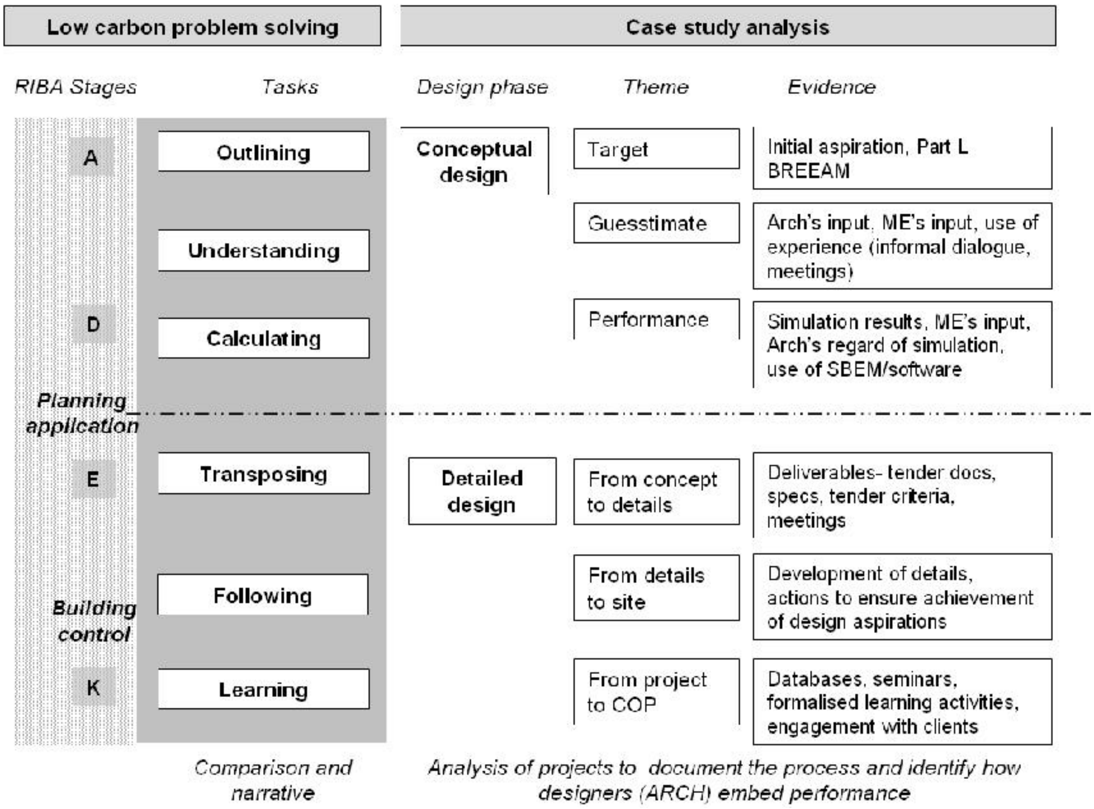


Figure 3.8. Representation of the low carbon problem solving framework

The low carbon problem-solving framework describes the process from the benchmarking of the requirements to the development of the detailed design, including the reflection and learning in the process. The following figure illustrates the low carbon-problem solving mapped against the RIBA Plan of Work 2007 (left hand side) and the data collected and analysed in the case studies (right hand side, case study analysis box). The data was obtained from the sources illustrated in the evidence column (far right). The figure illustrates the stages of research progression that led to the reporting of the findings in relation to the low carbon problem solving tasks (grey box on the left) based on the development of themes to analyse the field data (white boxes).

The use of different layers of analysis; official and informal, tools and knowledge, low carbon problem-solving; enabled the researcher to scrutinise different dimensions of the field data. These layers helped to interrogate the evidence from different but complementary angles. The analytical layers assisted in the theoretical saturation, informed the emerging concepts and theory and prevented the researcher's bias in the analysis and interpretation of the findings. These analyses informed the discussion about the design process, the official and the informal, the tools and knowledge.

The observations of the case studies described in relation to the *low carbon problem-solving* framework are presented in the following chapters. Several tables and figures have been included to highlight the commonalities and differences between cases in terms of tools used per case study in relation to the low carbon problem-solving tasks. The data extracts produced by the research participants such as quotes and graphs have been differentiated from the analysed data. The concepts inferred from the data analysis were made explicit by explaining the analytical models used to interrogate and present the data. However, as the concepts are grounded in the field data; the data analysis, the interpretation and the theoretical saturation is an interwoven process that cannot be fully separated. The ethnographer is a mediator between the field and the reader (Hammersley and Atkinson 1995; Coffey and Atkinson 1996; LeCompte and Schensul 1999; Silverman 2006) so by discussing the commonalities and differences between the case studies and reporting in detail the methodology, the researcher is making explicit the field data that informs the findings, the circumstances and limitations of the research.

3.5. Limitations

This study used ethnography as a research instrument to unveil the low carbon process in six case studies. There is not claim to follow the anthropological tradition of intense immersion in a single setting. The comparative ethnography favoured the comparative discovery across cases. It is acknowledged, however, that a comparative ethnographic study could lead to the asymmetry of information. Nevertheless, within the limitations of the method, the collected evidence allowed the comparison between the case studies and the interrogation of the field data as explained in this chapter. Given the variety in the case studies (design aspirations, strategies, research participants, circumstances of design development) and the range of tools and design episodes recorded, no simple cross comparison can be made. However, the findings reveal a number of interesting observations regarding the designers' enactment of the policy intentions which diverge from the conception of designers as rational goal-seeker agents.

The combination of data collection methods (observational studies, non-participant observation, interviews and document analysis) and the triangulation of data enabled the identification of commonalities and differences in the processes and in the social context. As previously explained, the researcher used a theoretical framework based on a critical literature review of prior research and social theories (Chapter 2, figure 2.1.) and the *low carbon problem-solving* framework (Chapter 3, figure 3.7) based on the field studies.

The researcher acknowledges that the findings of this research are specific to the case studies and observations of a small number of design processes enacted by architects in large architecture practices with experience in sustainability. Thus, no claim for generalisations or representativeness is made. The study investigated the design process of six case studies in four architecture firms so it is necessarily framed by their specific circumstances.

Chapter 4
Conceptual design process

4.1. Introduction

This chapter documents the findings of the field investigation about the design process. It focuses on the tools used by designers to embed energy performance in conceptual design (RIBA A-D) until planning application submission. It presents the low carbon problem-solving tasks performed by the designers, with emphasis on architects' work. The description of the low carbon problem-solving tasks (outlining, understanding and calculating) suggests how the understanding performance function is undertaken during conceptual design. The understanding about how designers embed performance informs the discussion about the knowledge conversion process in the design process and the influence of the social context in the design of low carbon buildings. The chapter concludes by elaborating the low carbon design process and discusses the assumptions about the designers' enactment of the policy intentions.

4.2. The low carbon problem-solving tasks in conceptual design

It was inferred from the field data that in spite of the variety of tools deployed by the designers, there are common tasks that were performed in order to embed performance. These tasks were identified by comparing the case study data and became the basis for the low carbon problem-solving framework. As outlined in Chapter 3, the tasks in conceptual design are outlining, understanding and calculating.

1. ***Outlining the aspirations***; choosing the indicators and measuring methods to assess the targets, translating the aspirations into quantifiable performance metrics.

2. ***Understanding the energy aspirations***; estimating the performance without seeking for accuracy and negotiating the benchmarks. This task implies the analysis of the energy aspirations in combination with project drivers such as cost.

3. ***Calculating the energy performance***; using calculation tools such as simulation to quantify the likely performance of the design and to produce the

evidence for compliance of BREEAM Energy requirements; for example, to satisfy the planning application conditions for the case of buildings located in Wales.

4.3. Outlining the energy aspirations (RIBA A-C)

4.3.1. Official guidance and standards

The design teams set the project requirements and the low carbon targets by identifying the statutory requirements and clarifying the clients' requirements. The energy performance was not a client's requirement to the design teams except in case 1 where the client requested a minimum of 10 per cent of energy supply by low zero carbon technologies. Case 1 was part of a development that included several buildings and the master plan for the site outlined the minimum sustainability requirements onsite. In the other case studies, no explicit performance targets were requested by the clients. In general terms, Part L and BREEAM were used by designers to set the targets as well as the following documents:

Building Bulletin 87: Guidelines for Environmental design of schools

Building Bulletin 90: Lighting Design for Schools

Building Bulletin 95: Schools for the Future- design for learning communities

Building Bulletin 98: Design Requirements for schools

Building Bulletin 99: Areas

Building Bulletin 100: Design for fire safety in schools

Building Bulletin 101: Ventilation and indoor air quality in schools

Approved Document Part E Resistance to sound

Approved Document Part F Ventilation

Planning requirements by local authorities in terms of low zero carbon technologies contribution, development plans and planning documents

One Wales: One Planet, Technical Advisory Note 12 Design, Technical Advisory Note 22 Sustainable Buildings (in Wales)

4.3.2. Low carbon design intentions, targets or aspirations

It was observed in all the case studies that the design teams defined the low carbon performance in two levels: as targets and as aspirations. The targets addressed the compulsory performance requested by Part L, planning conditions and statutory requirements. They were inscribed in the RIBA reports and in the documentation submitted for planning application. In parallel, at an informal level, the design intentions to achieve a performance that exceeded the minimum compulsory requirements were likely to emerge. These higher intentions have been termed 'low carbon aspirations'.

Informally, the designers could intent to design a building achieving higher performance targets that the ones outlined in the official project documentation. However, due to the lack of design definition and the need to develop a better understanding about the implications of the low carbon strategies, the low carbon aspirations remained as an informal goal of the design team that was negotiated alongside the design development.

Officially, the indicators used to define the energy targets and inscribed in the project documentation were:

- percentage improvement over Part L requirements '*reduction of 60 per cent on Part L 2006*' (case 1),
- a minimum percentage of low zero carbon technologies '*generate a minimum of 10 per cent of energy from renewable sources*' (case 1)
- the Energy Performance Certificate (EPC) '*EPC of 40 or better'* (case 2),
- the BREEAM rating '*achieve BREEAM Excellent rating*' (case 3),

The low carbon aspirations exceeding the minimum requirements in the case studies were:

- Case 1: Reduction of 60 per cent carbon emissions on Part L 2006
- Case 2: BREEAM Excellent was the initial aspiration. By RIBA C, the design team was aiming for BREEAM Outstanding.

- Case 3A: BREEAM Outstanding, 30per cent of energy supplied by renewable sources and excellent credits on Ene1 (officially BREEAM Excellent)
- Case 4A: BREEAM Outstanding, a zero carbon building, 70% reduction on Part L 2006

It was observed that these low carbon aspirations were negotiated in the course of the conceptual and detailed design process. The drivers of the process affected the continuity and stringency of the low carbon aspirations. The aspirations were defined on the basis of further design development, better cost information, value engineering and delivery matters. The knowledge about low carbon design is not limited to energy performance metrics such as CO2 reduction or percentage of renewable energy. The energy performance metrics have to be informed by knowledge about cost, buildability, users' preferences, maintenance, and stakeholders' drivers. Those aspects comprise a variety of expertise that is invoked as the design is developed. The knowledge has to be constructed collectively by the design team members to make appraisals about the energy performance in the light of the project drivers. The knowledge gained in later design stages affects the low carbon aspirations (informal goals).

The task of outlining the low carbon aspirations shows that the design process tends to operate in two levels: the official and the informal. The use of low carbon aspirations in the cases suggests that there are pre-existing contradictions between the official and the informal dimensions. The official dimension is concerned with the compliance of the statutory requirements. It is determined by the expectations and requirements established by the policy model which are focused on CO2 reduction without considering of the social context where low carbon buildings are designed. Some of the aspects that emerged in the social context and determined the low carbon aspirations were:

- the attitudes about low carbon performance as a project driver,
- the client's preference between capital and life cycle cost,
- the attitudes of the design team to undertake energy performance investigations

- the resources available to assess and embed the energy performance (tools, knowledge, expertise),

Informally, there could be a predisposition to meet only the minimum regulatory requirements in a perfunctionary fashion (compliance-only process) or the intention to exceed them (performance-driven process). The enactment of these different types of process affects the use of the tools and the knowledge flows in the process. It also reflects the differences in the understandings of what low carbon buildings are (target) and what their design entails (process).

The following excerpts by the research participants illustrate the contradictions between the policy intentions and the designers' dimension:

Perceptions	Quotes
Legislation is necessary for low carbon buildings	*'[Low carbon design] is not going to happen unless legislation makes you do it'* *'Legislation is key, it's all about enforcement'*
Legislation is necessary because cost is the driver of the process	*'I think legislation is playing a useful role in allowing better performing building to be designed. Things like sustainability, if they are not written down, they are not going to happen because at the moment, and certainly for the short term anyway, it's going to be cheaper to build it cheaper…'* *'With a market like the one that we have at the moment, people are extra strong to sort of push and save as much money as possible… It could be anyone: client, contractor… but there is a point below which they can't go.'*
The policy intentions (the official) are detached from the project level	*'The Welsh Assembly Government has imposed these [low carbon policies] desires or requirements without giving any thought or consideration whatsoever as to how they'll be delivered on the ground.'* *'What tends to happen is the legislation gets poorly criticised. So legislation comes out, it's got all these numbers in it that affect the way that we design, and a lot of people complain about it, or just deal with it, you know, it's like being given medicine by a doctor, you just take it, it's too late. And then, and then they [the building industry practitioners] have to go through these years of pain involved if the legislation doesn't work, and hope that by demonstrating it doesn't work it will, it will get changed.'*
The definition of low carbon performance is unclear	*'What we call low carbon now is going to get redefined. It's like moving the goalposts because the original targets aren't actually achievable.'* *'For the zero carbon definition, there was a bit of a flawed consultation process. They [the policy makers] will probably be able to achieve it only by being obscure in the definition of zero carbon performance.'*

Table 4.1. Perceptions of the research participants about the low carbon policy

The designers recognise that the policy model provides the material infrastructure for enacting the carbon reductions. The official tools such as BREEAM, Part L, standards and guidance offer a ground for the definition of low carbon performance. The use of BREEAM as a planning condition is perceived to enable the incorporation of the low carbon performance metrics from conceptual design. The planning application is an instrument where the low carbon aspirations from conceptual design are inscribed as commitments in the design process. In detailed design, Part L is the standard that sets the mandatory requirements. Nonetheless, the designers recognise that the low carbon policy agenda has to be accommodated to the stakeholders' individual perceptions and priorities about energy, preference between capital and life cycle cost and delivery phase drivers.

As a result of the conflicts between policy and project level, the energy-related strategies are selectively incorporated and abandoned overtime in relation to the stakeholders' interests and the project drivers. The pre-existing interests and expectations of stakeholders affect the definition of the low carbon performance and the enactment of the design process. The designers in the case studies defined the low carbon design intentions by identifying the official requirements and by setting higher design aspirations. In such way, they attempted to achieve a better performing building than the minimum regulatory requirements and push the design team and the stakeholders to analyse the energy performance before the policy gateways (BREEAM and Part L).

The layers of defining the building performance, the official target and the informal aspirations, suggest that the transition to low carbon buildings is taking place by benchmarking between the policy expectations for carbon reduction and the project drivers focused on cost reduction.

The design process could become the battlefield where the controversies between the energy and cost targets are settled. The concept of low carbon is tailored to the project drivers so the low carbon aspirations evolve as the building is designed. The designers engage with the stakeholders and the wider design team members in order to ensure the continuity and the engagement to the low carbon aspirations during the design process.

The following sections present the tools that are invoked for low carbon problem-solving. The tools invoked by designers assist in the definition, calculation and mediation of performance so the design team and the wider stakeholders (client, users, and developers) understand the implications of the low carbon performance in relation to the project drivers. The relationship between the tools configure a network that helps to align the visions about the low carbon performance definition and facilitate the enactment of the policy intentions.

4.3.3. Indicators of performance

In RIBA B+, the architects referred to passive strategies, U-values, BREEAM energy credits and percentage of low and zero carbon technologies to outline the low carbon aspirations. No evidence was found in any of the case studies that the energy target was defined in terms of CO2kg/m2y or kWh/m2/y until the design was assessed in the light of the policy compliance gateways, BREEAM and Part L (between RIBA D-F). It was noted that the energy indicators could be used intermittently in the process in the light of compliance.

In cases 1, 3A and 4A, the design teams referred to U-values, Part L compliance and BREEAM certification from RIBA B. These design teams evaluated the solar gain index, overheating risk and thermal comfort from RIBA C. The TER/DER and EPC were assessed from RIBA C+ and D. In cases 1, 3A and 4A, the energy performance and the indoor environment indicators were part of the conversations from RIBA B to define the building design. Those conversations also included the cost implications of the low carbon strategies. In these case studies, a life cycle cost analysis was developed as part of the BREEAM assessment of the issue Management 12, Life cycle costing.

In case 2, U-values and the BREEAM rating were referred to in the meetings, conversations and project documentation. Specific energy performance indicators such as TER/DER and EPC were limited to conversations related to compliance with Part L and BREEAM, treated as a 'Pass/Fail' benchmark. The design development in case 2 was focused on cost reduction despite the architect's intentions to surpass the minimum compulsory targets. While this case study started as a performance-driven process due to the architect's motivations to achieve a building that exceeded the minimum requirements, the process gravitated towards the minimum compliance by RIBA D:

'If it's not a mandatory requirement, we don't want it' (Client's quote)

The following table summarises how the low carbon aspirations were set up in the case studies:

Low carbon aspirations	**1**	**2**	**3A**	**4A**
Client requested a specific energy target	x			
Renewable energy supply as briefing target	x	x	x	x
U-values as briefing target	x		x	
EPC as briefing target	x		x	x
BREEAM	x	x	x	x

Table 4.2. Indicators to define the low carbon aspirations per case study

There is a variety of indicators that affect the indoor environment and the thermal conditions experienced by the occupants such as ventilation rates, daylight index, solar gains, internal gains, temperature, thermal comfort parameters. These indicators could lead to different patterns of energy demand for cooling, heating, lighting. The indicators related to indoor environment require the understanding of occupancy to determine the potential energy usage. The field studies suggest that more knowledge is needed to understand how the users are operating the building and the consequences in terms of energy consumption.

The indoor environment indicators could become parameters in the simulation model but not design parameters. The strategies intended to prevent overheating could be abandoned during delivery to reduce the cost. For instance in case 2, the thermal mass was modified due to change in the materials and the brisesoleils were eliminated despite those changes produced an increased risk of summer overheating (elaborated in detail in Chapter 5, Section 5.5.2.)

4.4. Tools for outlining the low carbon aspirations

The *outlining of the low carbon aspirations* entails the identification of the compulsory requirements, the clients' requirements, the selection of energy indicators and the identification of passive design strategies. It should be remarked that while the official standards and codes helped in the identification of the energy targets, the designers were also using informal tools in the performance dialogue..

Aspects	Tools used to inform the task	1	2	3A	4A
Identification of requirements	Official standards, guidance, statutory documents	x	x	x	x
	Commission for Architecture and the Built Environment (CABE) criteria for	x			x
	Design Quality Indicators for schools	x		x	x
	Sustainability cards			x	
	Sustainability checklist	x	x		
Selection of energy indicators	Part L % improvement TER/DER	x	x		x
	BREEAM rating	x	x	x	x
	Percentage of energy supplied by low zero carbon technologies	x	x		
	U-values	x		x	
	Performance indicators found on previous project summary information (databases)	x	x	x	x
	Conversations with architects, mechanical engineers and/or the energy specialists	x	x	x	x
Design process	Project gateways	x	x		

Table 4.3. Tools to outline the aspirations

Table 4.3. summarises the tools used to outline the aspirations. For example, in cases 1 and 3A, the mechanical engineers used *sustainability cards* to prompt the discussion with the client and present the strategies for sustainable buildings and the low zero carbon technologies. For the selection of energy indicators, it was observed in all the cases that the architects retrieved the project summary

information from the *company's databases* as a benchmarking reference. In order to evaluate the potential of passive design, it was observed that the architects in all the case studies used *rules of thumb* and had *conversations* with other design team members, especially the mechanical engineers. In cases 2 and 3A, a weather analysis was carried on *Ecotect* by the mechanical engineerIt should be noted that some of the informal tools used for *outlining the low carbon aspirations* were not calculation tools to estimate the energy performance. They were tools that mediated the performance dialogue and facilitated the negotiations about the low carbon aspirations informally pursued by the design team. For instance, *sustainability cards* were used by the mechanical engineer in meetings and workshops to explain the client the potential of the site, available financial incentives, feasible technologies and suitable energy strategies (case 3A). The sustainability cards in case 3A addressed climate change, waste, urbanisation, water and energy. The energy sub-topics included micro-generation, low zero carbon technologies, demand management and carbon emissions. The design team in case 3A discussed with the client the strategies to create a learning environment such as recording data from a weather station and comparing it with the energy consumption, using active display panels to show the collection of solar thermal arrays and smart metering.

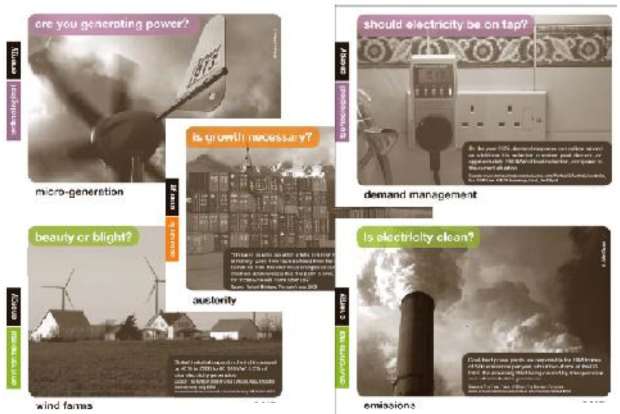


Figure 4.1. Sustainability cards

Cases 1 and 4A used similar cards in the meetings with the users and the clients but they did not address the energy or sustainability aspects. The cards in cases 1 and 4A were used to discuss about the architectural and visual qualities of spaces. The cards in case 1 had been developed by the educational sector to identify the client's preferences for key building areas: entrance, social spaces and performance spaces. In case 4A, the cards were used to visually compare the preferences for teaching and learning spaces, circulation areas, entrance, outside areas, major spaces and materials.

These cards were mediating objects that contributed in the dialogue between the design team and the stakeholders. For low carbon design, the cards addressing energy performance seemingly raised the awareness of the client about low carbon buildings, low zero carbon technologies and their benefits. The cards help the design teams to educate and engage the client in the identification of the low carbon aspirations.

Another tool that was reported by the architects in cases 1 and 2 was a *Project gateway* based on the RIBA Plan of Work. The architects said that the companies had created a model suggesting the deliverables and actions to take in the design process. In case 1, the *Project gateway* comprised the detailed description of deliverables, the design team responsibilities, the project milestones, the audit checks, risk management, contingency plan, document control, planning and statutory authority, guidance and references to codes and standards. The *Project gateway* had a checklist of tasks to be completed by the end of RIBA A, C, D and E. It included feedback at the end of the project. In case 2, the *Project gateway* was a checklist of tasks, actions, responsibilities and deliverables per design team member, guidance and good practice in relation to RIBA Plan of Work. However, the use of these *Project gateways* was not observed during the design process of the case studies.

In relation to the use of databases as tools for outlining, the field data suggests that the use of project summary information was retrieved from the databases for two purposes: to identify the targets in relation to past experience (benchmarking) and to network with the colleagues who had prior experience in low carbon design.

The databases in the case studies archived the summarised information of the projects developed in the companies. For example, in case 2, the summary information comprised the environmental approach for reduction of energy use, renewable energy, water reduction, green travel plan. The indicators included were the percentage of low zero carbon technology use, the BREEAM rating, EPC credits achieved on the issue Energy 1 and the credits achieved in the BREEAM categories. The name and contact information of the design team was part of the project summary information which help the architects to network with their colleagues. Similar databases were found in cases 1 and 3A.

The networking via databases facilitated conversations to disseminate experience and informal advice. In case 1, this form of knowledge dissemination was supported by the company intranet. The designers in case 1 had a forum where they could create blogs to share their experiences, consult their colleagues based in any office of the company and exchange advice. As the company in case 1 was a multidisciplinary practice, the forum was organised by different disciplines: mechanical engineering, civil and structural engineering and architecture.

The topics found in the mechanical engineering forum included: natural ventilation and noise attenuation, BB101 criteria (overheating) outputs from IES (a proprietary simulation software), certification requirements for oil/fuel storage and distribution system, comments about the 2010 revision of EPC, biomass boilers, design guidance for piping and valves and pressure control. In the architecture forum the topics found were related to materials and their installation, for example: phase change materials, lifespan of cedar cladding, sheet flooring, electrochromic glass, PVC skirting, underfloor heating, antigraffiti paint for brickwork.

To illustrate the use of the forum in case 1, the topic 'Building Bulletin 101 criteria outputs from IES' is presented. A mechanical engineer asked for advice about how to extract the data from the IES model to demonstrate the compliance with Building Bulletin 101 (Overheating). She wanted to show that the difference between external and internal temperature did not exceed 5^{o} C during peak cooling hours[1]. She was looking for a simplified method to identify the rooms that did not comply with this criterion. She received a reply from a colleague advising her to contact the colleague who created an Excel spreadsheet to filter and analyse the IES results. The spread sheet had a function to identify the 'out of range values' (values exceeding a 5^{o} C difference between the internal and external temperature).

The mechanical engineer who started the thread decided to extract the hourly temperature difference during peak hours in the cooling season from IES on the basis of her conversations with her colleagues. The hourly temperature difference was copied to the Excel spreadsheet where two functions were added to identify when the external temperature was over 18^{o}C and the rooms where the temperature differential was higher than 5^{o}C. This helped to identify the rooms that needed to be analysed in IES to determine whether the out of range hours occur in the hours when the building is not occupied. Four people from different offices participated in this query: the person who asked for advice, the one who knew about

[1] One of the Building Bulletin 101 criterion concerning overheating

the spreadsheet, the creator of the spreadsheet and another mechanical engineer who had used the spread sheet.

The following table summarises the 'outlining' tools found in the case studies:

Tools	Use
Official standards	To benchmark the project requirements and set the targets (all cases)
Company database	To network with colleagues who had experienced in energy strategies. The project summary information apart from being a repository of key indicators, it was a trigger to connect people and exchange experienced advice (all cases)
Workshops with clients	To identify clients' requirements, discuss about available energy strategies(all cases)
Sustainability cards	To facilitate the dialogue with the client about low energy requirements and aspirations, raise awareness about available energy strategies and financial aspects (case 3A). Visual and architecture cards used in cases 1 and 4A to identify the preferences of the users although these cards did not address energy performance.
Conversations	To exchange experience-based advice and knowledge (all cases)- between architects, architects and mechanical engineers, architects and energy specialists
Project gateways	Models of the process with deliverables based on the RIBA Plan of Work timeline. These project gateways attempted to suggest the tasks to consider low carbon and sustainable performance (cases 1 and 2)
Forum (blog)	Embedded in the company's intranet and used as a platform to exchange advice, post news, upload information updates. It was used by designers to consult their colleagues from other offices (case 1)

Table 4.4. Outlining: tools to embed performance and their use

4.5. Understanding energy performance (RIBA B-C)

This task involves the estimation of how the design strategies respond to the requirements and aspirations. It implies the translation of the energy benchmarks to specific design strategies. The understanding is gained by the use of experience, heuristics and qualitative estimation of performance. In RIBA B and C the design teams tried to develop a project-specific understanding of the potential performance of the design and the implications of the design strategies on aspects such as acoustics, ventilation, use/occupancy, capital/operational costs and maintenance. This understanding was gained through discussions between designers, experience-based advice and in-house tools for a 'rough estimation' of performance.

4.5.1. The architect's role in understanding

In RIBA B, the architects used *rules of thumb* to determine the geometry, massing, thermal mass and orientation of the buildings. The site conditions were considered to assess the feasibility of low and zero carbon technologies, ventilation potential, thermal mass strategy, solar strategies and daylight potential. It should be noted that none of the architects in the case studies used any tool to quantify the performance. Their understanding was based on experiential knowledge, advice and heuristics.

There were divided views about the use of rules of thumb between the architects in the case studies. Some said that the rules of thumb helped them to understand if the design strategies could achieve the desired performance. Other expressed their scepticism in the use of rules of thumb because they could constraint the design. They said that rules of thumb could become a tick-box exercise that might jeopardise the adoption of new strategies.

The table below summarises how the rules of thumb were reported to be used by the architects. They informed the orientation of the building in relation to solar use for heat gains, daylighting and glare avoidance, orientation for natural ventilation, the envelope properties for thermal mass and U-values, the potential of renewable technologies for the site.

Aspects assessed by Arch's rules of thumb per case study	**1**	**2**	**3A**	**4A**
Orientation-solar aspects	x	x	x	x
Orientation- ventilation aspects	x	x	x	x
Envelope properties (thermal mass, U-values)	X *	x	X *	X *
Low zero carbon technologies potential in the site	x	x	x	x
Room depth to height ratio	x			x
Low zero carbon technologies (maintenance, use and spacial requirements)	x			X *

**these aspects were set with the support of the mechanical engineers*

Table 4.5. Use of rules of thumb as input to the design per case study reported by architects

The field data suggests that the understanding of performance by the architects in early conceptual design is based on heuristics and experience. Nonetheless, it is unknown how the rules of thumb and heuristics could help to achieve the expected performance since the rules of thumb are based on intuitive understanding of performance. The rules of thumb were used to determine passive design strategies, likely percentage of low zero carbon technologies necessary for compliance, height/depth ratio of rooms for natural ventilation.

In relation to the design strategies, the architects in all the case studies stated their preference for passive design solutions over low zero carbon technologies because the performance of passive designs would not be affected by the quality of the installation, quality of construction work and the occupants' use and maintenance:

'Ultimately you put in all these systems but if the users don't use them, then [the systems] might even be working less efficient than the simple things that [the users] know how to use…'

The passive design strategies and energy efficient mechanical systems were viewed as cost-effective solutions while the low and zero carbon technologies were regarded as 'bolt on' and less commercially viable.

'Normally it is the same hierarchy... starting with passive design and avoiding add-on cost. It's better to avoid a high capital cost. Passive design and principles such as solar shading, daylighting, orientation are early decisions that cost nothing…'

The architects and mechanical engineers agreed that current requirements demanded a combination of passive design (envelope, orientation), the selection of efficient mechanical systems and the use of low and zero carbon technologies. For educational buildings, the rule of thumb was to supply 10 to 20 per cent of energy by low zero carbon technologies.

It should be noted that while the policy model is encouraging the adoption of low zero carbon technologies, it may not be addressing their installation and use. The financial incentives have been set to support the individual technologies without looking at the whole building performance. Nonetheless this situation has been addressed by the FIT which required an EPC band between A and D from 2012. Equally, the 2011 BREEAM version which superseded the 2008 version that was used to certify the case studies, has changed the way that the issue Energy 1 is assessed. BREEAM 2008 awarded the credits for Energy 1, Reduction of CO2 emissions, on the basis on the EPC rating. BREEAM 2011 uses the Energy Performance Ratio which is an index that considers the building operational demand, the energy consumption and the resulting carbon emissions. Each of these parameters has a weighting that determines the number of credits. The energy performance ratio uses a translator of performance which is an index that relates the modelling data of actual buildings compliant with 2010 Building Regulations and best practice (BREEAM 2011).

4.5.2. The mechanical engineer's input in understanding

The experience-based advice from the mechanical engineer helped in the understanding performance. A number of in-house and simplified calculation tools were deployed by the mechanical engineers and the energy consultants who worked with the architects. These calculations provided a quick feedback about the potential performance of the design and helped to compare different alternatives. The following quotes were expressed by one of the mechanical engineers:

'*They [the architects] need to consult us [the mechanical engineers] earlier than they used to… we are involved in the project from the very early but in different ways, sometimes with experienced-based advice and then later on with the modelling.'*

The experience-based advice was shared between the architect and other design team members during informal conversations and meetings. In case 1, the mechanical engineer gave general advice to the architect about the orientation, massing and U-values which was inscribed on the mechanical engineering briefing to the architect.

'We sort of start talking about the low carbon strategies quite early with them without any calculation so it is quite experience-based in a way. We look at the orientation, the form, the massing, the things that you could do without the calculations, the things that you know that will work. It is done in that way, it is more qualitative than quantitative…'

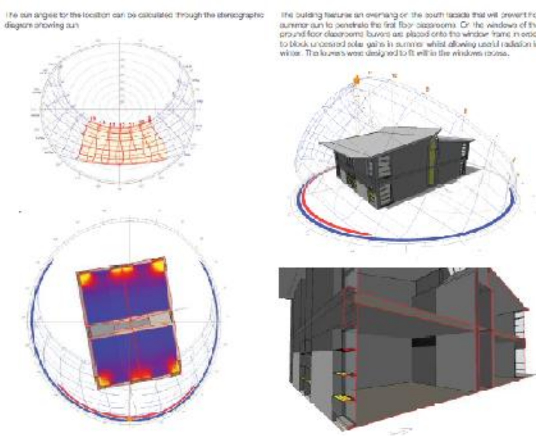


Figure 4.2. Weather analysis in Ecotect (case 2)

In case 2, the architect and the environmental engineer reported that they had a meeting to delineate a general architectural strategy based on site and climate conditions. The environmental team from the architecture company carried a weather analysis to identify daylight and energy strategies related to solar gains and reduction of overheating risk. However, the environmental team was not part of the design team in case 2. It was reported that the environmental engineer gave advice until RIBA Stage C, when the energy calculation was produced by the mechanical engineer who was a member of the design team of case 2.

The project documentation in case 2 included graphs and diagrams of weather studies done on Ecotect. The climate data was analysed to define the orientation, the ventilation strategy and the passive design strategies. Yet, the environmental engineer who carried the weather studies criticised the use of Ecotect for weather analysis. He argued that it could be used only to produce *‘pretty pictures’*.

In case 3, the mechanical engineer reported that when the architect had a preliminary building design, they had a meeting to discuss the environmental strategy and revise the orientation, thermal mass of the envelope, geometry and U-values.

‘We assess the energy matters, initially on sketches without the use of simulation. This is based on our experience in sustainability. We discuss and comment over the architect’s drawings about strategies, orientation, climate analysis.’

It was reported that quantitative assessments were also carried out by in-house tools in RIBA C. The mechanical engineer from case 1 reported an in-house tool to assess U-values and thermal mass, consisting of an Excel spreadsheet that collated data obtained from standards, CIBSE benchmarks and government publications:

‘*We do some hand calculations in Excel; we do some calculations using benchmark data to compare the building and see if it is on track, but that’s just approximate.’*

In case 2, the architect also reported the use of an Excel spread sheet to ‘play with U-values’.

‘Before we send the documents to the consultants to produce an energy simulation, we try to understand with our U-value tool what is happening...’

In cases 3A and 4A, the architects did not report the use of any in-house calculation tool to understand performance. The field observations suggest that the conversations between architects and mechanical engineers had a central role in the understanding performance by the architects in cases 3A and 4A. Despite cases 3A and 4A had no in-house mechanical engineer; the partnerships that the architects had developed with the mechanical engineers facilitated the conversations and the experience-based advice. The following excerpts illustrate the architects' perception about their collaboration with the mechanical engineers to evaluate the energy performance:

'We learned from our past experience working with the mechanical engineers on various projects. They run the SBEM calculations or simulation calculations and we learn what is good practice and what is basic.'

'The mechanical engineer is there to advise us on those matters [energy performance]. But you know, you learn from every project.'

'It is simply by working with some consultants that we are more confident in the ability to understand what we need to do to achieve the low energy building.'

It could be inferred that the conversations facilitate the social construction of the knowledge dispersed in the design team. The knowledge about low carbon design needs to relate the performance target and the information about cost, buildability, operation so to translate the performance targets to stakeholders' drivers and expectations. As the design development progresses, the experiential advice addresses the energy indicators in relation to the cost implications, maintenance aspects and likely users' occupancy patterns. The cost implications were assessed by life cycle cost analysis required by BREEAM issue Management 12 Life cycle costing (cases 1, 3A and 4A). The feasibility studies carried in cases 1, 3A and 4A compared different low zero carbon technologies in terms of energy generated per year (kWh/y), carbon offset per year (kgCO2/y and percentage), payback period (years), land use requirements, local planning criteria, noise impact, heat/electricity exporting potential, cost per unit of carbon savings (£/kgCO2), capital cost, financial options (FIT/RHI).

The maintenance and occupancy patterns were determined in workshops with the users. While consultations with users were undertaken in all the case studies possibly because of BREEAM requirements for issue Management 6 Consultation, only in Case 1 the mechanical engineers discussed with the client the prospective operation and maintenance of the technical systems by the building users throughout the whole design process. The design team in Case 1 attempted to estimate the occupation pattern of the building, the use of mechanical systems, the maintenance of mechanical systems and low zero carbon technologies. They revisited the design assumptions about the user at the end of each RIBA Stage. This information helped to refine the simulation model assumptions. Questionnaires were included in the reports produced at the end of the RIBA Work Stages for the client to clarify the assumptions made on the simulation models. The questionnaires addressed the hours of use throughout the year; schedule of use of classrooms, cafeteria and kitchen; users' control of radiator and windows; set point adjustments and mechanical ventilation flow rate; schedule of use of louvers; manual overrides of automatic lighting, heating and ventilation systems with automatic BMS reset; use of seasonal commissioning; IT equipment strategy for classrooms and offices. The update of the modelling scenarios informed by the clients' input helped to increase the certainty and quality of the simulation exercise so to represent the users' preferences and potential behaviours.

The following table summarises the tools for 'understanding' identified in the case studies:

Tools	Use
Rules of thumb	To gain a qualitative understanding of the implications of design strategies on the building performance (all cases
Workshops	To raise the clients' awareness of the benefits of low carbon performance and to obtain feedback about potential users' preferences and behaviours in the building
Experienced-based advice	To discuss and understand the performance by consulting experienced colleagues (all cases) and partnering with other team members such as the mechanical engineer (cases 1, 3A, 4A) and environmental engineer (case 2)
In-house tools	To evaluate U-values (cases 1 and 2)
Life cycle cost study	To analyse the cost implications of the low zero carbon technologies (cases 1, 3A and 4A)
Weather analysis	To evaluate the passive design strategies. It was undertaken in all cases by rules of thumb and in case 2 on Ecotect.
Documentation of assumptions about use and verification	To consult the client about the prospective profile of occupation by the building users (case 1)

Table 4.6. Understanding: tools to embed performance and their use

4.6. Calculating the energy performance (RIBA C-D)

While understanding implies a rough estimation of performance, calculating involves a more accurate prediction of performance by using the calculation tools and obtaining numerical indicators. In RIBA C, calculation tools were used by the mechanical engineer to quantify the performance. The estimation gradually focused on the accuracy and certainty of the performance appraisal.

'The model generally starts and develops as the design goes through, so your model might be more basic at the beginning of a project because you really don't know what systems and things are going to go in there, you know, so you get a

feeling for it and you know what results come out of it. You know it might be failing the EPC but you think, well, actually we don't know what the lighting systems are and we don't know what the heating systems are, so, you know, we develop the building the best we can…'

The in-house tools and the experience-based advice from designers were complimented by the use of proprietary simulation software such as IES (case 1 and 3A) and TAS (case 4A). In case 2, SBEM was used to calculate the energy performance and check the compliance. Despite the use of the official calculation tools, the conversations remained as a pervasive tool that accompanied the quantitative calculations.

In cases 1, 3A and 4A, the simulation tools were used from RIBA C to estimate the performance and evaluate the consequences of different design strategies. In these cases, the mechanical engineers were deciding when to switch from experience-based advice to simulation. In case 1, the mechanical engineer reflected that the use of simulation in RIBA C was early compared to the time when it has been invoked in other projects. In the past, first simulations using proprietary software had been done when the conceptual design was completed after RIBA D or later.

'We struggle to decide when to make the simulation model because it is quite a lot of work and the architectural design in the beginning changes very frequently. We haven't solved when it is actually a good time to do the modelling because you do not want to do it too late otherwise you may find that it's not going to work. But if you do the simulation model too early, you could be changing, changing, changing it… you could spend lots of time modelling but the design keeps changing so you wonder if it is worthy investing the time.'

In case 4A, the design team was intending to design a zero carbon building and one of the aspirations was to achieve a BREEAM Outstanding rating. The simulation was invoked to investigate the technologies that could help to achieve the energy credits for BREEAM Outstanding. The cost implications of the technologies assessed by the simulation exercise were analysed to determine if the zero carbon aspirations were financially viable.

In RIBA D, the simulation results were used to compare the building performance to the benchmarks for BREEAM and Part L compliance. In cases 1, 3A and 4A, the proprietary software (IES and TAS) were preferred over SBEM.

‘SBEM is quite tricky. It’s an Access database. There are lots of bugs. I’ve tried to use it in my last company but we did not find SBEM to be good. If you use IES you could get other benefits from it, so you can look at how summer time temperatures may be in a naturally ventilated spaces and you can get daylight performance and the energy performance certificates rating as well.’

‘SBEM is not very user-friendly for consultants.’

SBEM was used to produce the report to assess BREEAM energy credits as part of the planning application package in case 2. A dynamic thermal model was carried by an external energy consultant during detailed design. The simulation results suggested that some spaces may not comply with minimum BB 101 criteria and there was risk of overheating during summer peak season. A number of simulation models were produced with summer ventilation set points of 18°, 20°, 22°C. The criteria that required a maximum air temperature of 30°C was not met.

The table below summarises the tools deployed in the case studies:

Tools	Use
Rough models	To estimate the potential performance of the design and compare the results to the energy aspirations (cases 1, 3A and 4A). None of the architects in the case studies used calculation tools to quantify the energy performance.
Simulation	To calculate the performance as a design aid (cases 1, 3A and 4A) to inform the design development and to produce the evidence for planning application concerning BREEAM compulsory requirements (all cases). Case 2 was the only who used SBEM as a tool to calculate performance while the other Cases used proprietary software aligned to NCM.
Experience-based advice	To make quick decisions concerning the design development and to understand the simulation results in the light of what has been learned in the past by experience (all cases)
Customised schedule of operation	To improve the accuracy of the assumptions in the simulation model (case 1).

Table 4.7. Calculating: tools to embed performance and their use

4.7. Other mediating tools

The design process is unlikely to be focused on the energy performance quality therefore the low carbon aspirations have to be negotiated beyond the realms of the energy performance metrics by the designers. In order to resolve the conflicts between the drivers of the process (cost reduction) and the policy intentions (carbon emission reduction), the design teams were using tools to relate the energy indicators with aspects that influenced the stakeholder's decision-making rationale such as cost and buildability. The tools that mediated the performance dialogue in the case studies were the life cycle cost analysis, the energy bill saving estimator and the embodied carbon calculator.

A life cycle cost analysis was undertaken in cases 1, 3A and 4A as part of the BREEAM evidence requirements. In these cases, the life cost analysis contributed to the dialogue with the client and illustrated the benefits of low zero carbon technologies. No life cycle cost study was undertaken in case 2.

The life cycle cost study in case 3A used the CIBSE TM38, Renewable Energy Sources for Buildings (2006), to compare the feasibility of different low zero carbon technologies. The loads were based on the energy consumption from the Energy Consumption Guide 73 for schools (1996), BSIRIA Rules of Thumb and the *design experience* of the team. The aspects included in the study were the utility rates, the installation cost, annual running costs, payback period and the energy generated.

As the client in case 3A was interested in the long term benefits of the low and zero carbon technologies, the life cycle cost was a key tool to discuss the solutions from RIBA C:

'They [the clients] wanted to have the PVs on and all those things. They [the clients] wanted to know how much it would save them potentially off their bills because they get just a set budget every year to run and maintain the school, so obviously the more we can reduce the energy consumption, the more they can spend on text books and things like that for the kids.'

In general terms, the research participants felt that life cycle cost information could inform the energy strategies so as to find a balance between energy performance and cost. However, if the end users were not considered, the decisions could be biased towards capital cost.

Another mediating tool reported by the architect was the *energy bill saving estimator* which showed the operational cost savings from low zero carbon technologies. However, this tool was not use in the case studies. The architect mentioned that this tool was used to the design of a residential development for the elderly. He said that the developers were interested in investing in low and zero carbon technologies because they thought that a low carbon building had a commercial advantage if the building users were aware of the benefits and reduced the operational cost.

The *energy bill saving estimator* is a spreadsheet that calculates the weekly costs due to the energy consumption for space heating, water heating and lighting. The weekly cost is aggregated and compared to the basic income of the user to determine the percentage of basic income likely to be used to pay the energy bills.

Element	£/week
space heating	0.86
water heating	2.23
pumps and fans	0.25
lighting	1.15
standing charges	0.65
total energy costs	£5.13 per week
Age UK basic income	£132 per week
%of basic income spent on fuel	4% compared with 10% threshold for fuel poverty

Figure 4.3. Energy bill saving estimator created by the architect

The *embodied carbon calculator* was a tool in Case 1. It is an Excel spreadsheet that combines the benchmark data published by Bath University about the embodied carbon of steel, timber and concrete and compares the embodied carbon of the structural elements (Hammond and Jones 2008). The outputs of the *embodied carbon calculator* relate the carbon savings to data about operational cost. The design team could compare a naturally ventilated building with a heavy thermal mass to a light weighted air conditioned building in terms of embodied carbon and carbon reductions during operation. The civil engineer who created this tool expressed that:

'The regulations will focus in the future on embodied carbon. Then we will be running up against it. What I am trying to do is to analyse our building techniques now so that we can understand the embodied carbon from now so we can be ahead of the game.'

The development of the embodied calculator tool in case 1 suggests that the designers acknowledge the need to understand the implication of the regulatory requirements and anticipate how the requirements may affect the design strategies.

In case 4A, the design team calculated the embodied carbon of the structural elements but the results were not related to the operational costs. Despite that the embodied carbon was considered in cases 1 and 4A, the embodied carbon was not a design decision criterion[2].

Tools	Use
Life cycle cost studies	To analyse the potential medium and long-term benefits of the implementation of low zero carbon technologies in relation to the building lifespan (cases 1, 3A and 4A)
Energy saving tool	To calculate the potential savings in energy bills from the use of low zero carbon technologies (not applicable)
Embodied carbon tool	To calculate the impact of the building elements using a life cycle impact analysis that considers the extraction, manufacturing and transportation processes of building materials. This tool uses the data from the Bath University embodied energy and carbon database (case 1)

Table 4.8. Mediating tools and their use

The planning application requires addressing the aesthetics aspects of the building design. The designers used samples of the materials (all the cases) and models (cases 1 and 3A) to show the visual properties and the geometry of the building. While this visual display could be achieved by digital images generated by CAD tools, the designers used samples and models to facilitate the communication of ideas with planning authorities and clients to represent the aesthetic properties of the projects (observed in all the cases). This could mirror the situation of low carbon indicators which might need a *physical or tangible medium* in order to be understood by the non-energy expert. In other words, the low carbon indicators (i.e. CO2kg/m2/y, TER/BER) may require a translation so to be related to the concepts that the stakeholders could relate to; for example, cost and operational savings.

The use of mediating tools to relate the low carbon targets and the project drivers show how the designers solve the differences between the policy intentions and the stakeholders' expectations. It was observed in the case studies that the tools to embed low carbon performance are not only focused on benchmarking and calculating the performance. They help to engage the stakeholders, illustrate the low carbon performance in terms of operational cost reduction so to relate the energy performance to the concerns and understandings of the stakeholders. The use of energy indicators as an absolute metric to be delivered in isolation neglects the circumstances that shape the evolution of the low carbon aspirations during the design process. The energy performance metrics cannot be isolated from other

[2] BREEAM addresses embodied carbon in the Issues Material 1 and Material 6. Material 1, Specification of major elements, considers the environmental impact of the materials according to the Green Guide ratings (www.thegreenguide.co.uk). While Material 6, Insulation, assesses the impact of insulation relating the thermal properties to the embodied environmental impact based on the Green Guide ratings.

design concerns. The energy performance metrics have to be articulated with the expectations of the stakeholders. The mediating tools are adopted to affect the network of stakeholders' interests and align the project visions to the policy requirements.

Figure 4.4. summarises the tools found in the case studies according to the low carbon problem-solving tasks (grey box on the top) and the project timeline (grey box on the bottom). This figure includes the official project documentation (white boxes). The purpose of this figure is to summarise the tools found in the cases and map their use in relation to the project timeline. This figure should not be read in terms of linearity as the use of the tools was likely to be iterative and dynamic. This aspect is discussed in the following section corresponding to the low carbon process-tool map.

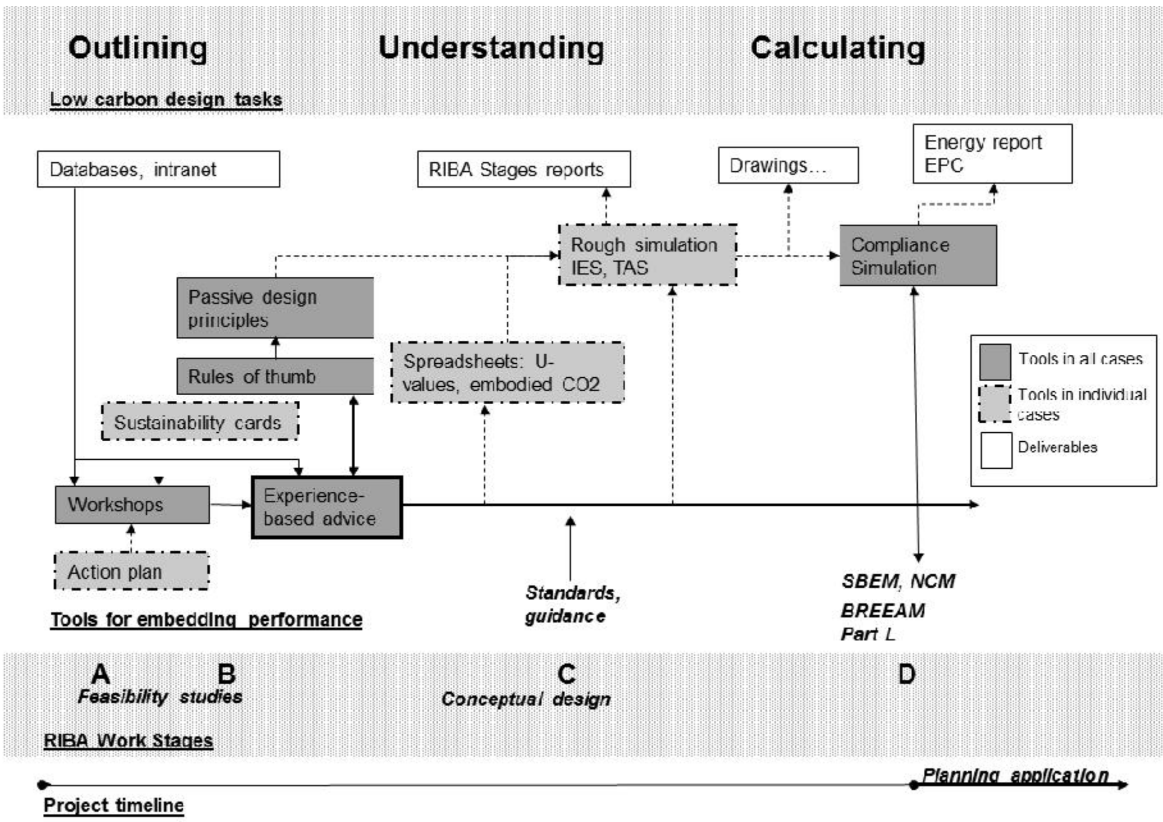


Figure 4.4. Summary of tools found in the case studies

4.8. Discussion

The previous sections have described the conceptual design process observed in the case studies with a focus on the tools to embed performance. The process has been described in relation to the low carbon problem-solving tasks. The field dat reveal the understanding performance cycle undertaken by the design teams. The field data suggest that the tools used in the process are entangled in networks. Therefore, the examination of the low carbon process timeline could increase the understanding about the performance appraisal cycle and the knowledge flows. From the analysis of the low carbon process timeline, we could detect how the policy intentions and the official tools are being adopted by the designers and portrait what is preserved from the official when introduced in the design process.

This discussion is developed in the following sections:

- the low carbon problem solving process timeline, tools in the social context; and,
- the adoption of the policy model by the designers in conceptual design

4.8.1. The low carbon process timeline, tools in the social context

The field studies suggest that there is a pre-existing social context where the official is to be incorporated and that there are contradictions between the official and the informal levels. The policy model expects the immediate incorporation of the low carbon requirements by the designers; however, the pre-existing social context could affect their implementation in the design process. The pre-existing social context could hinder:

- the drivers of the process (cost, time, energy, user's preferences);
- the pervasiveness and the use of tools to embed performance in the building design,
- the knowledge resources available to support and enhance the understanding, experience and expertise to embed low carbon performance in the building design.

The tensions between the social context and the expectations of the policy model could lead to conflicts between the definition of the project requirements (meeting a cost target) and the low carbon performance (meeting an energy performance target). As a result of these tensions, the design teams in the case studies defined and negotiated the design intentions in two layers: targets (as enforced by legislation) and aspirations (as intended by the design team and stakeholders). The tensions could result in the enactment of a compliance-only or a performance-driven process. Compliance-only process is one whose goal is meeting the minimum compulsory requirements. In compliance-only processes, the calculation tools appear to be used only to produce compliance evidence in the light of the policy gateways (BREEAM and Part L). The calculation tools are not deployed as design-aids. The low carbon targets are likely to be an intermittent aspect in the design process that emerges in response to compliance. Performance-driven[3] process is one where the goal is to exceed the minimum compulsory requirements. It is inherently an evidence-based process. There is a permanent performance dialogue between the designers and the stakeholders. The calculation tools are used to assist in the dialogue and understanding of performance alongside the design development.

	Compliance-only process	***Performance-driven process***
Project drivers and low carbon performance	Low carbon performance is not a project requirement so the energy targets are likely to be superseded by explicit project drivers such as cost	Low carbon performance is an aspiration. The design teams attempt to find a balance between the low carbon aspirations and the project drivers, especially cost.
Definition of the low carbon performance	The low carbon performance is not a project requirement so it is unlikely to be part of the design negotiations. It is an intermittent aspect that is settled in the light of the policy gateways (BREEAM for planning application and Part L for building control). The performance target is a theoretical indicator required by the policy model.	There is a collective definition and negotiation of the low carbon performance. The performance dialogue is part of the design process and it seeks to articulate the low carbon aspirations with the project requirements.
Tools	Deployment of tools to produce compliance evidence.	The tools help to calculate the performance to meet a target, to mediate the performance dialogue between the stakeholders and to illustrate the benefits of low carbon performance.
Knowledge	Fragmented knowledge conversion process, gaps in knowledge and breakdowns in the process	The knowledge is socially constructed and disseminated by the conversations between design team members.

Table 4.9. Differences between compliance-only and performance-driven processes

The field studies suggest that the way the designers solve the tensions between the official and the informal affects the low carbon performance target. It was observed

[3] According to Becker and Foliente (2005), performance-based building design is an approach where the objectives to be achieved on the building are defined in terms of desired results without prescribing specific strategies or methods achieve the objectives.

that the case studies could be located in different points of the spectrum between compliance-only and performance-driven processes, in relation to the negotiations and actions that are enacted to define the low carbon performance for the building i.e. benchmark, educate the client, illustrate the benefits of low carbon performance. The use of the mediating tools helped to articulate the variegated visions of the stakeholders so to achieve the policy intentions.

The design negotiations are necessary to reach a compromise between the cost and the energy targets because they are perceived to be mutually exclusive. The negotiations inform the performance dialogue, help to create knowledge about performance and contribute to a better understanding of performance among the stakeholders. These negotiations are assisted by the configuration of a low carbon network. The field studies suggest the official tools, standards and simulation tools are unlikely to be in the centre of the design negotiations. They are perceived to be compliance instruments that outline the minimum target but cannot be immediately linked to the stakeholders' concerns.

It has been inferred that embedding performance in conceptual design involves the calculation of performance and the understanding of the target to articulate the policy requirements and the project drivers. While some tools have the capability to calculate the performance, others could be used as part of the dialogue to define the aspirations (informal targets) i.e. sustainability cards, databases as benchmarking and network tools. The tools that mediate the dialogue may not have the capability to calculate the performance but they strengthen the network that supports the performance dialogue. The mediating tools help to articulate the project drivers, raise awareness of the stakeholders and increase their understanding about low carbon performance. The mediating tools facilitate the resolution of the tensions between the policy expectations and the project requirements since low carbon performance is unlikely to be driver of the process. The early deployment of calculation and mediating tools fosters the collective construction of knowledge and seemingly increases the understanding of what low carbon performance entails. While the stakeholders are engaged in negotiations about the target, compromises are found between the energy target and other expectations (cost, maintenance) and new knowledge is created and disseminated.

The field data suggest the following findings concerning tools to embed performance:

- The tools are invoked to facilitate the design negotiations, reconstruct the knowledge dispersed in the team and foster the knowledge conversion about performance.

- The official tools for compliance are not prone to be in the centre of the performance dialogue. They could become prescriptions of the process and may not get integrated in the design process. They could be used intermittently when invoked only to produce the evidence for compliance.

- The designers seemingly prefer the informal tools over the official ones. The informal tools are pervasive and unlikely to be fully replaced by the official tools. The informal surrounds the use of the official tools and could support the incorporation of the official tools in the process i.e. rules of thumb are embedded in the assumptions for the simulation exercise, experiential knowledge is used to interpret the simulation results, conversations help to benchmark the project targets

- The designers have developed in-house and informal tools to understand performance by combining experiential knowledge, benchmark data and standards.

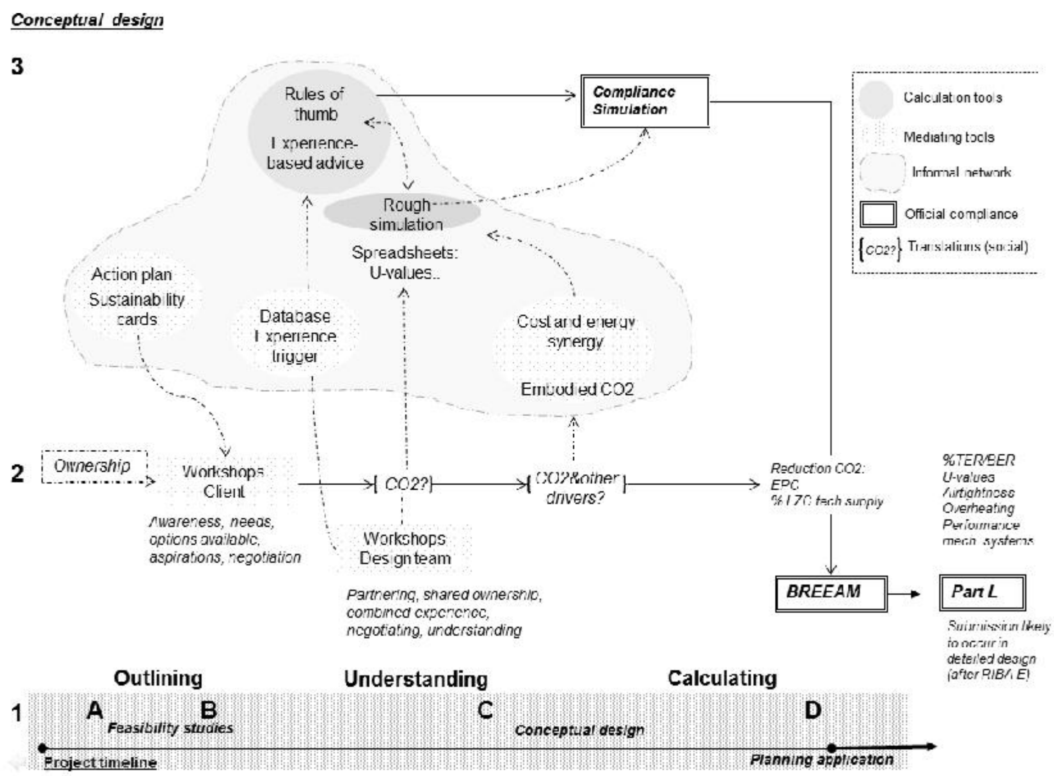


Figure 4.4. Low carbon problem-solving map in conceptual design

Figure 4.4. *Low carbon problem-solving map*, illustrates the relationships between the tools in conceptual design and their deployment throughout the process. It is a representation of the ways that the tools are used in relation to the social context (tensions between policy and design levels). It reads bottom-up. Section 1 refers to the project timeline and the low carbon problem-solving tasks found in the field during conceptual design (outlining, understanding and calculating). Section 2 represents the instances when the energy aspirations are likely to be negotiated. This occurs by articulating the official intentions (low carbon reduction) and the stakeholders' expectations (cost, users' preferences, maintenance aspects).

As different agendas and unarticulated visions emerged in the design process, translations are necessary to intervene in the pre-existing social context and realign the visions towards low carbon performance. The designers become the agents who bring together the collective aspirations and direct them towards the achievement of low carbon performance. The low carbon aspirations are likely to be defined and negotiated in these translations. The evolution of the low carbon aspirations (the informal goals) shows how the low carbon buildings are design as a result of the negotiations between the stakeholders. The low carbon design process is affected by the project-specific circumstances, the individual and collective attitudes of the stakeholders in relation to low carbon aspirations and project requirements. The use of tools in the process could affect the translation and the knowledge conversion process. They enable the knowledge conversion if used to define the performance, the hinder the knowledge conversion if they interfere with the social networks (dialogue, advice, experiential knowledge sharing). The simulation results ought to be related to a pre-existing performance dialogue that defines the low carbon aspirations in relation to the project requirements and stakeholders' expectations.

Section 3 illustrates the associations between the tools. The figure emphasises the role and pervasiveness of the social context and the informal tools in the design process. Contrary to the assumptions of the policy model, the central role of the compliance tools (Part L, BREEAM, simulation tools) is relative and intermittent for embedding performance. The performance appraisal cycle does not depend on the compliance and official tools. Whilst the official targets define the minimum performance, on their own they do not imply the enactment of a performance-driven process. The performance dialogue is supported by the informal. It was observed in the case studies that the informal tools were likely to be preferred and invoked before the use of official calculation tools. In compliance only-process the official and the calculation tools are invoked when the policy gateways demand the compliance documentation. The simulation and the official tools could develop a 'poor stickiness' in the process due to their low hierarchy within the low carbon network, resulting in their intermittent use by designers as shown by the episodes described in this chapter.

The low carbon problem solving map is a representation of the field findings to portrait the relation between the social context and the use of tools for low carbon problem-solving and for the social construction of knowledge. The low carbon problem-solving map illustrates establishment of the material and social conditions to achieve the low carbon aspirations.

The performance-based process seeks the articulation between the policy requirements and the project drivers. This is enabled by the use of tools to mediate the performance dialogue and the calculation of performance. Both aspects contribute to the social construction of knowledge. The conversations and the experience-based advice facilitated the knowledge flows and the reconstruction of the collective knowledge dispersed in the team. The designers in the field studies made appraisals about performance based on conversations and experiential advice. The social networks in the design process contribute to the information exchange and to generate situated knowledge about performance. This was reflected in several episodes described in this chapter, for example the use of databases for networking, the blog for exchanging advice, the informal advice between mechanical engineers and architects, sustainability card to show the benefits of low carbon design.

The field studies suggest that the understanding performance could be based on the informal. The informal has reached a legitimised albeit tacit status by the designers. The informal could trigger the situated and embodied knowledge about energy performance and project drivers such as cost, buildability, maintenance, users' preference.

The episodes described in this chapter contest the rational view that locates the simulation tool in a clearly defined simulation environment. The field data suggest that such assumption is a misconception about the performance analysis in the conceptual design process. The function of embedding performance reduced to a calculation exercise detached from other design concerns does not fit the performance appraisal cycle nor the performance dialogue observed in the case studies. This artificial representation takes away the social resources that enable the collective creation of understanding performance by the designers based on conversations, experience-based advice and informal tools.

The experiential knowledge and informal tools are deployed in the design negotiations and the performance dialogue. The simulation tools were likely to compliment the use of the informal. The experiential knowledge has been combined with benchmark data to create in-house tools such as the U-value calculator, the fuel poverty calculator to estimate energy bill savings, the embodied carbon tool. The databases, calculation tools, fuel poverty calculation, sustainable targets, as mediating tools, trigger the existing collective knowledge, connect experience and mediate the dialogue for the social construction of knowledge. This argument highlights the significance of the social context for knowledge creation which has been found in socially-led knowledge management literature (Chapter 2, section 2.4) and communities of practice literature (Wenger 1998, Lave and Wenger, 1995).

4.8.2. Adoption of the policy model in conceptual design

The field studies suggest that the policy tools might not be immediately incorporated in the design process. The drivers and expectations emerging from the social context could hinder the adoption of the policy model due to the tensions that arise between the policy model and the design process. Some of the key findings about the ways that designers embed performance are:

- the use of informal aspirations (higher performance than the regulatory requirement)
- the configuration of networks for knowledge flows
- the use of experiential knowledge for performance appraisals
- the definition of the energy performance in relation to other indicators

One of the weaknesses of the compliance model is its reliance on the simulation results that could fail to assess the performance achieved during construction and operation. The performance metrics such as EPC, TER/DER, U-values, percentage of renewable energy are assessed by desk-based studies that produce the compliance documentation without demonstrating how such models compare to the as-built and in-use performance[4]. The reliance on the simulation as a compliance route might:

- aggravate the knowledge gaps;
- discourage the designers to understand the performance target in relation to later design phases;
- undermine the simulation trust because the simulation exercise is perceived to be a theoretical study;
- result in compliance-only processes where the compliance with the regulations is based on the skills of the simulationist to generate the evidence for compliance rather than the designers' abilities and competencies to design a low carbon building.

There are building performance aspects such as structures and safety that require better certainty in the evaluation than the energy performance. For example, it was observed that the design teams in the case studies were carrying detailed analysis related to structures, flooding risk, acoustics, geotechnical aspects and land contamination. For energy performance, the design teams were not encouraged to develop performance studies to revisit the design assumptions and consider the quality and certainty of the simulation assumptions and scenarios. The policy model should consider how the carbon reduction targets are achieved in the buildings once they are occupied. While higher reductions are desirable for the decarbonisation of the new building stock, it is important to ensure that the expected reductions are being delivered in operation. The reliance on the prediction of the energy consumption by a simulation model could result in opportunistic behaviours where the focus is the production of compliance documents rather than the use of calculation tools to inform the design development.

[4] While there is a post-construction evidence by BREEAM 2008 and Part L requires as-built tests; there is high reliance on the updated simulation model for the verification of compliance.

Chapter 5
Detailed design process

5.1. Introduction

This chapter documents the tools used by designers to embed energy performance in detailed design (from RIBA E) after planning application submission. It presents the low carbon problem-solving tasks performed by designers, with emphasis on architects' work. The scope of this investigation is the design process. The delivery, construction and operation are included in the analysis of detailed design in relation to their overlap with the design process. For the purpose of this discussion, the detailed design phase concerns the design development carried out in the architecture studio that enables the realisation of the project on site.

The description of the low carbon problem-solving tasks (transposing, following and learning) suggests how the understanding performance function is undertaken in the design process. The understanding about how designers embed performance informs the discussion about the knowledge flows and dissemination in the design process and the situated learning that occurs in the design of low carbon buildings. The chapter concludes by elaborating the low-carbon design process timeline that emerged in the process and compares it to the policy assumptions about the designers' enactment of the low carbon policy intentions.

5.2. Design team composition in detailed design

The architecture team in all of the case studies were novated so the same architecture firms were involved in the design and delivery phases. Three types of team composition were observed in the cases from detailed design (RIBA E), illustrated in Table 5.1. The different design team composition reflects the design expertise developed by architects, whether the participate in the whole design process (cases 1 and 2) or they specialised in discrete phases: conceptual design, detailed design or delivery (cases 3A, 3B, 4A and 4B):

1) The same architects worked on conceptual design, detailed design and delivery phase; case 1 and 2 (RIBA A to J)

2) One team of architects worked on conceptual design and detailed design (RIBA A- E/F) and another team from the same company on the delivery phase (from RIBA G); Case 3B

3) One team of architects worked on conceptual design (RIBA A-D) and handed over the work from detailed design and delivery phase to another team from the same company (from RIBA E); case 4B

RIBA	A	B	C	D	E	F	G	H	K
	Conceptual design				Detailed design				
Case 1									
Case 2									
Case 3B*									
Case 4B*									

**C ses 3B   d 4B were   ot stud ed   co ceptu l des g*

Design work undertaken from conceptual design by the conceptual architecture team
Design work undertaken by an architect team different from the conceptual design team
Stages that were not studied in the investigation*

Table 5.1. Architectural team arrangements in the case studies

5.3. Low carbon problem-solving tasks in detailed design

Transposing the design intentions: making explicit the design intentions from conceptual design and inscribing them in the development of details.

Following the design intentions: auditing and following the development of the details during delivery so to inform the design assumptions and receive feedback from the construction team on site.

Learning from the process: reflecting about the lessons learned in the process, how energy was embedded within the drivers and constraints of the process and the dissemination of the experience gained in the process.

5.4. Transposing

Transposing links the conceptual design aspirations to their realisation during detailed design. This facilitates the continuity of the energy aspirations in the light of the likely drivers of the delivery phase: cost and buildability. According to the research participants, these drivers jeopardised the achievement of the low carbon aspirations outlined during conceptual design.

Transposing entails the inscription of the design aspirations and the forecasting of how the low carbon performance could be translated to deliverable details. Inscribing is to make explicit the aspirations from conceptual design phase to ensure the continuity and ownership of the targets by the design and the delivery teams. Forecasting is to anticipate the constraints and limitations that might affect the achievement of the energy aspirations during delivery and construction.

5.4.1. Experience-based advice in the development of details

It was observed that experience-based advice and conversations were the pervasive tools to disseminate the knowledge about low carbon design dispersed in the design team. The architects consulted to experienced architects, mechanical engineers and suppliers for the development of details. The users and the contractors could also be involved in the detailed design phase by being consulted about their preferences in terms of equipment and systems' maintenance (cases 1 and 3B) and by explaining the design rationale intentions to the bidding contractor team to ensure the continuity of the aspirations (cases 1 and 3B). During detailed design, the dialogue albeit informal, was a *leg t m sed tool* to share low carbon knowledge and experience, to combine the knowledge dispersed between stakeholders. The legitimation implies the acceptance and trust held by those who used the conversations to circulate experiential advice and tacit knowledge. While it was a tacit tool, it complemented the rough estimations and scenarios obtained from the calculation tools. The experiential and intuitive knowledge about energy performance was used to relate the low carbon performance target to other requirements; for example cost, time, delivery, workmanship, users' preferences and to inform the assumptions embedded in the modelling scenarios.

The field data suggests that the detailed design phase was informed by the following tools:

- Statutory compliance documentation (mandatory standards and guidance) Part L, Part F, BREEAM, Building Bulletin 101 Ventilation and indoor air quality in schools (2006), Building Bulletin 93 Acoustics, Non-domestic Building Services Guide, CIBSE Technical Memorandum 39 Building Energy Metering (2006)

- Installation information and generic product details (trade literature)
- Previous experience gained from past details retrieved from project folders and fabrication studies developed in the past in the companies
- Conversations and informal advice
- Simulation tools (IES, TAS)

The detailed design knowledge was invoked as early as RIBA D to inform the conceptual design. The conceptual design architects discussed the performance of materials and proposed the elements build-ups with architects experienced in delivery and construction phases. Despite the RIBA Plan of Work (2007) suggests to develop the technical information in RIBA E-F, it was observed in the case studies that the designers were invoking knowledge about details from RIBA D, before planning application.

The data also suggests that the design teams inscribe the official design intentions in the submission for BREEAM (planning application) and Part L (building control) (U-values, renewable energy provision, improvement TER/DER). Informally, the designers set higher low carbon aspirations than those inscribed in the official project documentation. More precise information about cost and buildability emerges after RIBA D so the informal aspirations are redefined.

If there is a drive for performance quality, the team is likely to consider the development of details from RIBA D, organise workshops with clients and contractor bidders to explain the design rationale and consider the possible compromises between performance aspirations and other project requirements.

5.4.2. Detail development of details

In case 1, an architectural technician was involved from RIBA D to start developing the details and identify the implications of improved U-values on build-ups. In Case 3B, the conceptual architect had conversations with the architect specialised in delivery phase. These conversations helped the development of details. In case 4B, the architect who worked from RIBA E had prior experience in delivery and construction phases.

The details used in previous projects informed the detailed design but their retrieval was an informal procedure. None of the companies had an official database or repository of detailed documentation from previous projects. There were databases to archive the project summary information but no similar database was found to systematically organise the details of the projects for future consultation. The architects reported that they consulted their colleagues who had worked in the past on similar projects to find information for the development of details.

Case 4B was the only case where the details were to be archived in the knowledge management system of the company, as an exemplar project. In this case a pilot investigation about wall build-up was undertaken in collaboration with the supplier. The architecture drawings of the details and the tender package in case 4B included information about the build-up, the sequence of construction and 3D views of the details. During the delivery phase, the design team documented the development of the details on site and recorded their construction on a construction diary. The onsite changes of the details were recorded as well as the feedback from the construction team to the design team in relation to the drawings and details.

In relation to experienced-based advice from suppliers and manufacturers, the architects discussed with them the U-values of build-ups when developing the detailed drawings and specifications. In cases 1 and 4B, it was reported that manufacturers assessed the U-value of the build-ups based on the thermal standards included in table 5.2. In Case 4B, the U-value calculation method for ground floor details by the manufacturer was based on the standard BRE IP3/90. The U-value calculator software Build-U desk was used in this case study. According to Part L requirements, the Competent Person Scheme is used to determine the U-values of the elements. For insulation elements, Kingspan, Rockwool and Knauf Insulation were contacted by the architects in the case studies.

Standards used in detailed design	
BR 443	Conventions for U-value calculators
BRE Information Paper 3/90	The U-value of ground floors: application to building regulations
BS EN ISO 6946	Building components and building elements - Thermal resistance and thermal transmittance - Calculation method
BS EN ISO 13370	Thermal performance of buildings. Heat transfer via the ground. Calculation methods
BS EN 12152:2002	Curtain walling. Air permeability. Performance requirements and classification
BS EN 1026:2000	Windows and doors. Air permeability. Test method
BS EN 12207:2000	Windows and doors. Air permeability. Classification
BS EN 12412-2:2003	Thermal performance of windows, doors and shutters. Determination of thermal transmittance by hot box method. Frames
BS EN ISO 10077-2:2003	Thermal performance of windows, doors and shutters. Calculation of thermal transmittance. Numerical method for frames
BS EN 13162:2008	Thermal insulation products for buildings. Factory made mineral wool (MW) products. Specification
BS EN 13165:2008	Thermal insulation products for buildings. Factory made rigid polyurethane foam (PUR) products. Specification

Table 5.2. List of standards used to assessed the performance of materials

The conversations about detailing started in RIBA D and addressed the elements build-ups, insulation details and junctions. These early conversations sought the experience-based advice; similar to what occurred in RIBA B and C when the conceptual design architect received the advice of the mechanical engineer to understand the energy performance before invoking calculation tools. The conversations about the build-ups and details occurred during informal meetings between designers, opportunistic face-to-face consultation and during design team meetings. The experience-based advice about details raised the awareness of early detailed design development so as to avoid overlooking the practicalities of construction such as the spacial requirements, delivery time, workmanship, tolerances, verification of performance on site and remedial work.

The architects expressed that a poor understanding of detailing could lead to problems in achieving the expected as-designed performance in later design and construction phases. For example, the walls may be designed without considering the width needed to achieve the U-values (case 3B), certain types of glazing might not feasible from the cost viewpoint (case 4B), louvres may be cost prohibitive (cases 1 and 2), the expected U-values of curtain walls may be difficult to deliver on site (case 1).

The selection of wall build-up in case 2 illustrates that aspects related to buildability, tolerances on site, workmanship, risk of delays could affect the selection and replacement of materials and as-built performance. In case 2, the architects suggested the use of strawbale for the envelope to create a heavy mass building and to reduce the embodied carbon of the envelope. The strawbale supplier participated attended two delivery team meetings, explained the use of the product and instructed the contractor and the project manager about how the material should be used on site (around RIBA D-E). He recommended that the site had to be levelled. The maximum deviation tolerance between the proprietary panels was 10mm and the assembly of the parts had to be coordinated to ensure precision. In order to speed up the process, some of the work had to be carried offsite. This raised concerns in relation to the buildability and possible delays in the wall construction. The contractor and the site operatives had no prior experience with this product so they had to be briefed on these construction matters. The users also had to be informed about what could be hung and done in the walls due to the limited structural capacity to carry loads; for instance, wall-mounted shelves could not be located in certain areas. During construction, the straw bale proposal was replaced by cross-laminated timber (CLT) due to concerns to deliver the building within schedule. This change resulted in the loss of BREEAM credits for the Material category and reduced the potential rating of the building from ’Outstanding’ to ’Excellent’.

In cases 1 and 3B, the detailed design process also included the dialogue with the wider stakeholders, the contractor and the clients in order to ensure the continuity and the ownership of the low carbon aspirations. The architects perceived that the contradictory expectations of the different stakeholders hinder the achievement of the low carbon aspirations because the design intentions were not well understood by the delivery team and the clients. This is illustrated by the following excerpts:

‘…e v ro me t l mp ct ssessme ts, l sts of c r o mp cts d so o d so forth, the building is a lot more than just a set of drawings in a completed form. And again it’s getting the client to do it and you know, there’s a fair number who don’t really understand what it entails. And it’s going to get more and more complex, as regulations start to get more and more onerous.’

‘There’s a reason why the building is like that, you know. And I think [achieving a low carbon building] it’s about educating people. I feel that contractors don’t understand what [architects] we’ve been doing, to the depths that we’ve taken it. So you have someone, like well, we can do a frame in steel because it’s cheaper. Hang on a sec, no, no, the frame isn’t just there to support the building, the frame actually has other parts to play in the whole environmental model of what the building is. Yeah, and I think that’s shown when we get the questions going, can we use this as an alternative? And you go, well it doesn’t work for this reason, that reason and that reason. I can see you want to use it because it looks the same, but that’s where the similarity ends. So it’s about educating them [the contractors] to really understand … being more attentive to things like that.’

The architects in case 1 organised a workshop for contractors who were bidding for the project to present the strategies and the rationale of the design. The workshop with the contractor and subcontractors were done to make the energy aspirations explicit and transfer the ownership to the delivery team. In cases 1 and 3B, the design team had workshops with the clients to present the energy aspirations and explain the sustainability aspects of the design. The workshops with the clients helped to explain the potential benefits of achieving the low carbon aspirations. This could address the different and understandings.

The wider stakeholders might not be well addressed by the policy model. It is necessary to understand how the energy targets relate to the tangible aspects (cost, buildability, use). However, the information of low carbon performance benchmark in relation to incidental things is not widely disseminated. The field data suggest that the design teams used the workshops to address this problem. Seemingly, it is necessary to disseminate the benefits of low carbon buildings among clients, developers and contractors in order to increase their understanding of low carbon performance; otherwise, the conflicts between policy intentions (carbon reduction) and the wider stakeholders' expectations (primarily cost reduction) might lead to changes in the design and hinder the performance aspirations later in the process.

5.4.3. Completeness in tender packages

The degree of completeness and the rigour of the tender packages were claimed by the architects to limit the changes that could be detrimental to the design aspirations. This was referred as 'bullet-proof information'. The wording and the precision of the tender specifications and the technical drawings served to inscribe the delivery requirements to the contractor. The specifications stating the minimum performance enable the continuity of the low carbon aspirations and prevented onsite changes that might compromise the low carbon aspirations.

Whilst the completeness in the tender packages was recognised to act as an inscription of the requirements, it was observed that the indicators in the tenders could be defined with different levels of precision. There were explicit performance metrics such as U-values, G-values and airtightness. Nonetheless, other aspects that could ensure the execution of the details on site might not be included, for example the minimum standards of workmanship, tolerances on site, site tests, remedial work.

The most commonly referred energy indicator in the case studies were the U-values of the build-ups (all the cases). The technical drawings in cases 1 and 4B had notes that stated the minimum U-value of the envelope i.e. walls, windows and roof. In cases 2 and 3B, the U-value was not annotated on the technical drawings but it was stated in the technical specifications. In case 4B, the detail drawings included the sequence of construction, the maximum tolerances and the minimum performance to be achieved onsite. The energy performance indicators included in the technical specifications and drawings were:

Indicators	Case studies			
	1	2	3B	4B
U-values	x	x	x	x
G-value	x		x	
Airtightness	x			x
Workmanship	x			x
Tolerances on site	x			x
Remedial work	x			x
Sequence of construction in tender packages	x			x
Tests on site results to return to architecture firm	x			
BREEAM requirements	x	x	x	x
Update of simulation results by contractor		x	x	

Table 5.3. Indicators included in the technical specifications and drawings

It was observed that some of the tender packages did not state a specific performance indicator. Instead, the tender documentation referred to the minimum mandatory requirements; for example:

- For roof insulation: *'a maximum thermal transmittance to comply with building regulations'*
- For glazing: *'performance to current building regulations or BREEAM excellent rating requirements, whichever is more onerous.'*

No evidence could be obtained to clarify whether that form of specification enabled the flexibility to develop the technical details or if it is indicative of the lack of knowledge about how the performance metric could be related to construction concerns (workmanship, sequence of work, tolerances on site).

In the tender specifications of case 1, when describing the types of walls, the architects included a description of the workmanship required on the brickwork: laying, conditioning of blocks, accuracy, vertical tolerance, thickness, level, permissible deviation, finishing of facework, recycled content, general requirements and preparatory work. For the roof glazing, the specification stated that it was required to have a double sealed glazing and U-values test to prove that the average heat conservation did not exceed 1.79 W/m2K. The workmanship, fabrication, installation, insulation and installation requirements were also defined. In case 4B, the details of the walls also included a similar list to the accredited details checklist concerning the thermal performance of junction, air barrier continuity, air barrier options and general notes about the detail.

It was noted that acoustics and structural requirements were likely to be specified in more detail than the energy requirements on the tender packages and requested to be evaluated during construction. For the acoustics and the structural aspects, the performance specification involved a specific target i.e. Rw and onsite samples.

Specific tests were required to the contractor and remedial work was necessary if the as-designed performance was not met on site. The expected acoustic performance was more often annotated on the technical drawings than the U-value. The minimum acoustic standards by the Building Bulletin 93, Acoustic design in schools, should be achieved to satisfy the BREEAM issue Acoustics Performance and post-construction tests should be carried. In the tender packages, independent laboratory tests by the wall systems manufacturers were requested to prove that the acoustic requirement was met. If the performance is not delivered, remedial work has to be undertaken for the credit to be awarded. The statutory compliance with structures is similar, the contractor team was demanded to produce evidence of achieving the expected structural requirements. For example, for the concrete of the structural elements, the contractor had to take samples and test the properties of the material. The request of laboratory tests and performance evidence for aspects other than energy is similar to the emphasis on undertaking investigations during conceptual design to assess flood risk, geotechnical properties and land contamination. Conversely, the energy target was not assessed with the same rigour and stringency. Thus, it tacitly became an optional requirement.

5.4.4. Final remarks about transposing

Transposing intends to overcome the fragmentation in the process and the increase the knowledge in the transition from conceptual to detailed design. Transposing enables the continuity and ownership of the energy aspirations. The tools used by the designers to transpose the energy aspirations include dialogue, workshops, annotations on drawings, completeness of tender packages and simulation. The development of the details and tender packages to include construction considerations seemingly prevented the possible disconnections between the design intentions and site work in later phases.

The designers perceived that in the transition between design and delivery, factors like cost, buildability and time might jeopardise the continuity of the energy aspirations. The low carbon intentions from design are allegedly misunderstood by other stakeholders. The tensions arising between design and construction phases were considered led to the fragmentation of the process and jeopardised the energy aspirations from conceptual design. The tensions between design and construction phases hindered the knowledge flows and discouraged the evaluation of the energy targets in the light of delivery.

Tools	Use
Experienced based advice	To understand performance. Indicators: U-values of build-ups (all cases); G-value (cases 1 and 3B). Experience-based advice could be invoked before detailed design through informal dialogue, workshops and meetings. The advice was given to architects by architects experienced in delivery, mechanical engineers and energy consultants.
Dialogue with manufacturers and suppliers	To examine the suitability and compliance of specific details, related to thermal performance of the envelope (all cases).
Details retrieval	To develop details, previous details tended to be consulted informally. No formal database of details was found in any of the cases. The investigation about the wall details and performance in case 4B was the only example of detail information to be documented in the company database.
Tender packages completeness	To prevent changes on site, rigour of information was necessary ('bullet-proof' information). The indicators were U-value (all cases), G-value (cases 1 and 3B), airtightness (cases 1, 3B and 4B). In case 4B, 3D details were developed with a suggested sequence of construction to investigate thermal performance of a wall construction to be studied and documented during delivery.
Annotation on drawings	To clarify the performance of the elements in terms of U-values and G-values (cases 1 and 4B). Sequence of detail construction was included in case 4B and construction considerations to address thermal bridges.
Simulation (energy calculation tools)	To assess the detailed design and improve the accuracy of the model. In cases 1 and 3B, the model was factored against cost so to prioritise the cost-effective low carbon strategies. In case 2, SBEM was used for compliance. In none of the architects in the case studies deployed any quantitative method to evaluate performance; simulation was used by the mechanical engineers.
Workshops to contractors bidding	To make the energy rationale explicit, inscribe the energy targets so to raise the delivery team's awareness of the design aspirations (cases 1, 3B)
Workshop with clients	To raise awareness and engage the client in the commitment to energy aspirations, especially in the light of the transition between design and construction (case 1).

Table 5.4. Transposing: tools to embed performance and their use

5.5. Following (RIBA G-H)

Following entails the comparison between detailed design and their development on later design stages and during delivery. The architects, as delivery team members, are able to examine the site proposals and provide their design advice. Following the development of details on site could increase the designers' knowledge about buildability, as-built performance and construction work.

For the low carbon task of *following*, episodes illustrating the instances where the designers in the case studies undertook performance investigations are presented. These performance investigations draw attention to the disconnection between design and construction and the need for better design knowledge about construction.

The episodes observed in the case studies were:

- Case 1: Value engineering and energy aspirations conflicts
- Case 2: Overheating risk

- Case 3B: Clients' performance target: implications to the simulation exercise and the inclusion of the building users
- Case 4B: Construction diary: tracking the design changes during delivery

5.5.1. Value engineering and energy aspirations conflicts

The value engineering exercise was undertaken in RIBA E in case study 1. There were 94 suggestions which were estimated to reduce £ 514,000 of the budget for construction. Thirteen key value drivers were determined in the value engineering workshop. The issues 12 and 13 corresponded to sustainability and energy related matters and added up for 5 per cent of the priorities in the decision-making rationale:

- *'Issue 12: Enable operational efficiencies'*
- *'Issue 13: Fulfil the objectives of learning works development and side wide sustainability strategy: sustainability criteria, respond to urban form and presence ecology, ventilation systems, daylight and ventilation'*

It was stated on the value engineering summary document that *'the client could not confirm whether cost, quality or time was of most importance.'* This confirms the perception that there is not a clear requirement by the clients, despite the master planning document[1], Sustainable Energy Strategy (2007) outlined a sustainability strategy for the development.

The main value engineering ideas that affected the energy performance suggested the elimination of the earth tubes, the increment of the U-values of the elements and a change in the heating, lighting and cooling strategies.

The earth tubes were selected by the design team because of the estimated energy generated per year, the potential carbon offset per year and the cost per unit of carbon savings. However, the value engineering exercise suggested the elimination of the earth tubes due to the lack of funding. The following table created by the designers in case 1 compares use of the photovoltaic and earth tubes.

[1] According to the initial aspirations, the design targets were an EPC of 40 or better, a carbon reduction of 60 per cent on Part L 2006 and a minimum reduction of 10 per cent of carbon emission from low zero carbon technologies.

	Photovoltaic panels	Earth tubes
Estimated energy generated per year (kWh/yr)	28856	295852
Equivalent carbon offset per year (kgCO2/yr)	16390	92521
Cost saving per unit of carbon savings (£/kgCO2)	20.59	2.81
Available grants	Feed in tariffs (included in payback calculation)	No appropriate funding streams available

Table 5.5. Comparison between photovoltaic panels and earth tubes, extracted from the documentation in case study 1 (created by the research participants)

This table was extracted from the documentation in case 1. It can be noted that the earth tubes may be a better solution from the carbon reduction point of view. They were able to generate more energy per year and the carbon offset would be greater than photovoltaic panels. The cost per unit of carbon savings for earth tubes was calculated to be a tenth of the cost of photovoltaic panels. However, there were no funding streams available for earth tubes.

The value engineering suggested the reduction in the specification of the glazing, walls and roof and the replacement of the Velfac windows. The response of the design team to the value engineering suggestions explained that the windows were specified due to the durability of the window, the performance, security, environmental requirements and appearance. The design team remarked that the U-values of the envelope were chosen to avoid heat losses and reduce the energy consumption in winter. Another proposal was to change ventilation strategy. The design team designed spaces which could be natural ventilated but provided mixed ventilation to meet the overheating requirements. The value engineering exercise suggested eliminating the back-up system, to remodel the spaces to verify the summertime comfort performance and to replace the earth tubes with indirect evaporative cooling. An alternative suggestion was to use a mechanical only strategy in some spaces by increasing the air handling unit capacity and removing the radiators by the use of warm air heating and increasing the heating coil capacity within the air handling units.

The design team questioned the changes in the natural ventilation strategy by referring to the summertime comfort performance, energy consumption in winter, risk of lower comfort due to winter draughts. A more accurate energy model would be developed to determine the effects of the changes while reviewing the funding opportunities for low zero carbon technologies.

The value engineering suggestions arguably reflect the delivery team proposals might not be articulated to the design rationale and intentions. This suggests that the cost and energy are mutually exclusive requirements in the light of delivery. This aspect is aligned with the perceptions of the research participants about the differences between the expectations of the designers and the other stakeholders. This incident highlights the focus on cost reduction and how the target cost tends to be pursued in detriment to the performance targets. The energy target could become an optional requirement. The low carbon targets tend to gravitate towards minimum, compliance in the light of delivery.

As a result of the value engineering exercise, the earth tubes were eliminated. Therefore, the air handling units had to be resized to ensure the achievement of thermal comfort. There were no changes in the U-values. The design team considered to increase the provision of photovoltaic panels to reduce the carbon emissions of the building.

The following table summarises some of the changes to the original design proposals that occurred during delivery phase, as observed in the case studies:

Case study	Design phase proposals	Changes/reconsideration in delivery phase
1	Ventilation strategy, solar protection strategy, earth tubes	Elimination of earth tubes, changes in specifications of the mechanical systems
2	Wall build-up, solar shading protection devices	Replacement of wall build-up, elimination of solar protection devices
3A	Solar protection strategy and passive design	Elimination of louvres
4A	Zero carbon aspirations, proposals of PV and LZC technologies	Reduction of PV array

**Cases 3B and 4B were only investigated in detailed design. They have not been included in this table as the original design strategies were not available for comparison with the delivery phase.*

Table 5.6. Changes to the original design proposals of the case studies during delivery

5.5.2. Overheating risk

This section will start by describing the appraisal of overheating risk in case 2 and then it will discuss the potential inadequacy of the model to assess overheating risk, as inferred from the observations in the case studies.

The overheating risk is addressed by Part L in the criterion 3: limiting solar gains. For educational buildings, the Building Bulleting 101 is the method used to evaluate this aspect. Building Bulleting (BB) 101 Ventilation and indoor air quality in schools (2006) is the guidance for ventilation design in schools. It assesses the overheating risks during the cooling season (April to September). BB 101 is used on Part L criterion 3 (limiting the solar gains), where two of three criteria have to be met for compliance:

Criterion 1: Maximum of 120 hours over 28^{o}C

Criterion 2: the difference between internal and external temperature shall not greater than 5^{o} C

Criterion 3: The temperature shall not exceed 32^{o} C in occupied spaces during occupied hours

The compliance is shown by the as-designed simulation model. In Case 2, for the purpose of planning application, an SBEM model was developed by the mechanical engineer. A dynamic model was commissioned to an external energy consultant to verify the compliance with overheating requirements. The dynamic model followed the climate change provisions outlined by CIBSE Technical Memoranda 36 Climate Change and the Indoor Environment: Impacts and Adaptation (2005). The dynamic simulation model was issued during detailed design, after the works on site had started. It should be noted that in Case 2 the schedule of design and delivery of the building was twelve months so the detailed design overlapped with the construction work.

In case 2, the SBEM and the dynamic simulation models had the same assumptions for the internal temperature, outdoor conditions and latent heat. The dynamic model suggested that the resultant indoor temperature would exceed 32^{o} C if considering the effects of climate change on the future weather according to the CIBSE TM 36. The energy consultants carried a first simulation exercise using 20^{o} C, 22^{o} C and 24^{o} C as set points for winter, mid-season and summer ventilation. The results identified the potential overheating of five classrooms and the reception (south and east orientation). Another scenario was made with ventilation set points of 18^{o} C, 20^{o} C and 22^{o} C. In this scenario, the building met two of the three BB 101 criteria and satisfied the Part L criterion 3.

The energy consultants ascertained that BB101 was minimum standard and that the building occupants might feel uncomfortable as the air temperature may exceed 32^{o} C. The compliance of two of BB101 relied on the ventilation rate which is a design assumption that may not be achieved during construction. Therefore, the energy consultants advised the improvement of the ventilation rate in summertime to avoid discomfort in the cooling season. The mechanical engineer who carried the SBEM calculation argued that the changes in the design may have aggravated the overheating risk. The building envelope was initially designed to be strawbale but it was replaced by cross-laminated timber (CLT) during construction. This change was proposed by the contractor to speed up the onsite work and reduce the risk of delay on site.

Concerning the overheating risk in other case studies, no evidence was found that the overheating risk was considered when proposing construction changes to the design strategies. Explicit requirements to achieve comfort conditions were not referred to during detailed design. The tender packages did not require the contractor to demonstrate the delivery of strategies to avoid overheating. This lack of accountability might lead to changes in the design strategies; for instance, elimination of louvres and solar protection devices on the façade, changes in the product specifications (U-values of walls and glazing), replacement of products and changes in the ventilation strategy.

The overheating indicator seemed to be inadequate because it was considered only on the as-design performance estimation based on a simulation model. As an energy indicator, overheating was not measured in later phases of design, delivery nor operation, leading to a poor understanding of the effectiveness and suitability of strategies to prevent overheat. The onsite changes driven by the cost target were unlikely to account for the overheating risk during occupation. Consequently, the overheating indicators remained theoretical and unconnected to the developments during construction. Conversely, if the overheating criterion had to be demonstrated during operation, the corresponding design strategies might be adopted during construction.

It is acknowledged that aspects such as overheating may not be directly measurable during design and construction. Overheating is to be evaluated during operation, in the cooling season in relation to occupancy parameters. However, it is necessary that design and delivery teams are accountable for the building quality and responsible to assist the users in achieving comfort. The lack of connection between the energy metrics of design, construction and operation; the designers could develop the perception that energy is an optional requirement. The aspects that might affect the energy performance might not get ‘picked up’ during construction i.e. changes of ventilation strategies, modifications to build-up (U-value), changes to details and junctions that might affect the thermal bridges. The differences could result in gaps between as-designed and as-built performance. For operational phase, the discrepancies could be aggravated by poor or incomplete handover exercises and the absence of professional support to the building users to reduce the energy use, manage the energy usage and adapt the building to their needs.

5.5.3. Client's energy target

In case 3B, the client requested the target of 27kgCO2/m2 year to satisfy the goals of the Partnership for Schools programme[2]. That represented a 15 per cent reduction of carbon emissions as calculated by the Department for Children, Schools and Families (DfCSF) Carbon Calculator tool. The DCfSF carbon calculator tool comprises guidance and benchmarks for design teams to compare the design strategies and demonstrate the compliance with the DCfSF target of 60 per cent reduction of carbon emissions on new school buildings. The data was obtained from average historical data of other similar buildings. The calculator compares cost per m^2 and CO2 savings in $kgCO_2/m^2$year. The strategies that could be compared are orientation effects, low zero carbon technologies, the use of lighting control and efficiency, energy use due to ICT and low energy equipment. For case study 3B, the 62.70 per cent reduction resulted in an increased cost[3] of £68.13 per m^2, according to the project documentation.

The design team had two strategies to ensure the achievement of the target: accuracy in the modelling and the inclusion of the user. The simulationists sought accuracy in the modelling assumptions to improve the simulation results. CIBSE typical practice guidance and historical data about the consumption of appliances and the kitchen was used. The assumed kitchen annual electricity consumption was 58833kWh and the assumed kitchen annual gas consumption was 75236kWhrs.

Special attention was made to incidental energy use due to occupation such as pupil numbers for hot water calculation and revised allowance water consumption per pupil, increased small power allowance and lower level of lighting loads, percentage of lighting controls, schedule of occupation of the sports hall (core hours 7am-4.30pm). It was assumed that 85 per cent of school area would be used for

[2] The Partnership for Schools Programme sought to implement the renewal of school, Building Schools for the Future during the period between 2005 and 2020.

[3] The Building School for the Future (BSF) programme aimed to fund additional low carbon strategies and technologies implemented in the building, up to an equivalent of £50 per m^2. The average cost of a BSF school was £ 1850 per m^2.

teaching spaces and offices would have daylight dimming. 25 per cent of this area was assumed to be adjacent to windows and a load reduction factor of 0.75 was applied. A further 35 per cent of the area was estimated to be the middle row of lights so a load reduction factor of 0.25 was applied. A 25 per cent was estimated for the third row of lights, where the load reduction factor was 0.10.

The modelling scenario was improved to account for the most probable hours of use and the energy demand of the window actuator (assumed use: twice every workday for 5 minutes each time). The energy use and emissions associated to small appliances (unregulated energy) was considered for one-cup-boil kettle, small fridge and LED energy-saving clocks that operated 11hr[4]. It was estimated that those small appliances will require 4114kWh per year and produce 0.21kgCO2/m2/y. This figure was to be offset by 37m2 PV generating 900kWh/annum per 8m2 of PV panel facing due south at 30 degrees, apart from the 150m2 of photovoltaic panels used to mitigate the energy consumption for regulated processes (cooling, heating, lighting, water heating).

The users were involved so as to foster their behavioural change to reduce the energy consumption in the building through *'Save it campaigns'* based on the BMS data. The user was encouraged to limit the use of small power (mobile phone chargers), ICT use (laptops are turned off if not used), specialist ventilation when not needed, switching lights on when necessary, closing doors and windows and encouraged to share the ICT equipment.

This case shows that the design team evaluated the modelling scenarios and sought to improve the quality of the simulation exercise by obtaining historical data from the users' consumption. During the operation of the building, the users would be part of educational campaigns to reduce the energy use so as to achieve the CO_2 target requested by the client.

5.5.4. The fabrication study

In Case 4B, the architect reported the investigation of the U-value of a wall build-up. This investigation was undertaken in partnership with the supplier. The designers developed axonometric details were developed to illustrate the wall build-up components, the sequence of construction, the tolerances, checklist of tasks to

[4] The design team consider Bodet MED HMT 40 range LED Clocks with an energy saving function that could automatically switch off the clock on set times. The clocks specified in the project were to run for 4015 hours a year, equivalent to 11hrs of operation per day.

undertake for the execution of the air barrier continuity and remedial work were part of the detailed information. During construction, the delivery of the details was recorded on a construction diary by an external consultant appointed by the material supplier. The main concerns were the delivery of the air barrier and the insulation. The technical details were updated according to the changes on the construction phase and the feedback from the site team. An infra-red thermography was planned upon completion though it did not overlap with the timeline of this PhD research. This information was to be uploaded in the firm's database.

The design team proposed a non-load bearing cavity wall made of a 140mm thick inner skin in medium density 7.0N/mm2 concrete block with a 210 mm cavity with partial-fill cavity insulation and an external brick 102.5mm thick skin of frost resistant brickwork. The insulation material was Rockwool. The U-value to meet was 0.2W/m2K.

Fifteen construction diary reports were produced between the 3rd of August and the 17th of September 2010. The purpose of these construction diaries was to document the implementation of the as-designed detail and the onsite changes. The aspects reported included:

- *Design:* comparison between the detail drawings and the site delivery if changes were necessary or if unanticipated difficulties were experienced during the construction of the wall and details
- *Materials:* specifications of materials, delivery delays to the site
- *Buildability:* workmanship, care to install the materials, punctures, tears and tolerances in the installation, installation process (mitre, thermal bridge, air barrier membrane, insulation)
- *Construction sequence:* comparison between the detailed drawings and the site delivery, difficulties in implementing the proposed construction sequence, changes of the as-designed detail
- *Trade issues:* skills needed by the site team, specialised subcontractors
- *Feedback from the site team:* suggestions on the improvement of the proposed details on the basis of construction
- *Photographic evidence*: photos in the construction diary reports

Some of the situations recorded in the construction diary included:

- the delay in the delivery of the 102.5mm blocks
- the health and safety concerns in lifting the 140mm blocks
- the cut of 140mm blocks to replace the 100mm ones to mitigate the work delay due to the lack of 100mm blocks
- the replacement of bricklayer workers to improve the quality of the work
- the appointment of a specialised subcontractor to install the air barrier membrane
- the creation of a jig cutter to achieve the mitre of the corners
- the change of the design detail where the cavity between the blocks was 215mm but the cavity closers covered 195mm. The 20 mm gap between the cavity closer and the external brickwork was sealed with aerosol applied expanding foam.

The design team in case 4B was following the development of the details on site and evaluating the design assumptions, buildability aspects and workmanship. The architectural team received the feedback from the site team. The monitoring of the onsite changes prompted a better understanding of the construction of the detail; for instance, health and safety issues and materials' availability (102.5 mm blocks, cavity closers to the right specifications, mirtre). The updated details were to be uploaded on a database to share the information produced in the project within the firm.

This example suggest that the designers need to increase their understanding about *how the energy performance is achieved on-site* (delivery aspects, on-site indicators, installation of systems and technologies, procedures to monitor the construction quality and onsite tests). The examination of the detailed design during delivery could enhance the designers' knowledge about buildability and bridge the knowledge gaps between design and delivery phases.

5.5.5. Final remarks about following

Despite the differences in the episodes presented per case study, all of them illustrate the need to engage in further studies to gain a better understanding of performance. These studies suggest that the energy targets have to be related to other aspects such as value engineering (case 1), comfort (case 2), users' factors (case 3B), and construction aspects (case 4B).

In order to increase the design understanding about energy performance, the designers need to be aware of the building use, drivers, cost/benefit analysis, users' engagement, capabilities and limitations of simulation tools. However, the performance investigations undertaken on specific projects were unlikely to be disseminated beyond the project level and they may not widely inform the design assumptions about performance.

The episodes described in the previous sections illustrate the arrangements that the designers are making to deliver the energy target and the performance studies to evaluate the design assumptions. These examples highlight the need to connect the design process with the delivery and operational phases. The model of selection of the target, use of simulation tools and compliance is a simplistic assumption of how the energy aspirations are resolved in the design process. It assumes the linearity of the process and fails to consider the feedback that designers obtained from construction and operational phases to gain knowledge about low carbon performance.

Tools	Use
Experienced based advice	To understand performance in the light of buildability, cost, workmanship and delivery so as to recommend or dismiss a site change. (all cases)
Simulation (energy calculation tools)	To articulate detailed design, energy aspirations and site work. Simulation was invoked as a design aid to inform decisions (cases 1, 3B and 4B); as a tool to negotiate with the contractor changes suggested by value engineering (cases 1 and 3B) and as compliance tool to produce compulsory evidence for regulation (all cases)
Construction diary	To record the implementation of details and track changes on site, part of a specific investigation about thermal performance. In case 4B, the documentation was updated on the basis of design development on site. Site tests reports returned to the architecture firm. This information was documented and uploaded in the database of the company (case 4B)
On site tests	To verify airtightness and mechanical systems performance due to Part L requirements (all cases). Results unlikely return to the architecture firm to inform the design assumptions made.
Delivery team meetings	To discuss site matters and changes proposed in the light of delivery. To negotiate the energy aspirations and construct a share understanding and ownership of design aspirations between design and delivery team.
Specific studies per case study	Value engineering cost/energy (case 1), overheating risk results by SBEM and by dynamic simulation model (case 2), user's historical data of energy consumption and users' engagement for energy reduction (case 3B), fabrication study and construction diary (case 4B)

Table 5.7. Following: tools to embed performance and their use

5.6. Learning, the missing task?

Learning implies the reflection about the process to increase the design knowledge about performance as a result of the experience gained while designing. The lessons include the knowledge gained about aspects such as design assumptions, delivery, cost, simulation accuracy and workmanship. Despite the design knowledge and skills improve during the problem-solving activities (while designing), the formal knowledge management systems tend to encourage the task of learning at the end of the project. The field data suggest that the low carbon design knowledge is situated, experiential and created as a consequence of the design development and the negotiations to define the low carbon aspirations.

This section presents the knowledge management procedures and the tools used in the firms to capture and disseminate the experience gained in the projects. The firms in the case studies were managing the knowledge through databases, in-house seminars, sustainability champion and feedback from the users during occupation[5].

5.6.1. Databases

The databases were used to upload updates about regulation, low carbon information and technologies:

'We share information [in the office]. We have a sector of our network where we have all the regulations and support documents, statutory guidance, British standards so people refer to them…'

'We have the intranet, technical notes, people have a big experience on something and they write a note on the website so people can access… firstly you got to write it, then you have to broadcast that you've done it and then other people have to know that it is there to look at it …'

In cases 1 and 2, the information uploaded on the database comprised a summary sheet and a short executive summary which describe the energy credentials (U-values, percentage of renewable energy, energy strategies). Apart from featuring the energy indicators, the project summary sheet enabled the designers to network with experienced colleagues, as discussed in Chapter 4.

[5] It should be clarified that the learning task was not observed during the design in action in the case studies. It was inferred from the knowledge invoked in the development of the case studies, the self-accounts and research participants' reflection about knowledge and learning.

The intranet in the firm of case 1 had a blog that supported the dialogue between people working in different offices within the firm. As described in chapter 4, the blog was used by the designers to post enquires, receive and give feedback, upload and exchange information.

'We do have a forum to talk about technical issues, this forum maybe started a year ago so the people are just starting to use it. In the company intranet we have lots of information but I don't know how much is used… informally, every day at somebody's desk informal sort of design and conversations are going on... everybody is sort of designing altogether.'

Surprisingly, the data suggests that the designers are using the databases and intranet to network and identify the experience of their colleagues to seek for design advice. An online blog in case 1 facilitated the configuration of social networks for knowledge exchange and dissemination. Even in firms 2, 3 and 4 where the communication was not intentionally supported by the intranet and databases, informally, the designers used the project summary information to identify the experience and knowledge held by their colleagues.

However, no evidence was found of a systematic repository of details in the case studies. The detailed information was considered to be protected material which was not uploaded in the general firm database. It was treated differently than the project summary information. It was observed that the designers invoked the past details through their colleagues (word of mouth). In case 4B, the architect reported the implementation of a new knowledge management system where the information produced about the delivery of the details onsite described in section 5.5.4., Fabrication study, was to be uploaded for the dissemination within the firm.

5.6.2. Seminars and presentations

In cases 1, 2 and 3B, in-house seminars and informal presentations were scheduled to present exemplar projects and best practice. The in-house seminars addressed topics related to sustainability, regulations, and general updates about standards and regulations.

'We have lunch time sessions… yeah, power point presentation half an hour,-something informal. People send around emails all time with headlines. You know, are you aware of this? Are you aware of that?. And you can go away and think

about it yourself and do a bit of research. Then every few months we have a sit-down session where everyone just discusses their thoughts.'

Suppliers and manufacturers presented the regulatory changes and demonstrated the capability of their products to satisfy Part L and BREEAM requirements.

In the architecture firms 1 and 4 there was a noticeboard for information and news dissemination within the office. While in case 1 the notice board was used to post sustainability news, best practice information and case studies of projects developed by other firms, in case 4B the notice board referred to projects developed within the firm. In cases 2 and 3 there was no physical notice board. The visibility and accessibility to the physical notice board could be favourable for the quick dissemination of news. The physical noticeboard strategically located could be read casually by the designers. All the firms that participated in the case studies had a section in their intranet for posting news and updates.

5.6.3. Clients' and users' feedback

The feedback from the clients and users could not be observed because the research timeline did not match the completion of the case studies. The architects reported that there were hand-over workshops to users and debriefing meetings with the clients to receive the feedback from users and clients. In case 2, there was a client review to assess the satisfaction of the client concerning the business aspects of the consultancy service provided by the architects.

In case 3B, a workshop for the users was to be scheduled to explain aspects related to the building operation and implement a *'Save it campaign'* for reduction of energy use:

'We'll have workshops so occupants really understand how the building works. The contractor will provide posts in each room to understand what the user can and can't do…'

Such campaign was to be undertaken to achieve the operational target requested by the clients.

5.6.4. Final remarks, the learning community?

The design knowledge could be constrained by formal knowledge management that overemphasise on the capture of information and explicit knowledge. Information-centred knowledge management systems tend to focus on capturing lessons learned, key performance indicators and strategies for their application in subsequent projects, overlooking the evolution of the low carbon aspirations during the process. Such approach undermines the reflection about the process and might lead to the loss of knowledge gained while designing.

One of the limitations of the knowledge management systems is their overemphasis on the capture of explicit information. The project learning is often conducted as a snapshot of the project indicators achieved at the end of the project. Ascribing to a learning model focused on the final targets ignores the potential to learn from the changes that occur during the process which are deemed to embed situated and embodied knowledge. In other words, the learning that results from the evolution of the low carbon aspirations and the changes in the design may be overlooked. The energy metrics need to be informed by a better knowledge of the implications of the energy performance in relation to other project drivers (cost, delivery, user factors).

For low carbon understanding performance, the knowledge required to embed performance is created and disseminated between the design team members throughout the process. The field studies that the knowledge flows were enhanced by informal social networks. The advice informally obtained by the designers from other colleagues helped to circulate the experiential knowledge about energy performance. The designers held conversations with:

- *Other design team members* (architects, mechanical engineers and consultants) to benchmark the project requirements, to get experience-based advice about the design strategies and feasible technologies, to gain a qualitative understanding of performance, to improve the performance appraisal
- *Suppliers and manufacturers* to develop the details, to anticipate the performance of the materials to determine the U-values, the sequence of construction, the onsite requirements
- *Delivery team members* to consider the buildability of the details and the construction issues that may hinder or delay the development of the detail onsite
- *Clients and users* to understand the preferences of the users and the interface between the users and the building during operation

The conversations between stakeholders enable the knowledge flows and leverage the knowledge distributed in the design team.

Tools	Use
In-house presentations	To disseminate information about targets and design experience in the office by presenting the projects to colleagues in the company (all cases)
Project summary info	To summarise information including energy aspects such as BREEAM rating, renewable sources, passive design. It was part of the database of projects.
In-use data (monitoring exercise)	To obtain the energy usage of the building. Only the clients in Case 3B requested a specific target as contractual requirement (27kgCO2/m2year). In Case 3B, the simulation reports included assumptions about occupancy and patterns of use to track discrepancies between as-designed and in-use performance. For other cases, the metering reading was a referential value to record. However, the data was not available during the PhD collection period.
Users workshop	To inform about the operation of the building, use and maintenance of the systems. In Case 3, there was an emphasis on educating the users about energy reduction. In all cases, a manual of operation was produced for the facilities manager.

Table 5.8. Learning: tools to embed performance and their use

The following figure collates the official and informal tools observed in the case studies in relation to the low carbon problem-solving tasks (grey box on the top) and the project timeline (grey box on the bottom). This figure includes the official project documentation (white boxes). This figure illustrates the tools found in the case studies and documents their use overtime. This figure should not be read in terms of linearity as the use of the tools was likely to be iterative and dynamic. It is a simplified representation of the use of tool overtime in relation to the low carbon problem-solving tasks and the project development timeline.

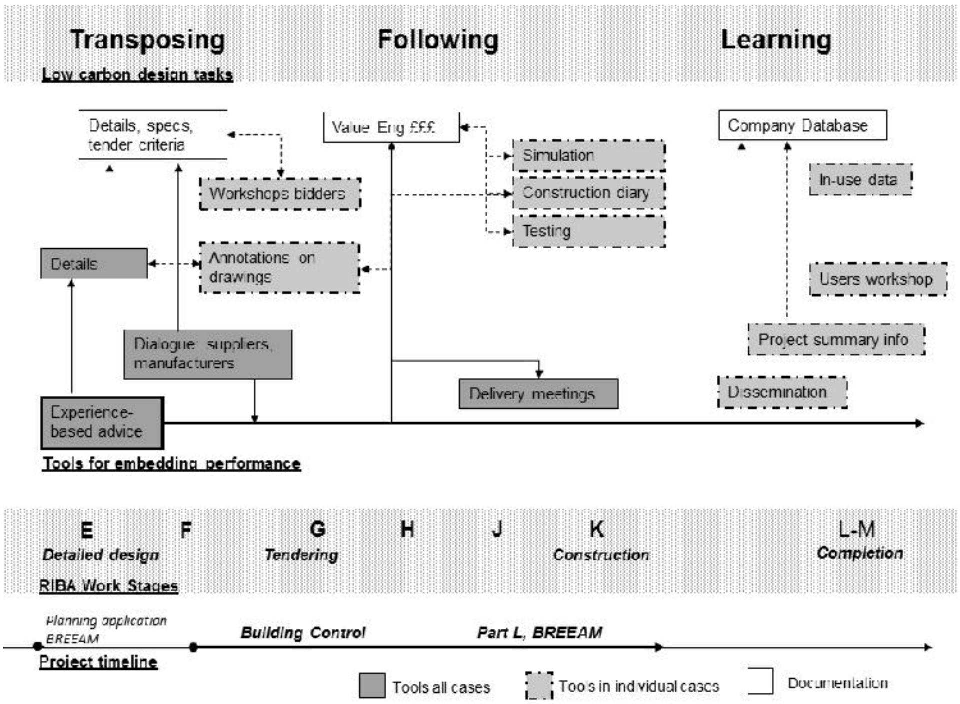


Figure 5.1. Tools to embed performance in detailed design

5.7. Discussion

The previous sections have documented the tools to embed performance in the detailed design process in the case studies. The narrative has used the low carbon-problem solving framework to compare the field observations and highlight the commonalities and differences found in the case studies. The field data reveal the understanding performance cycle undertaken by the design teams.

The main findings of the detailed design process are:

- The conversations and exchange of experiential knowledge are pervasive tools for the dissemination of design knowledge, especially in detailed design when the use of calculation tools is sparse.
- The use of simulation in detailed design is bound to gravitate around compliance. It may not be used to assess the detail development and changes to the design during delivery.
- The designers are developing indicators that link the energy target to the delivery aspects. The energy targets are being translated into delivery requirements such as onsite standards, tolerances, remedial work, tests on site and contractor's experience.
- Energy performance investigations are being undertaken to gain a better understanding of the energy targets in the light of delivery and operation.
- Knowledge gaps emerge during detailed design possibly due to the fragmentation between design and delivery phases.
- Formal knowledge management approaches in the firm tend to emphasise on the capture of energy indicators at the end of the projects. The learning is encouraged after finalising the design despite the design knowledge is created during the problem-solving activities and the negotiations of the low carbon aspiration[6].

In detailed design, the fragmentation between design and delivery team seemingly affected the knowledge flows and the trust in the simulation results. The design phase may not get connected to delivery and operation, undermining the

[6] This situation could be related to the difficulties of recording information during the event and devising mechanisms to encourage the reflection in action.

opportunities to learn how the design proposals delivered the expected performance in later phases.

5.7.1. Low carbon problem-solving process timeline in detailed design

The low carbon design process is developed in an atmosphere of tensions and conflicts in which divided and potentially competing agendas (design and delivery) are pursued. The project drivers were unlikely to prioritise the energy aspiration. The low carbon aspiration could be intermittent throughout the process. It could remain on the periphery and reappear due to the regulatory gateways, BREEAM and Part L. It should be noted that the informal tools are the focal nodes in the low carbon process. The official, represented by the simulation tool and Part L, could be positioned on the periphery of the process only invoked to produce evidence for compliance. The low carbon design is unlikely to be achieved in isolation, the low carbon aspirations have to be weighted and defined against the delivery and operational aspects (cost, buildability, maintenance). Embedding performance during design was not only matter of calculating the performance, it required the collective construction of knowledge by the design team.

Figure 5.3. illustrates the official and informal tools to embed performance found in the case studies in relation to the project timeline and the low carbon problem-solving tasks, section 1 (grey box on the bottom). Section 2 represents the instances where the low carbon aspirations are likely to be negotiated between the designers and stakeholders. The design negotiations to define the low carbon aspirations enabled the knowledge flows and a better understanding of the energy performance; they helped to create the collective knowledge about low carbon performance. The gap between the tools for following and the ones for learning is a means to illustrate the poor connection between design and operational phases and the lack of closure of the design learning. The incomplete design learning loop might be the consequence of the disconnection between the design process, delivery and operational phases. The fragmentation of the process reduced the designers' knowledge of how the low carbon aspirations were delivered on site (as-built performance) and the preferences and behaviours of the users during operation (in-use performance). The lack of understanding of the performance achieved in construction and operation could create gaps between predicted and actual performance. Little evidence was found to suggest that as-built and in-use

performance data returned to the architectural firm as feedback for designers to inform their assumptions about construction and operation.

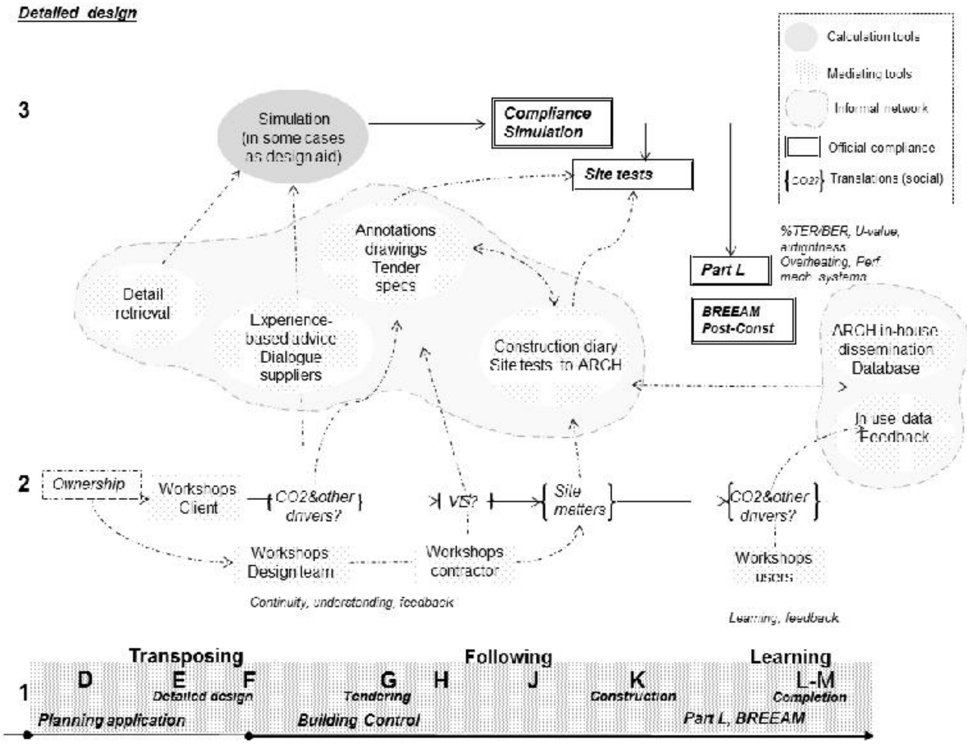


Figure 5.2. Low carbon problem-solving map in detailed design

The section between the tools and the project timeline (grey box on the bottom) represent the translations. It illustrates the instances where the low carbon aspirations are likely to be renegotiated in relation to the stakeholders' concerns and priorities. Detailed design starts by creating the ownership of the low carbon aspirations and as more knowledge about the design is created, the low carbon aspirations are deemed to be reconfigured:

- in the light of delivery
- due to value engineering exercises
- in relation to onsite matters
- in relation to the interface between the user and the building, by adaption of the user and fine-tuning of the building

There are fewer calculation tools to assess performance during detailed design. This differs from the conceptual design phase where the designers have developed in-house tools to estimate the energy performance and mediating tools for engagement and awareness about low carbon design. During detailed design, the simulation is the main physical tool to inform the design decisions although its use could be limited to the production of compliance evidence, BREEAM and Part L.

Despite the official tools contribute to the benchmark of the low carbon performance, they could become prescriptions if they are not incorporated in the process. The lack of integration of the official was reflected on the intermittent deployment of simulation throughout the process. The limited number of physical tools invoked in detailed design suggests the reliance on situated and embodied collective knowledge.

5.7.2. Final remarks about the tools in the design process

The tools to embed low carbon performance show dynamic moves throughout the process. A number of relations between the tools and the knowledge agents (the designers) are established to facilitate the inclusion and consolidation of low carbon aspirations. The informal tools were ubiquitous and the incorporation of the official tools could be assisted by the pre-existing structures: the social context and the informal (routines, practices, tools). The following aspects have been withdrawn from the field data:

- The tools that build up on the social context and the informal preferences are prone to be more suitable than the official tools to respond to the designers' support needs, the iterative nature of the design process and the incremental understanding performance gained while designing.
- The official tools are external structures that could fail to get incorporated in the process. They could be used intermittently due to compliance, creating gaps in understanding performance and eroding the trust to calculation tools.

Figure 5.3. summarises the tools used in conceptual and detailed design process. Section 1 refers to the project timeline, section 2 shows the policy gateway (BREEAM and Part L), section 3 shows the official tools and section 4 shows the tools found in the case studies. As the tools deployed in the case studies varied, the tools common to all the cases are illustrated in grey boxes with black borders and the tools used in specific cases are represented in white boxes with dotted grey borders. The figure is indicative of the tools deployed and the instance when they were invoked.

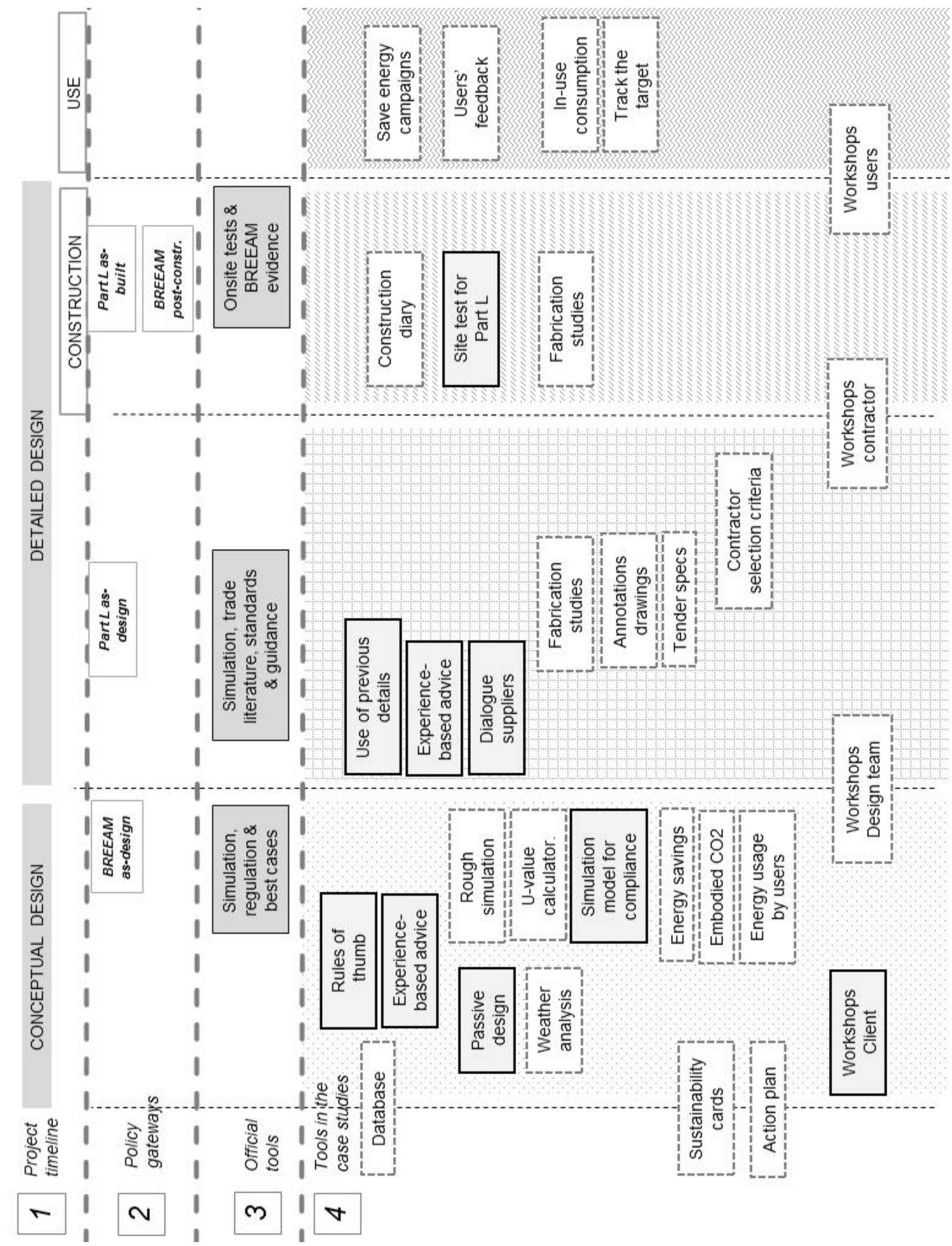


Figure 5.3. Tools in the design process

The observations about the use of tools in action and in interaction reaffirm the argument by Berger and Luckmann (1967) about the ‘span of relevance’ (Chapter2, Section 2.3.) and the principles by human computer interaction literature about the appropriation and legitimation of tools (Chapter 2, Section 2.5.). The deployment of tools depends on the perceptions and attitudes held by the group about the importance of low carbon performance.

5.7.3. Adoption of the policy model in detailed design

The field data suggest that there is a lack of connection between the different phases of the building lifecycle which results in poor knowledge to materialise the design intentions in later phases. The designers need to develop a good understanding of the design proposals, the assumptions that inform the energy estimation for as-designed performance, the delivery of the design and the performance during operation.

Despite the requirement of post-construction BREEAM and the as-built Part L submissions, there is a poor monitoring of how the details are realised on site. The onsite changes are unlikely to be used as feedback for designers about the design proposals. The information related to construction details and site delivery does not tend to return to the studio to inform architects' detailed design and delivery assumptions in future projects. The design changes that occur on site are unlikely to be documented comprehensively. The chain of changes is rarely tracked, reducing the opportunities to learn about the design in the light of delivery phase evidence. There was no intended learning and reflection to link different stages of design and delivery though experiential knowledge and heuristics were central to understand performance.

The energy aspirations are likely to remain uncertain and theoretical because the as-built and in-use energy performance are not compared to the as-designed performance predictions and the design assumptions. There are lessons to be learned from the whole design process: validity of the design assumptions, the simulation scenarios, the delivery aspects and operational aspects of performance during the building use (users' satisfaction, indoor environment, maintenance and operation of the building and the systems, the energy use and the energy produced by low zero carbon technologies or energy savings due to design features).

However, as-built and in-use data are unlikely to return to the architectural firm to link the design assumptions to the achieved performance. The lessons learned from the process are limited to theoretical scenarios based on simulations fail to consider the design changes during delivery, undermining the opportunities for enhancing the designers' understanding of the design proposals. Equally, the lessons learned within the process (onsite changes, difficulties of delivering the details and design strategies, overtime changes to the informal low carbon aspirations) are unlikely to be disseminated; aggravating the knowledge gaps.

Another observation that should be highlighted is that the learning model by formal knowledge approaches tends to overlook the learning that occurs while designing. The knowledge management approaches tended to be focused on the capture of explicit information, without addressing the development of transferrable skills and embodied competences necessary to design low carbon buildings (practical and tacit knowledge).This discourages the reflection of the lessons learnt about the evolution of the low carbon aspirations and the challenges in implementing the energy strategies overtime. It discourages the designer to understand performance beyond the simulation or compliance tool; and, therefore, interferes with the designers' understanding of delivery and operational phases.

Chapter 6

Tools and knowledge for low carbon design

6.1. Introduction

The following sections will address the two central themes of the investigation: *t   ls and knowledge for low carbon design.* The discussion of these themes highlights what the designers are doing to embed energy performance in the real-time design. Unlike chapters 4 and 5 where the focus was the chronological description of the design process, this chapter focuses on the themes ‘tool’ and ‘knowledge’ in relation to the theoretical framework discussed in chapter 2. The chapter presents the performance appraisal cycle enacted in the design process and the knowledge gaps that are likely to emerge. The discussion articulated in this chapter leads to the identification of the designer’s enactment (responses) to incorporate the policy intentions in routine project design and the overall discussion of the research findings in the light of prior work in the field and prevailing literature.

6.2. Performance appraisal cycle in the design process

While the official regulations and standards such as Part L were the references for designers to define the performance targets, the performance understanding was assisted by experiential knowledge and the social networks to share knowledge dispersed in the design team. The field observations suggest that the performance appraisal cycle is not executed in a linear fashion from benchmark to appraisal but rather developed in overlapped and recurrent cycles. The designers enacted the performance appraisal cycle by:

1. benchmarking the target on the basis of regulation, guidance and past experience (outlining task)

2. using of rules of thumb, experiential advice, heuristics, in-house tools and simulation (understanding and calculating tasks)

3. anticipating the buildability and detailing matters of the conceptual design (transposing task)

4. considering the delivery matters to inform the detailed design development
5. gaining a better understanding of users' factors, preferences and behaviours during operation; for example, through users' feedback

When designers design low carbon buildings, they include their experiential knowledge and assess the energy target in relation to cost, past experience, buildability, standards on site and users' preferences. The knowledge about these aspects is distributed in the design team; therefore, the conversations facilitate the combination of information, experience and knowledge between different design team members.

In the design process, the exchange of energy performance information is facililated by conversations and social networks. The performance appraisal cycle by designers is reliant on the experiential knowledge. People create dynamic associations between experiential knowledge and physical tools. The conversations are ubiquitous throughout the design process between the different stakeholders that are involved in the process. The architects receive and give advice from/to the mechanical engineer about performance, from the suppliers about buildability aspects, from the contractor about delivery on site, from the building occupants about the preferences in the operation of the buildings. The conversations enhance the performance knowledge of designers in relation to construction and operation phases, facilitating the continuity of the design aspirations and the use of performance metrics that are evaluated throughout the whole building life cycle. The conversations enable the collaboration and the identification of knowledge and expertise for the realisation of the low carbon aspiration.

It should be noted, that the performance understanding could be undertaken without the immediate deployment of calculation tools. The simulation is *not the most pervasive nor the preferred tool* deployed for performance understanding in the design process. The designers estimate the performance on the basis of past experience, rules of thumb, advice and confirm those appraisals by simulation tools. In the context of regulation compliance and routine project design, the field data suggests that there is an overemphasis on simulation use that misrepresents the cycles of performance understanding. This tool-centred stance underestimates the informal tools and the social context that could affect the realisation of the low carbon aspirations.

The following tables summarises how the performance appraisal cycle was developed in the case studies:

	Conceptual design RIBA B/C	Transition between conceptual and detailed design RIBA C/D	Detailed design in the light of delivery RIBA F
Performance evaluation	Understanding of the relation building-site, benchmarking against statutory requirements and use of previous experience	Performance analysis switches from qualitative to quantitative. The initial performance estimation focuses on compliance by the end of RIBA D.	Simulation for compliance but unlikely to be used for the analysis of design changes on site/design decision iterations in the light of construction
Preference	Intuitive understanding and qualitative tools	Qualitative and quantitative tools	Compromises between the energy aspirations and cost, site concerns, workmanship, tolerances
Criteria	Passive strategies, potential of low zero carbon technologies, climate analysis	Implications of the performance on the project drivers: cost, payback cost of low zero carbon technologies, maintenance, use	Compliance in relation to cost and buildability
Indicators	Architects focus on the U-values and the mechanical engineers assess the heat gain, thermal conditions, overheating risk, feasibility of low zero carbon technologies	Energy consumption per use (heating, cooling, lighting), indoor thermal conditions, heat gains, temperature variations, thermal comfort indexes, overheating risk, TER/BER, percentage of low zero carbon energy supply	Compliance driven, production of Part L evidence Pass/fail- Part L and BREEAM (official requirements), cost and time onsite
How the indicators are presented	Visual outputs linked to numerical data, diagrams, solar diagram, graphical analysis of the sun path	Time-series tables, graphs, EPC report, BRUKL document (Part L 5 criteria)	Part L report, EPC
Backdrops	Uncertainty in the assumptions that are based on heuristics; the graphical display may mask the performance implications 'pretty pictures'	Computational effort, domain expertise needed, difficulties in relating the results to parameters for design improvement, simulation distrust and lack of integration	Performance analysis during delivery gets eroded, lack of reflection about prior performance studies and the rationale of decision making in previous phases. The experience gained on site, design assumptions and modelling scenarios about standards achieved during delivery are unlikely to be linked to simulation exercises i.e . safety factors. Performance investigations in the light of delivery tend to be isolated exercises, not an official policy in the companies.

Table 6.1. Performance appraisal cycle during the design process

6.2.1. Use of simulation in the design process

It was observed that there were two types of energy analysis: compliance-only and performance-based. The compliance-only analysis is focused on producing the documentation for compliance and meeting the minimum regulatory requirements. Therefore, the simulation tool is likely to be invoked only in the light of policy gateways such as BREEAM and Part L from the transition between conceptual and detailed design and before construction. The simulation tools could be applied retrospectively to fine-tune an already designed building without informing the design development. In performance-based analysis, the performance dialogue is part of the design negotiations and the dialogue throughout the design process by continuous benchmarking and appraisal.

The designers recognised the need to estimate performance from RIBA B onwards and this was done using qualitative methods and in-house tools that had been created by the participants in the case studies.

The following table summarises the use of the calculation tools to estimate the performance by the mechanical engineers in the case studies:

Case	Performance cycle
1	In-house tool to assess the U-values, the estimation of thermal mass (RIBA B) Rough model on IES (RIBA B+, C) Users' input throughout the process to revise the assumptions about occupancy Accurate model on IES (RIBA C+, D) Simulation model on IES for planning application (RIBA D) Simulation model for value engineering Compliance model for building control
2	Ecotect to analyse the weather data –primarily for daylighting analysis (RIBA C) SBEM calculation (RIBA D) Compliance model on SBEM for planning application (RIBA D) Dynamic thermal simulation on IES (RIBA E) Compliance model for building control SBEM and dynamic thermal simulation with minimum climate change provisions to consider overheating
3A*	Ecotect for weather analysis (RIBA B+) Rough model on IES (RIBA B+) Accurate model on IES (RIBA C, D) Compliance model on IES for planning application (RIBA D)
3B**	Revision of the input data for more certainty in the model on IES Compliance model on IES for building control Inclusion of the users' and dissemination of operational patterns in the building
4A*	Rough model on TAS (RIBA C) Revision of the input data for more certainty in the model on TAS (RIBA C+, D) Compliance model on TAS for planning application (RIBA D)
4B**	Compliance model on SAP (Community houses in phase 1 of the development) Construction studies to compare the specifications, detailed design and construction Thermographic surveys at the completion of the project

Table 6.2. Performance appraisal cycle observed per case study
* Cases 3A and 4A where analysed in conceptual design only
** Cases 3B and 4B were analysed only in detailed design

It was observed that the simulation was bound to be used in the transition between conceptual and detailed design. Despite several methods recommend the use of simulation as early as RIBA B/C (RIBA Plan of Work 2007); RIBA Green Overlay 2012, Carbon Trust 2011, BSRIA Soft Landings 2010, BREEAM 2008), the teams were struggling to incorporate the simulation tool earlier than RIBA C. In other design phases, designers in the case studies seemed to experience difficulties deploying the simulation tools. For example, in early design the designers used heuristics and experiential knowledge and rough estimation on simulation proprietary software (case 1, 3A, 4A).

Figure 6.1. illustrates tools used in the process. Section 1 represents the project development timeline: conceptual and detailed design (design process phases); construction; and, use. The RIBA 2007 Plan of Work stages have been included as a temporal reference: conceptual design from A to D and detailed design from E. Section 2 shows the instances when the compliance tools (SBEM, proprietary

simulation software) are likely to be invoked in the process. Notice that in compliance-only analysis, the simulation tool does not tend to be part of the problem-solving process and it is likely to be limited to the transition between conceptual and detailed design, before construction (RIBA D-F). In detailed design, the compliance tool is invoked only to produce compliance evidence and not to assess design changes onsite.

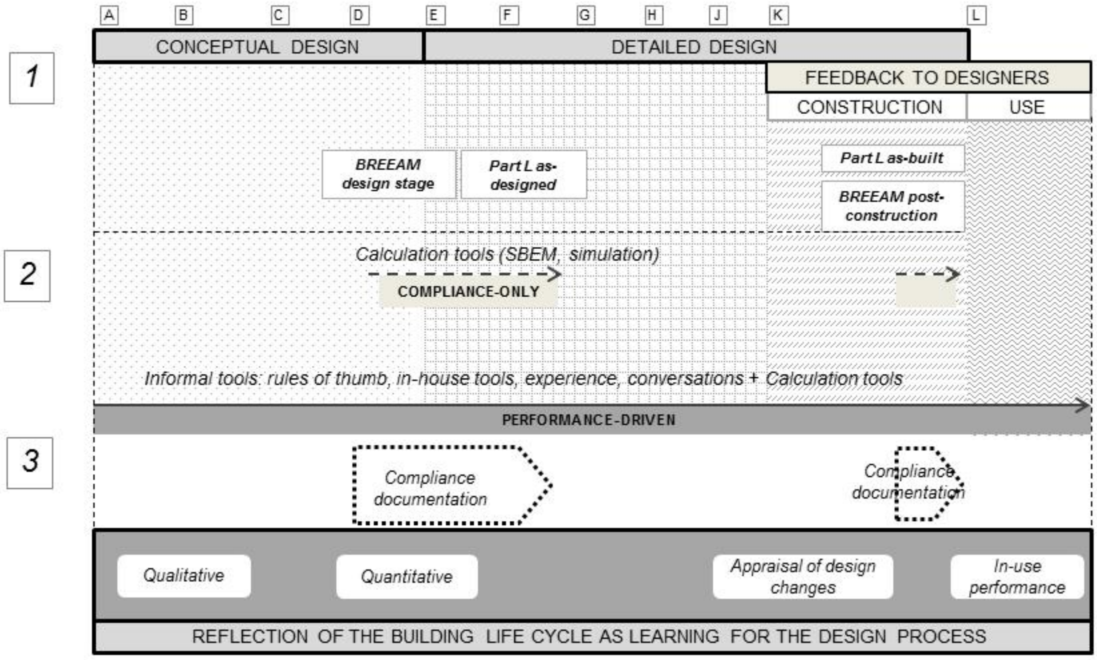


Figure. 6.1. Tools to embed performance in the process, comparing the timeline for compliance-only and performance-driven processes

Notice that Figure 6.1. suggests that the simulation tool could be ‘plugged-in and plugged-out’ discretely in the process around compliance, to produce the evidence for BREEAM or Part L (dotted arrow on Section 2). Conversely, on performance-based analysis, the appraisal of performance is ubiquitous (blank arrow marked throughout conceptual and detailed design, Section 2). The designers invoked a variety of tools to estimate the performance (rules of thumb, experience-based advice, in-house tool) for a quick understanding of the implications of the design strategies. In the performance-based analysis, the compliance tools were likely to be used in combination with other calculation tools throughout the design process. The performance appraisal is conducted by informal and official tools to inform the design decisions, value engineering and delivery changes. The performance appraisal cycle in the performance-based analysis is prone to establish connections between the design assumptions from conceptual and detailed design to later building life cycle phases (construction and operation).

Section 3 shows that for compliance-only purposes, the tools are used in a perfunctionary fashion; merely to produce compliance documentation (doted white boxes on Section 3). On the contrary, in performance-based analysis, the designers seek to achieve the understanding of performance throughout the process: qualitative understanding; quantitative estimation; appraisal of the design changes during site works; and, possibly, the feedback from operational phase (grey boxes on the bottom of Section 3).

Some of the potential reasons for the slow uptake and intermittent use of simulation in the process are:

- The designers' perception that energy is not a project requirement because clients are unlikely to demand it. Consequently, the performance analysis is not considered to be a design task and the simulation could be as a regulatory instrument not a tool for design exploration or performance understanding.
- Energy is perceived to be a variable moving target. Thus, the energy performance analysis is optional. This differs from other performance requirements such as structures, fire safety, cost, flood risk where the design teams developed investigations from conceptual design to improve their understanding about these aspects and make provisions in the design proposals.
- There is an incomplete understanding about the simulation tools, their capabilities and limitations which could result in distrust because of the expertise and background knowledge needed to undertake a suitable performance analysis, appropriate choice of tool, acceptable assumptions and simulation scenarios.
- The computational effort and time needed to create the simulation models are not suitable for the design situations where rapid feedback is needed to advance the design.
- The simulation results and estimation scenarios do not get connected to the wider building life cycle stages. If used, simulation might be invoked around

the compliance thresholds on the transition from conceptual to detailed design and before the construction phase (between RIBA D and F). Therefore, the designers perceived simulation tools as theoretical or compliance instruments where the as-designed performance estimation is an uncertain representation that may not get connected to as-built and in-use performance. In other words, the simulation tools could be seen as limited tools for the appraisal of performance due to the uncertainty embedded in the as-designed evaluation in relation to as-built and in-use performance.

6.2.2. Designers' perceptions about simulation tools

This section will show the architects' perceptions and understandings about the simulation tool. The architects in the case studies held different interpretations about the role of simulation as a compliance and as a design tool. The architects expressed that they distrusted the simulation because it was perceived to be a theoretical exercise. The simulation was viewed as a regulatory requirement with a limited capability to predict the performance due to the uncertainty embedded in the analysis.

The simulation tool could be seen as a source of *theoretical results* where the scenarios are based on the simulationist's assumptions. The *trust* on simulation implies the understanding about the performance analysis, the simulation scenario and the proficiency of the simulationist who carries the calculation. The acceptance of simulation results entails the acceptance of the *knowledge and expertise of the simulationist*. Other perceptions of simulation bring attention to some barriers in the process such as *the need of better coordination, design power (loss of control due to simulation), the use of simulation as a weapon and the difficulties in determining the time when simulation is used.*

The continuous use of simulation as part of the design process in combination with experiential knowledge, informal tools and early performance invocation gave it legitimacy. The case study data suggests that the simulation legitimation is based on the working relation and trust held between the designers and the simulationist. Accepting the simulation results implies the designer's trust and understanding of the assumptions embedded in the model and the acceptance to the knowledge and expertise of the simulationist.

The following excerpts illustrate some of the perceptions held by designers about the simulation tools:

Perceptions	Quotes
Theoretical results	*ARCH: 'The mechanical engineering did the calculation and produced the figures. The key point that they made is that those figures were academic. They were just numbers.'* *MECH ENG: 'Sometimes I strongly disagree with simulation and its pretty pictures… is this helping to understand or just generating pretty pictures, images of performance that can't be mapped against actual energy use?'*
Distrust	*ARCH: 'How reliable is the use of advanced simulation tools?'* *ARCH: 'You'll never reach the [energy] target; it's some kind of false target really. It's uncontrollable, because you can't control people. You can control lights to a degree; you can obviously control heating and ventilation. But on the modeling we've managed to reach the target and that's completely right if no one is going to switch a plug.'*
Knowledge and expertise	*ARCH: 'It's about basic principles; do you need software to tell you that?'* *MECH ENG: 'Even in our discipline [mechanical engineering], there is sub-expertise with people who can produce models and worry about Part L and the other engineers who have not been trained in producing models who will rely on the modelling group…'*
Simulation as a weapon	*ARCH: 'The energy results are pessimistic. The wording is rather negative. It seems like they are blaming the design but the ventilation rates are not design factors.'* *ARCH: 'The response from the simulation people was interpreted by the contractor to modify things...'*
Control	*ARCH: 'We used to have to do an average U value calculation and think about the position of windows and all the rest, but now to have a thermal model, or a daylight model, that tells us precisely what impact is happening, it's another tier of coordination, yeah. But we can't necessarily do all of those modeling exercises ourselves, so it means you have to go out to someone else to do it for you, and it takes that design, control of the design if you like, out of your hands.'*
Difficulties to time the use of simulation	*MECH ENG: 'The time that the model is done often depends to certain extent on the complexity of the building. The one that I am working at the moment has nearly 500 rooms… there was certainly no wish to trying modelling before it was reasonably fixed but of course, the point at which that will happen is a bit transient, it is a bit fluid.'* *ARCH: 'Simulation was just issued. If we had it before, we could have changed something but it's too late now. The building is designed and on site. We could do something now but no huge changes.*

Table 6.3. Designers' perceptions of simulation

In the design context, there are different types of simulation users (i.e. novel, proficient, expert), functionalities (i.e. goals of rapid assessment, accuracy, compliance, exploration and comparison of design alternatives) and affordances (i.e. capabilities to mediate the dialogue between the energy specialist and the non-specialist, calculation of the target, compliance verification). Thus, the simulation tools appeared to be used in flexible ways by the designers.

The performance estimation by the official compliance tools (SBEM, proprietary software aligned with NCM) relies on the expertise of a single design team member, the simulationist. The simulation results generated by the simulationist may not get connected to the experience and intuition about performance developed by the other design team members. If the simulation tool is imposed in the process, it may interfere with the performance appraisal cycle based on dialogue and heuristics.

The incorporation of the simulation tool in the process should not interfere with the social connections that enable the exchange of experiential knowledge and information by social networks between architects, mechanical engineers, suppliers. While simulation might improve the accuracy of the performance assessment, the designers in the case studies did not seek for accuracy of the result until reaching the policy gateway. The designers assess the low carbon aspirations based on the pre-existing knowledge about the low carbon targets, design strategies, delivery matters and operational factors. This argument does not deny the assisting role of the simulation tools in the process; it simply suggests that there should be a pre-existing performance dialogue for the simulation tool to be part of the process as a design-aid and to inform the design decisions. In the design process, the simulation tool could be featured differently in relation to the purpose of the analysis; to inform the design throughout the process or only to produce compliance evidence in the light of BREEAM and Part L (policy gateways); as illustrated in Figure 6.1. This finding from the field is aligned to the notions of human-tool junction and society-tool junction advocated by philosophy of technology (chapter 2).

6.3. Knowledge gaps in the design process

The field analysis suggests that:

- Knowledge is created *socially and informally* in the process i.e. conversations, inferred from the field observations of the design process (chapters 4 and 5)
- Performance studies are undertaken *on project basis as discrete and isolated investigations* rather than as an overarching company policy i.e. following task (section 5.5 in chapter 5)
- The knowledge about low carbon design is not limited to energy performance metrics. It requires a good understanding of cost, buildability and the user, suggested by the field observations and documented in chapters 4 and 5.
- The formal knowledge management systems in the firms tend to focus on capturing performance indicators at the end of the project neglecting the

learning that occurs while negotiating the low carbon aspirations and the knowledge that is created as result of the design changes (section 5.7, chapter 5).

The analysis of the performance appraisal cycle and the knowledge dissemination in the design process suggest that there are instances prone to fragmentation where knowledge about performance is incomplete.

The knowledge gaps reflect obscured or incomplete knowledge and indicate the interruption of the knowledge conversion process or the ineffective social construction of knowledge. These instances are indicative of a poor understanding of the policy targets; poor understanding of the performance assessment; lack of knowledge about construction (detailing, buildability, cost impact, delivery on site); poor awareness of the low carbon rationale especially when there is an excessive focus on cost reduction and a poor understanding of the relation between the building and occupants (in-use performance). These instances reflect the moments in the design process where the designers experience difficulties in maintaining the low carbon aspiration in the case studies. It should be remarked that these instances are common to all the case studies despite the differences in the ways the designers coped with the knowledge gaps. It should be noted that these instances refer to the architects' knowledge needs.

The knowledge gaps emerge in the instances where the collective knowledge is necessary to relate the energy metrics to other project requirements and when the design is handed-over among the parties (to the detailed design team, to the delivery team and to the user). The following figure illustrates the instances where knowledge gaps are likely to emerge, according to the case studies observations:

- *Transition from qualitative to quantitative understanding*
- *Transition from conceptual to detailed design*
- *Transition between detailed design and delivery phase*
- *During delivery:* realisation of the design intentions on site
- *Operational performance.* Although this phase is not part of the design process, the understanding of the building-user interface could inform the design strategies and the performance estimation scenarios.

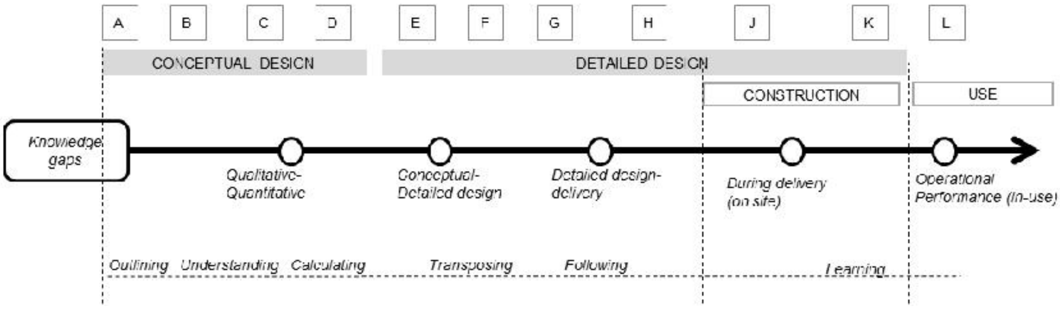


Figure 6.2. Architects' knowledge needs

6.3.1. Transition from qualitative to quantitative understanding

In this instance, the architects benchmark the energy aspirations and seek a rough understanding the implications of the design strategies (described in detailed in sections 4.4 and 4.5, chapter 4). This is achieved by:

- Benchmarking against existing experience
- Disseminating and obtaining knowledge through conversations and experience-based advice
- Using in-house tools for a quick estimation of performance
- Using historic data and obtaining the users preferences in terms of strategies (workshops with the users)

The qualitative understanding of performance is likely to be gained by experiential knowledge. Calculation tools such as simulation are invoked to increase the certainty and the accuracy of the performance appraisal, after using simplified methods: rules of thumb, in-house tools, experiential advice. The transition between qualitative and quantitative estimation implies the improvement of the accuracy of the performance estimation. It was observed that the designers developed workshops with the users to obtain data about occupancy, energy usage and preferences and identify opportunities to reduce the energy consumption. This was based on historical data of use recorded in an occupied building whose users were to be relocated in the new building undergoing design (cases 1 and 3A). The workshops were also used to explain the benefits of low carbon design and encourage the ownership of the low carbon aspirations by clients and users.

The two-way communication between the designers and the users could facilitate feedback from the users about the preferred technologies, concerns about maintenance of technologies, preference in terms of ventilation strategy and operation of the mechanical systems. The inclusion of the occupants is a form of participatory design where the users develop an awareness of the features of low carbon buildings while creating the ownership of the building. This task seemingly enhances the simulation scenarios about occupancy.

It was observed that in the transition from qualitative to quantitative understanding; the designers were using cost studies to determine the financial feasibility of different strategies and sought funding opportunities for low zero carbon technologies. The cost estimation could relate the low carbon aspirations to operational and maintenance cost to illustrate to the clients and to the users the potential benefits and savings of low carbon buildings.

In summary, the transition between qualitative and quantitative understanding requires knowledge of regulations and planning requirements to establish the target, the use of past experience (strategies and targets) for benchmarking, the awareness of cost implications, users' preferences and behaviours to propose suitable strategies that respond to those preferences.

6.3.2. Transition from conceptual to detailed design

During this instance, the architects transpose the low carbon aspirations from conceptual to detailed design to ensure the continuity of the design intentions during delivery. The architects need to know how to embed the design intentions in the development of details and technical specifications that will guide the delivery team's work. The following quote illustrates the perception of one of the research participants about the understanding of the conceptual design by the team involved in later design phases:

'The procurement method is absolutely critical. Normally, in design and build procurement, it would not necessarily be the same design architect carrying through. Somebody else may come on board and he doesn't have the embedded knowledge in the job, he does not understand the design strategies.'

This quote suggests the importance of understanding the underlying design rationale in detailed design phase to achieve the design intentions in detailed design and delivery.

In order for the design aspirations to inform the later development stages, the details and specifications should define the energy performance indicators for delivery. The architects need to know about materials, construction techniques and site tolerances and embed construction knowledge in the details and specifications. In other words, this instance requires the understanding of the design strategies, available products, technical information, cost, execution of the details on site, alternative products, standards on site, workmanship, tolerances, the experience needed from the sub-contractor to achieve the expected performance.

The knowledge about delivery helps the architects to anticipate how the design intentions translate to buildable details and specifications. This knowledge is supported by trade literature, technical guidance and product brochures. For example, the product information by Kingspan includes product description and dimensions, typical detail drawings, the specification of the product in relation to regulatory compliance, the accredited construction detail for compliance, site work considerations, installation principles, product performance in relation to environmental impact, thermal properties, durability, fire performance and resistance to solvents, fungi and rodents (Kingspan 2011). Kingspan offers technical advice for designers and calculations of U-values and insulation thickness. The architects in the case studies contacted the material suppliers for technical advice to inform the development of the details and include the construction considerations in the details and specifications. The architects also obtained advice from experienced colleagues, past details, fabrication studies. The detailed design knowledge could be gained during the delivery phase if the designers follow-up the development of the design onsite, examine the design changes and obtain the feedback from the delivery team. The detailed design could be informed by knowledge about buildability so as to anticipate potential problems that could arise during delivery i.e. the selection of indicators for delivery: tolerances, standards on site, experience required by the site operatives and remedial work.

6.3.3. Transition from detailed design to delivery

Due to the perceived opposing agendas between design and delivery phases, there was a tension between design and delivery phases which could become a hindrance to the distribution of knowledge between design and delivery, especially in design and built procurement route where design and delivery teams tend to be separate entities. The transition between detailed design and delivery is prone to fragmentation when the design team transfers the design to the delivery team led by the main contractor. The following excerpts illustrate the perceptions of the designers about the delivery team:

'The biggest issue to get around is to get the contractor to build the things properly and that needs the biggest education…contractors don't understand the design intentions. The contractors are cynical about it, they don't think it is important. They think it is a joke.'

'The delivery team doesn't understand everything that's in this final package... There is this aversion to risk which is totally understandable, but I think it's about getting them to understand that you know they're new products. Sometimes they put in excuses to find something which is, you know, more economic. That's always going to be a problem. And it's a challenge, it's a real challenge.'

It was observed that the architects make explicit the design intentions to the delivery team in order to facilitate the continuity of the targets by:

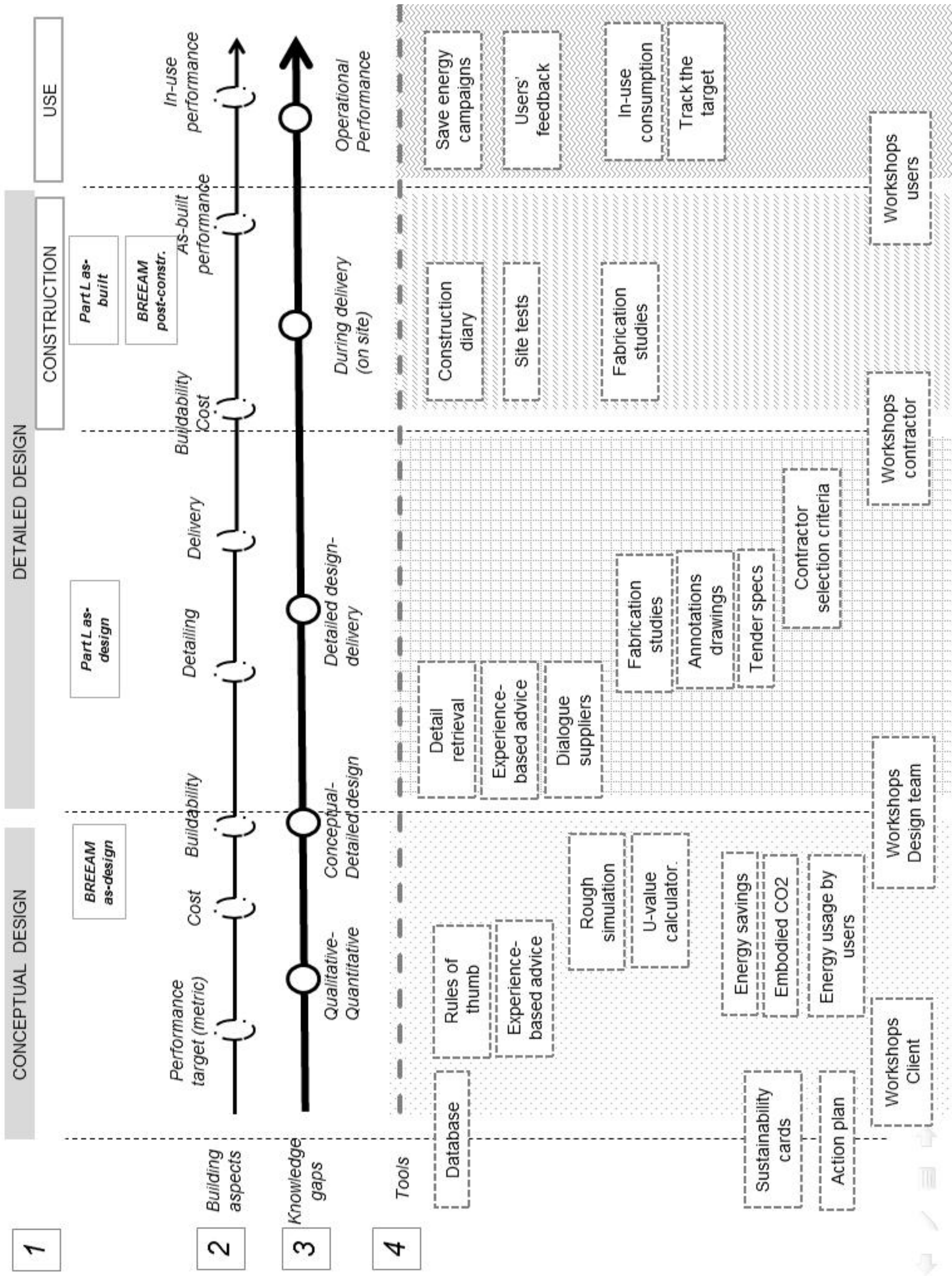
- developing workshops with the contractors bidders and subcontractors
- explaining the rationale in the selection of contractor (experience, skills)
- partnering and getting advice from design team members with experience in construction

6.3.4. Onsite, materialisation of the design intentions

While the architects do not undertake onsite work, their awareness of the construction process could enhance their knowledge about buildability matters that affect the performance. Despite Part L requires the as-built airtightness test, the commissioning of systems and BREEAM requires post-construction evidence based on observation and photographic evidence; the field data suggests that the results of tests conducted during construction are unlikely to be used as feedback for the architects.

It can be inferred from the case study data that there could be a weak link between the design and delivery phases. There is a lack of fabrication studies to examine the onsite execution of the design proposals. The tests on site are unlikely to provide feedback to the design assumptions and the as-designed simulation scenarios. Although the delivery of the finished building is outside the scope of this investigation, it is important to notice that the overlap between the detailed design and the delivery phase could be used by designers to compare the design proposals to the solutions onsite and increase their knowledge of performance. During construction phase, the as-built performance and construction tests are likely to be used as feedback to designers. The results of site tests such as airtightness requested by Part L are unlikely to return to the architecture studio.

The onsite performance investigations could be undertaken to identify the discrepancies between as-designed and as-built performance and increase the designers' knowledge about delivery matters i.e. construction diary in case study



4B. The investigations during delivery could inform the simulation scenarios and enhance the design knowledge about specifications and technical requirements. Conversely, the lack of performance investigations during delivery and the poor architects' knowledge of construction may undermine the opportunities to improve the designers' knowledge about delivery, suitability of details, the recommended practice to install products, possible errors, safety factors, special care to warranty the expected performance, workmanship, precision and tolerances on site, sequence of work and remedial work.

This instance draws attention to the need to compare as-designed and as-built performance and the combination of methodologies to analyse the as-built performance such as co-heating test, airtightness test, thermal imaging and inform the design assumptions and as-designed estimation scenarios.

6.3.5. Operational performance

This stage is outside the scope of this study but it has been included as part of the learning task in low carbon problem-solving. At the end of delivery phase if the designers do not reflect about the process, the opportunities to increase their design knowledge could be lost. The designers' performance knowledge could benefit from the understanding of the interface building-user. The knowledge about operation could inform the design assumptions about occupancy and improve the as-designed scenarios on the basis of in-use data. However, no evidence was found that the architects in the case studies obtained the feedback and data from operational phases.

Officially, the knowledge management systems in the architecture firms promote the capture of indicators and strategies of the projects. The project summary information is a snapshot of the strategies and targets achieved at the end of the design process. The project summary information does not include the data about as-built and in-use performance, users' feedback, documentation of changes and incidental factors that affected the aspirations. As discussed in chapter 5, such knowledge management approach does not take advantage of the learning that occurs during the process and the evolution of the design aspirations over time. However, these aspects were disseminated informally between architects in lunchtime seminars, workshops or while sharing experience-based advice.

The field studies suggest that the designers need to understand the *users' factors* so as to determine the human factors that are likely to affect the energy performance of the building during operation for example occupancy patterns, practices and preferences in the operation of the building, adaptability opportunities and systems maintenance. While this was not observed in the case studies, the architects reported that when there are long-term relationships with the same developer, there could be some feedback from the developers in relation to the achievement of the design intentions during operation.

The designers' understanding of operational performance could lead to informed design proposals that build upon users' preferences and identify the opportunities for energy reductions. This could improve the scenarios that characterise the building user and underpin the as-designed estimation models.

Figure 6.3. illustrates the process breakdowns and the cycle of incremental performance understanding likely to be enacted by the architects to link the energy considerations and the project drivers. The figure emphasises the connection between design knowledge about low carbon and the different building lifecycle phases. It should not be read in terms of linearity but in relation to change overtime.

The figure relates the following aspects:

- Design process timeline (Section 1)
- Building aspects that affect the low carbon performance overtime (Section 2)
- Knowledge gaps (Section 3)
- Summary of tools deployed throughout the process to embed performance (Section 4)

The design process timeline illustrates the conceptual and detailed design, including constrution and use. While construction and operation are outside the scope of the architects' work, these phases could inform the design assumptions (section 1 in the figure). Section 2 illustrates the building aspects that are likely to affect the low carbon aspirations:

- Performance benchmark (policy targets, project requirements, site potential in relation to passive design and low carbon strategies)
- Cost (funding streams, financial incentives, cost estimation of the operational savings due to low carbon strategies)
- Buildability (build-ups to achieve U-values, details to reduce thermal bridges, products available, sequence of construction)

- Detailing (development of details for the reduction of thermal bridges resolution of the build-up to achieve the expected U-value)
- Delivery (sequence of construction, remedial work, tolerances).
- Buildability and cost in the light of delivery and during construction (cost including delays, replacements and changes in the construction sequence)
- Site performance (as-built performance)
- In-use performance (actual energy use during operation due to the interface between the occupants and the building)

Section 3 illustrates the instances prone to fragmentation that relate to potential knowledge gaps by architects elaborated in this section:

- *Transition from qualitative to quantitative understanding*
- *Transition from conceptual to detailed design*
- *Transition between detailed design and delivery phase*
- *During delivery: realisation of the design intentions on site*
- *Operational performance.* Although this phase is not part of the design process, the understanding of the building-user interface could inform the design strategies and the performance estimation scenarios.

Section 4 in the figure summarises the tools used to embed performance in conceptual and detailed design (including construction and operational phases) as identified on the observations of the architect's work and his/her interface with other design team members. As described in chapters 4 and 5, the architects in the case studies did not use calculation tools (e.g. U-value tool, simulation). The architects used rules of thumb and experiential knowledge to qualitatively estimate the energy performance.
Notice that the figure below relates the knowledge gaps, the process breakdowns (in the case of poor or incomplete knowledge) and the tools invoked in the process.

Figure 6.3. Knowledge gaps and design process breakdowns

6.3.6. Design expertise

The architect's knowledge of low carbon design should connect the performance targets, the site realisation and the operational aspects. The lack of a comprehensive understanding of low carbon performance could lead to the selection of low carbon strategies deemed to fail because they do not consider the cost, buildability and the user's interaction with the building. The poor consideration of construction and operational aspects undermines the architects' understanding of how the building performs in later phases of the building life cycle.

Figure 6.4. illustrates that the design expertise could be confined to the specific design process phase that the designer works on. Section 1 represents designers who only work in conceptual design (grey arrow) and their need to consider detailed design, construction and operational performance to inform the conceptual design (dotted lines). The grey dotted lines in section 1 represent the areas where the conceptual designer can get feedback from the detailed designer if the architecture team is divided in conceptual design and detailed design teams. Section 2 shows the timeline in the process when the designers who specialised in detailed design work (grey arrow) and the consideration of conceptual design rationale and construction that inform their work (black dotted lines)

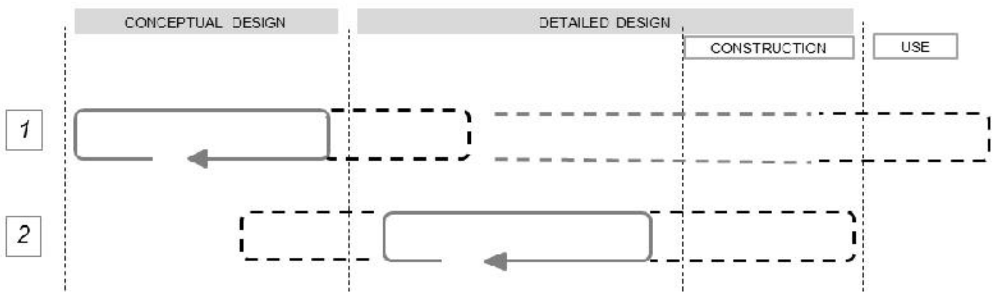


Figure 6.4. Representation of the design expertise in the design process

Figure 6.4. suggests that despite the specialisation of designers in discrete design phases, they need some understanding and knowledge about how the building performance gets realised in other building life cycle phases. In such way, conceptual designers would benefit from understanding the performance issues that arise in detailed design, construction and in-use and that could affect the expected low carbon performance. Equally, designers specialised in detailed design could benefit from understanding the design aspirations and rationale outlined during conceptual design as well as the issues that emerged during construction and operation that could affect the expected low carbon performance.

6.4. Conclusions

Chapters 4 and 5 described the low carbon problem-solving tasks to illustrate the performance appraisal cycle to which the designers subscribed in order to enact the low carbon policy aspirations. The description of the process has shown the evolution of the project aspirations and the adoption of the energy targets in the light of other project requirements. The low carbon problem-solving and the performance appraisal cycle are analytical resources from which we could understand the knowledge flows, the knowledge gaps, the designers' support needs, the preferences for information exchange and the process of knowledge creation. In describing the tools deployed to embed energy performance in the design process, aspects related to the performance appraisal cycle and the knowledge flows have been addressed within the localised practice of the design process. Those topics have helped to reveal the variegated role of tools in the coproduction of knowledge.

Figure 6.5. represents the performance assessment enacted by the designers. Section 1 illustrates the project timeline (conceptual, detailed design, construction and use) and the low carbon policy gateways (BREEAM and Part L).

Section 2 exemplifies the instances where designers carry the performance assessment (benchmark and estimation). The *diamond shapes* in the arrow in section 2 represent the instances where the *performance assessment is prompted by the policy gateways (perfunctionary compliance assessment)*: BREEAM as-designed for planning, Part L as-designed on detailed design before construction and Part L as-built and BREEAM post-construction after finishing the construction. Those are the points where compliance evidence was likely to be produced. The boxes under the diamond shapes provide some examples of the official tools for designers to embed performance in the light of the policy gateways. The *circles* in the arrow in section 2 *represent the instances in the process where the designers make appraisals of the low carbon aspirations to gain a better understanding of performance, without the specific goal of producing evidence for compliance*. It should be noted that these circles are representations of the performance appraisal in the process: qualitative to quantitative estimation, performance estimation in the light of detailed design and performance appraisal in relation to delivery.

Section 3 includes the tools that were used on the performance estimations, for performance understanding and for compliance.

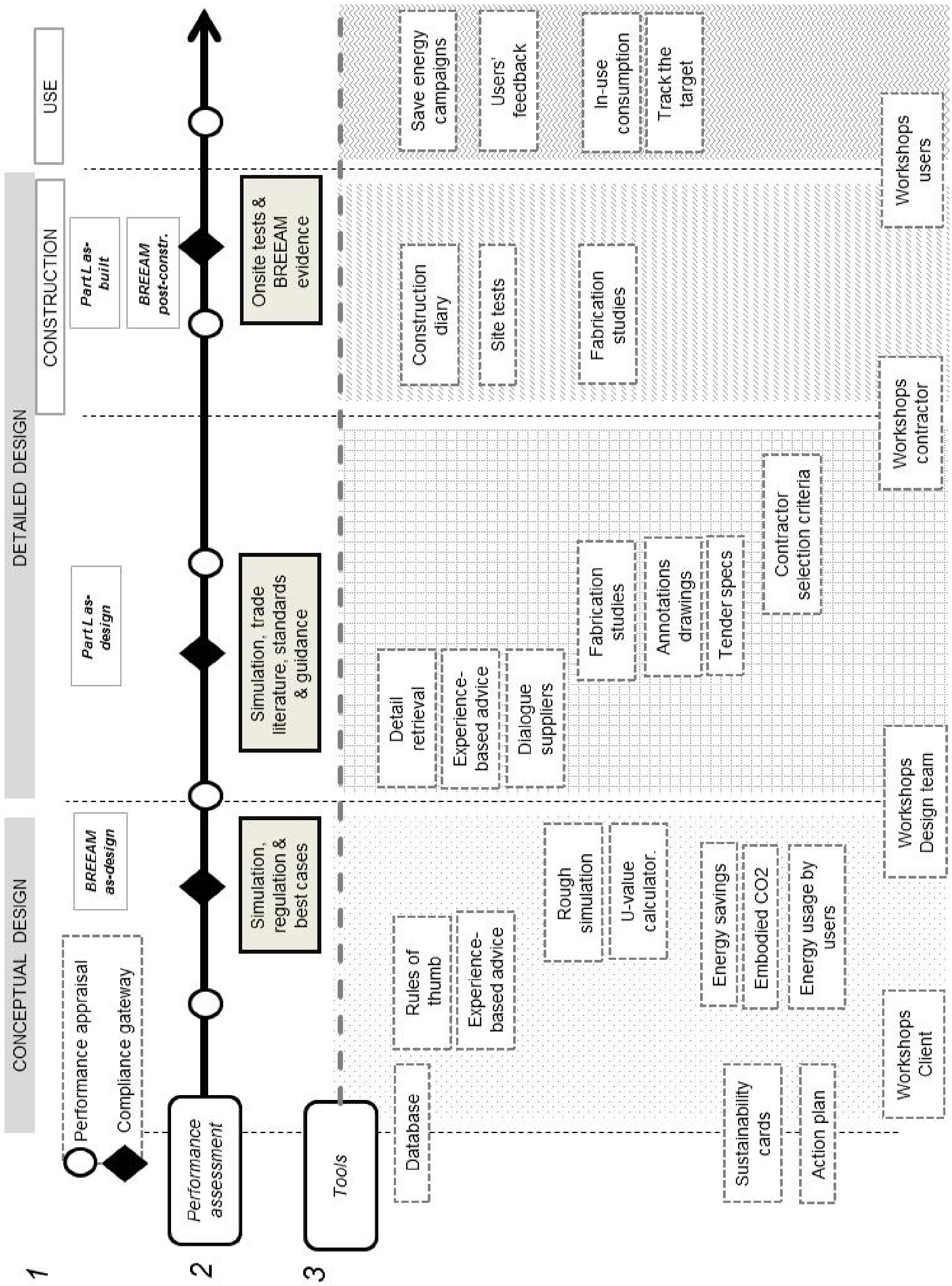


Figure 6.5. Performance assessment throughout the design process. Note that this figure represents the performance assessment throughout the process in relation to the policy gateways (1), official tools (2) and tools found in the case studies (3).

It should be noted that Figure 6.3. *Knowledge gaps and design process breakdowns* and Figure 6.5. *Performance assessment throughout the design process* represent the relationship between the knowledge needs and the tools invoked in the design process, as inferred from the case studies. These figures are relevant in that they identify the critical instances where knowledge is needed to advance the design:

- *Transition from qualitative to quantitative understanding*
- *Transition from conceptual to detailed design*
- *Transition between detailed design and delivery phase*
- *During delivery: realisation of the design intentions on site*
- *Operational performance*

These instances suggest information needs and tool support required by designers to evaluate the compatibility between the energy aspirations and the project requirements and integrate the dispersed knowledge the design team.

The design information about performance tends to be restricted to the technical performance of the whole building and its elements. The tools for performance offered to the designers tend to be focused on the calculation of the energy metrics. However, the field data suggest that there are social attitudes and behaviours that impinge upon the building energy performance such as the perceptions of low carbon performance of the stakeholders, design practices and relationships between design team members. The analysis also suggests that construction and operational aspects could affect the achievement of the low carbon aspirations, for instance site practices, conflicts between design and delivery teams and occupants' involvement in the design process. That has been inferred from the interface between design and delivery during detailed design and the relationship between the designers and the users in defining and estimating the performance. Nonetheless, it should be remarked that construction and operation are outside the scope of the investigation. They have been included in the discussion to address how they could inform the design process.

From the understanding of the design process (chapters 4 and 5) and the discussion about tools and knowledge in the design process (chapter 6), the next chapter will summarise the designers' enactment of the policy aspirations, discuss the field data in the light of the theoretical framework and identify the main implications of the field findings.

Chapter 7
Discussion

7.1. Introduction

This research has investigated the enactment of the design process and the dynamic changes to the low carbon aspirations that occur overtime, with emphasis on the tools and the knowledge in the design process. The analysis of the performance appraisal cycle and the knowledge gaps in the process served as analytical resources to identify how designers embedded energy performance in the design process.

Prior research concerning the implementation of the low carbon agenda identified some of the challenges that practitioners experienced for the incorporation of the energy standards. However, the real-time responses remained unknown. In other words, while the barriers against the implementation of the low carbon agenda were known, *the designers' responses to the challenges, designers' enactment of the policy intentions during routine design process, remained unknown*. By using ethnographic methods and observational studies, this work has revealed the real-time design process of six non-domestic buildings developed by four large architecture practices in England and Wales.

In terms of knowledge management, previous work has used socially-led approaches. These knowledge management studies (reviewed in Section 2.4.3) recognised that social aspects arising in the process were likely to contribute to knowledge creation and dissemination in project environments, such as architectural design. However, to the best of the author's knowledge, previous studies have not directly examined knowledge aspects arising from design practice in the context of convoluted changes in performance-based requirements. This work has explored *how the designers created and disseminated knowledge while designing and has looked at the social aspects that contributed to learning about low carbon performance during regulatory changes*. The case studies were developed during the 2010 incremental change of regulations enforced in England and Wales.

The literature review about simulation tools for designers identified that there was a lack of observational studies of designers in action developing routine project design. This investigation used ethnographic methods to observe the *use of tools in the real-time design development*. This work used Dewey's notion of tool so as to include a wide variety of design aids used by designers to embed the standards. In such way, the investigation has considered principles of human-computer interaction theories and philosophy of technology studies. This broad notion of tools enabled the *identification of informal tools that contribute to low carbon design, the latent and potential affordances of calculation tools and the diverse roles that tools could adopt in the process. This approach allowedto identify the connections between different types of knowledge (tacit and explicit) and the deployment of tools to advance the design*.

Themes investigated	Gaps found in the literature	Contribution of the work
Nature of the design process	Prior design studies have focused on individual design expertise, specific design process phase or analyse the design process isolated from other building life cycle phases.	Architects' problem solving activities in the light of the design team members' work and input; design knowledge in relation to construction and operation
Designers' enactment (adoption of policy model)	Challenges had been identified by prior literature but real-time responses remained unknown.	Designers' enactment of policy intentions and flexible responses to embed low carbon performance in routine design
Knowledge in design	Prior studies have considered social aspects that contribute to knowledge creation and dissemination in project environments. However, there were lack of studies about knowledge in design practice in the context of changes of performance-based requirements and the relationship between knowledge and tools for problem solving in real-time routine design.	Knowledge creation and dissemination during the design process in the context of energy regulation changes and interface with tools for problem-solving; instances of the process that are prone to fragmentation
Tools in the context of use	Lack of observational studies of designers in action developing routine project design using tools in the context of routine design. Some previous studies have analysed tools without linking the use of tools to the knowledge creation and dissemination process while designing.	Performance appraisal cycle, use of tools in action and in interaction, affordances of tools, variegated roles that tools adopt in the process and interconnections between design knowledge and the deployment of tools

Table 7.1. Summary of the gaps suggested by the literature and the findings of this work

Chapters 4 and 5 presented the findings in terms of timeline project development, highlighting the tools and knowledge invoked to inform the building design. Chapter 6 discussed the challenges that designers experienced concerning the use of tools and knowledge creationthroughout the design process, discussing the multiple roles that tools adopt in practice and the knowledge gaps that are likely to emerge in the design process due to fragmentation between design and other building life cycle phases.This chapter finalises the discussion by articulating the designers' enactment and brings together the connections between social context, tools and knowledge (Section 7.2.). Section 7.2.summarises the findings concerning the designers' enactment of the policy intentions by presenting the key designers' responses to implement the low carbon agenda, inferred from the case studies. Themain research findings are discussed in Section 7.3. They were inferred from the interrogation of the field data in terms of project development timeline: Conceptual and Detailed design process (chapters 4 and 5); Tools and knowledge in the process (chapter 6); and, Designers' enactment of policy intentions (Chapter 7, Section 7.2.). Finally, this chapter concludes by discussing the implications of the work (Section 7.4) and the relation of the findings with the prevailing literature (Section 7.5.).

7.2. Field findings: Designers' enactment of the policy intentions

The field observations suggest that designers hold conflicting views of regulations. The regulations are supported in that they aim to improve the building performance by forcing the stakeholders to achieve a minimum standard. Conversely, there is criticism of the policy due to the lack of demand for low carbon performance and poor understanding of the low carbon targets. This conflicting perception of the policy model is an indication of the disconnections between the policy and the designers' dimensions. It was found in the case studies that the designers were experiencing the following challenges:

- Unclear definition of low carbon performance target
- Difficulties in the integration of the compliance tools in the design process (i.e. SBEM, proprietary simulation);
- Lack of knowledge, skills and experience to embed low carbon performance in building design
- Fragmentation and lack of continuity in the process
- Unarticulated drivers between design and delivery phases
- Energy is not perceived to a be a project requirement
- Cost and energy are considered to be mutually exclusive aspects

The study suggests that designers do not conform to the description of agents who immediately adopt the standards and the compliance tools to inform the design because *their enactment of the policy enters already formed design processes that reflect a multitude of concerns and precedents, a pre-existing social context.*The low carbon design process is situated in a context of purposes and meanings that are alien to the rational model of what the process should be like. The field studies suggest that even designers with experience in sustainable design are struggling to incorporate the regulatory requirements because there is a need to increase the understanding and experience in performance-based design.

The adoption of the low carbon policy agenda is affected by the project-specific circumstances (Table 7.2.), namely *the social context*, in terms of:

- Different drivers of the stakeholders: cost, time, energy; focus on developers' agenda or user's agenda.
- Different motivations of the designers: attitudes about low carbon, goals, expertise

- Pervasiveness and continuity of low carbon aspirations throughout the process. The pervasiveness refers to the uninterrupted relevance of the low carbon aspirations throughout the process as a ubiquitous goal of the process.
- Architects' design expertise and experience (working models in the architecture firms):
    - Architects who only work in conceptual design,
    - Architects who only work in detailed design,
    - Architects who work in conceptual and detailed design,
    - Architects who work in detailed design who have experience in delivery
- Working relationship between design team members: architects and mechanical engineer (or energy specialist) during design, architects and contractors during delivery (nature of the relationship: tension or harmony)
- Relationship between design team members and the wider stakeholders: architects and suppliers, architects and clients, architects and planning authorities/building control bodies
- Company's identity: experience and credentials in sustainable design

Project-specific circumstances		**Illustrative quotes**
Drivers of the stakeholders	Cost, time, energy; focus on developers' agenda or user's agenda	*'The low carbon target can be very aspirational. People could say anything but not commit.'*
Motivations of the designers	Attitudes about low carbon, goals, expertise	*'[Moving towards low carbon design] implies changing the current mindset to understand the value of carbon'*
Continuity of low carbon aspirations throughout the process	Articulation of the design and the delivery agendas	*'Splitting up the process between two separate people with different agendas. The design is likely to deteriorate and also its performance.'* *'There is a degree of interpretation on that design and build procurement offers. There are opportunities for changes which could get abused so you lose the rigor of the design intent and of what gets finally implemented in a building.'*
Designers' expertise and experience	Architects who work throughout the process v architects who are specialised in specific phases of the process (conceptual design, detailed design, delivery)	*'The procurement method is absolutely critical. Normally, in design and build procurement, it would not necessarily be the same design architect carrying through. Somebody else may come on board and he doesn't have the embedded knowledge in the job, he does not understand the design strategies.'*
Working relationship between design team members	Architects and mechanical engineer (or energy specialist) during design; architects and contractors during delivery (nature of the relationship: tension or harmony)	*'It's about getting the contractor and the delivery team to be more 21st century rather than stuck in their ways. If you can show that it has commercial benefit on the overall picture, that's a start… you can show that sustainability has its commercial merits…'*
Relationship between design team members and the wider stakeholders	Architects and suppliers, architects and clients, architects and planning authorities/building control bodies	*'I don't see a problem on actually getting to zero carbon buildings but it requires the clients to buy it, it requires the contractors to actually build it properly… that's the issue.'*
Company's identity	Experience and credentials in sustainable design	*'I guess is part of the philosophy of the firm to push a bit and be ahead of the game but we can't always do it. Some clients, we have to give them the minimum because we could draw it but they won't have the money to build it.'*

Table 7.2. Research participant's perceptions

It was observed in the field studies that the aspects emerging from the social context affected:

- *the (intermittent) presence of the low carbon aspirations in the design process and the establishment of a performance dialogue throughout the process.* The presence of the low carbon aspirations throughout the process has been addressed in Chapter 4, sections 4.4.1 (Low carbon design intentions, target or aspirations) and 4.4.2 (Indicators of performance); Chapter 5, Section 5.5. (Following). The performance dialogue has been outlined in Chapters 4 and 5 when documenting the design process and in Chapter 6 when referring to the performance appraisal cycle (Section 6.2.).

- *the use of tools (for compliance-only or as design-aids to increase the designers' understanding of performance), the trust and legitimacy of tools throughout the process.* The use of tools was outlined in Chapters 4 and 5 and further discussed in Chapter 6, Section 6.2.

- *the knowledge flows and dissemination between designers (conceptual, detailed design, delivery) and the attitudes towards learning that the designers adopt (whether they attempt to gain skills, understanding and learn in the process or if they are just meeting the regulatory target in a perfunctory fashion).* The documentation of the process in chapters 4 and 5 outlined the knowledge exchange and dissemination observed while designing. The discussion focused on knowledge was elaborated in Chapter 5, Section 5.6. (Learning, the missing task?) and in Chapter 6, Section 6.3. (Knowledge gaps).

The ways that the designers in the case studies enacted the process and achieved the high aspirations in later phases exemplify the designers' flexible responses to adopt the policy agenda in routine project design. These responses suggest the relative importance of the low carbon targets throughout the process and show the actions taken by designersto facilitate low carbon design processes. Themain responses inferred from the case studies are as follows:

- designers set up higher aspirations than the official targets mandated by regulations

- designers translate the energy metrics to other project requirements to facilitate the continuity of the low carbon aspirations throughout the building process (design, construction and operation)

- designers develop performance investigations throughout the building process (design, construction and operation)
- designers create and disseminate knowledge while designing by creating social networks of design advice and knowledge sharing

Previous work on the implementation of the low carbon agenda by the building industry (discussed in chapter 1) identified the challenges experienced by practitioners. The findings of this investigation are in agreement with those barriers. In addition, this investigation has presented the details of why and how those barriers emerged throughout the design process and what designers were doing to overcome them (designers' responses). Figure 7.2.illustrates the designers' responses to incorporate the policy agenda and what designers did to embed energy performance in routine project design, as observed in the case studies (white boxes on Figure 7.2.). Section 1 represents the three-stranded model; section 2, outlines the links offered by the policy model to connect the policy intentions and design practice; section 3, presents the barriers experienced by designers; and section 4, summarises the designers' responses to enact the policy agenda inferred from the field data.

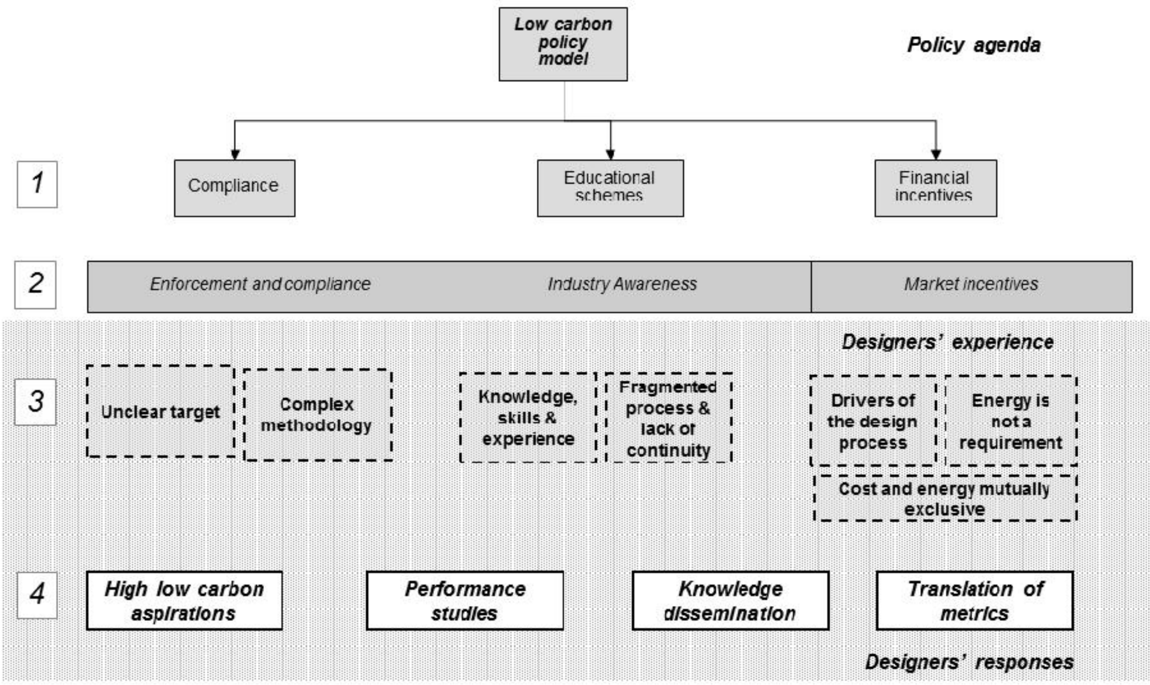


Figure 7.1. Designers' enactment of the low carbon policy agenda

7.2.1. Low carbon aspirations higher than the official targets mandated by regulations

The design process tends to be driven by capital cost reduction which diminishes the attention to the energy performance targets. In order to increase the relevance of the energy performance target, the designers were informally setting low carbon aspirations higher than the official targets mandated by regulations, response that conforms to the propositions of the literature reviewed in Chapter 2, Section 2.3 concerning the social context and the span of relevance. By setting a high performance target (exceeding the minimum regulatory target), the designers were increasing the importance of the low carbon performance as a project requirement. The time when the low carbon targets are set appears to bean indication of the enactment of the process (compliance-only v performance-based design).

The higher aspirations encouraged the performance dialogue and the configuration of informal networks of advice, experience sharing and estimation of performance e.g. advice from experienced colleagues, use of past experience for benchmarking the project aspirations, in-house tools for performance appraisal before the use of calculation tools such as SBEM and proprietary simulation software or when the simulation tool was not suitable for a quick performance understanding. In addition, the higher aspirations motivated the early use of mediating tools to engage the wider stakeholders i.e. sustainability cards, lifecycle cost studies, energy saving bill tool. The mediating tools did not calculate performance nor serve for compliance; however, they enabled the alignment of variegated visions and expectations about the building held by the stakeholders (further discussion in Chapter 2, Section 4.7). The inclusion of the stakeholders, especially the users, provided opportunities for designers to learn, question and reflect about the design strategies and design assumptions about occupancy and the interface between the users and the building during operation. For example in cases 3A and 3B, the design teams used knowledge cards to discuss with the client about the benefits of low zero carbon technologies. The discussions with the users helped to identify how the occupants were likely to use the building. In Case study 3B, the designers obtained the historical data about gas consumption in the kitchen, estimated the number and characteristics of the electrical appliances to inform the estimation scenarios about performance. In Case 1, the design team consulted with the client the assumptions about occupation from early design for an informed representation of users' factors that might affect the building performance during operation.

Due to the high aspiration, the designers were prone to undertake informal performance estimations by loops of benchmark and estimation of the target throughout the design process. The target tended to be continuously reassessed and the use of calculation tools appeared to not be limited to the production of compliance evidence in the light of policy gateways (BREEAM and Part L). This was elaborated in detailed in section 6.2. and illustrated in Figure 6.6. *Performance assessment throughout the design process*.

7.2.2. Translation of the energy metrics and continuity of the aspirations

There is a lack of unified metric to define the low carbon performance which leads to different understandings and expectations by the stakeholders CO_2 emissions reduction, energy demand, heating demand, percentage of renewable energy use, use of passive design, BREEAM rating, Part L improvement, EPC, U-value, users' practices during operation and cost savings during operation. However, these metrics cannot be translated to the everyday knowledge of the stakeholders (users, clients, contractors, designers) and they remain unrelated to their concerns and expectations.

Therefore, the designers in the case studies were translating these metrics to alternative indicators that could be better understood by the wider stakeholders, for instance, the operational energy savings (client, users) and onsite delivery such as construction standards, tolerances and workmanship skills (contractor). The translation of energy metrics entailed the consideration of how the energy targets were affected by other requirements such as:

- the *cost implications* of low carbon technologies and energy-efficient strategies (capital cost, life cycle cost and operational cost savings). The designers in the case studies used this information to illustrate the benefits of low carbon buildings in terms that were relevant and tangible to the clients and users.
- the *buildability*. The designers anticipated the likely standards on site, workmanship, tolerances, potential problems that could arise during construction, the experience needed from sub-contractor in order to propose a design that achieves the expected performance. These aspects were embedded in the technical specifications, detailed design drawings by defining the u-values, airtightness, insulation requirements (rigor and granularity of the tender packages)
- the *users' factors.* The designers tried to gain a better understanding of the schedules of occupation, the users' ability to operate the building, systems maintenance practices, flexibility of use and adaptability opportunities. In other words, the designers characterised thepractices,behaviours and preferences specific to the potential user of the building.

The translation of metrics suggests that designers need a good grasp of the incidental factors that affect the realisation of the energy performance target: cost information, suitability and reliability of design strategies, causes of poor performance during construction, user-building interaction. By considering how the energy strategies and metrics were likely to be delivered in later building life cycle phases, the designers were increasing their understanding and knowledge of performance. The use of metrics to consider construction and operational phases facilitated the continuity of the low carbon aspirations and increased the relevance of low carbon performance as a building requirement.

7.2.3. Knowledge creation: Development of performance investigations

The designers in the case studies were developing performance investigations to gain a better understanding of low carbon performance. The designers connected their knowledge of the energy metrics (kgCO2/m2y, kWh/m2y) to information about cost, buildability, standards on site, practicalities of different low carbon strategies, potential difficulties in adopting specific strategies. The energy performance investigations were informally carried throughout the design process to increase the designers' knowledge about energy performance.

	Examples of performance studies
CS1	Thermal comfort adaptation theory informing the mixed-mode ventilation strategy
CS2	Weather analysis and passive design
CS3A	Solar strategy (use of solar gains, avoiding overheating, solar protection devices)
CS3B	Improvement of energy performance prediction: calculation method, modelling assumptions, educational campaigns to the building user (client's requirement of specific CO2 target), use of historical data of energy consumption (based on existing patterns of energy use of future building occupants)
CS4A	Zero carbon aspirations- comparison of low zero carbon technologies and cost implications
CS4B	Fabrication studies, construction diary and feedback to designer from the delivery work

Table 7.3. Examples of performance studies undertaken in the case studies

The performance investigations seemingly fostered the designers' understanding of low carbon performance and design strategies in relation toother building life cycle phases. The performance studies were likely to be informally undertaken throughout the design process. The better understanding of how to achieve performance throughout the process seemed to increase the designers' knowledge of construction and operational phases. The case studies observations suggest that the designers need to develop knowledge specific to low carbon problem-solving and have the ability to carry critical appraisals about the performance estimation scenarios, buildability of design proposals, construction aspects that might affect the performance of the design. The performance studies appeared to help designers to:

- define the low carbon target appropriate to the project-specific circumstances and constraints;

- translate the energy metrics to tangible metrics for the stakeholders (convey the relevance of low carbon performance and align the expectations and understanding of low carbon performance of the non-energy expert);
- forecast the incidental matters that affect the low carbon targets i.e. buildability, cost, users' preferences;
- consider the interface between as-designed, as-built and in-use performance and anticipate how the low carbon strategies might be realised during the construction and operational phases;
- understand the applicability and limitations of the methods to estimate the energy performance;
- assess the quality of information and advice about low carbon strategies and their implementation;
- improve the estimation scenarios and models in the light of occupancy feedback, historical data and preferences of the users and enhance the performance estimation assumptions about occupancy: schedule and hours of use, users' control of mechanical systems, set point preferences and IT strategies likely to be adopted by the users;
- develop the details and design strategies to achieve the standards on site: build-ups of the envelope to achieve the expected U-value, details of junctions for adequate airtightness, tolerances on site and remedial work in case of poor construction work;
- outline the criteria for skills and experience required from the main contractor and specialist subcontractors of key low carbon strategies (insulation, windows, envelope, low zero carbon technologies);
- select the measurement methods and contractual clauses to ensure the achievement of the expected performance.

7.2.4. Knowledge dissemination: Social networks and experience-based advice

In terms of learning, the formal knowledge initiatives in the architecture firms investigated in this research focused on the capture of energy indicators at the end of the projects to be transferred in future projects. However, other forms of knowledge creation and dissemination were observed in the case studies; for example, the exchange of experiential knowledge, knowledge creation while designing by performance investigations, the use of social networks to disseminate advice and experiential knowledge (intranet, informal conversations), the creation of a common understanding about low carbon performance between the design team members and the wider stakeholders.

The field studies suggest that the knowledge creation and dissemination while designing is dynamic, opportunistic and reliant on social networks, reflecting the non-linear nature of design problem-solving.Knowledge was disseminated by social networks in design. The field data showed that the lessons learned in the projects were disseminated in the architecture firms on debriefing meetings, brainstorm exercises, presentations to colleagues and design workshops. The databases and the intranet portals were used as networking tools to share the experience between designers. For example, in case study 1, the intranet enabled the communication between designers based in different offices and facilitated the exchange of information and experiential advice.

In terms of knowledge dissemination between designers and other team members, the designers gained a better understanding of construction on the basis of advice and conversations with other designers experienced in delivery and construction phases, delivery team members, suppliers and manufacturers. For example, conversations and informal experience-based advice informed the design proposals and experiential knowledge was disseminated between architects and engineers (i.e. to quantify the performance of the building), architects and manufacturers/suppliers of products (i.e. to develop the details that satisfied the expected U-values, airtightness), architects and contractors (i.e. to anticipate challenges on site, buildability of the design strategies and standards onsite), architects and user/client (i.e. to improve the design assumptions concerning occupation that informed the performance estimation scenarios). In general terms, the development of detailed design was informed by trade literature, standards, trade information and social networks of advice. The designers sought to understand the opportunities and risks of adopting different low carbon technologies as well as the care necessary on site to prevent underperforming building elements i.e. delivery of details, tolerances on site, airtightness strategy, construction defects, errors and critical details and other construction aspects that could affect the low carbon performance.

The knowledge creation and dissemination also involved the clients and users. The designers in the case studies were presenting the benefits of low carbon buildings to the stakeholders to raise their awareness and interest. The inclusion of clients and users in the definition of low carbon aspirations facilitated the continuity throughout the process and raised the understanding about performance matters for the non-energy expert.

The examination of the knowledge creation and flows in the design process suggests that designersgain a collective understanding of performance and align their vision of low carbon performance as a project goal. This was elaborated in the discussion sections of Chapters 4 and 5 and in Section 6.3. concerning knowledge in the design process.

7.2.5. Tools in design

The observations of design in action have shown that tools and design aids are facilitators of design problem-solving; however, the use of tools in action and in interaction may be incongruent with the rational model of tool deployment in practice. The analysis of the affordances and changing roles of tools in the process suggests that tools were closely related to prior design knowledge, as shown on the episodes described in conceptual and detailed design processes (chapters 4 and 5). The field data illustrated how experiential and tacit knowledgewere invoked in combination to physical tools to advance the low carbon design. Conceptual tools seemed to surround the designers' interaction with the physical tools for performance (both mediating and calculating tools). Conceptual tools were deployed during the designers' interaction with the non-energy expert i.e. client, users, delivery team members. In other words, physical tools alone, particularly simulation and compliance tools (calculation affordance), appeared to rely on experiential and tacit knowledge (know-how). Experiential knowledge and situated problem-solving skills were the structures upon which knowledge creation and dissemination were enacted and fostered in parallel to the design activity.

The analysis of tools in relation to the design problem-solving activities has highlighted that the visions and drivers of the process have to be aligned for the enactment of performance-based processes (Discussion sections of chapters 4, 5 and Section 6.2. in Chapter 6). The field data showed that when achieving low carbon performance was a goal of the process, the tools were likely to be part of the process to inform the design development over time. While negotiation, tensions and changes in the low carbon aspirations would still emerge, tools were likely to be used for better understanding, knowledge creation and dissemination while designing.

7.3. Generalfield findings

This section highlights the findings of this investigation grouped in headings that correspond to the theoretical framework summarised in Table 2.2. (Chapter 2):

- Nature of the design process
- Knowledge creation and dissemination while designing
- Tools in the context of use

It should be noted that the findings summarised below are *indicative of the observations in the case studies which corresponded to the design process of non-domestic buildings developed by large practices under the design and build procurement method*. The design team arrangements of the case studies presented three specific typologies[1]which were outlined in Chapter 3, Section 3.2.2. and illustrated in Table 3.3. Therefore, the findings are illustrative of how the design processeswere enacted in the case studies and thedesigners' responses to the challenges that emerged throughout the process. The findings do not attempt to predict trends nor prescribe how the design process might be developed. The findings are bounded by the specific circumstances of the case studies. Nonetheless, the findings are relevant in revealing the use of tools, knowledge flows and knowledge dissemination in the real-time design of non-domestic routine buildings, particularly in the context of changing performance-based regulations.

7.3.1. Nature of the design process and policy model of enactment

The field findings are in agreement with prior literature that investigated the challenges to implement the low carbon agenda due to the disconnections between the market demand and the regulatory drivers, unclear targets and modelling methods, cultures in the industry and lack of stakeholders' engagement (Chapter 1, section 1.2.1). In relation to the practitioners' perceptions about the low carbon agenda, the findings of this investigation reiterate the barriers found by literature such as the unclear definition of the low carbon targets, the inappropriate working methods and the poor knowledge (Chapter 1, section 1.2.2.).

[1]The three types of architecture design team arrangements were discussed in detail in Chapter 3 and are summarised below:

1. Same architects working in conceptual and detailed design. During construction, these architects worked the design consultants for the contractor (cases 1 and 2)
2. One architecture team working in conceptual and detailed design up to construction. During construction, another architecture team became the design consultants for the contractor (cases 3A and 3B)
3. One architecture team working in conceptual design and another team working from detailed design. During construction the architecture team who worked in conceptual design became the design consultants for the contractor (cases 4A and 4B).

As a process investigation, the research has analysed the evolution of the design aspirations, the use of tools and creation of knowledge in relation to the development of the process. This research gas presented in detail the challenges that emerged during the design process and how the designers were overcoming the challenges through a variety of practices. This work has also studied the use of toolsin action and identified key instances in the design process where knowledge gaps were likely to emerge. The summarised findings are as follows:

Findings related to the nature of the design process:

- The design process is a battlefield where the controversies between the energy and other project requirements are settled.
- The design negotiations are necessary to reach the compromise between the energy and the project requirements, create knowledge and increase the performance understanding of the stakeholders.

Findings related to the policy model for enactment

- The official is an external structure which has to be incorporated in the process.
- The adoption of the low carbon policy agenda is affected by the project-specific circumstances, namely the social context.
- The social context is the pre-existing structure where the design process develops, affecting the expectations and understandings about low carbon building performance.

7.3.2. Knowledge

Previous research of knowledge management in the built environment has used social perspectives to investigate the creation and management of knowledge in the industry (Chapter 2, section 2.4). This investigation has built upon that research to explore in detail the process of knowledge dissemination in the design process, in the context of regulation compliance. This investigation has inferred the instances in the process where knowledge gaps emerged and the knowledge needed to make appraisals of energy performance in relation to other project requirements. In summary, it was found that knowledge was socially created and disseminated. The situated problem-solving and the changes overtime to the low carbon aspirations provided opportunities to create collective knowledge and to articulate a common understanding of the low carbon aspirations. However, the arrangements of the process and project-specific circumstances (team expertise, drivers, pre-existing goals and concerns) might be detrimental to the creation and dissemination of knowledge throughout the process.

Findings related to knowledge:

- Design knowledge is created while designing.
- Knowledge is socially created and disseminated by social networks of design.
- Designers' knowledge could be localised (specialised only in conceptual design, only in detailed design, only in delivery).
- There are instances prone to fragmentation where designers need to develop better knowledge about low carbon performance.
- The designers' knowledge about low carbon performance is informed by construction and operational phases.
- The knowledge management systems that focus on the capture of explicit knowledge tend to overlook the role of the social networks, experiential knowledge and the process itself in the dissemination of knowledge.

7.3.3. Tools in the context of use

A vast majority of building simulation research has assumed the immediate adoption of the simulation tools in the design process (Chapter 1, section 1.5.1). Some building simulation research, however, has acknowledged that the use of tools in the design process varied from the assumptions held by the tool developers (Chapter 1, section 1.5.2. *Procedural and user-centred debates*; and, section 1.5.3.*Simulation tools in the context of use*). This investigation presented in detailed the use of tools in the context of compliance informed by human-computer interaction and social theories. Dewey's broad notion of tool was adopted to investigate the trajectories of use of tools in relation to the nature of the process and the social context (compliance-only v performance-based design).

It was inferred from the case studies that the design process was assisted by informal structures emerging from the social context i.e. social networks, experiential knowledgeand the collective construction of knowledge between designers, design team members and stakeholders. The pre-existing social context (elaborated in Section 7.2.) seemed to affect the use of tools, their latent and perceived affordances. As a consequence, tools could be used in opportunistic and flexile ways to accommodate the ever-changing challenges and drivers of the process.

Findings related to tools:

- The designers gain understanding of performance by continuous and overlapping cycles of benchmarking and appraisal.
- The tools play a variety of roles and can present multiple trajectories of use in relation to the purpose of the analysis (compliance-only or performance-based design).
- The calculation of performance is one of the variegated roles of the tools.
- The simulation tools have to be incorporated in the process without interfering with the performance dialogue or interrupting the social construction of knowledge between the design team members.
- The simulation tools to estimate the performance are likely to be used in the transition between conceptual and detailed design (close to the policy gateways BREEAM and Part L).
- Designers experience difficulties in using the simulation tools in early design and advance stages of detailed design.
- The results of simulation tools could be regarded as theoretical due to their lack of connection between as-design, as-built and in-use performance.

The following table summarises the field findings in relation to the theoretical framework that informed the investigation (summarised in Chapter 2, Table 2.2.):

Themes investigated	Social theories postulates (theoretical framework)	Field findings inferred from the case studies
Nature of the design process	Design is a negotiation of worldviews. Designers learn by doing.	The design process is a battlefield where the controversies between the energy and other project requirements are settled. The design negotiations are necessary to reach the compromise between the energy and the project requirements, create knowledge and increase the performance understanding of the stakeholders.
Designers' enactment (adoption of policy model)	The official might contribute to low carbon buildings although as an external element, it could become a prescription. The informal (dirt) is part of the process. The social context (situatedness) of the design process might affect the enactment of the policy agenda.	The official is an external structure which has to be incorporated in the process. The adoption of the low carbon policy agenda is affected by the project-specific circumstances, namely the social context. The social context is the pre-existing structure where the design process develops, affecting the expectations and understandings about low carbon building performance.
Knowledge in design	Knowledge is socially created and distributed. Design knowledge could be constrained by knowledge management approaches that focus on the capture of explicit information.	Design knowledge is created while designing. Knowledge is socially created and disseminated by social networks of design. Designers' knowledge could be localised (specialised only in conceptual design, only in detailed design, only in delivery). There are instances prone to fragmentation where designers need to develop better knowledge about low carbon performance. The designers' knowledge about low carbon performance is informed by construction and operational phases. The knowledge management systems that focus on the capture of explicit knowledge tend to overlook the role of the social networks, experiential knowledge and the process itself in the dissemination of knowledge.
Tools in the context of use	The design process could be assisted by informal structures emerging from the social context. The tools for low carbon design could present the 'human-tool' juncture therefore it is necessary to understand tools in their social context.	The designers gain understanding of performance by continuous and overlapping cycles of benchmarking and appraisal. The tools play a variety of roles and can present multiple trajectories of use in relation to the purpose of the analysis (compliance-only or performance-based design). The calculation of performance is one of the variegated roles of the tools. The simulation tools have to be incorporated in the process without interfering with the performance dialogue nor interrupting the social construction of knowledge between the design team members. The simulation tools to estimate the performance are likely to be used in the transition between conceptual and detailed design (close to the policy gateways BREEAM and Part L). Designers experience difficulties in using the simulation tools in early design and advance stages of detailed design. The results of simulation tools could be regarded as theoretical due to their lack of connection between as-design, as-built and in-use performance.

Table 7.4. Summary of the field findings in relation to the theoretical framework

7.4. Implications of the work

This work has explored in detail how the low carbon targets were delivered on the ground by designers working in four large architecture practices. The case studies were six non-domestic buildings located in England and Wales. The processes analysed reflected the enactment of designers during routine project design. Although the sampling is limited in number and specific in terms of arrangements and circumstances; the findings of this work are relevant in highlighting the challenges experienced by designers and the real-time design responses to implement the low carbon policy agenda and in illustrating the complexities of moving towards performance-based regulations. The insights gained from this investigation pose a number of implications in three broad areas: policy, practice and research.

In terms of policy, the field data suggest that low carbon aspirations are the result of the alignment of variegated visions of the stakeholders. This highlights the need to address the conflictive goals that arise throughout the process in order to realise low carbon design. This work calls upon the need to consider carefully how to encourage the adoption of low carbon design. The mere provision of compliance tools and low carbon information are unlikely to ensure the achievement of the policy intentions because of the complexities and barriers that arise in the process. As there is no explicit driver for low carbon performance, the pressures of time and cost reduction might compromise the achievement of low carbon aspirations. Another aspect that may require attention is the compliance model itself. The research participants perceived that the compliance model was mainly based on the prediction of as-designed performance despite as-built performance informed the final performance estimation (Part L, post-construction evidence). Nevertheless, this approach embeds uncertainty in relation to the quality of the performance estimation by simulation models; for example, the use of acceptable as-designed assumptions; construction quality that might affect the as-built performance; and, occupation factors that might have a bearing on the in-use performance. The challenge for the policy level is to address the quality of the mechanisms to verify compliance and possibly considering additional instruments to assess the as-built and in-use performance as part of the compliance model.

In relation to practice, this research highlights the complex ways that knowledge and tools are interwoven in design practice. Firstly, the data warns the need to consider carefully how designers interact with physical artefacts and tools during design activities. This work has revealed that the social aspects and the informal were the structures that enabled the penetration of new technologies and the (re)configuration of the affordances of technologies. Therefore, the technologies aimed to foster performance-based design and to increase design knowledge have to be informed, managed and incorporated in the light of what actually occurs in the broad context of design. The broad context of design assembles a variety of concerns, drivers and attitudes held by the designers themselves and the influence of the wider stakeholders (clients, users, delivery team members, etc.) in the building design and in the design process. The failure to consider the broad design context, the natural patterns and informal structures that enable the design development might lead to creation of burden and interference in the process. The developers of design tools, whether focused on knowledge or performance assessment, would benefit from adopting user-centred approaches that build upon routine practices and are informed by the view of the design process as a social process of negotiation. This perspective recognises that there are pre-existing concerns that are likely to tailor the tools used by designers and their affordances in action (during problem-solving activities) and interaction (the use of the tool by the specialist in relation to the non-specialist and in the wider design/building life cycle context). In addition, this work has brought attention to the variation and flexibility of designers' approaches to develop their work. In situations where the span of relevance is significantly different between design team members and wider stakeholders; education, negotiation and articulation of common aspirations and understandings may be necessary to ensure the coherent articulation and continuity of the process. As to design knowledge needs, the work has revealed instances of the process where designers appear to reflect and anticipate how their assumptions and proposals materialise in later stages. The lack of reflection and continuity of the process on those instances may lead to knowledge gaps and fragmentation in the process. It should be noted, however, that the instances prone to fragmentation cannot be directly map onto a discrete design tasks, deliverables or specific points of the design development timeline. The instances are relevant in illustrating the design problem-solving and the reflection-in-action enacted by designers.

The identification of the instances prone to fragmentation might potentially unfold in two directions. Firstly, the instances are indicative of designers' support needs and call upon further research to build up the links between building life cycle phases (design, construction and operation) and to device mechanisms to encourage the designers' reflection throughout the process. Secondly, the instances appear to suggest leverage points for intervention by policy mechanisms, knowledge fostering, learning initiatives and tools for design support.

Concerning the theory implications, by adopting the view of design as a social/negotiation process, this work has been able to identify practices associated to knowledge creation and dissemination while designing and the affordances of tools for low carbon design. The socially-informed approach adopted in the study has revealed the interface of knowledge and tools during design problem-solving activities. The findings of the work suggest that tools and knowledge are entangled in multifaceted ways, complementing each other during problem-solving activities. The field findings also bring attention to the role of social processes in problem-solving activities and building design development. Further discussion of the findings in the light of the prevailing literature is presented in the next section.

7.5. Reflection about the relation between the field findings and the prevailing literature

The description of the design development overtime, the performance appraisal cycle, the low carbon design knowledge and the designers' enactment of policy intentions have shown the relevance of socially-led research to analyse designers in action and the interface between policy and design practice in action. This section will conclude this chapter by discussing the relation between the findings and the prevailing literature.

The work suggests that the notion of designers as rational problem-solving agents whose main goal is optimisation is over simplistic when applied to real-time routine design and to the study of routine design process. The data provided evidence that the interpretation of the design process as a mere reasoning/rational linear problem-solving exercise was likely to be misleading to represent the design in action. This work has shown that the problem-solving is in essence non-linear, opportunistic and unpredictable. These complexities pose limitations to the rational descriptions and assumptions that reduce the design process to a linear continuum of discrete tasks. In such sense, this study expands prior design studies that have questioned the linearity of the design process and the applicability of rational descriptions of design problem-solving. Unlike prior design research, this study was conducted within routine design practice and compared the design in action enacted in six non-domestic buildings developed by designers in large architecture firms.

It should be noted, however, that this investigation did not intend to negate or be confrontational to the rational views of the process. The use of a socially-led approach to investigate low carbon design provided an alternative view to analyse designers' activities, the development of the process and how the process unfolded in relation to the social context. By showing the complex interrelations between design process, social context and design development, the work has reinforced the notion of ***design as a social process of negotiation***. Therefore, it could be argued that models of the process are relevant mainly as simplified abstractions to represent the design development overtime or to schedule deliverables of the process but not as determinants of action.

The interpretation of design as a social process of negotiation built upon three key literature propositions: reflection in action (Schon 1983), worldview negotiation (Bucciarelli 1994) and span of relevance (Berger and Luckman 1967). The case studies observations illustrated that Schon's model of reflection in action and Bucciarelli's worldview negotiation were suitable models for the study and analysis of real-time routine design process. The field data showed that designers created and disseminated knowledge by examining the design problem in detail, anticipating consequences of design strategies, questioning their understandings and invoking further knowledge from experienced peers. The problem-solving tasks, knowledge creation and dissemination processes involved negotiations between design team members and wider stakeholders. The construction of design knowledge was closely intertwined to the negotiation of the low carbon aspirations for a common understanding that enabled the continuity and coherent enactment of the process.

Specifically referring to reflection in action, the episodes described and the instances prone to fragmentation suggest moments where designers engaged in conversations with the design problem to scrutinise its different dimensions. In a way, design problem-solving was advanced by establishing links and articulating the solution, goal and outcome altogether.As to Bucciarelli's interpretation of design as a worldview negotiation, the field data reinforce the proposition that design is a dynamic process where common understandings and collective knowledge are negotiated and constructed throughout the process. Collaboration, common goals and coherence in the process cannot be assumed. As the process unfolds, the agreements and compromises lead to collective visions and knowledge. Design can be considered as a battlefield where compromises and changes are bound to be negotiated.

Previous work tended to focus on specific disciplines that work on creative project environments; for example, analysing the design problem-solving by architects or engineers in their own settings. In such sense, this work expands prior design studies that followed a socially-informed approach by looking at architects' work in relation to the design team and the wider building life cycle phases. In other works, this design study albeit focused on architects, has considered the wider context of design practice by including other design team members as research participants, by inferring the input of the whole building life cycle on conceptual and detailed design and by linking social context and design process.

In terms of tools and knowledge in design, the field findings show how the dominant understandings and expectations could affect the coherent development of the process; use of tools; and, knowledge creation and dissemination within design practice. This work has used real-time observations of designers in action to investigate the influence of the social context in the design process, with a focus on tools and knowledge. It should be remarked that the data did not attempt to link the use of tools, knowledge flows or pre-existing knowledge to the final outcome of the process. However, the theoretical framework informed by social perspectives, human-computer interaction, philosophy of technology, communities of practice and socially-led knowledge management views enabled an alternative analysis of tools and knowledge in design.

Dewey’s definition of tool that considersthe broad notion of means to end (calculation and mediation, physical and conceptual tools, official and informal tools) provided a powerful theoretical lens for understanding the latent, potential and perceived affordances of tools; their use in action and in interaction; and, how tools related to the process of knowledge creation/dissemination and target negotiation throughout the design process. Dewey’s definition of tool enabled to address the materiality of tools, their significance in the process, their affordances and their relation with design knowledge. By using that approach the study has brought attention to the ways that social process were intertwined with tools and knowledge in the context of performance-based design.

Human-computer interaction and philosophy of technology postulates were appropriate to understand of the use of tools by designers in action and brought attention to unarticulated practices and situated activities that appeared to tailor the tools and their affordances. The propositions of the human computer interaction and philosophy of technology allowed the analysis of tools in relation to design practice. The work, though limited in scope and sampling, provided evidence that contests the interpretation of simulation software as ‘the performance tool’ and that questions the position of simulation as design aid within the process. This is in agreement withliterature arguing that tools tend to be used for strategic design decision to confirm the intuition and prior knowledge of designers.

Communities of practice theory also provided interesting principles to analyse the process of knowledge creation and dissemination while designing. This was evident in the observations regarding social networks, informal advice, learning while doing and the performance investigations developed at project level. It should be remarked that information and knowledge appeared to be complementary aspects whose boundaries were not clearly defined. Equally, experiential knowledge, tacit knowledge and use of tools for low carbon design were entangled in complex ways in the light of problem-solving. While the starting point of the investigation was the identification of three clear themes: nature of the design process, tools and knowledge in design; the field data showed that those themes had to be analysed altogether and in relation to each other. By adopting a comprehensive process model about the interface of tools and knowledge in relation to social context and design process development, this work extended the work that has addressed social practices and knowledge management. Moreover, it has built links between the fields of simulation and knowledge in design. As a result, the field findings have challenged the info-centred and tool-centric perspectives that argue that designers embed performance only on the basis of access to low carbon information and calculation tools.

Finally, the case studies observations have confirmed the applicability of the concepts of official and informal when analysing the designers' responses and enactment of the policy intentions. As advocated by the literature, whilst the official appeared to be instrumental to the achievement of low carbon aspirations; it seemed to be regarded as an external element and a potential prescription in the process. The social aspects (drivers, attitudes, understandings about low carbon performance), informal practices and informal tools surrounded and tailored the use of the official instruments and contributed to the incorporation of the official in the process. This suggests that the social context and the informal are likely to assist the use of the official.

Chapter 8

Conclusions

8.1. Introduction

This research investigated the design process adopted in six low carbon non-domestic buildings developed by four architecture firms during the 2010 energy regulation transition in England and Wales. It has documented and analysed what the designers were doing to embed energy performance in the context of convoluted policy and regulation changes. The period where the research was conducted (2009-2013) experienced rapid changes: the consultation of 2010 energy regulations in 2009, implementation of 2010 energy regulation changes from October 2010, change in BREEAM version in July 2011, devolution of Welsh regulations in 2012, separate Welsh and English consultations of 2013 energy regulations in 2012, to cite few. The work was focused on the architect’s work during conceptual and detailed design for buildings procured by design and build route; with emphasis on official, informal tools and routines to embed low carbon performance. This concluding chapter discusses the achievement of the research objectives, summarises the original contribution of this work, identifies the limitations of the research and outlines further areas of investigation.

8.2. Achievement of the research objectives

The research objectives were outlined in the introduction and stated in Chapters 1 and 2:

To identify the barriers experienced by designers working in low carbon non-domestic building

Chapters 4 and 5 addressed this objective by describing the design process in-action and identifying the difficulties experienced by designers. These chapters showed that the enactment of low carbon aspirations is not simply about defining the targets and providing calculation tools to verify the compliance. It is about implementing progressive changes that transform the design process to a performance-driven process. It has been observed that the policy gateways, BREEAM for conceptual design and Part L for detailed design were pushing the understanding performance and the inscription of low carbon aspirations earlier in the process. However, the compliance model fails to assess the energy performance during construction and operation.

The compliance is based on the as-design performance prediction. While Part L requires the results of post-construction tests (airtightness, systems commissioning) and the provision of users' operational manual to assist the users, the policy model does not directly address as-built and in-use performance. The compliance relies on paper-based evidence. Such approach seems to discourage the designers to undertake the performance investigations that link the performance achieved in different phases of the building lifecycle. As a consequence, the designers are unlikely to verify the validity of the design assumptions, the quality of the performance estimations undertaken during design. The carbon emission reductions are unlikely to be achieved by imposing compliance models that rely on the use of theoretical targets based on simulation predictions that overlook the as-built and in-use performance. The enforcement of stringent targets without an effective control could lead to opportunistic behaviours that focus on producing a compliance report instead of designing and delivering a better quality design. This aspect could jeorpardise the achievement of the expected reductions.

To identify the models and routines that facilitate the understanding and the inclusion of low carbon performance in buildings during conceptual and detailed design

The social context is the pre-existing structure where the low carbon design process develops. The low carbon design process could be enacted in the spectrum from compliance-only (meeting the minimum statutory requirements) to performance-driven process (exceeding the regulatory requirements) in relation to the pre-existing social context (attitudes, expectations, motivations and power relations between the designers and stakeholders). The design negotiations are necessary to define the low carbon aspirations, create their ownership and ensure the continuity throughout the design process. New knowledge is created as a result of the negotiations to define the low carbon aspirations. The tools are part of the negotiation process, becoming enablers or hindrances of the performance dialogue in relation to the pre-existing social context. In other words, the low carbon design process entails the collective construction of knowledge and deployment of a variety of tools to mediate the performance dialogue between the designers and the stakeholders.

The evolution of the low carbon aspirations and the adoption and abandonment of design strategies over time show the intermittent relevance of low carbon targets and the perception that cost and energy are mutually exclusive requirements.

While it is acknowledged that the design process is not linear, the low carbon problem-solving process enacted by designers can be characterised by cycles of benchmarking and assessment; outlining, understanding and calculating during conceptual design and transposing, following and learning during detailed design.

Chapters 4, 5 and 6 revealed the different forms of design knowledge (explicit, tacit; qualitative, quantitative; knowledge about energy in relation to other building aspects; expertise in conceptual and detailed design; design knowledge about delivery) and the diversity of tools used by designers to embed performance (official and informal; mediating and calculating tools). The social context, the social construction of knowledge and the informal tools are aspects that have been overlooked by rational approaches that assume the immediate incorporation of the policy agenda by the designers. The setting of the target and the enactment of the process has revealed lessons about how low carbon design is achieved given the conflicts between policy and design dimensions (chapter 7).

To reveal the use of tools in routine project design

Chapters 4 and 5 documented the use of tools, in the broad Deweyian notion, during the design in-action. The discussion sections of these chapters outlined the use of tools in the social context of the conceptual and detailed design processes. These are the main findings concerning the tools for low carbon design:

- There are informal tools that designers are using to build upon previous experience, facilitate the dissemination of experiential knowledge and the social construction of the knowledge dispersed in the design team.
- The official tools have to be incorporated in the pre-existing structure. They have to be legitimised and validated by the design teams. Thus, problems could emerge when adopting the official tools if they interfere with the existing performance appraisal cycle that is enabled by conversations and experiential knowledge.

- The tools to embed performance could have a variety of roles in the design negotiations beyond the calculation of performance. They are mediators of the performance dialogue between the designers and the stakeholders; therefore, they could become enablers or barriers in the design process in relation to the pre-existing social context (span of relevance and motivations).
- The designers have created some in-house tools based on experiential knowledge and benchmark data. Mediating tools have also been created in order to enable the performance dialogue with the wider stakeholders who are not aware of the energy or low carbon performance aspects of buildings.

In chapter 6, the understanding performance cycle wss elaborated to describe the tools in the design process in the light of social theories about the human-tool junction and appropriation of tools.

To explore the social mechanisms that encourage the inclusion of low carbon considerations, their dissemination and learning across projects (social factors that enhance knowledge and learning)

In the documentation of the conceptual and detailed design process in chapters 4 and 5, the investigation has revealed that design knowledge is created *socially and informally* in the process during the design negotiations and the conversations to determine the low carbon aspirations. It was inferred that the social networks and the informal conversations had achieved a legitimised albeit tacit status as a tool to disseminate low carbon knowledge within the design teams and between designers.

In chapter 6, the knowledge section identified the instances prone to fragmentation where the design knowledge about low carbon performance is incomplete. The knowledge about low carbon design is not limited to energy performance metrics; it requires a good understanding of cost, buildability (construction) and the way the user interacts and adapts in the building (operation). It was inferred that the designers ought to develop performance knowledge in relation to construction and operational phases. The knowledge gaps could be overcome by performance investigations which are informal project-based analysis by designers to gain a better understanding of performance throughout the building life cycle. The performance investigations are not limited to the use of calculation tools; some examples include the auditing of the low carbon aspirations, the follow-up of the delivery of the details on site and the inclusion of the users in the definition of the design strategies. The lack of performance investigations during delivery and operation aggravate the design knowledge gaps and lead to an incomplete closure of the design learning loop. The performance investigations, if present, were undertaken *on project basis as discrete and isolated investigations* rather than as an overarching company policy because the formal knowledge management systems tend to focus on the capture of performance indicators at the end of the project overlooking the learning that occurs during the design process.

8.3. Final remarks

This investigation increases the understanding of the designers' adoption of official standards, tools and guidance during the real time design process. It reveals how designers use the standards and compliance instruments in relation to the design practices and routines to embed performance. The research suggests that the pathway towards low carbon design is not only about imposing higher targets by the policy agenda or disseminating the low carbon information and regulatory updates. The mere acquisition of technical information is not sufficient for low carbon design. The designers need to gain awareness of the requirements and the corresponding skills and experience for the performance appraisal. Designers may need to reconfigure the design process and their ways of thinking and addressing performance so as to be engaged in intended processes of learning and reflection about the design assumptions, estimation models and calculation scenarios in relation to as-design, as-built and operational performance. It was observed that designers gained better knowledge about performance by:

- defining the energy metric in the light of the project requirements;
- comparing and connecting the aspects that affect performance in the different building phases (design, construction and operation);
- disseminating the knowledge while designing;
- developing performance investigations throughout the design process.

There are a number of themes which were not explored in detail in the investigation due to the research scope, timeline constraints, the nature of the case studies and other research limitations. For example, the emerging differences between Wales and England due to the higher Welsh interim policy targets. The study analysed two case studies located in England. One of them was only studied during detailed design; therefore, no observations were possible in relation to the definition of the aspirations during conceptual design (Case 3B). The other case located in England (Case study 2) was developed by a Welsh-based office. The evidence is not conclusive to establish noticeable differences between England and Wales. Despite the Welsh low carbon policy agenda by 2009 intended to enforce higher interim targets than England, no significant differences occurred in the 2010 energy transition, the period that corresponded to the timeline of this investigation. The carbon reduction target for new non-domestic buildings by 2010 was 25 per cent in England and Wales. The main difference in 2010 between England and Wales policies on non-domestic buildings was the use of BREEAM as a Welsh planning instrument (not required in England). However, all the case studies were BREEAM certified so it was not possible to observe potential differences emerging as a result of the Welsh planning condition.

The investigation selected four large architecture firms on the basis of a sampling criteria related to communities of practice principles (Chapter 2). Such approach aimed to examine the differences between in the enactment of the process and knowledge management initiatives. The evidence obtained did not suggest significant differences between the knowledge management systems and policies in the architecture firms that participated in this study, possibly due to their pre-existing experience in sustainable design.

In relation to the RIBA Plan of Work, it should be clarified that the RIBA Plan of Work 2007 was used as a temporal reference to the project development timeline. It is not indicative of the design tasks but rather of the official deliverables. Possibly due to the scale of the projects, it was observed that the RIBA Plan of Work was used to schedule the project development timeline.

It was found that the linear models of the design process such as the RIBA Plan of Work, project gateways (Case study 1) and sustainability action plan (case study 2) may be resisted by designers because they seem to contradict the informal arrangements of the process. The negotiations and tensions are solved in opportunistic and flexible ways by designers. The preferences and patterns to embed energy performance during the process do not follow a linear sequence. The field data confirms that the RIBA Plan of Work is helpful to schedule the deliverables but it does not mirror the problem-solving for low carbon design (outlining, understanding, calculating, transposing, following and learning) nor the performance appraisal cycle. This confirms the findings of studies about the potential limitations of process models (Mackinder and Marvin 1982; Schon 1983). This investigation recognises that while RIBA Plan of Work does not prescribe the tasks that are developed in the process, it could be a useful model for a general description of the design process.

These findings do not aim to predict the design process, the problem-solving activities, behaviours or characteristics of the social context. They are relevant in highlighting the challenges posed by the low carbon policy agenda and in showing how the designers enact the design process. The field findings suggest that there is a complex articulation of informal routines and practices surrounding the adoption of the official tools and standards (knowledge exchange, tool use, configuration of the process, evolution of the target). The pre-existing social context and the project-specific circumstances determine how the design process develops over time; and, the adoption and abandonment of the low carbon strategies.

8.4. Limitations of the study and reflections of the method

The findings of this work have been inferred from case studies of non-domestic buildings in England and Wales developed by four large architecture practices with experience in sustainable design. The observations and field findings are indicative of the design process enacted in the case studies. The focus of the work was to understand the designers' responses and enactment of the low carbon policy agenda; therefore, ethnographic research methods were adopted to reveal real-time design process by architects, with focus on tools and knowledge invoked in the design process.

Additional studies could have investigated construction matters (contractors' perspective, detailed monitoring of the changes that occurred onsite and the discrepancies between design proposals and onsite development, comparison between as-design and as-built performance) and operational matters (users' practices in operation, comparison as-design and in-use performance). However, this research was focused on the design process from the architects' perspective with an awareness of the input of construction and operation in increasing the architects' knowledge of low carbon performance. The research did not intend to assess the pre-existing design knowledge, investigate the communication, power-relations or partnership dynamics in the design team nor explore the decision-making process. This study was conducted to investigate the adoption of the policy agenda by designers and divulge how the designers were coping with the regulatory requirements in a convoluted period of change (2010 Part L in England and Wales and the adoption of BREEAM 2008 as planning condition in Wales).

In terms of method, this investigation is bound by the limitations related to ethnographic research and the research circumstances for instance; access to the research setting, availability of participants and information, data confidentiality, asymmetry of data obtained from the case studies and localism of the data. The researcher, being an outsider for the practices, did not impose her research agenda to the participants. The author has been explicit in presenting the research circumstances, the nature of the data and the analytical process (Chapter 3 and Appendices). The reflexivity was encouraged in the data analysis and interpretation by using a theoretical framework based on social theories (Chapter 2). The similarities and differences in the case studies have been presented to the reader in detail and represented on figures and tables to reduce the complexity of the field data and illustrate the inferences. In order to improve the quality and rigor of the work, the evidence was collected by triangulating several methods: non-participant observation, shadowing of work, interviews and document analysis.

One of the main limitations of ethnographic research is the transferability of the field findings. The ethnographic outcomes are to be cautiously considered before transposing to different situations or to the wider context as the field findings are bounded by the specific milieu where the research was conducted. No claim for generalisation is made; the study is specific in scope, limited in scale and sampling. The reader should be cautious in transposing these findings to other situations; for example, different procurement methods, the design process of low carbon buildings where different legislative context applies, different nature and arrangements of the design team members, to small and medium size companies working in low carbon design. It should be emphasised that this research does not attempt to determine a trend in the process. The findings do not intend to prescribe or predict the design process nor the designers' enactment of policies. However, the detailed descriptions presented by this work reveal interesting insights about the complexities of the process, the designers' enactment of the policy intentions, the knowledge to design low carbon buildings and the understanding performance cycle.

It is emphasised that the findings are specific to the case studies and therefore, they should be treated with caution. However, by observing few low carbon design processes, in-depth information was obtained about the challenges experienced by designers in the adoption of policy and regulations. The findings are likely to have a global relevance in terms of knowledge creation and use of tool in the social context of design.

The strength of ethnography as a research method lies on its capability to disclose the multiple layers of complex problems, as experienced by the research participants in the milieu where the phenomenon unfolds. For problems that overlap policy and practice, ethnography is a powerful method for bottom-up studies that inform interventions. In addition, the use of a theoretical framework built upon key postulates of social theories, human-computer interaction, philosophy of technology, communities of practices and knowledge management approaches provided powerful theoretical lenses to examine the complexities of the design process and the interrelation between tools, knowledge and social context.

8.5. Further work

This research advances the knowledge and understanding of the design process and its complexities. It is a generative research that creates further directions of enquiry. Further areas of work are suggested:

- Exploration of how informal understandings, experiential knowledge , rules of thumbs and informal tools relate to the use of simulation tools and the appraisal of performance in design practice and throughout the whole building life cycle.
- Investigation and proposals of mechanisms to encourage practitioners' 'reflection in action' and 'learning while doing' to connect the knowledge created throughout the process by different agents that participate in design, construction and operation. This could potentially be undertaken as a review of the development and outcomes of the building processes.
- Studies to address the disconnections and gaps between as-design, as-built and in-use performance and explore how the knowledge created during the whole building life cycle could be disseminated throughout the process.
- Development of design tools and/or knowledge management approaches and initiatives that address the instances of the design process that are prone to

fragmentation and that consider the complex dynamics within the design process and in relation to other building life cycle phases.

- Exploration of the design decision-making rationale and/or the power-relations between stakeholders that influence the attitudes adopted to achieve building performance in the different phases of the building lifecycle (management and influence of attitudes and motivations).
- Investigation of the construction process by observational and qualitative studies focused on the work of contractors and subcontractors and the site practices that may affect the achievement of the as-design performance. This could be complemented by the identification of control mechanisms that could be implemented by building control authorities and regulatory bodies to improve the quality of the construction works and the proposal of safeguards to ensure the alignment of the design aspirations and the as-built performance.
- Investigation of the low carbon design and delivery processes with focus on the financial aspects to find the acceptable balance between the economic agenda and the low carbon policy intentions.
- Study on governance to inform the policy interventions that aim to produce change in the building industry and to inform the policy responses to the challenges emerging on the pathway towards low carbon built environment.

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Appendices

Appendix A. Codes for the analysis of field data

Abortive work
Arch-contractor perception (changes)
Architect's drivers (aspirations)
Artefacts for partnership
Artefacts-official
Balancing triangle cost-time-quality
BREEAM
BREEAM others non energy
Client's drivers
Construction practicalities
Contractor's drivers
Coordination
CoP-reflecting
Cycle of learning
Design progress and construction documentation
Early calculations
Linking D+B
Literature written references consulted
Low carbon strategy in the building
Making things explicit
ME input
Official CPD
Outlining target
Part L indicators
Part L perception
Part L update
Partnership arch+others
Policy makers vs practice disconnections
QS' drivers
Rules of thumb
Simulation
Simulation+arch
Unique artefacts
Use of previous experience-ethnography observation
Use of previous experience-reporting

Appendix B. Codes for the analysis of meetings material

Energy	Regulation compliance
	Renewable energy
	Passive design
	Others
BREEAM	Energy category
	Energy related
	Others
	Evidence
Other	Sustainability
	Time
	Cost
	Risk
	Buildability
	Planning
	Spacial needs
	Maintenance
	Others (client driven)
	Simulation
	Tools
	Routines

Appendix C. Codes for the analysis of the design process incidents

Design process incidents (codes)	
1	coordination details studio site
2	annotations on drawings
3	early calculations
4	other ways to transmit ideas- non energy
5	research with others
6	process gateways
7	simulation
8	arch-contractor perception
9	detail development
10	rules of thumb
11	BREEAM comparison
12	use of previous experience-ethnography
13	use of previous experience-intranet
14	target setting voluntary
15	target setting mandatory
16	outlining target
17	RIBA process
18	developing product-by dialogue
19	internal QA procedures
20	trade off capital-operational cost
21	other studies -performance non energy
22	simulation and archs
23	partnership arch and others
24	building management systems
25	literature written references consulted
26	architect as employee
27	balance between triangle forces
28	intranet dissemination of projects
29	construction documents
30	profile of the company
31	learning organisation
32	testing on site before handover
33	Part L indicators- EPC timeline
34	making explicit simulation assumptions and changes
35	factors affecting outcome
36	reflection about the process and future learning
37	BREAM non energy category credits related to energy
38	Regulations
39	Diary log/Tracking progress during construction

Appendix D. Document checklist per case study

Document checklist	Case study					
	1	2	3a	3b	4a	4b
Site picture	x	x	x	x	x	x
Location plan	x	x	x	x	x	x
Background	x	x	x	x	x	x
Site study	x	x	x	x	x	x
Spatial needs diagram	x	x	x		x	
Design strategies	x	x	x		x	
Model	x		x			
Floor plans	x	x	x	x	x	x
Sections	x	x	x	x	x	x
Elevations	x	x	x	x	x	x
Materials	x	x	x	x	x	x
3D/views	x	x	x		x	x
Photos	x	x	x	x	x	x
Energy strategy	x	x	x	x	x	x
BREEAM	x	x	x	x	x	x
EPC	x	x		x	x	
Part L	x	x	x	x	x	x
Schedule	x	x			x	x
Tools	x	x	x	x	x	x
Routines	x	x	x	x	x	x
Meetings	x	x	x	x	x	x
U-values	x	x	x	x	x	x
Details	x	x		x		x
Tender	x	x		x		x
LZC LCC	x	x	x			
Dissemination best case	x	x	x	x	x	x

Appendix E. Case study information

This section includes tables and figures extracted from chapter 3. They have been included in this section to introduce the summarised template of the case study information.

e.1. Architectural team arrangements in the case studies

RIBA	A	B	C	D	E	F	G	H	K
	Conceptual design				Detailed design				
Case 1									
Case 2									
Case 3A*									
Case 3B*									
Case 4A*									
Case 4B*									

**Cases 3A and 4A were not studied in detailed design. Cases 3B and 4B were not studied in conceptual design*

Design work undertaken from conceptual design by the conceptual architecture team
Design work undertaken by an architect team different from the conceptual design team
Stages that were not studied in the investigation*

(Table 3.3. in Chapter 3)

e.2. Design team composition and the architects' input in the process in each of the case studies

Cases	***Partnership Arch and design team members***	***Type of project***	***Location***	***BREEAM***	***Phases studied***
1	ME, acoustics and lighting consultant in-house	Educational	South Wales	Excellent	Conceptual and detailed design
2	No partnership with consultants	Educational	England	Excellent (outstanding)	Conceptual and detailed design
3A	Previous work with ME and sustainability consultants	Educational	South Wales	Outstanding	Conceptual design
3B	No partnership with consultants	Educational	England	Excellent	Detailed design
4A	Previous work with ME and sustainability consultants	Educational	South Wales	Excellent (outstanding)	Conceptual design
4B	Previous work with ME and sustainability consultants	Health care and housing	South Wales	Excellent	Detailed design

(Table 3.4. in Chapter 3)

e.3. Performance targets of the case studies

Case 1. Ebbw Vale, 9411m2 EPC 31, BREEAM Excellent

Case 2. London, 6000m2 EPC 40, BREEAM Excellent

Case 3A. Bridgend, 14500m2 EPC 7, BREEAM Outstanding

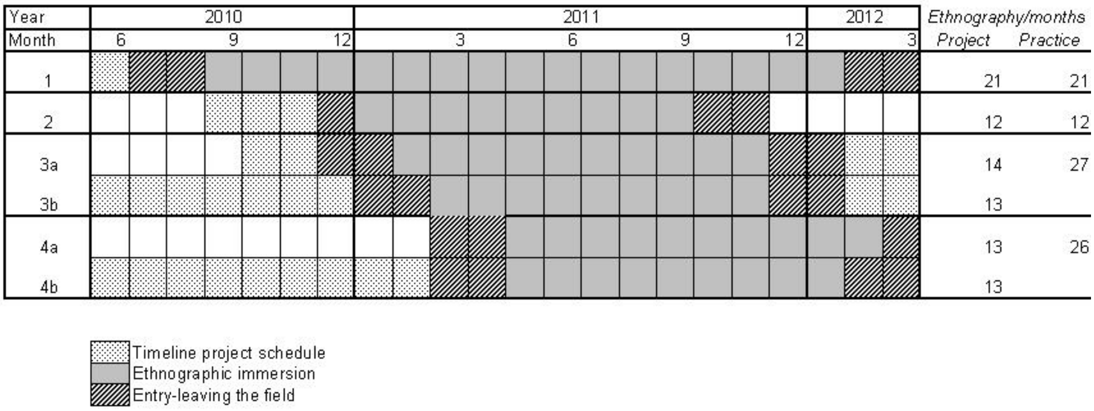
Case 3B. Somerset, 9440m2 EPC 40, BREEAM Very Good

Case 4A. Llanelli, 3500m2 EPC 17, BREEAM Outstanding

Case 4B. South Wales, 9570m2 EPC 28, BREEAM Excellent

(Figure 3.2. in Chapter 3)

e.4. Length of ethnographic study



(Figure 3.3. in Chapter 3)

e.5. Targets per case study

	1	2	3a	3b	4a	4b
Roof	0.15	0.18	0.18	0.15	0.15	0.10
Walls	0.15	0.26	0.26	0.18	0.16	0.16
Glazing	1.20	1.60	1.60	1.60	1.60	1.50
Floors		0.32	0.19	0.21		0.12
Airtightness	3	1	3	5	5	5
EPC	31	40	19	40	40	28
% LZC tech	10	20	30	15	15	10

e.6. BREEAM credits per case study

BREEAM credits	1	2	3a	3b	4a	4b
Management	90	17.00	19.00	18.00	12.00	9.00
Health and wellbeing	76.47	11.00	11.00	13.00	12.00	8.00
Energy	52	16.00	19.00	14.00	14.00	15.00
Transport	66.67	6.00	6.00	6.00	4.00	9.00
Water	87.5	6.00	6.00	7.00	5.00	5.00
Materials	60	11.00	5.00	4.00	7.00	6.00
Waste	85.71	6.00	5.00	3.00	4.00	3.00
Land use and ecology	91.67	11.00	11.00	7.00	3.00	5.00
Pollution	66.67	11.00	5.00	4.00	8.00	4.00
Innovation		3.00	2.00	4.00	4.00	2.00
Total	71.85	81.70	89.00	64.00	73.00	66.00
Rating	Excellent	Excellent	Outstanding	V Good	Excellent	V Good

Appendix F. Project summary information

F1. Case study 1

Analysis	Conceptual and detailed design
Location	South Wales
Building type	Educational
Area	9411 m2

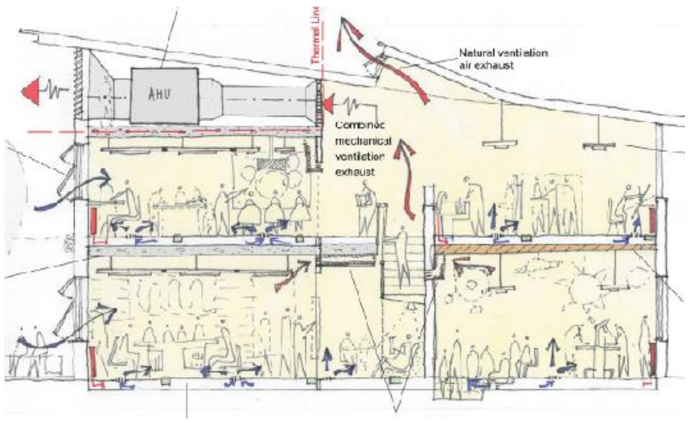
Low carbon aspirations

Energy targets	EPC 40 or better (EPC 31 predicted) , 60% reduction on Part L 2006
LZC technologies	Minimum 10% CO2 reduction
BREEAM target	Excellent
Airtightness	3 m3h/m2 @ 50Pa

Envelope elements	**U-values**
Roof	0.15 W/m2K
Walls	0.15 W/m2K
Glazing	1.2 W/m2K

BREEAM credits per category

Categories	**Credits**
Management	90.00
Health and wellbeing	76.47
Energy	52.00
Transport	66.67
Water	87.50
Materials	60.00
Waste	85.71
Land use and ecology	91.67
Pollution	66.67
Innovation	-
Total BREEAM Score	**71.85**



Design strategies

Use of mixed mode ventilation (adaptive thermal comfort principles), daylighting, thermal mass, back-up mechanical system in case of summer overheating (provisions for climate change)

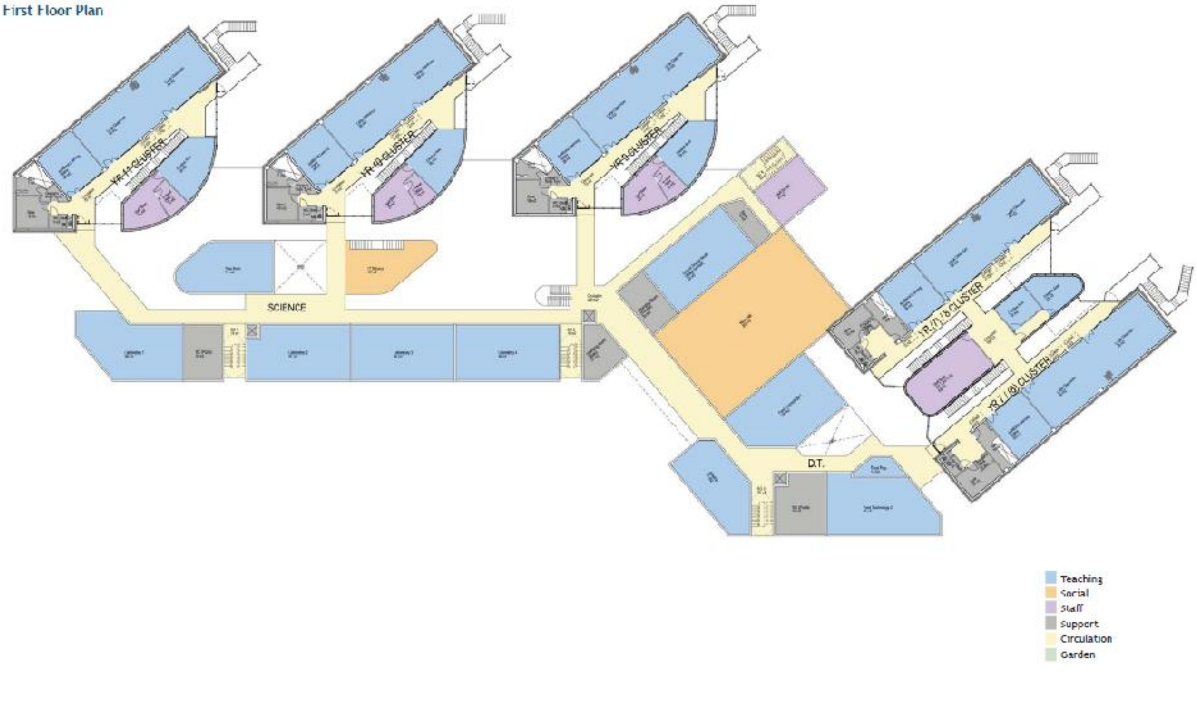
Targets requested by the client

Reduction of embodied energy in materials, materials locally sourced

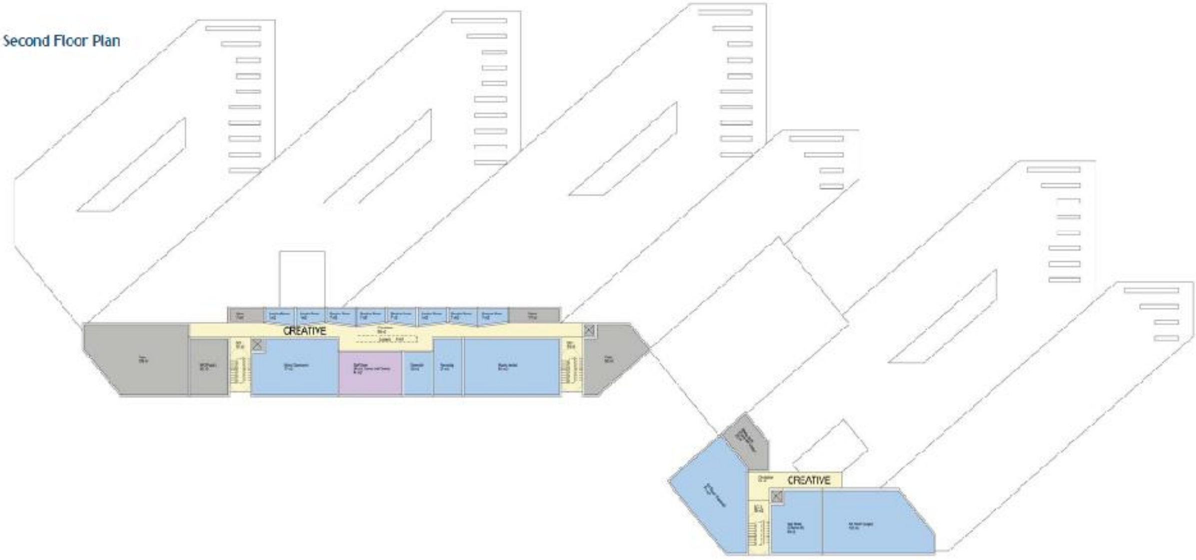
Plans

Ground Floor Plan

First Floor Plan



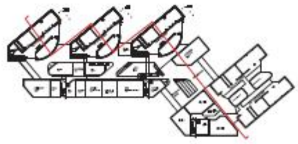
Second Floor Plan



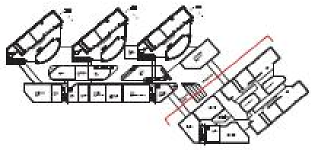
- Teaching
- Social
- Staff
- Support
- Circulation
- Garden

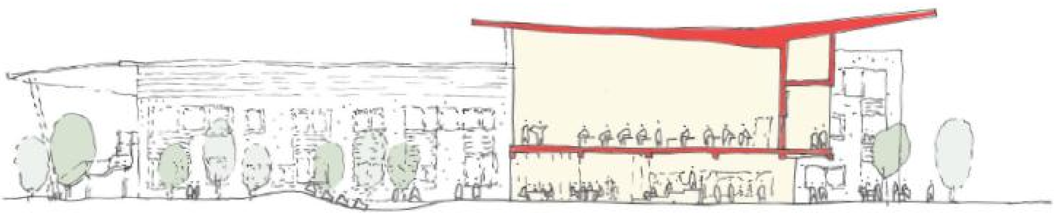
Elevation 1 (West, Main Street)

Section DD



Section CC



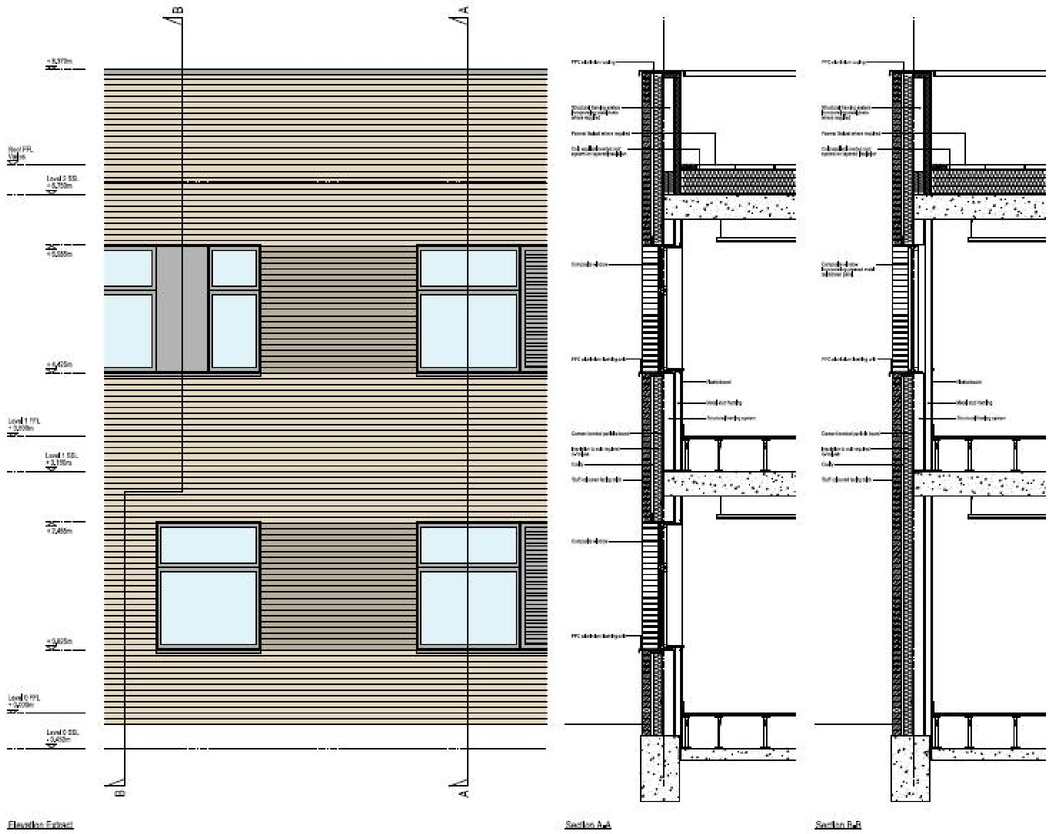


Aerial view from North

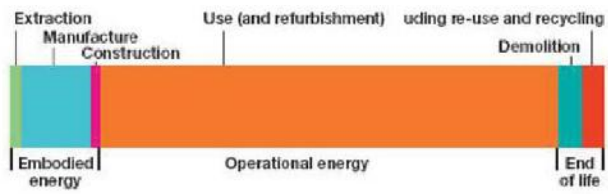
Aerial view from South

Aerial view from East

Education Square (southern approach)



Examples of tools



Cards for discussing visual characteristics of spaces and embodied CO2 tool

F2. Case study 2

Analysis	Conceptual and detailed design
Location	England
Building type	Educational
Area	6000 m2

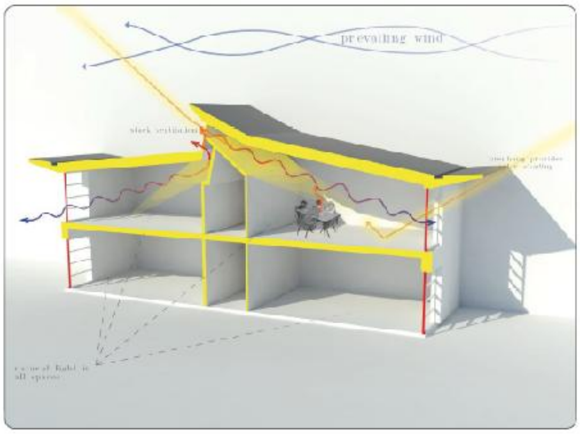
Low carbon aspirations

Energy targets	EPC 40 or better
LZC technologies	20% CO_2 reduction
BREEAM target	Excellent (initially Outstanding)
Airtightness	1 m3h/m2 @ 50Pa (maximum 5)

Envelope elements	**U-values**
Roof	0.18 W/m2K
Walls	0.26 W/m2K
Glazing	1.6 W/m2K
Roof	0.32W/m2K

BREEAM credits per category

Categories	**Credits**
Management	17.00
Health and wellbeing	11.00
Energy	16.00
Transport	6.00
Water	6.00
Materials	11.00
Waste	6.00
Land use and ecology	11.00
Pollution	11.00
Innovation	3.00
Total BREEAM Score	**81.70**



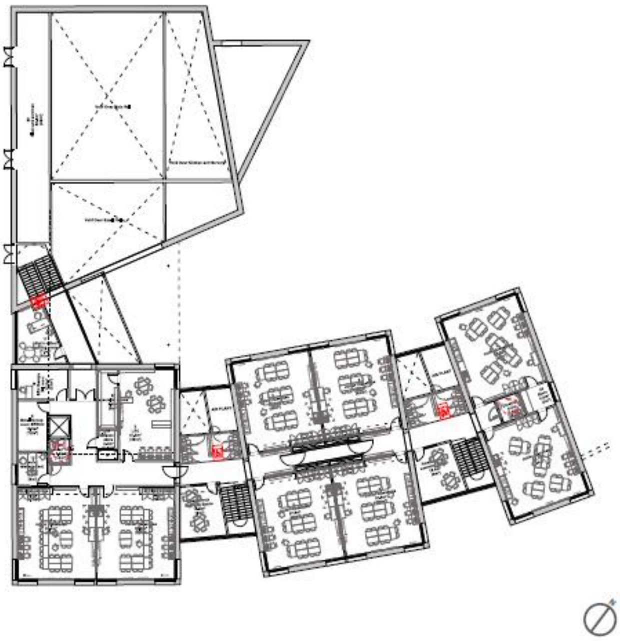
Typical Cross section through classrooms

Targets requested by the client

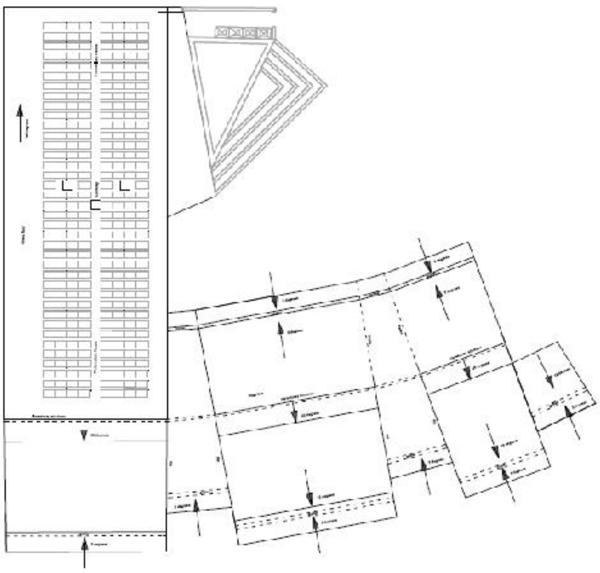
n/a

Plans

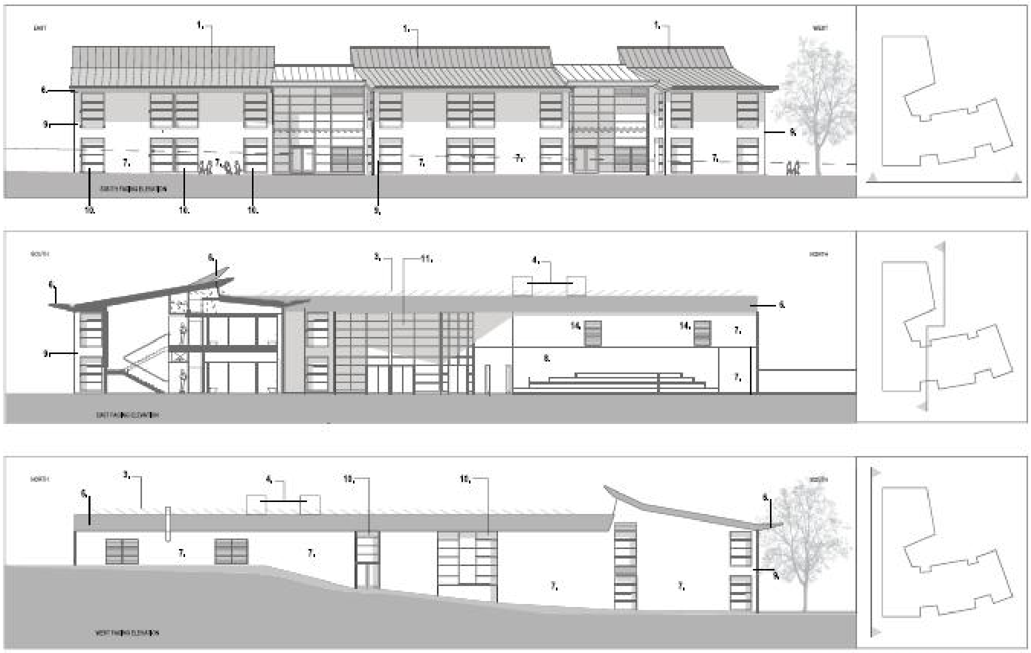
5.3 DESIGN PROPOSALS
GROUND FLOOR PLAN



DESIGN PROPOSALS
FIRST FLOOR PLAN 5.4



5.5 **DESIGN PROPOSALS**
ROOF PLAN

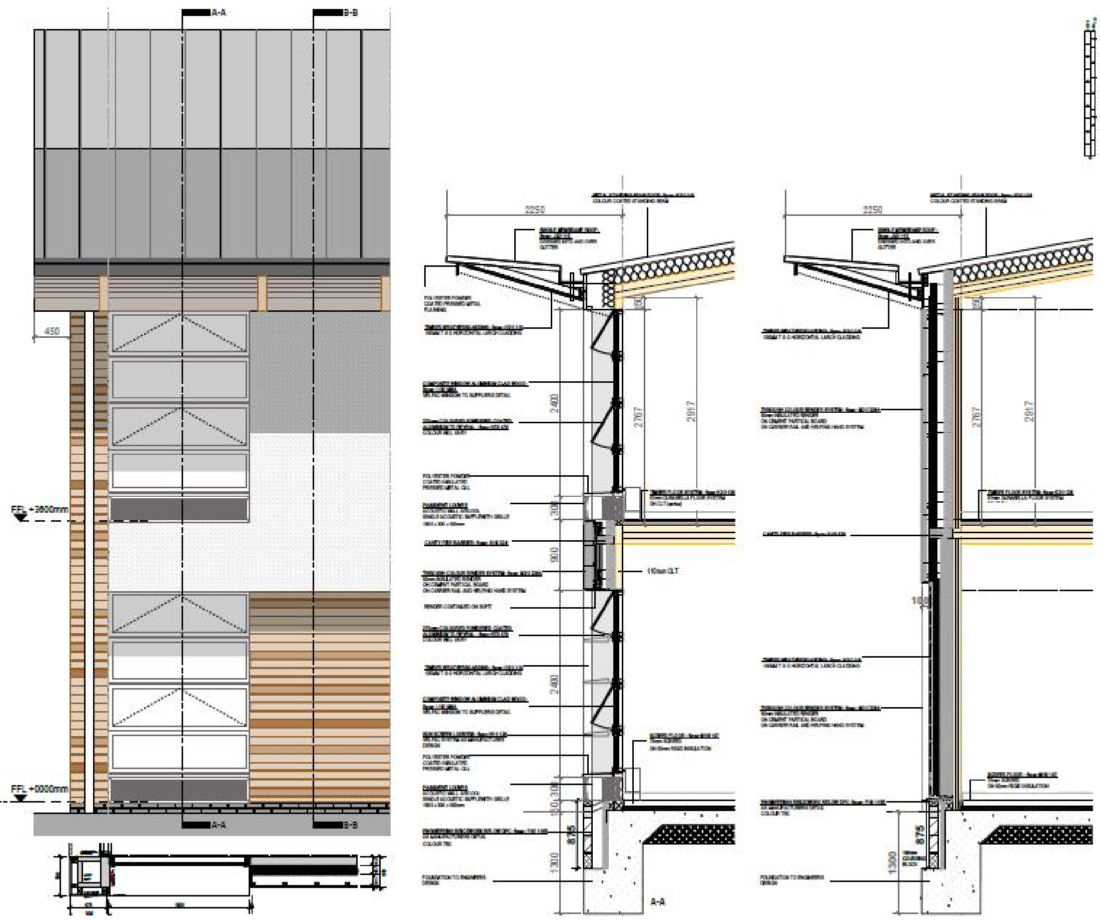


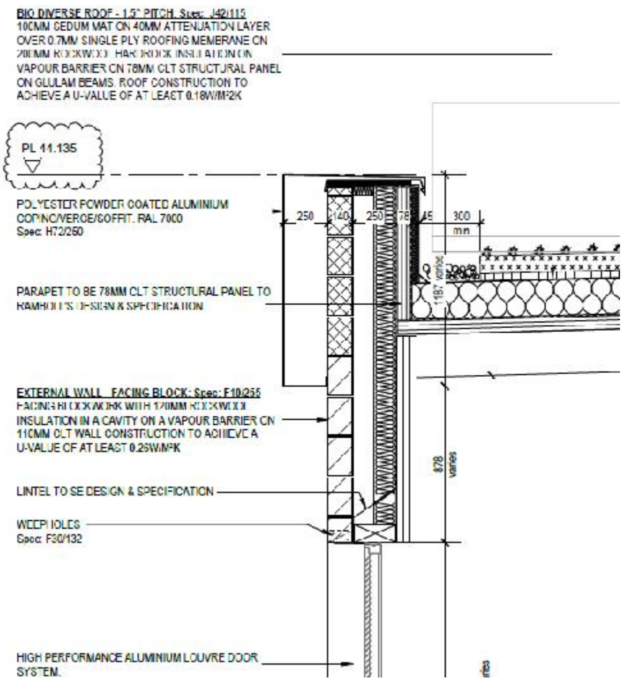
DESIGN PROPOSALS
SITE ELEVATIONS 5.12

5.7 **DESIGN PROPOSALS**
ELEVATIONAL TREATMENT

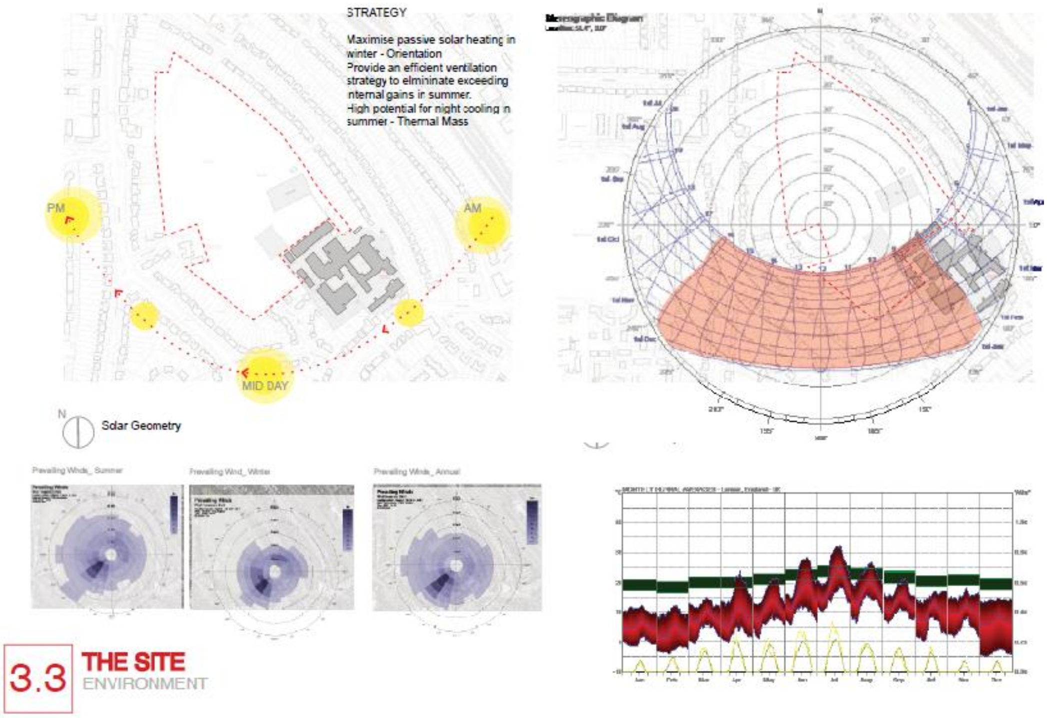
DESIGN PROPOSALS
ELEVATIONAL TREATMENT 5.7

5.13 DESIGN PROPOSALS
3D VISUALS

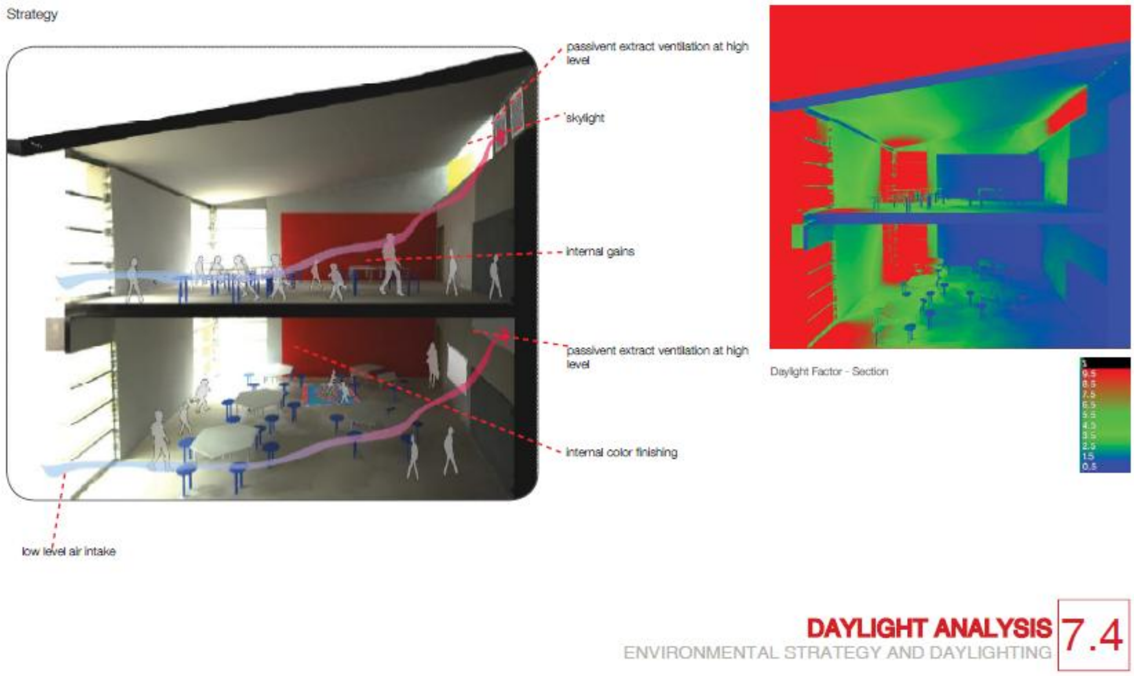




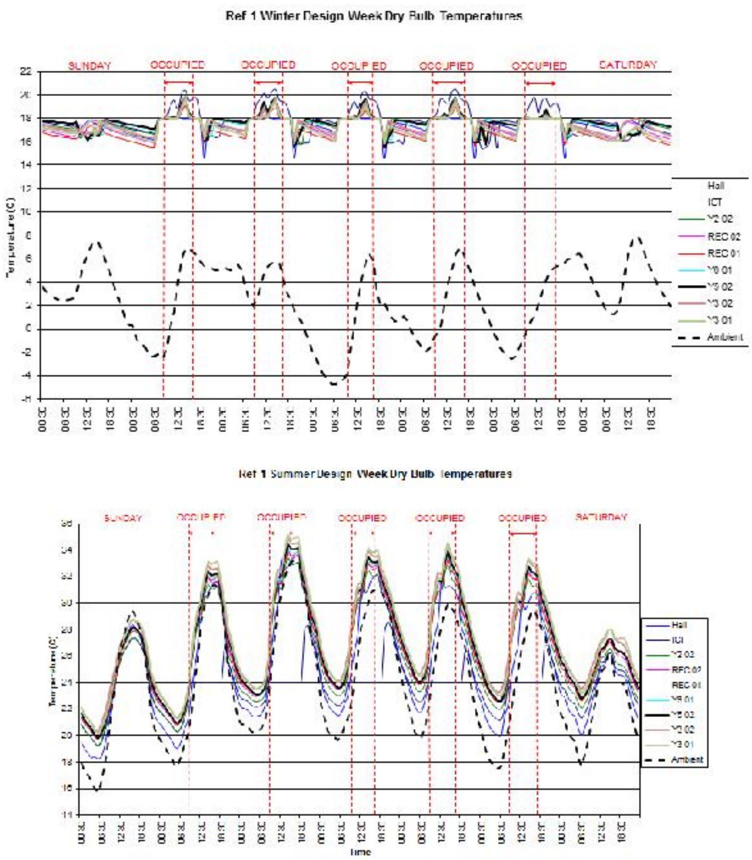
Examples of tools



Ecotect used for weather analysis and passive design strategy



Daylighting studies



Thermal comfort studies

F3. Case study 3A

Analysis	Conceptual design
Location	South Wales
Building type	Educational
Area	14500 m2

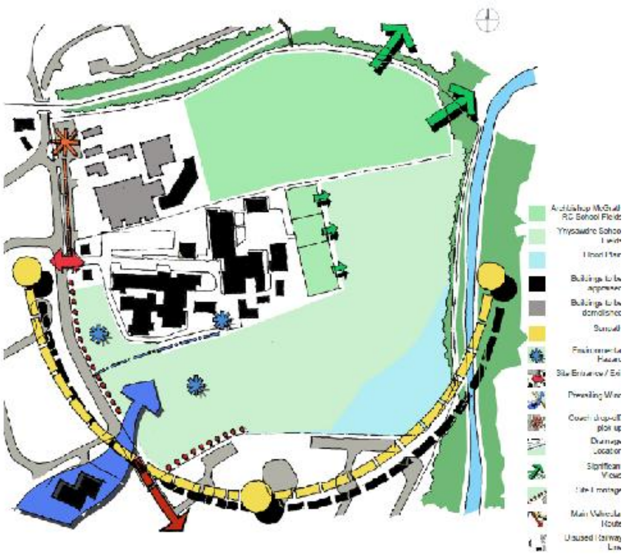
Low carbon aspirations

Energy targets	EPC 19 (aspiration 7)
LZC technologies	30% CO2 reduction
BREEAM target	Outstanding
Airtightness	1 m3h/m2 @ 50Pa (maximum 5)

Envelope elements	**U-values**
Roof	0.26 W/m2K
Walls	0.18 W/m2K
Glazing	1.2 W/m2K

BREEAM credits per category

Categories	**Credits**
Management	19.00
Health and wellbeing	11.00
Energy	19.00
Transport	6.00
Water	6.00
Materials	5.00
Waste	5.00
Land use and ecology	11.00
Pollution	5.00
Innovation	2.00
Total BREEAM Score	**89.00**



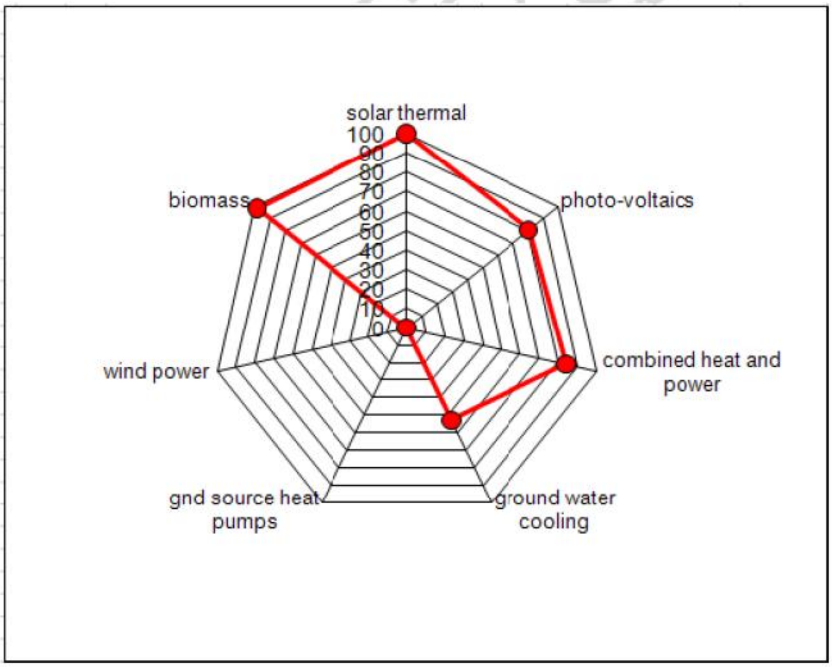
Plans

Site plan

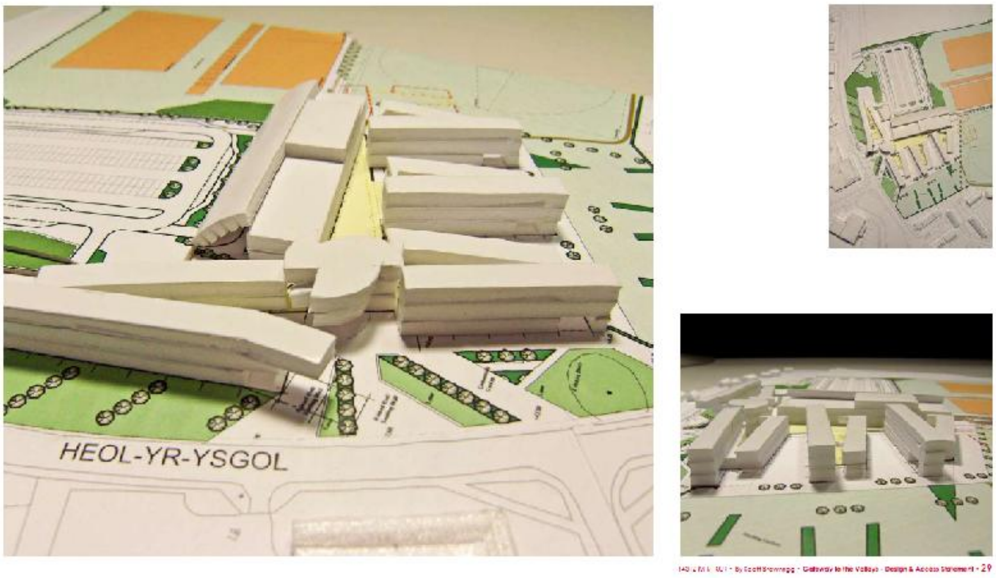
West Elevation

Elevations

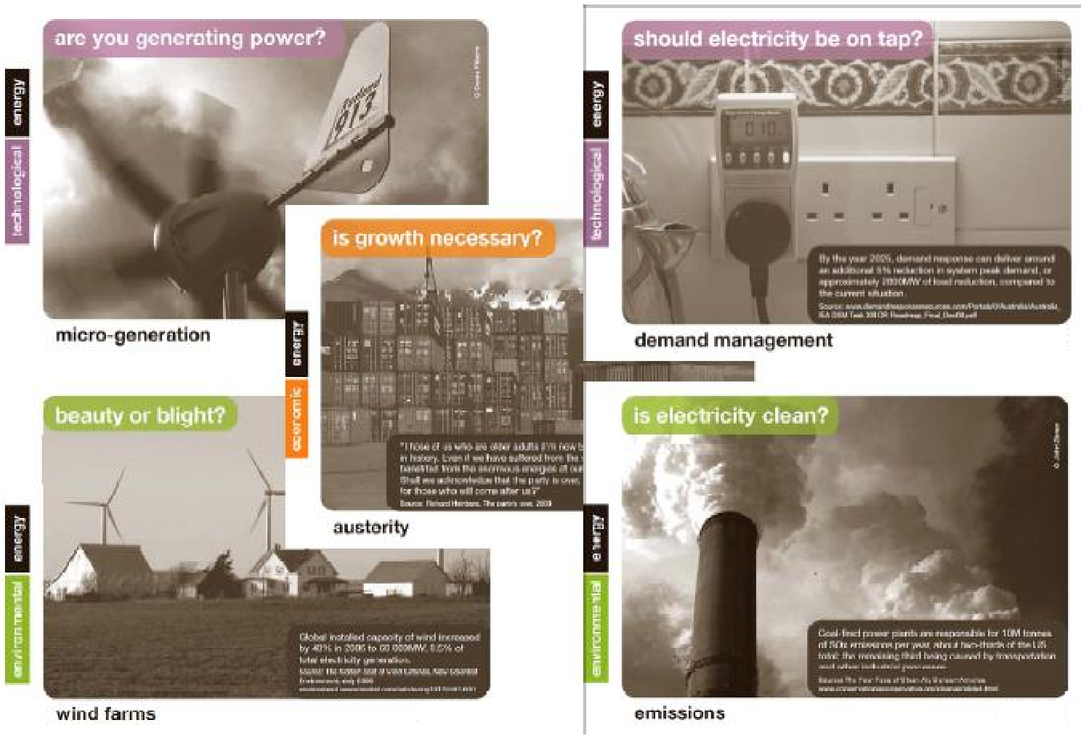
Examples of tools



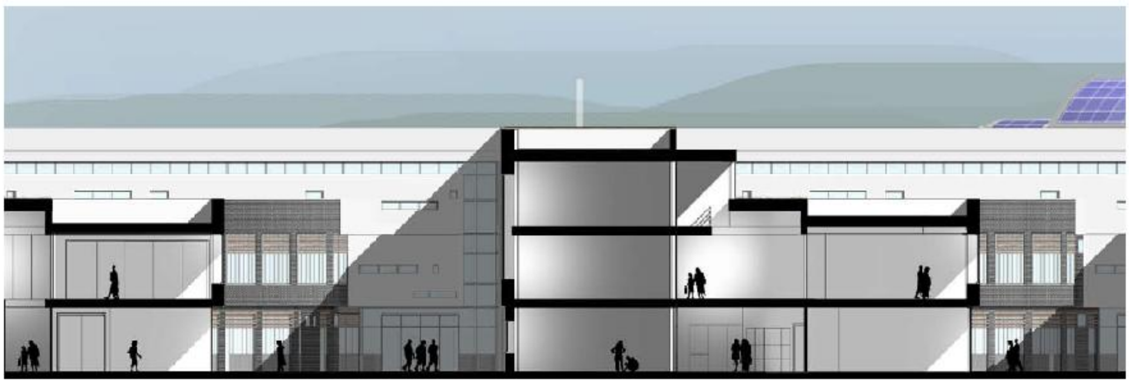
CIBSE TM38 tool comparison of low carbon technologies



Project models



Sustainability cards



Proposed Section DD

Project representation

Project representation

F4. Case study 3B

Analysis	Detailed design
Location	England
Building type	Educational
Area	9440 m2

Low carbon aspirations

Energy targets	EPC 40
LZC technologies	15% CO_2 reduction
BREEAM target	Very good
Airtightness	5 m3/m2 @ 50Pa

Envelope elements	**U-values**
Roof	0.18 W/m2K
Walls	0.26 W/m2K
Glazing	1.60 W/m2K
Floors	0.19 W/m2K

BREEAM credits per category

Categories	**Credits**
Management	18.00
Health and wellbeing	13.00
Energy	14.00
Transport	6.00
Water	7.00
Materials	4.00
Waste	3.00
Land use and ecology	7.00
Pollution	4.00
Innovation	4.00
Total BREEAM Score	**64.00**

Targets requested by the client

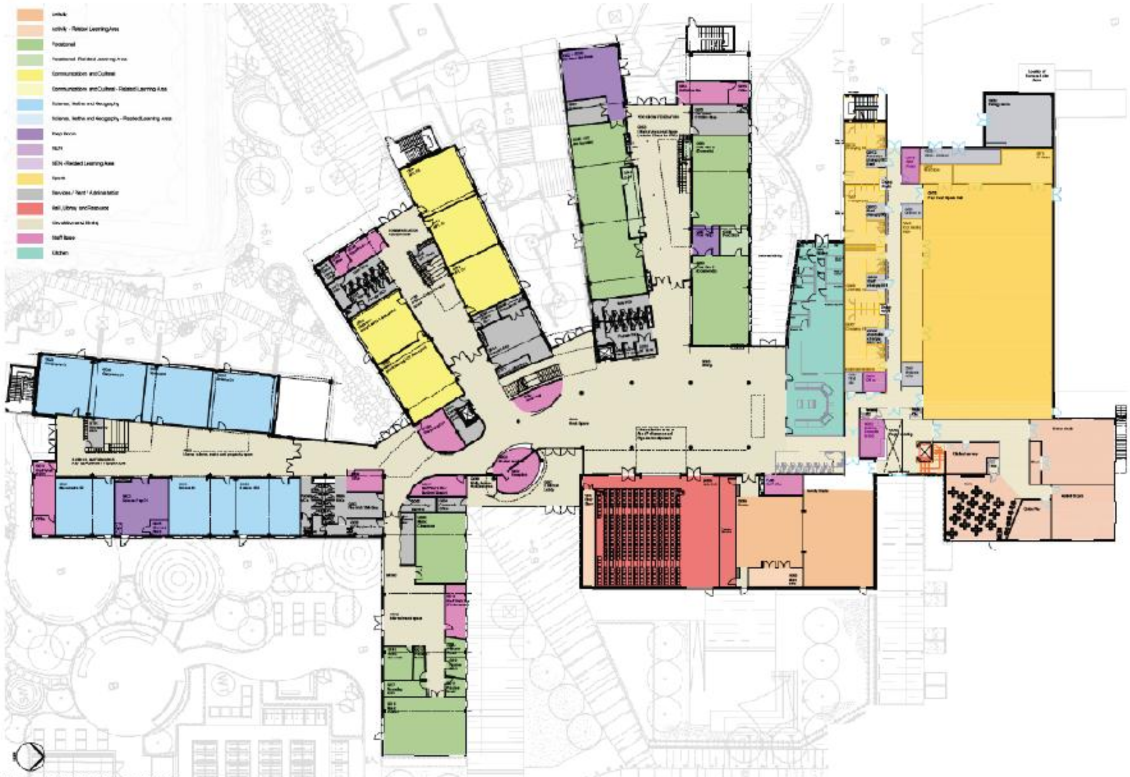
27Kg Co2/m2y

15% CO_2 emission reduction

Strategies

Use of well-insulated building fabric, use of daylighting, energy efficiency lighting and daylight-linked dimming and presence detector; natural ventilation (stack effect); thermal mass; solar control to reduce overheating.

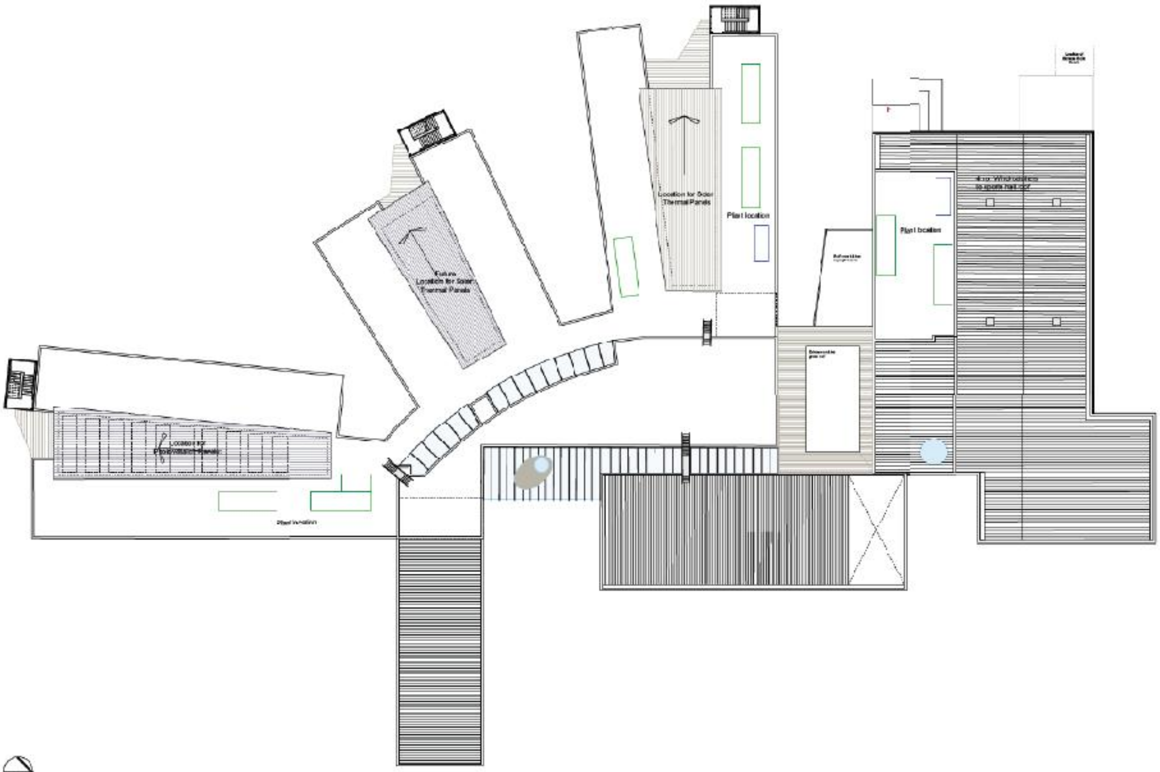
Plans



Proposed Ground Floor Plan

4053-MRT-001 • By Scott Brownrigg • Chilton Trinity Technology College - Design & Access S

Proposed First Floor Plan

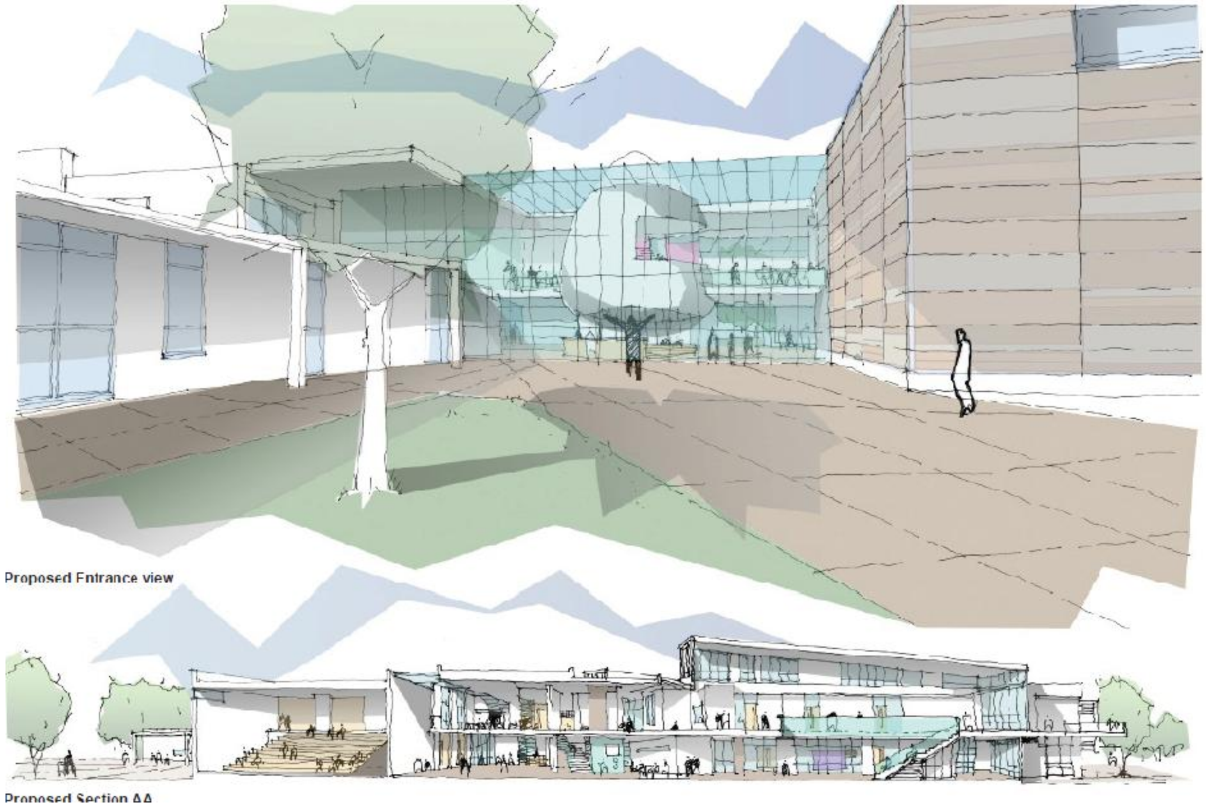


Proposed Roof Plan

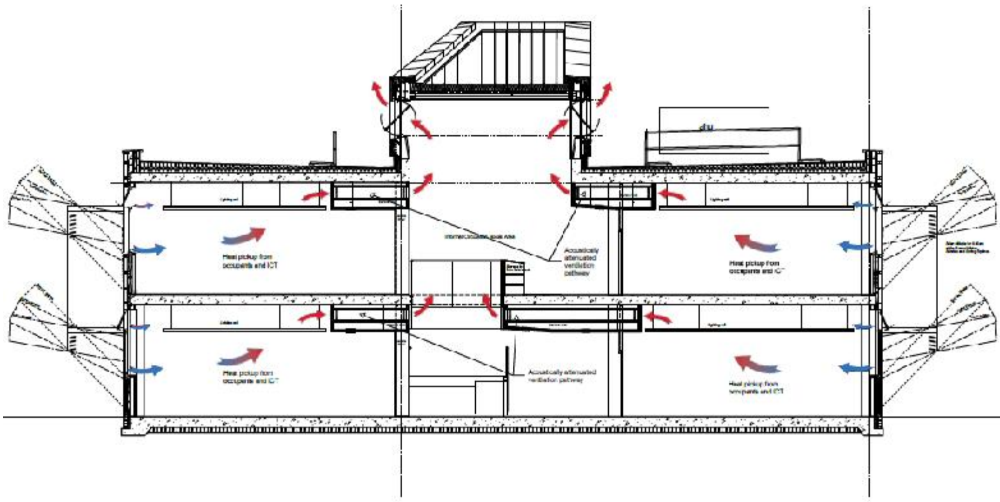
East Elevation

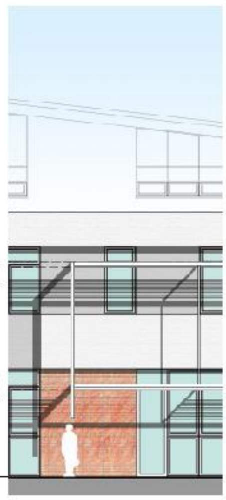
South Elevation

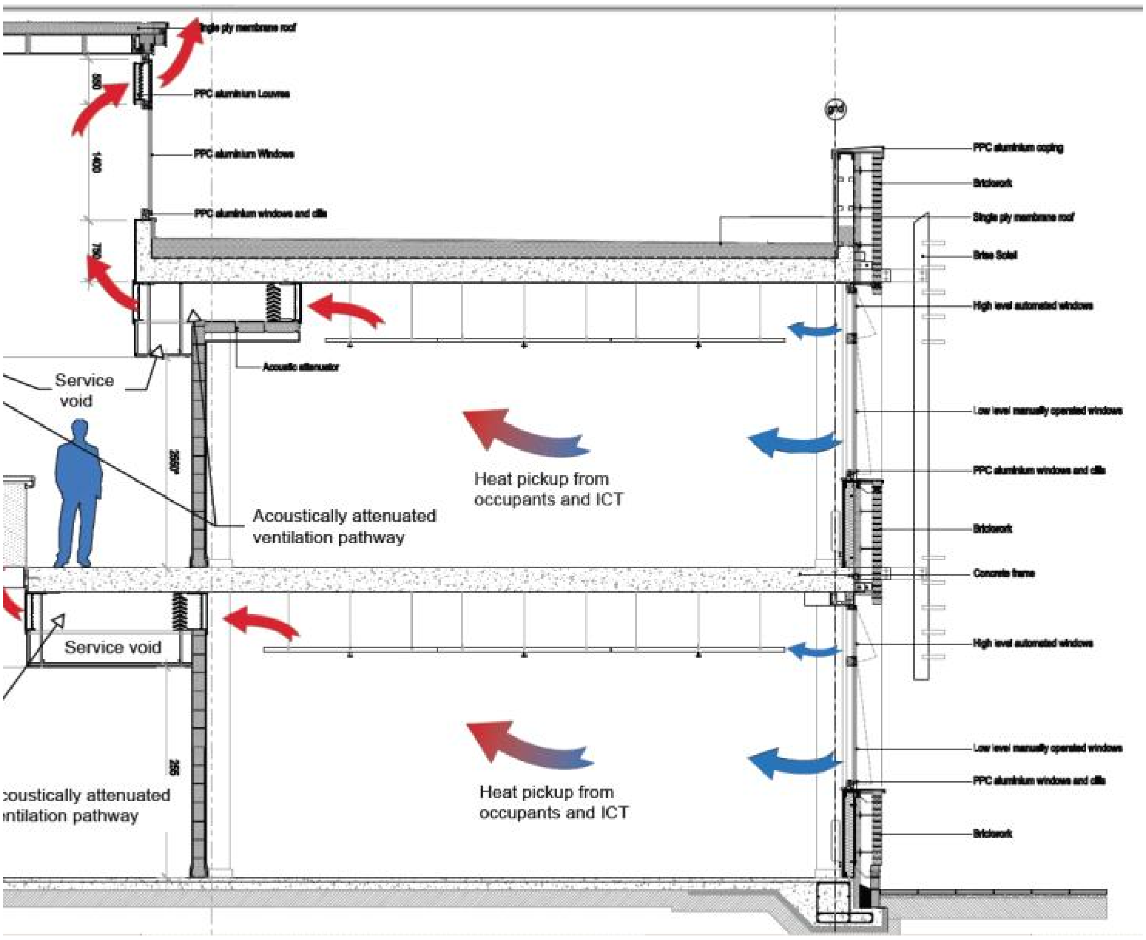
West Elevation

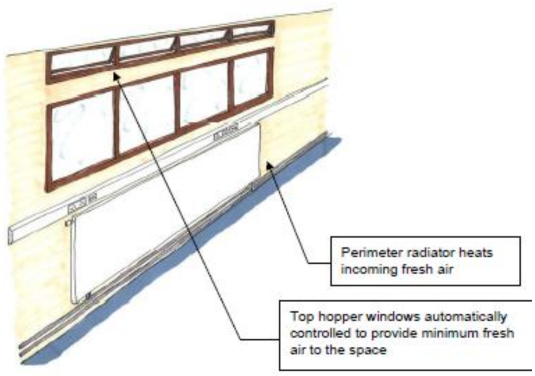


Examples of tools



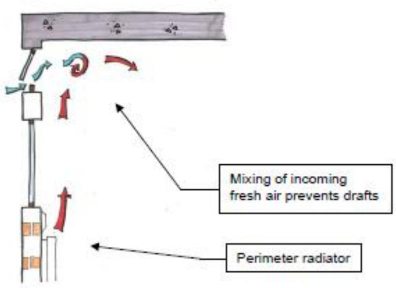






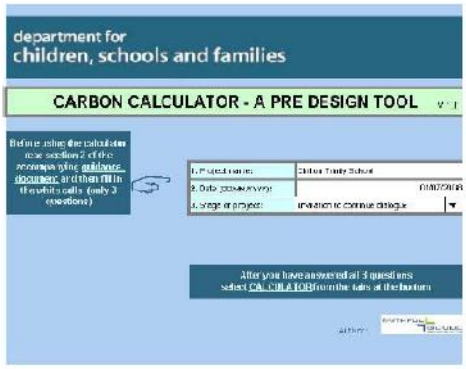
Winter Operation

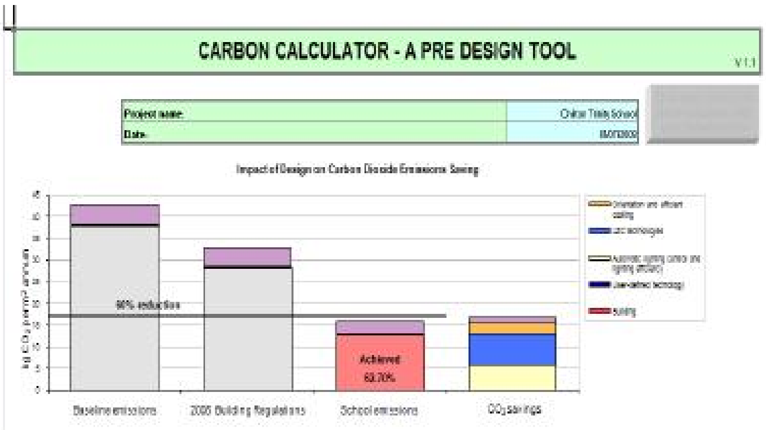
drafts in the space that could be caused by an inflow of cooler external air during the winter. The external air with warmer room air just as it enters the building.



Mixing of incoming fresh air during winter-time operation minimises effects of drafts

Materials Boards





F.5. Case study 4A

Analysis	Conceptual design
Location	South Wales
Building type	Educational
Area	9440 m2

Low carbon aspirations

Energy targets	EPC 40
LZC technologies	720m2 PV
BREEAM target	Excellent (aspiration of Outstanding)
Airtightness	5 m3/m2 @ 50Pa

Envelope elements	**U-values**
Roof	0.15 W/m2K
Walls	0.16 W/m2K
Glazing	1.6 W/m2K

BREEAM credits per category

Categories	**Credits**
Management	12.00
Health and wellbeing	12.00
Energy	14.00
Transport	4.00
Water	5.00
Materials	7.00
Waste	4.00
Land use and ecology	3.00
Pollution	8.00
Innovation	4.00
Total BREEAM Score	**73.00**

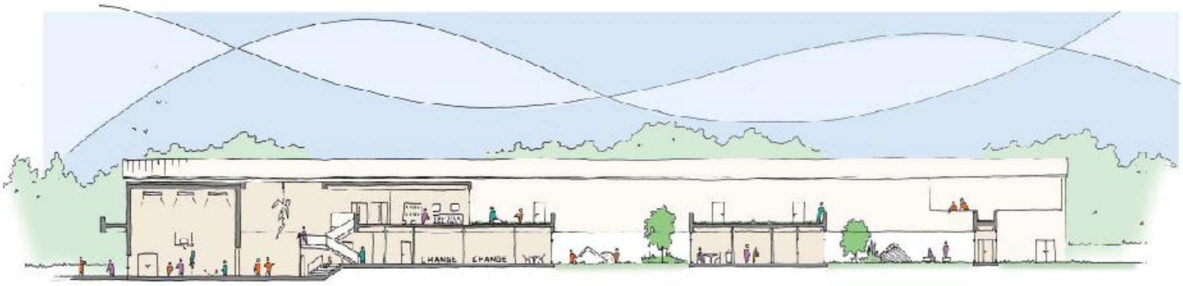
Strategies

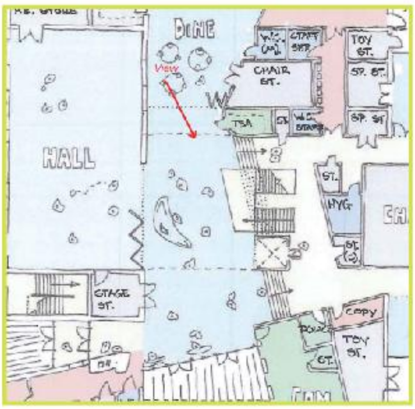
Natural ventilation, CO2 monitoring, motorised actuators; air source heat pumps as primary heating source; solar thermal panels; solar gain control (brise soleils, glare control)

Plans


PL
KIT
DINE
STAFF
HALL
SP.
REC.
W.C.
KS1
LIB.
NU.
COM.
OFF.
MEET
CH.
CH.
GROUP


KS2
KS2
KS2
KS2
W.C.
ST.
SP.
DEP.
Books
GRP.
TERRACE



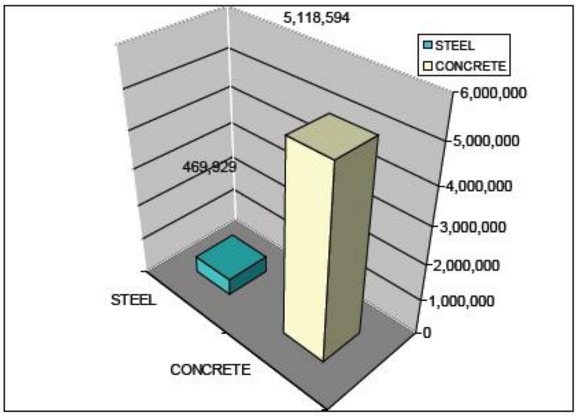


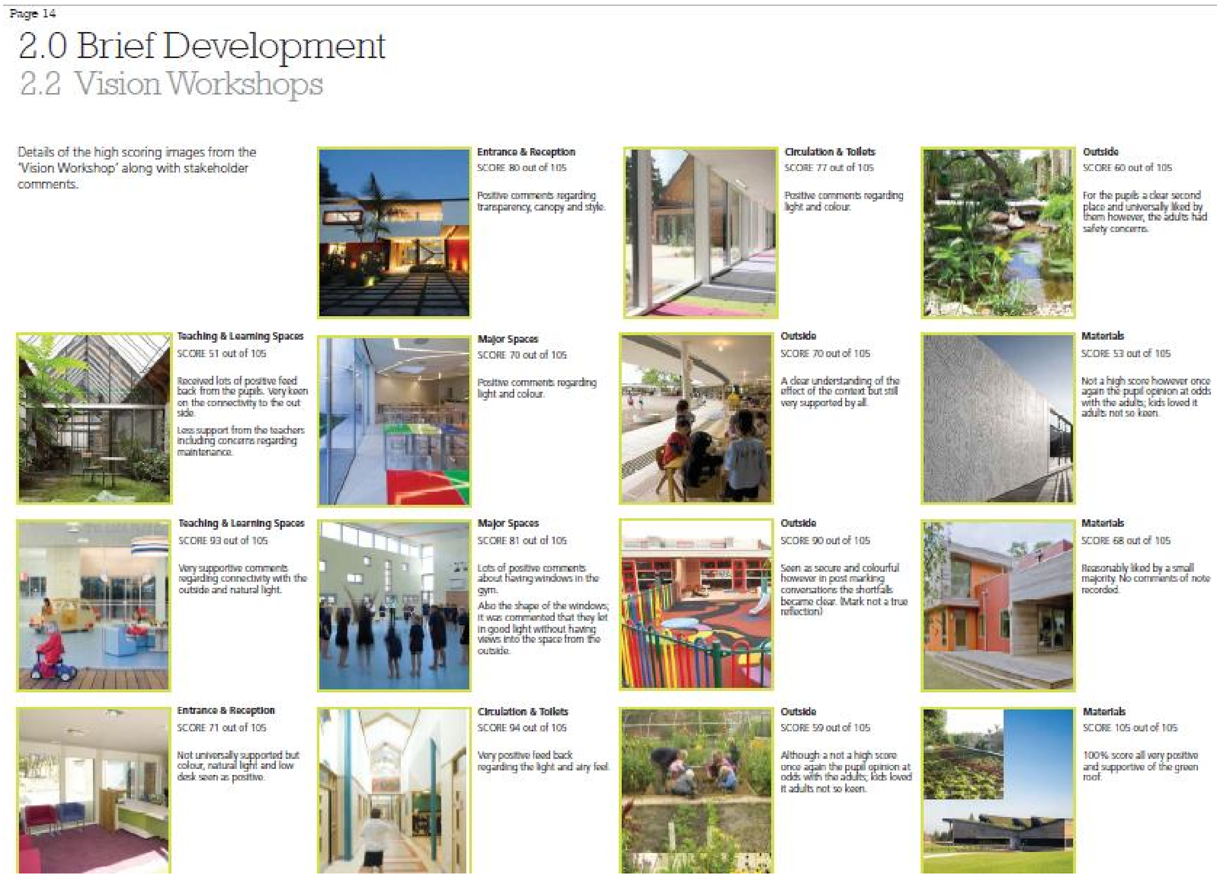
Conceptual Heart Plan

Conceptual Heart Perspective

Examples of tools

	Item embodied carbon [kgCO2]
Steel	469,929
Concrete	5,118,594





Page 14

2.0 Brief Development

2.2 Vision Workshops

Details of the high scoring images from the 'Vision Workshop' along with stakeholder comments.

Entrance & Reception
SCORE 80 out of 105
Positive comments regarding transparency, canopy and style.

Circulation & Toilets
SCORE 77 out of 105
Positive comments regarding light and colour.

Outside
SCORE 60 out of 105
For the pupils a clear second place and universally liked by them however, the adults had safety concerns.

Teaching & Learning Spaces
SCORE 51 out of 105
Received lots of positive feed back from the pupils. Very keen on the connectivity to the out side.
Less support from the teachers including concerns regarding maintenance.

Major Spaces
SCORE 70 out of 105
Positive comments regarding light and colour.

Outside
SCORE 70 out of 105
A clear understanding of the effect of the context but still very supported by all.

Materials
SCORE 53 out of 105
Not a high score however once again the pupil opinion at odds with the adults; kids loved it adults not so keen.

Teaching & Learning Spaces
SCORE 93 out of 105
Very supportive comments regarding connectivity with the outside and natural light.

Major Spaces
SCORE 81 out of 105
Lots of positive comments about having windows in the gym.
Also the shape of the windows; it was commented that they let in good light without having views into the space from the outside.

Outside
SCORE 90 out of 105
Seen as secure and colourful however in post marking conversations the shortfalls became clear. (Mark not a true reflection)

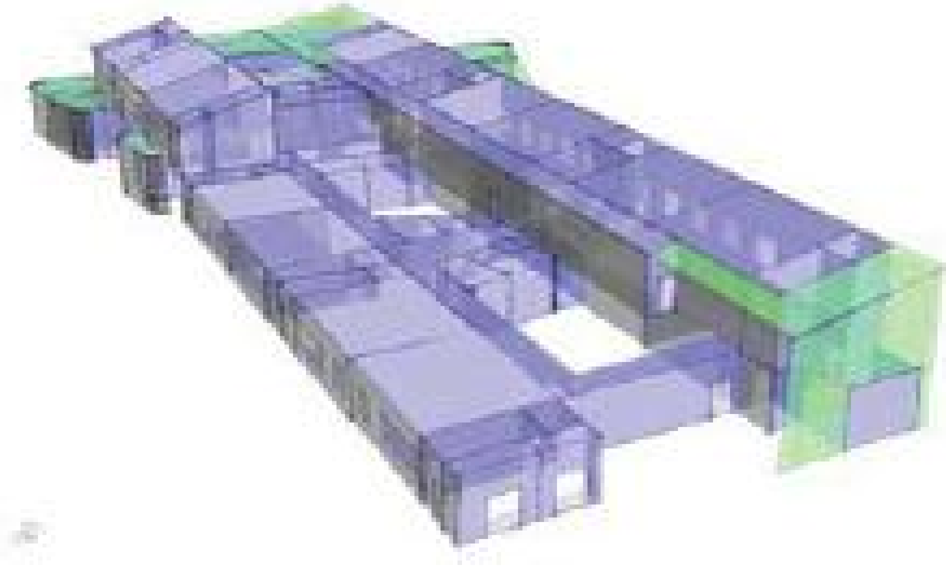
Materials
SCORE 68 out of 105
Reasonably liked by a small majority. No comments of note recorded.

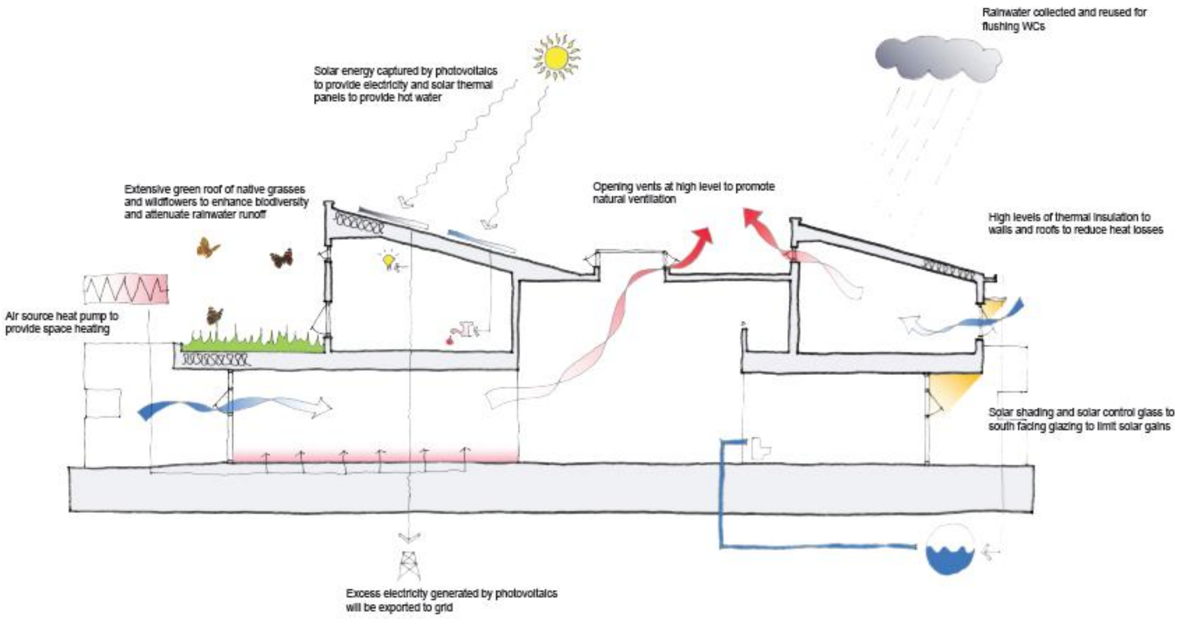
Entrance & Reception
SCORE 71 out of 105
Not universally supported but colour, natural light and low desk seen as positive.

Circulation & Toilets
SCORE 94 out of 105
Very positive feed back regarding the light and airy feel.

Outside
SCORE 59 out of 105
Although a not a high score once again the pupil opinion at odds with the adults; kids loved it adults not so keen.

Materials
SCORE 105 out of 105
100% score all very positive and supportive of the green roof.




Rainwater collected and reused for flushing WCs
Solar energy captured by photovoltaics to provide electricity and solar thermal panels to provide hot water
Extensive green roof of native grasses and wildflowers to enhance biodiversity and attenuate rainwater runoff
Opening vents at high level to promote natural ventilation
High levels of thermal insulation to walls and roofs to reduce heat losses
Air source heat pump to provide space heating
Solar shading and solar control glass to south facing glazing to limit solar gains
Excess electricity generated by photovoltaics will be exported to grid

F.6. Case study 4B

Analysis	Detailed design
Location	South Wales
Building type	Health and community centre
Area	9570 m2

Low carbon aspirations

Energy targets	EPC 28
LZC technologies	Solar power
BREEAM target	Very good (aspiration: Excellent)
Airtightness	5 m3/m2 @ 50Pa

Envelope elements	**U-values**
Roof	0.10 W/m2K
Walls	0.16 W/m2K
Glazing	1.5 W/m2K
Floors	0.12W/m2K

BREEAM credits per category

Categories	**Credits**
Management	9.00
Health and wellbeing	8.00
Energy	15.00
Transport	9.00
Water	5.00
Materials	6.00
Waste	3.00
Land use and ecology	5.00
Pollution	4.00
Innovation	2.00
Total BREEAM Score	**66.00**

Strategies

Use of natural Lighting using Daylight modelling; limited mechanical ventilation; lighting Control System; Building Management System controls thermal zoning for varying occupancies; improved U values

Plans

Figure 46: Health Centre Elevation

Figure 47: Retail Unit Elevation

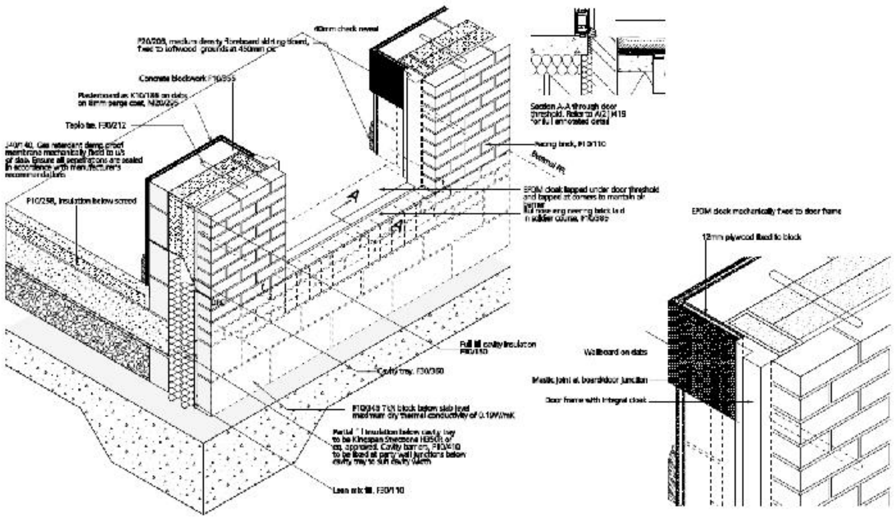
Figure 37: Entire Development

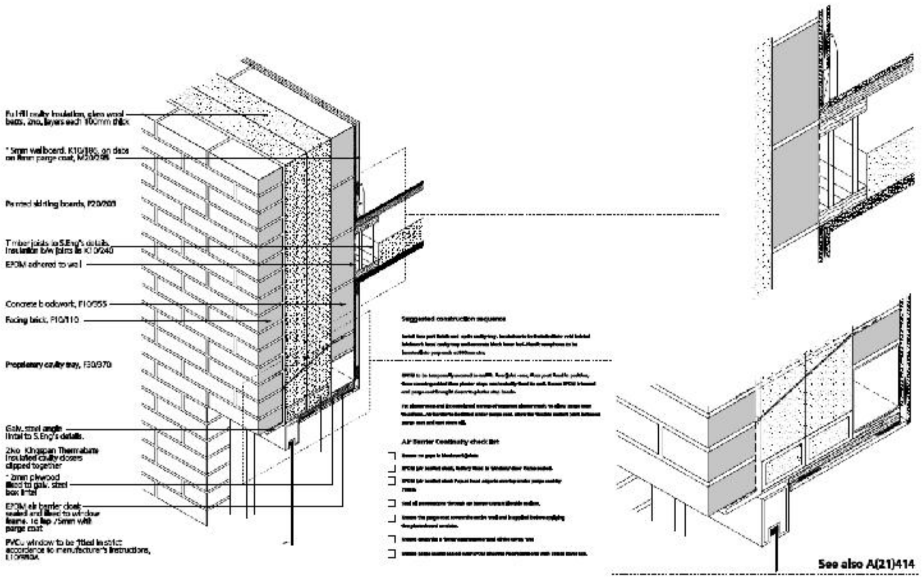
Figure 39: Retail along Bute Street

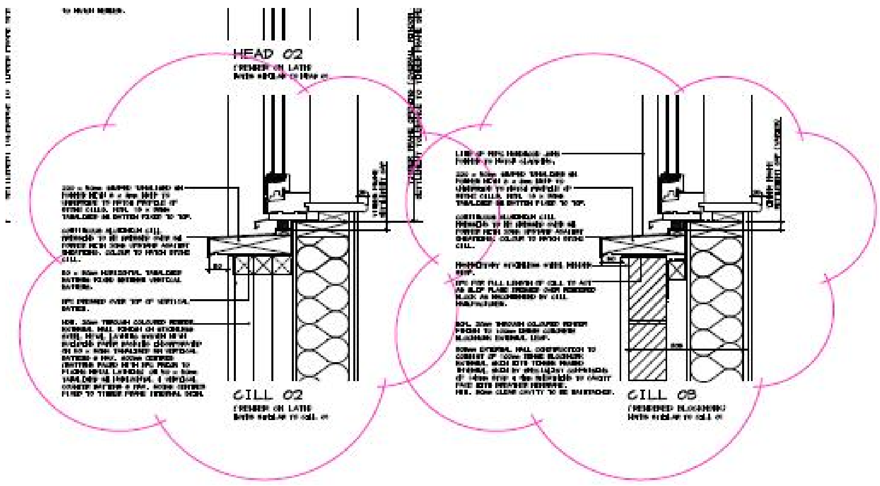
Figure 38: Entire Development

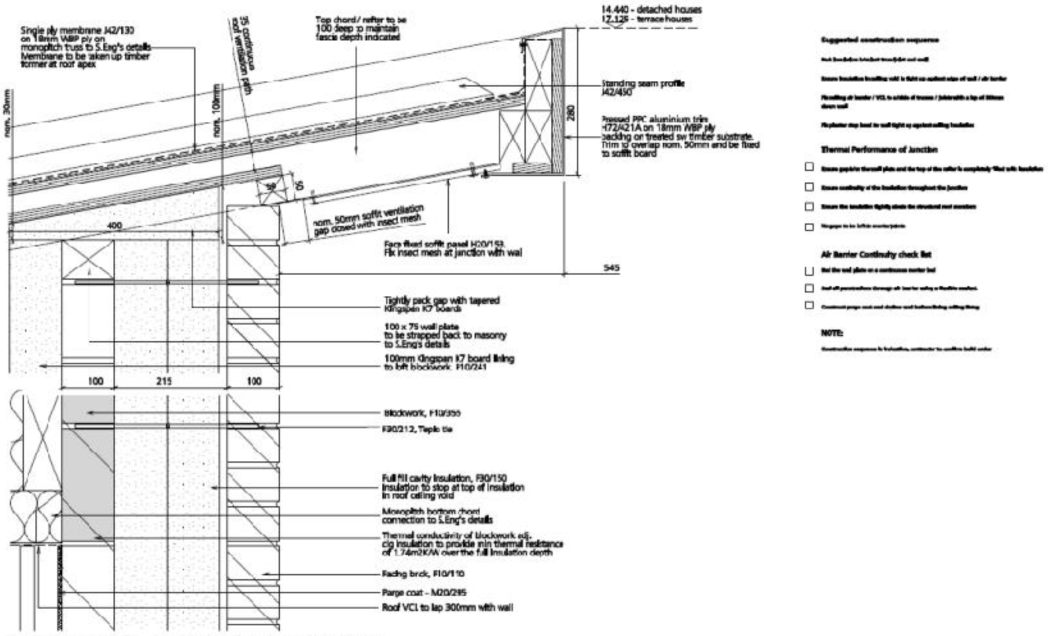
Figure 40: Retail Wrapping onto South Loudoun Place

Townhouse Detail 25 - For detail location refer to L(00)400 series









Townhouses Detail 18 - For detail location refer to L(C0)400 series

E

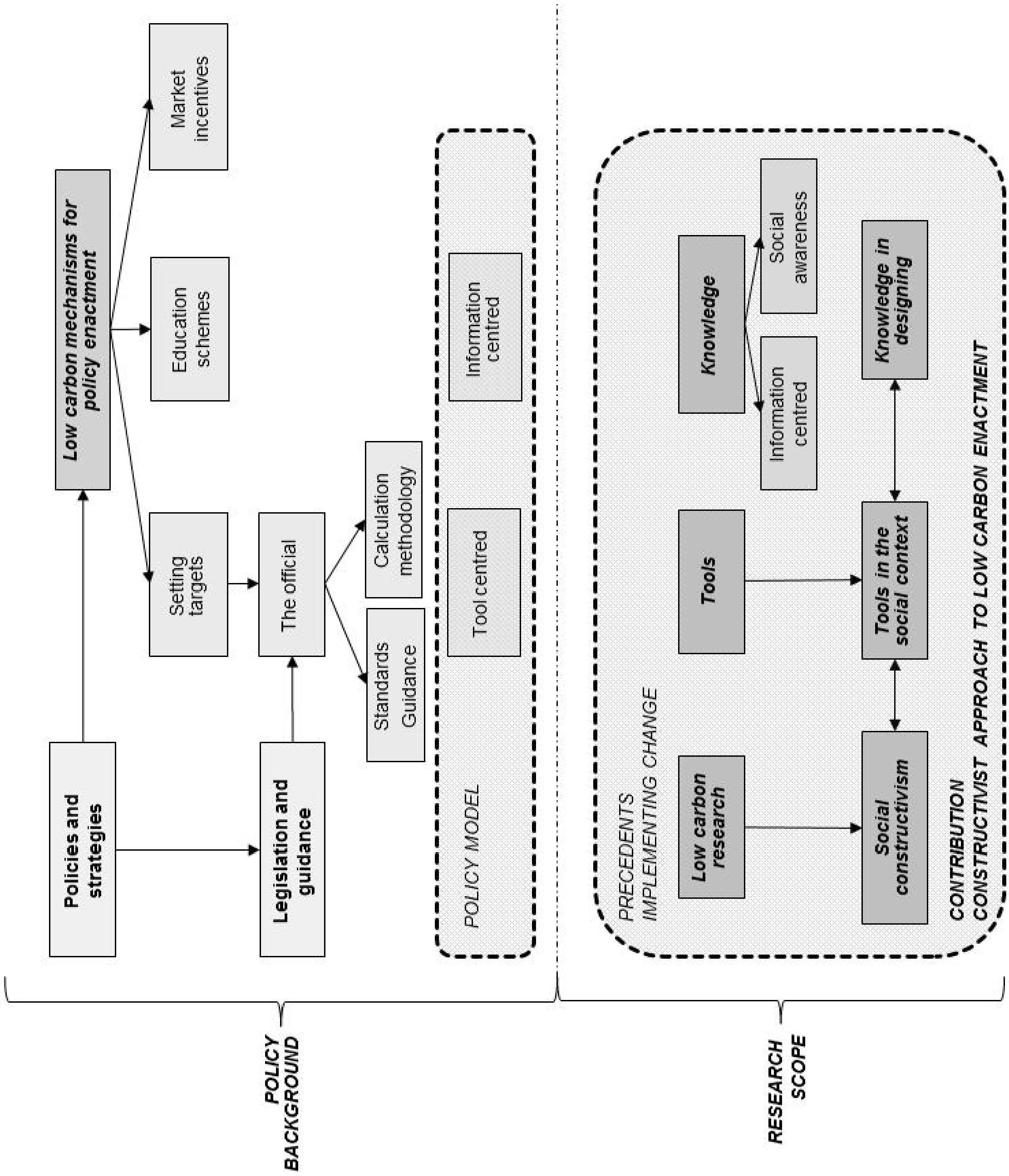
Examples of tools

Photograph 4 – Panoramic construction progress plots 9-13 inc.

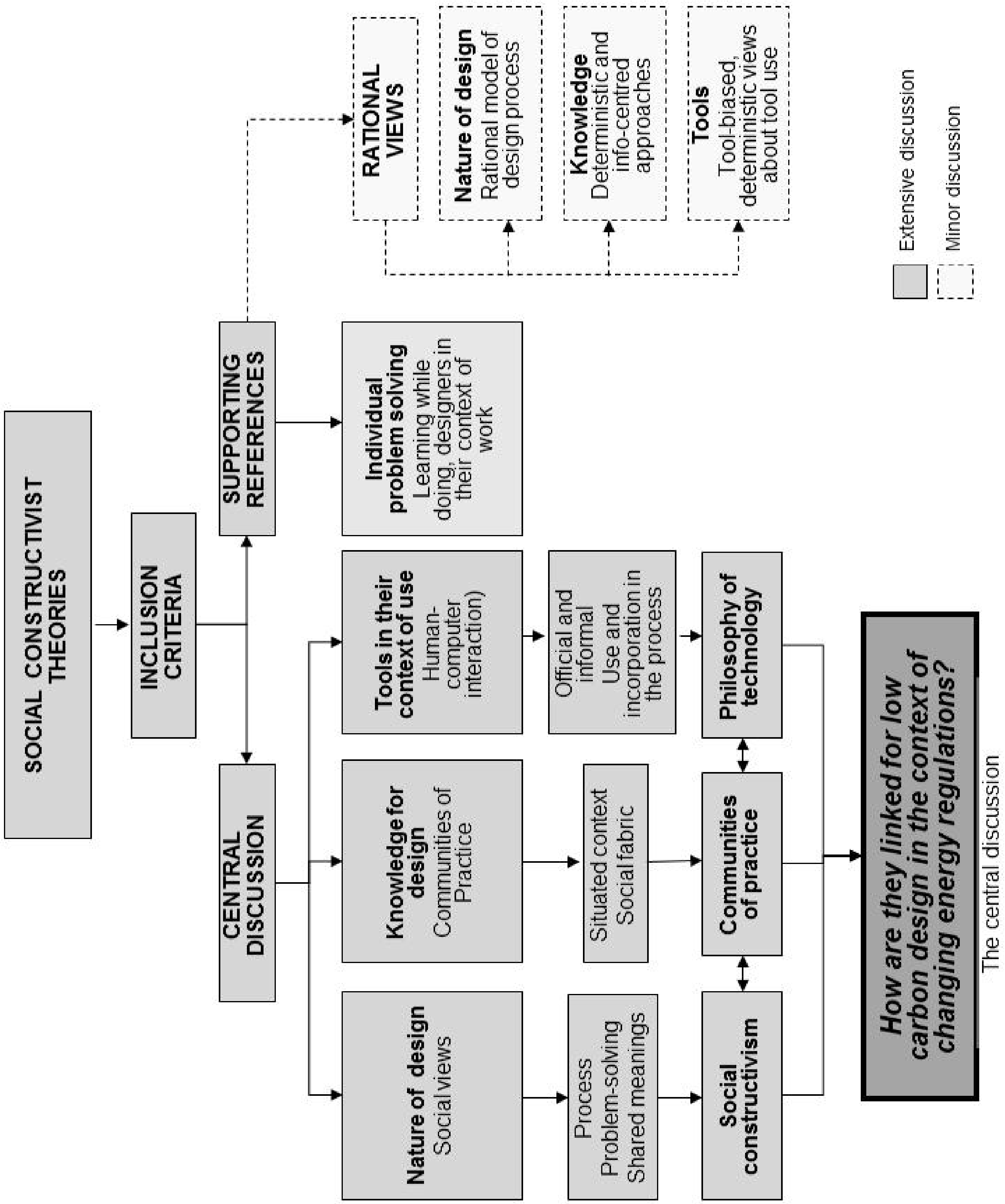
Photograph 5 – Plot 8 door showing additional insulation at base and additional brick course and dpm at cavity tray level (photos 03/09/10)

Photograph 6 – Insulation in cavity plot 1 (front, L/H, R/H, rear)

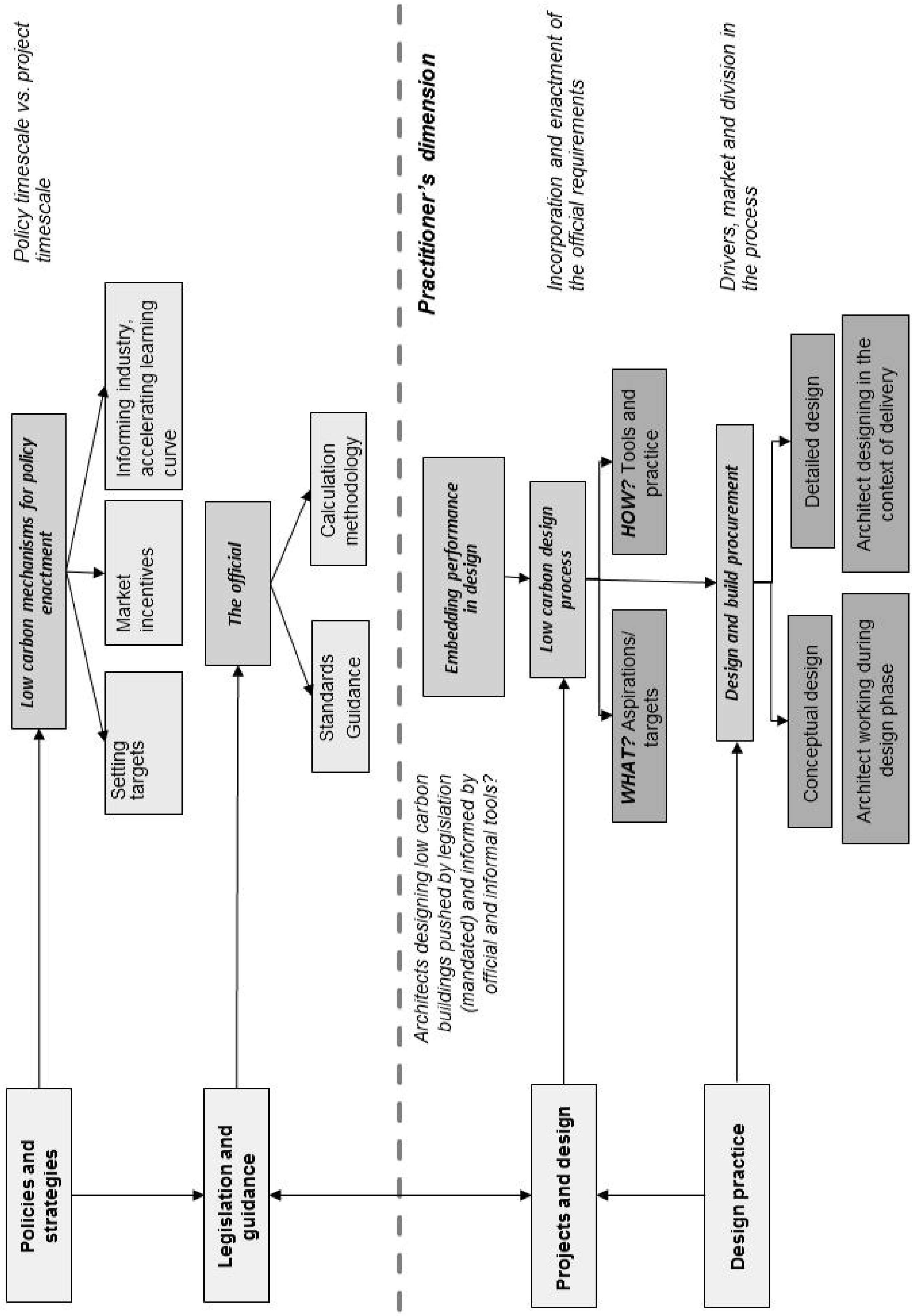
Appendix G. Research summary by figures produced during the data analysis



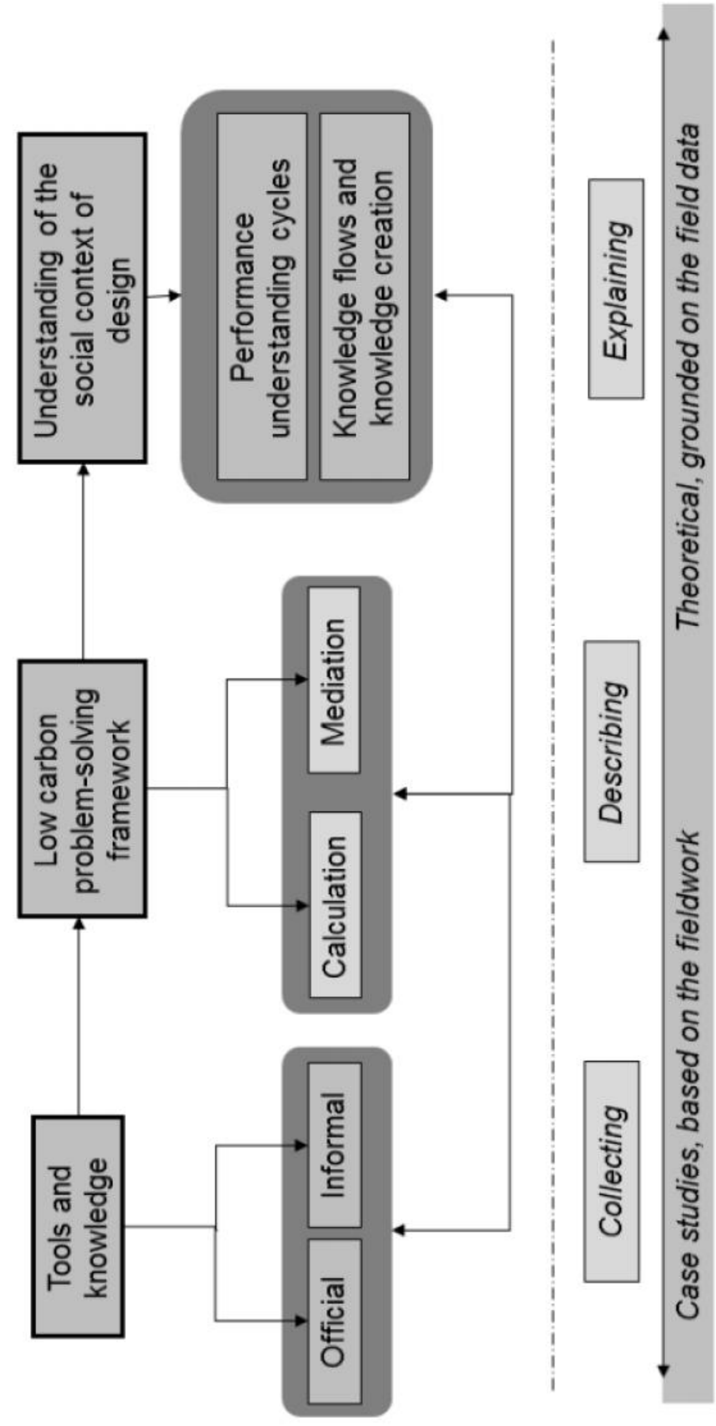
Research scope (Figure 3.1.)



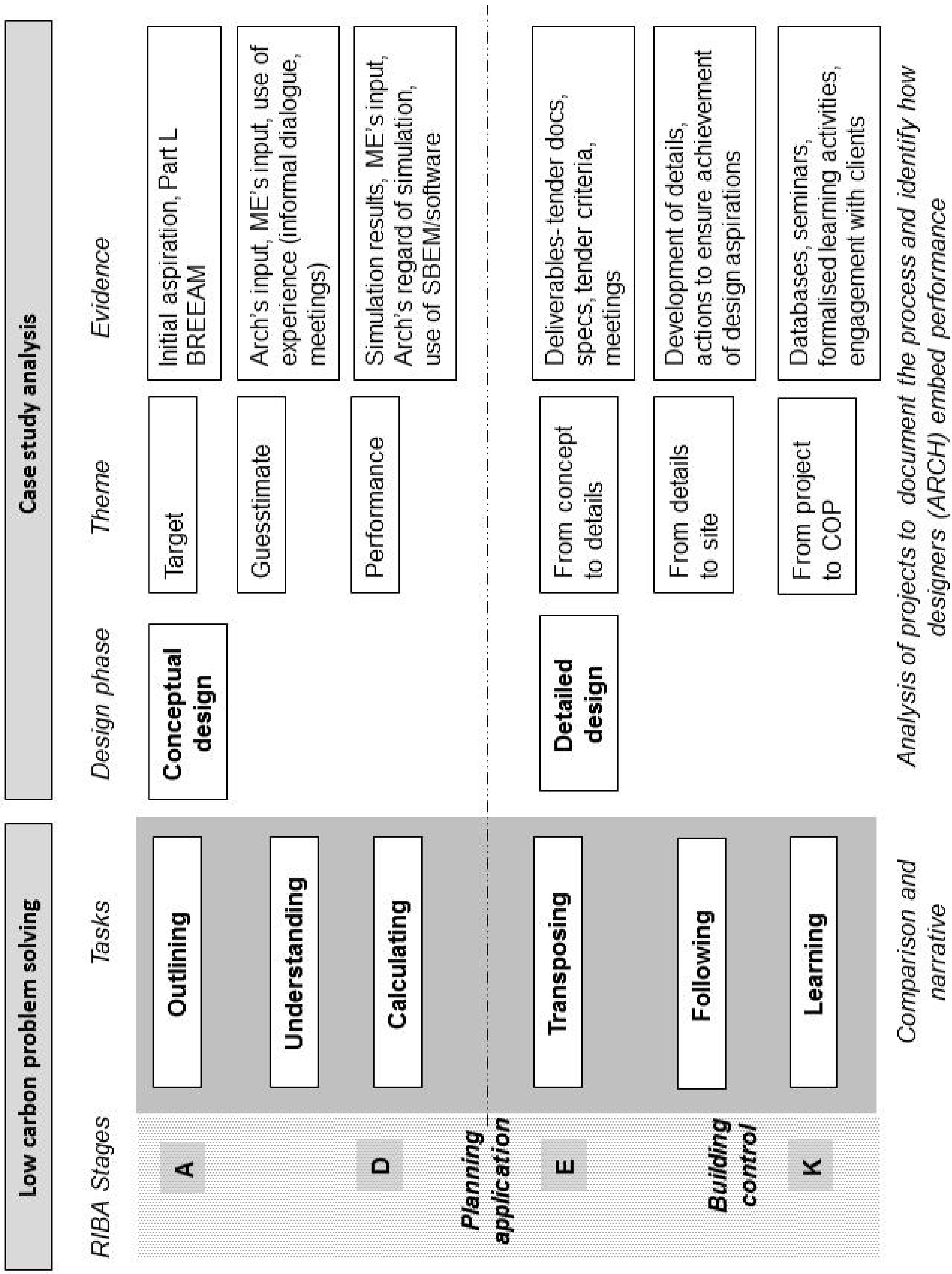
Themes addressed in the literature review (Figure 2.1.)



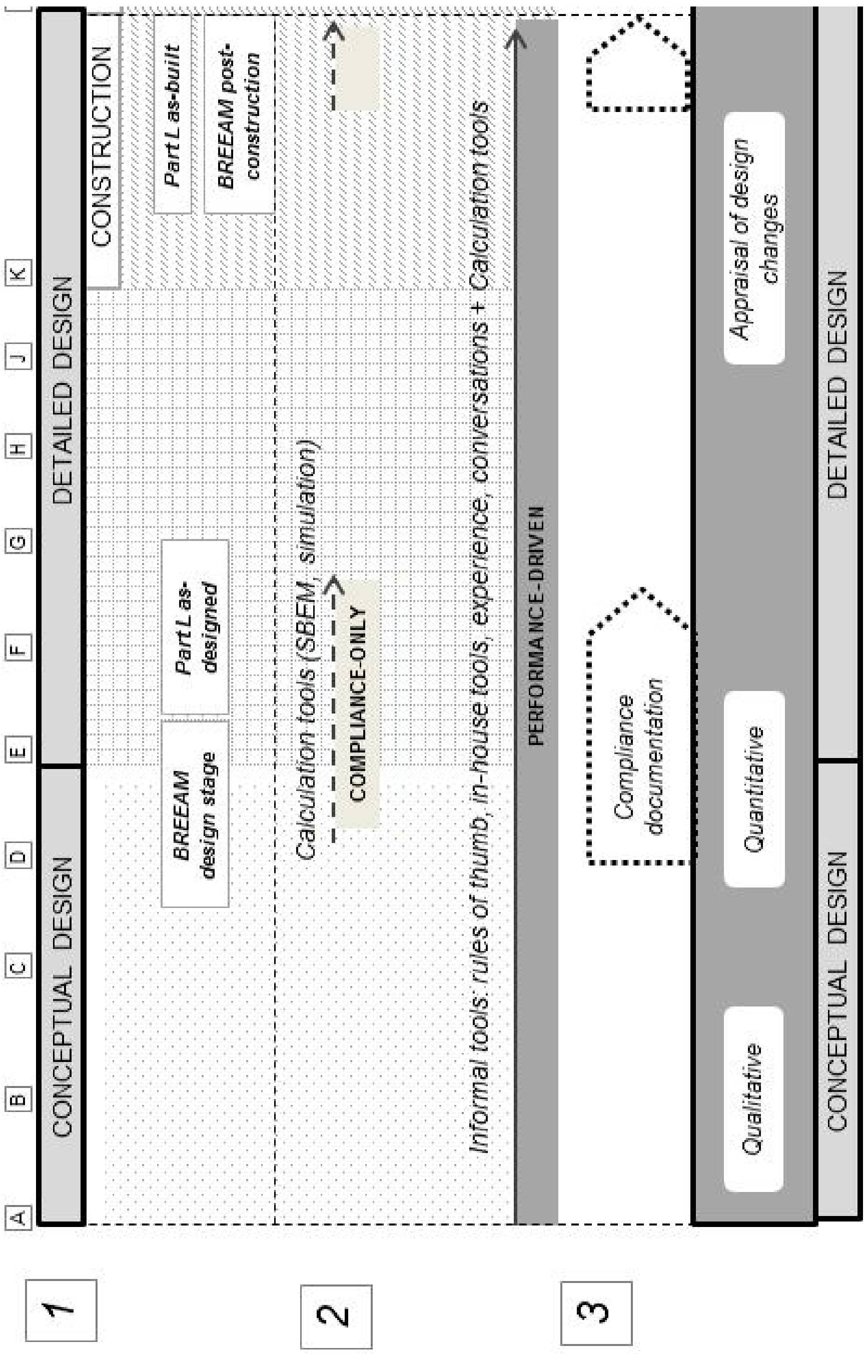
Research scope in relation to the British low carbon policy model for new buildings (Figure 1.1.)



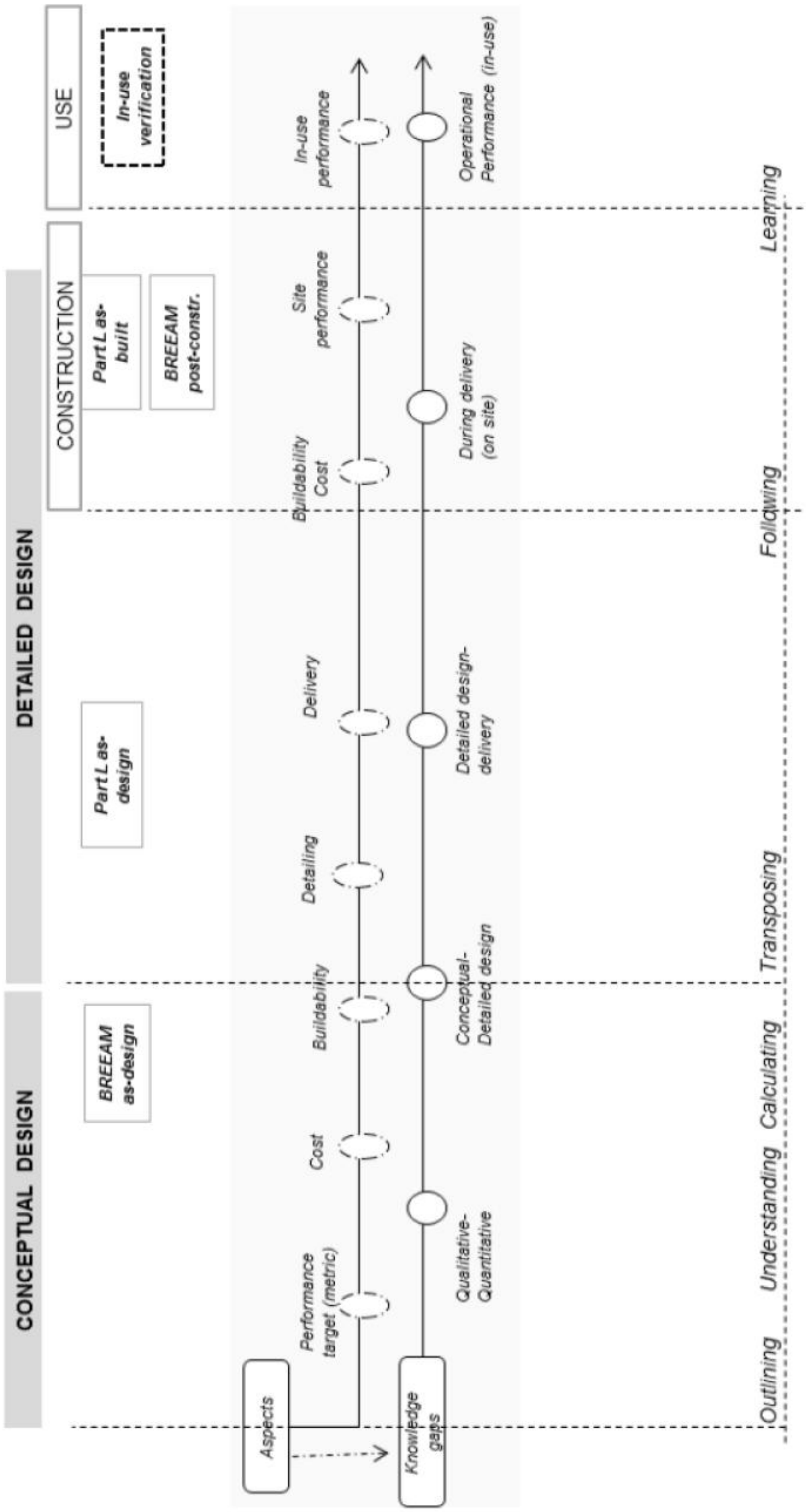
Layers of data analysis (figure 3.6)



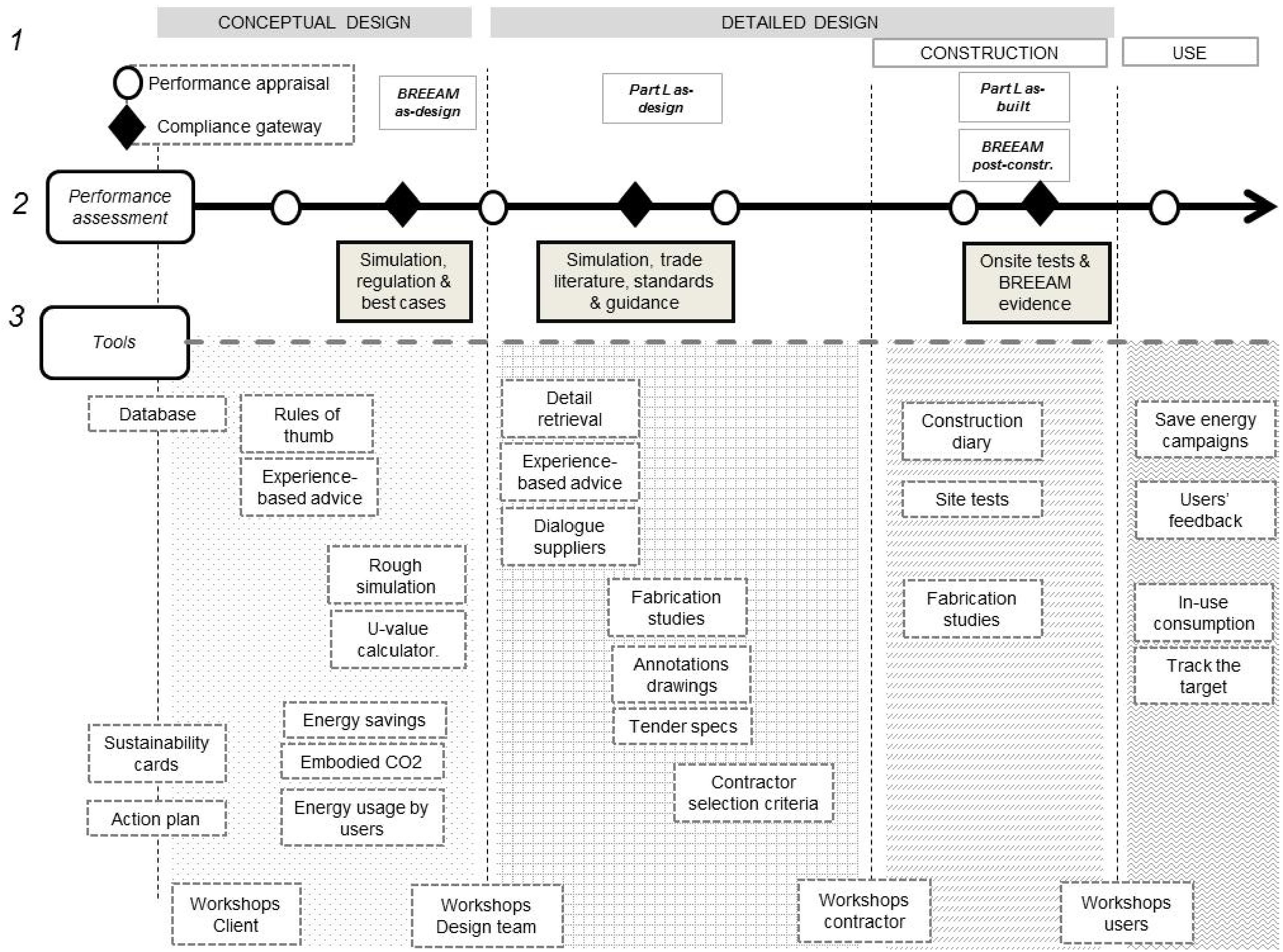
Representation of the low carbon problem solving framework in relation to project timeline with some examples of the field data sources (figure 3.7.)



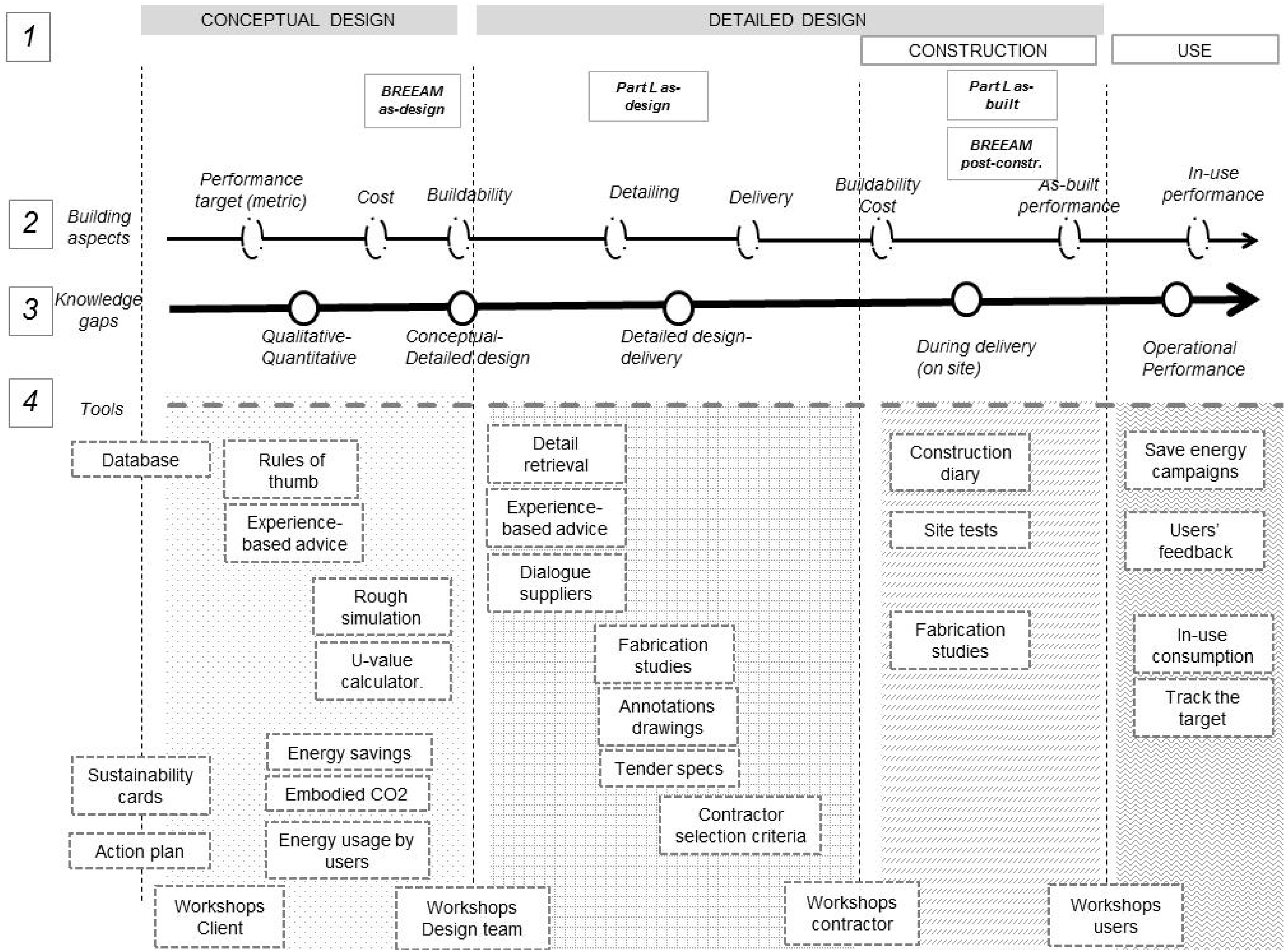
Performance understanding cycle, comparing the timeline for compliance-only and performance-driven processes (Figure. 6.1.)

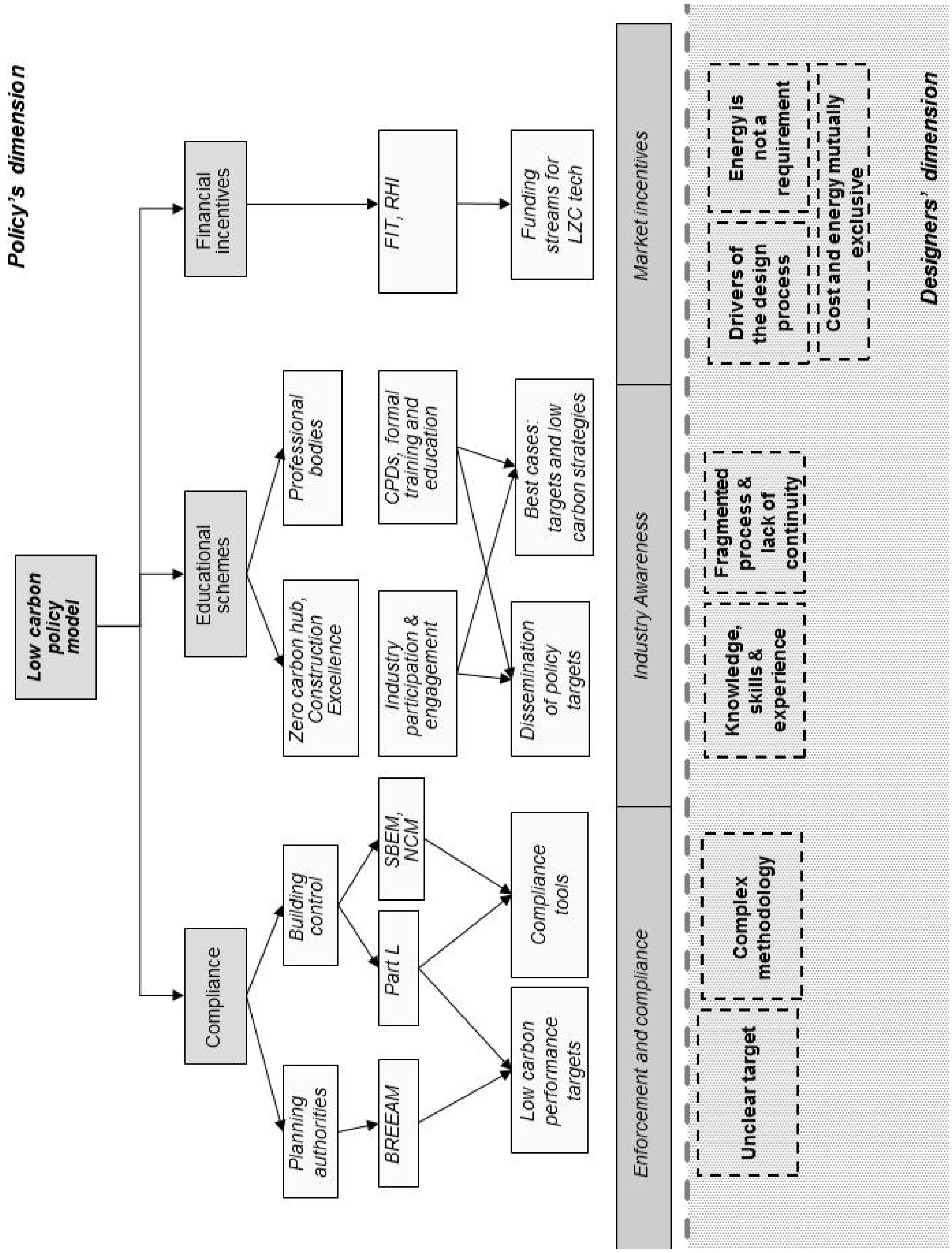


Overlap of the design process timeline, building aspects that affect the energy aspirations, knowledge gaps and the low carbon problem-solving tasks

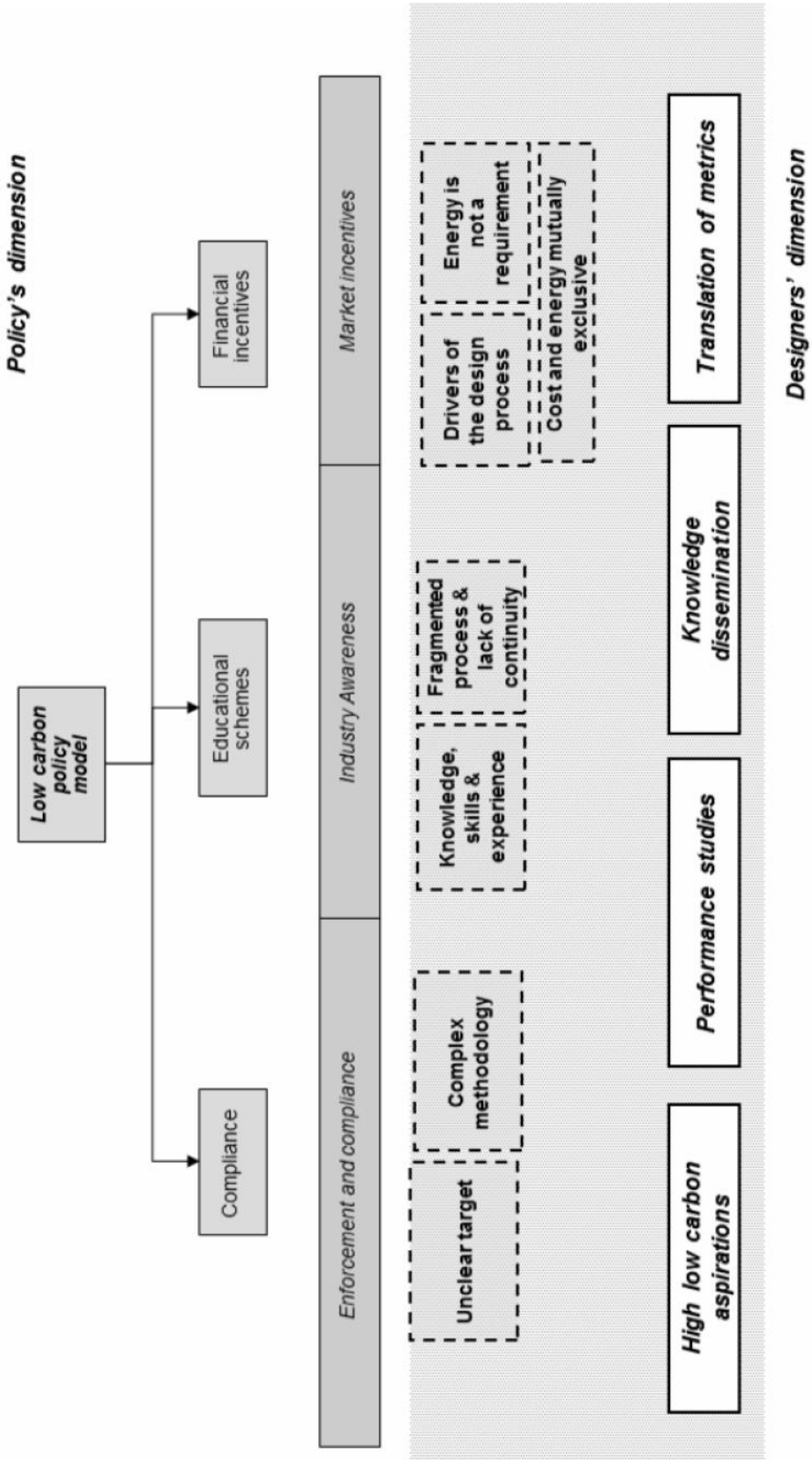


CONCEPTUAL DESIGN
DETAILED DESIGN
CONSTRUCTION
USE
1
2
3
Performance appraisal
Compliance gateway
BREEAM as-design
Part L as-design
Part L as-built
BREEAM post-constr.
Performance assessment
Simulation, regulation & best cases
Simulation, trade literature, standards & guidance
Onsite tests & BREEAM evidence
Tools
Database
Rules of thumb
Experience-based advice
Rough simulation
U-value calculator.
Sustainability cards
Action plan
Energy savings
Embodied CO2
Energy usage by users
Workshops Client
Detail retrieval
Experience-based advice
Dialogue suppliers
Fabrication studies
Annotations drawings
Tender specs
Contractor selection criteria
Workshops Design team
Construction diary
Site tests
Fabrication studies
Workshops contractor
Save energy campaigns
Users' feedback
In-use consumption
Track the target
Workshops users

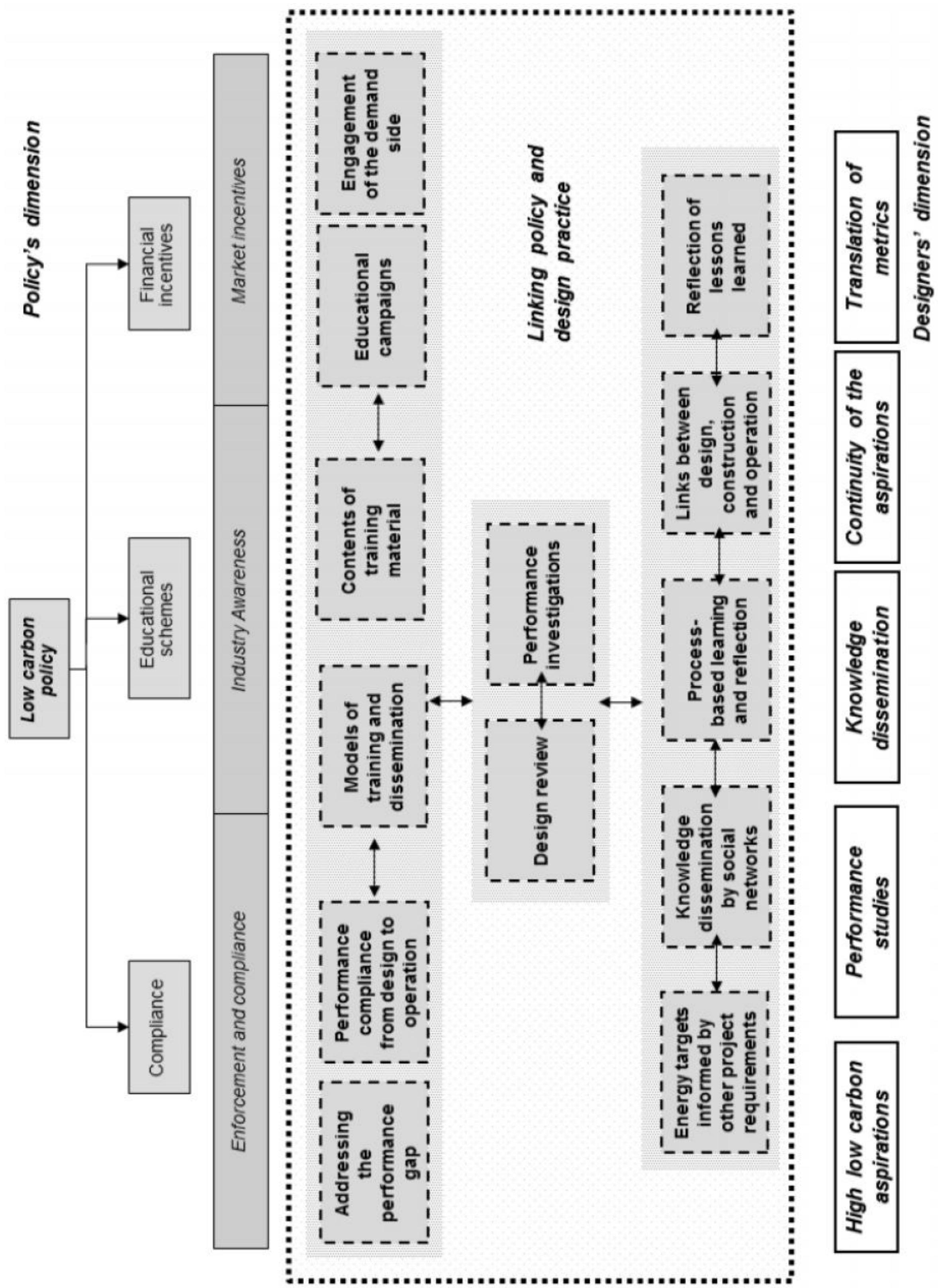

1
CONCEPTUAL DESIGN
DETAILED DESIGN
CONSTRUCTION
USE
BREEAM as-design
Part L as-design
Part L as-built
BREEAM post-constr.
2
Building aspects
Performance target (metric)
Cost
Buildability
Detailing
Delivery
Buildability Cost
As-built performance
In-use performance
3
Knowledge gaps
Qualitative-Quantitative
Conceptual-Detailed design
Detailed design-delivery
During delivery (on site)
Operational Performance
4
Tools
Database
Rules of thumb
Experience-based advice
Rough simulation
U-value calculator.
Sustainability cards
Action plan
Energy savings
Embodied CO2
Energy usage by users
Workshops Client
Detail retrieval
Experience-based advice
Dialogue suppliers
Fabrication studies
Annotations drawings
Tender specs
Contractor selection criteria
Workshops Design team
Construction diary
Site tests
Fabrication studies
Workshops contractor
Save energy campaigns
Users' feedback
In-use consumption
Track the target
Workshops users



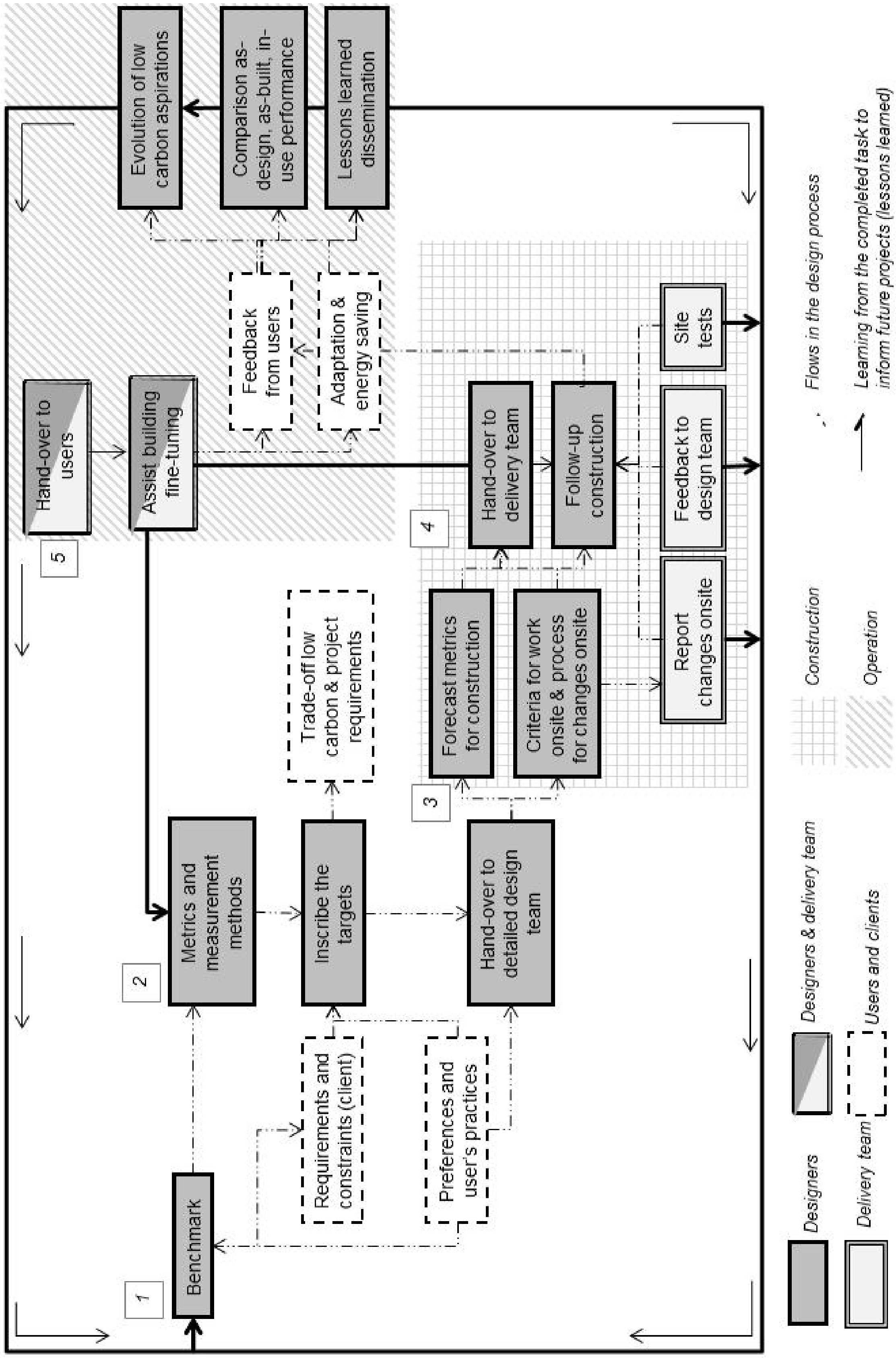
Policy and designers' dimensions disconnections (figure 7.1.)


Policy's dimension
Low carbon policy model
Compliance
Educational schemes
Financial incentives
Enforcement and compliance
Industry Awareness
Market incentives
Unclear target
Complex methodology
Knowledge, skills & experience
Fragmented process & lack of continuity
Drivers of the design process
Energy is not a requirement
Cost and energy mutually exclusive
High low carbon aspirations
Performance studies
Knowledge dissemination
Translation of metrics
Designers' dimension

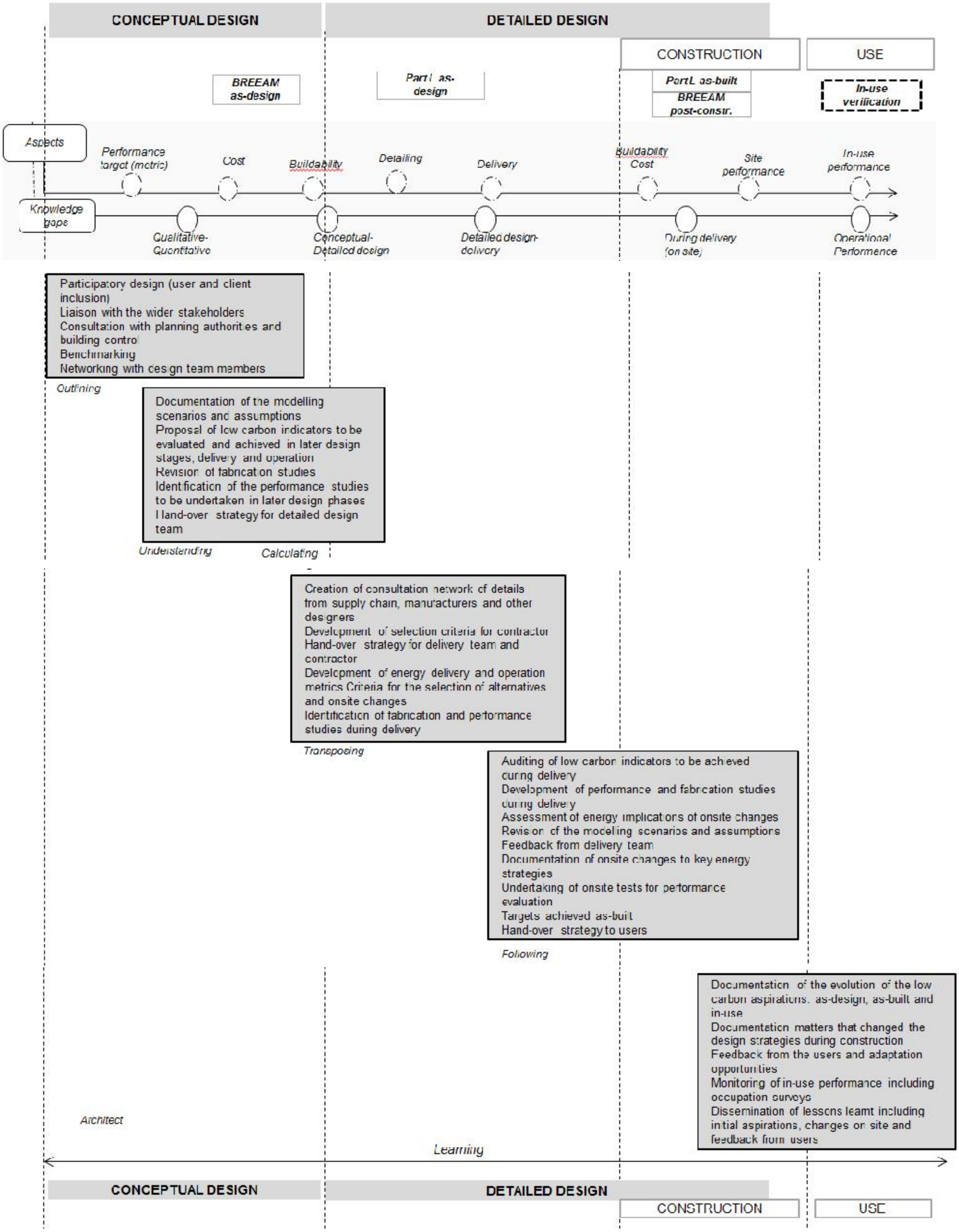
Designers' enactment of the low carbon policy agenda



Learning from low carbon design.



Design review flowchart

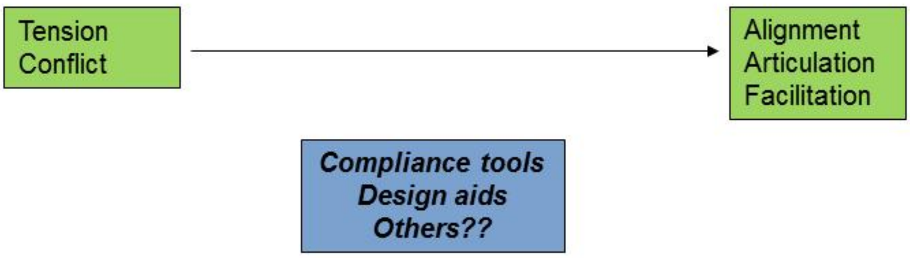


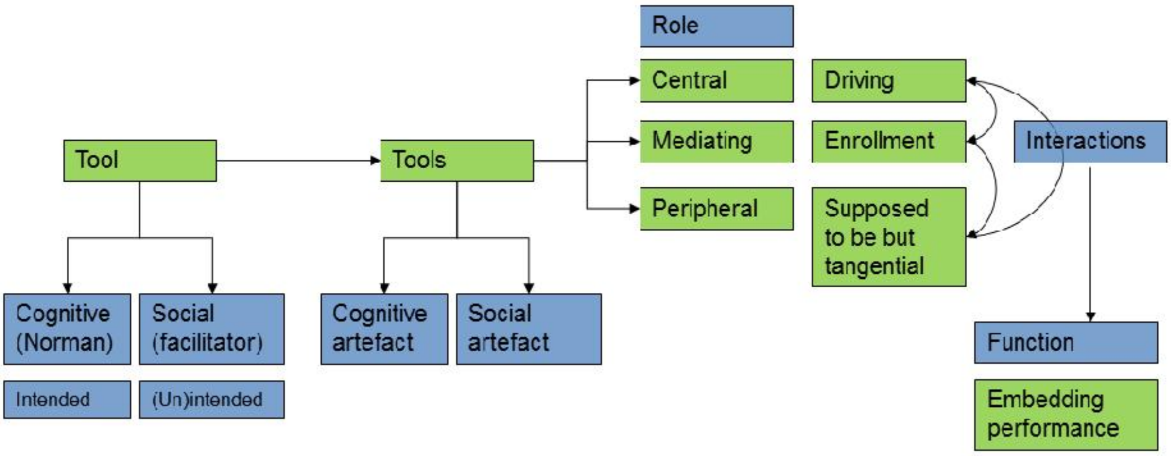
Design review example

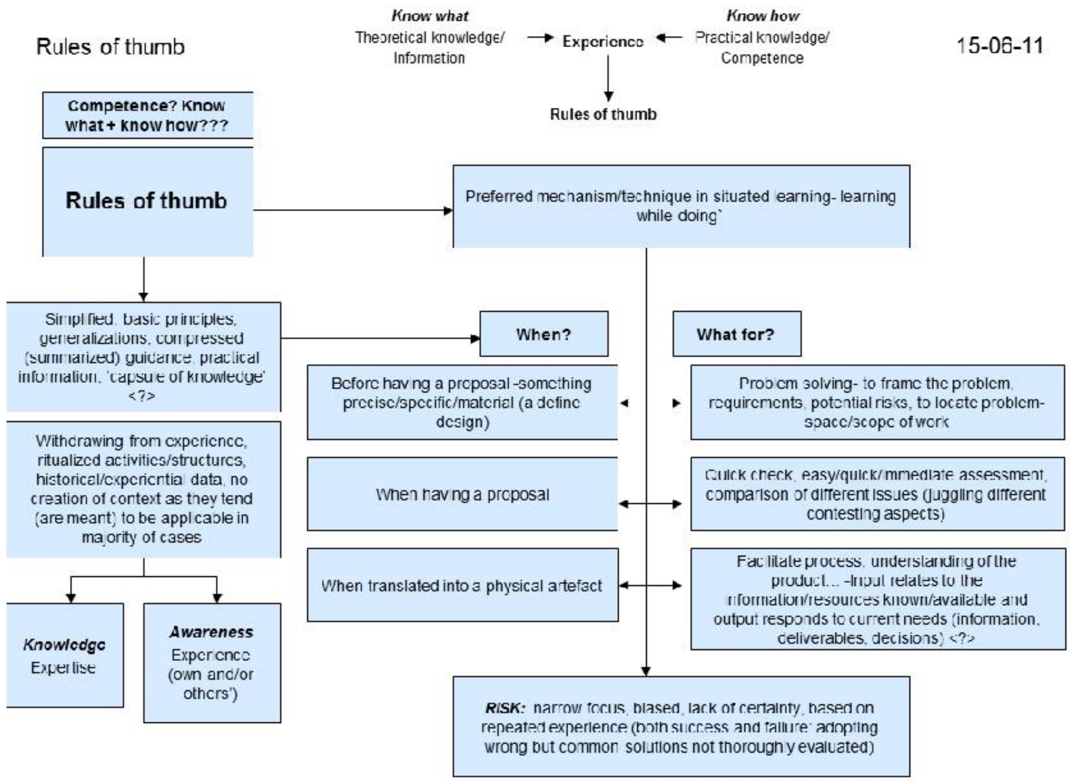
Appendix H. Field analysis- examples of techniques used to analyse the data

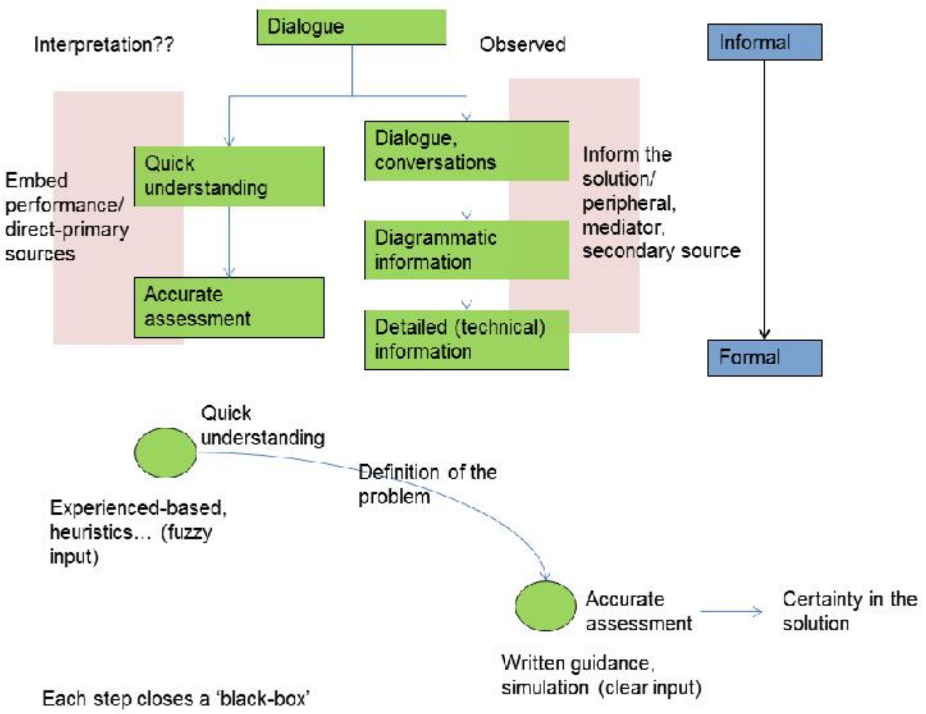
This section includes examples of diagrams, mindmaps and figures produced to analyse the data.

- Systems view: person + task + artefact
- Subject-artefact asymmetry
- Artefacts: mediators of action
- Social and cultural dimensions
- Objects in development
- Dependence on the situation

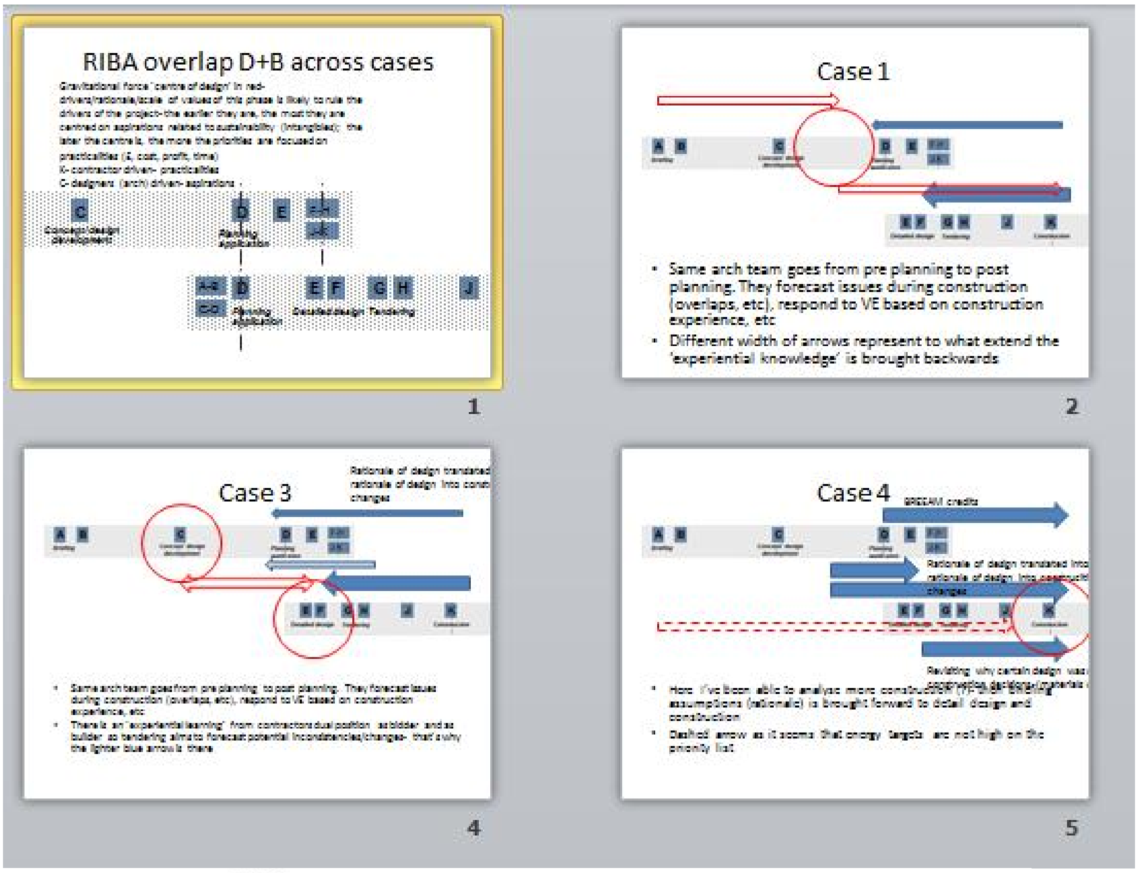


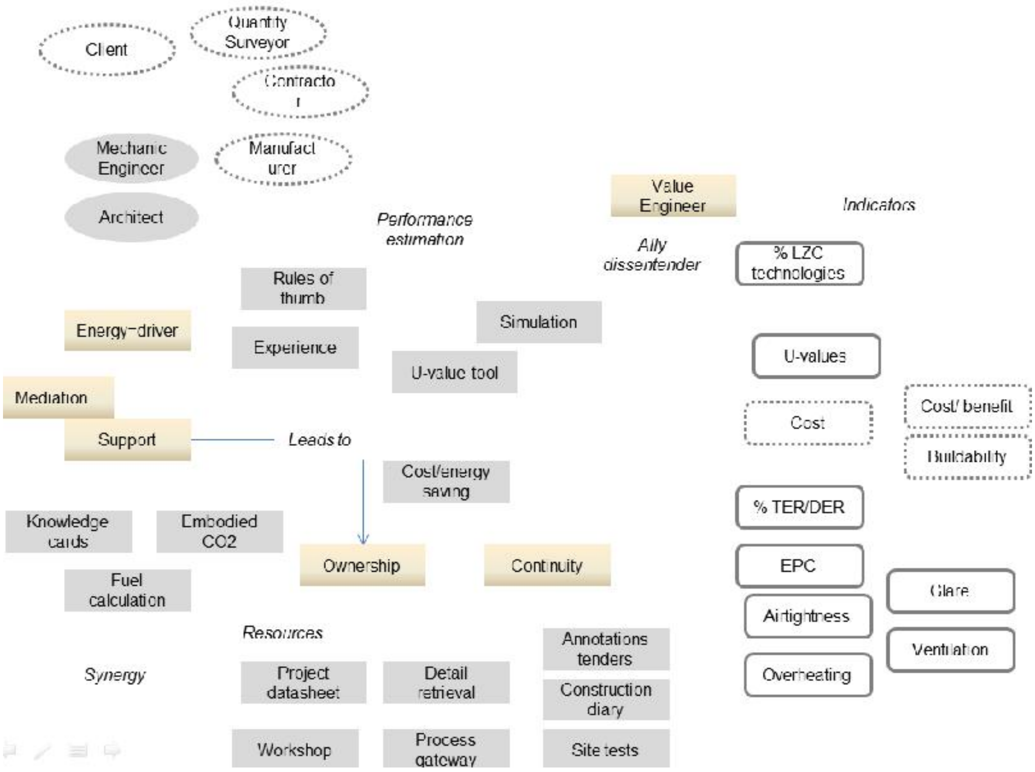



Rules of thumb
Know what
Theoretical knowledge/ Information
Experience
Know how
Practical knowledge/ Competence
Rules of thumb
15-06-11
Competence? Know what + know how???
Rules of thumb
Preferred mechanism/technique in situated learning- learning while doing'
Simplified, basic principles, generalizations, compressed (summarized) guidance, practical information, 'capsule of knowledge' <?>
When?
What for?
Before having a proposal -something precise/specific/material (a define design)
Problem solving- to frame the problem, requirements, potential risks, to locate problem-space/scope of work
Withdrawing from experience, ritualized activities/structures, historical/experiential data, no creation of context as they tend (are meant) to be applicable in majority of cases
When having a proposal
Quick check, easy/quick/immediate assessment, comparison of different issues (juggling different contesting aspects)
When translated into a physical artefact
Facilitate process, understanding of the product... -Input relates to the information/resources known/available and output responds to current needs (information, deliverables, decisions) <?>
Knowledge
Expertise
Awareness
Experience (own and/or others')
RISK: narrow focus, biased, lack of certainty, based on repeated experience (both success and failure: adopting wrong but common solutions not thoroughly evaluated)

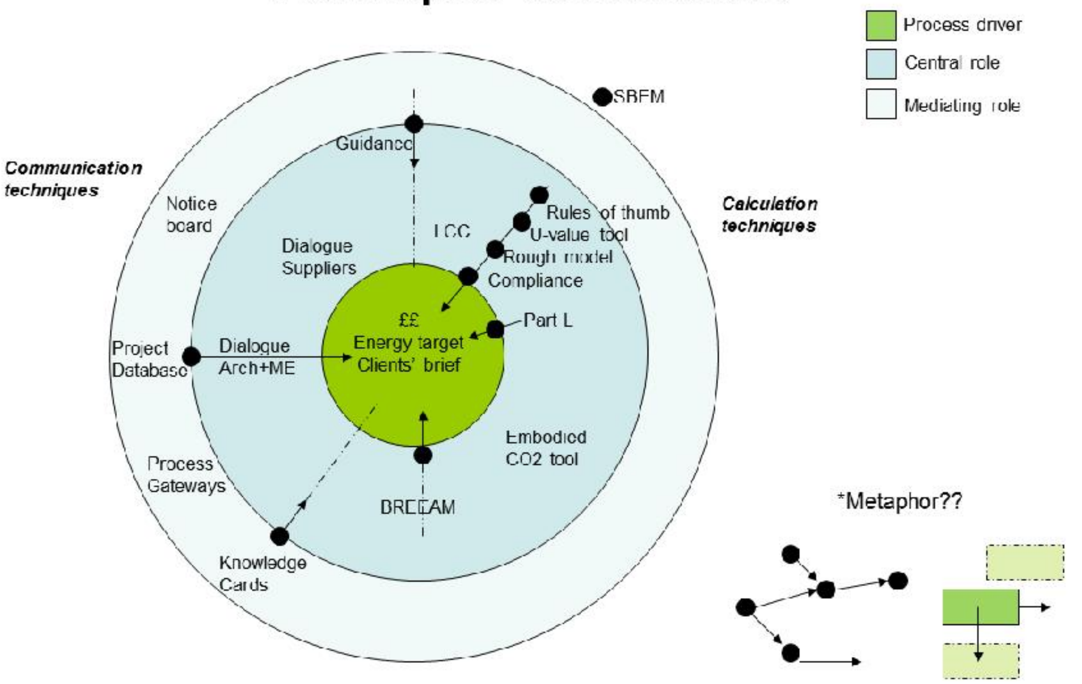

Dialogue
Interpretation??
Observed
Informal
Quick understanding
Dialogue, conversations
Inform the solution/ peripheral, mediator, secondary source
Embed performance/ direct-primary sources
Diagrammatic information
Accurate assessment
Detailed (technical) information
Formal
Quick understanding
Definition of the problem
Experienced-based, heuristics... (fuzzy input)
Accurate assessment
Certainty in the solution
Written guidance, simulation (clear input)
Each step closes a 'black-box'

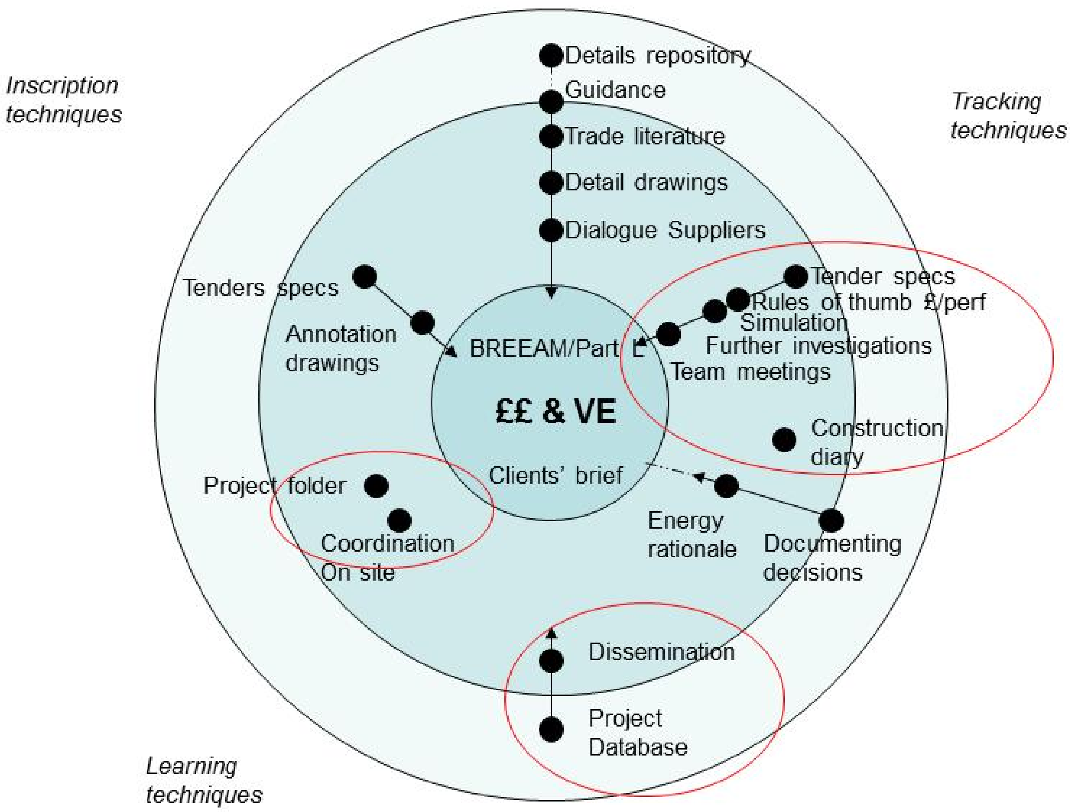

Testing
Tracking
Embedding performance
ARCH
OUTLINING
CALCULAT
Time


RIBA overlap D+B across cases
Gravitational force 'centre of design' in red- drivers/rationale/scale of values of this phase is likely to rule the drivers of the project- the earlier they are, the most they are centred on aspirations related to sustainability (intangibles); the later the centre is, the more the priorities are focused on practicalities (£, cost, profit, time)
K- contractor driven- practicalities
C- designers (arch) driven- aspirations
C
D
E
Planning Application
E F
G H
J
Detailed design
Tendering
1
Case 1
Same arch team goes from pre planning to post planning. They forecast issues during construction (overlaps, etc), respond to VE based on construction experience, etc
Different width of arrows represent to what extend the 'experiential knowledge' is brought backwards
2
Case 3
Rationale of design translated
rationale of design into const
changes
Same arch team goes from pre planning to post planning. They forecast issues during construction (overlaps, etc), respond to VE based on construction experience, etc
There is an 'experiential learning' from contractors dual position as bidder and as builder so tendering aims to forecast potential inconsistencies/changes- that's why the lighter blue arrow is there
4
Case 4
BREEAM credits
Rationale of design translated into rationale of design into construction changes
Revisiting why certain design was
Here I've been able to analyse more construction (?) their existing assumptions (rationale) is brought forward to detail design and construction
Dashed arrow as it seems that energy targets are not high on the priority list
5


Client
Quantity Surveyor
Contractor
Mechanic Engineer
Manufacturer
Architect
Value Engineer
Indicators
Performance estimation
Ally dissentender
% LZC technologies
Rules of thumb
Energy-driver
Simulation
Experience
U-value tool
U-values
Mediation
Cost
Cost/ benefit
Support
Leads to
Buildability
Cost/energy saving
% TER/DER
Knowledge cards
Embodied CO2
Ownership
Continuity
EPC
Fuel calculation
Glare
Airtightness
Resources
Annotations tenders
Ventilation
Synergy
Project datasheet
Detail retrieval
Construction diary
Overheating
Workshop
Process gateway
Site tests

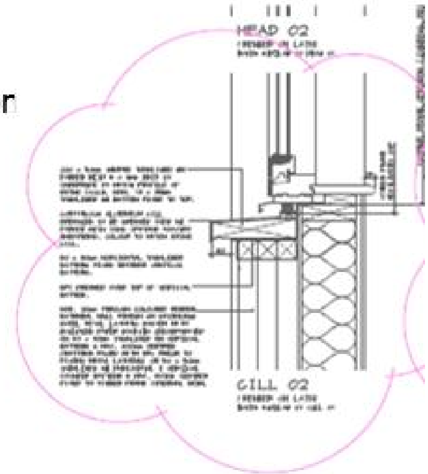
CS1 Conceptual Design Techniques associations





Construction gets closer: let's make the target explicit RIBA E-F

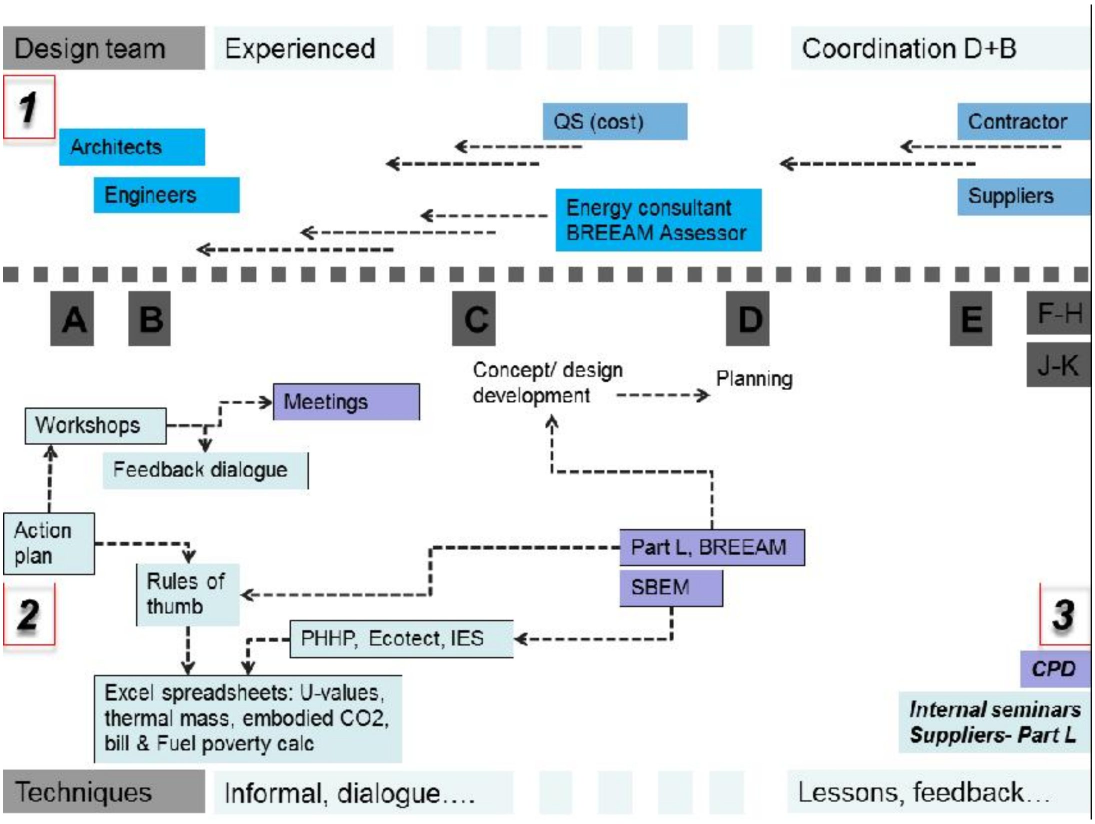
- Tender packages- details and specs (perf)
- Detail development: repository; consultation buildability
- Avoiding clashes: CS1 TECHN drawings, CS2 setting criteria, CS 3 BIM- REVIT
- Workshops and presentations to novated architecture team (RIBA G), clients, contractors CS1, CS 3; CS 4 – advice/co-design



'It's about getting the contractor and the delivery team to be more 21st century, rather than stuck in their ways'

'Information should be as rigorous as possible, a bit bullet-proof'

'We have to make sure that the sub-contractor's bits fit into an overall strategy and require minimum things to be achieved'



	Compliance-only	Performance-driven
Perceptions about energy	Energy is a burden superseded by project drivers	Energy is a driver or a project requirement whose synergies are sought with other requirements
Aim	Production of documentation for compliance	Evidence-based, informed design
Tools	Which ones.when SBEM and compliance evidence	Negotiation, understanding, mediation
Indexicality- what is it	Lost, no common context, know-that (energy-only) indicators obtained in isolation	Common construction around energy aspirations, rich dialogue to collectively inform know-how and know-why
Tool use	To produce the reports for compliance of policy gateways	To communicate with stakeholders and team members, to assist in the understanding
Social context	It is ignored undermining collaboration. Centred on deliverables and the production of official documentation	It is acknowledged and nurtured, utilised as a resource for common dialogue and understanding
Regard of performance (by?)	Theoretical compliance indicator based on an academic model	A process of construction of ownership and engagement to seek for an outcome or result
Knowledge creation in?	At best project dependant showing individual personalisation (Sexton) inept codification and no feed forward	Experiential, collective knowledge whose dissemination is done by dialogue, involving the awareness of the wider community from project to company level
Borderline (brown)	Boundaries act as barriers that obscure communication	Boundaries are the arena for negotiation and construction of shared understanding
Design and Built procurement	Fragmented, isolated work	Partnership, collaboration and negotiation

Example of table produced to withdraw inferences from the case studies

Appendix I. Ethnographic data examples

Theme	Quotes
Low carbon definition	*'What we call low carbon now is going to get redefined. It's like moving the goalposts because the original targets aren't actually achievable.'* *'For the zero carbon definition, there was a bit of a flawed consultation process. They [the policy makers] will probably be able to achieve it only by being obscure in the definition of zero carbon performance.'* *'The low carbon agenda is doable but leadership is key. We have to be pragmatic; being unrealistic is not helpful…'* *'The low carbon target can be very aspirational. People could say anything but not commit'* *'We'll never reach the target; it's some kind of false target. Nobody realized how difficult it was to achieve it'*
Part L, the regulatory instrument	*'[Low carbon design] is not going to happen unless legislation makes you do it'* *'Legislation is key, it's all about enforcement'* *'I think legislation is playing a useful role in allowing better performing building to be designed. Things like sustainability, if they are not written down, they are not going to happen because at the moment, and certainly for the short term anyway, it's going to be cheaper to build it cheaper…'*
Part L	*'Part L has become one of the first things you need to thing about'* *'Legislation has changed and become much more sophisticated over the last five years'* *'When 2006 Part L came in, obviously change was harder, but now we understand what is likely to be sufficient [to comply]'* *'We are based on what we know for 2006 and then we say we need to reduce this so we are about in the right place...'* *'For quite a lot of people, Part L is a bit of mystery, they will worry about it but they will not necessarily know exactly what to do with it. So some projects have had to be scheduled so to pass building control before Part L 2010'* *'Part L can be complex, even in our discipline [mechanical engineering], it is creating a sub-expertise with people who can produce models and worry about Part L and the other engineers who can't produce model or have not been trained in producing models who will rely on the modelling group…'* *'Part L uses a very sophisticated language and it heavily relies on the modelling, the TERs and DERs. Five or six years ago it was much more simple, you could say: this wall satisfies the u-value requirements…'* *'The problem with 2010 [is that] the notional building is much more accurate making the benchmark an ever changing target.'* *'Part L is not very obvious. It's quite overly complex and SBEM is not very user-*

	friendly for consultants'
BREEAM, the Welsh policy instrument	*'We have to make explicit the intangible agenda and BREEAM has helped in the process'* *'BREEAM certification is massively significant, better quality. It forces the clients to spend a bit more… BREEAM engages them more. Knowledge goes up, people are better informed.'* *'Knowledge about sustainability has been raised in the last few years possibly due to BREEAM awareness'* *'I think BREEAM is helping to embed performance because it's a badge, it's a selling point.'* *'Sometimes BREEAM adds a little bit of work to the already considerable workload… but once you have the experience of what you need to do, it becomes part of the process'*
	'BREEAM addresses far too much within one umbrella, too many factors…' *'I think the problem is that what makes you get BREEAM excellent a lot of the time might not be appropriate on certain buildings, do you see what I mean? Like, because a lot of the things are about, a lot of the credits can be about like transport and cycle racks(?) and stuff. But if you've got a building, in the middle of nowhere, it's just not practical to have, for anyone to cycle there because people live like ten, fifteen miles away. But because the building has to get BREEAM, they're kind of wasting money by putting a load of bike racks in, that will never get used…'* *'I think that BREEAM has too much gravity around and that in its own right is a limitation. That could misguide people. Are things there because there is an actual benefit to the design or because you get an extra BREEAM tick in the box for them? And fundamentally, lot of sustainable aspects are about being efficient. ‚If you're just putting something there that you're not going to use, that's about as inefficient as it gets. And I think that could be an interesting reality check I think, because I think there is a lot of smoke and mirrors…'* *'I think BREEAM could be a lot better… the zero carbon definition is this slightly strange concept. I think BREEAM is not rigorous. For example, I think something as Passivhaus is a different thing because it is purely about energy. BREEAM is useful but needs to be improved.'* *'BREEAM could be unnecessarily bureaucratic'*
Policy instruments as means to avoid changes (volatility of targets)	*'With a market like the one that we have at the moment, people are extra strong to sort of push and save as much money as possible… It could be anyone: client, contractor… but there is a point below which they can't go.'* *'BREEAM stops people from chipping away of sustainable targets later in the process'* *'If BREEAM is engaged to [in the project], then everyone is forced to do things that wouldn't be included otherwise'* *'2008 BREEAM brought in the post-construction [assessment] which was a big leap then. Now you say that you're going to design this and you do know actually that you will do it, you can't just pretend.'* *'We are all under financial pressures and the contractor wants to get it [the building] done for as little money as possible. Changes happen, eroding the design and you wonder whether there is respect for statutory requirements'*
Knowledge to implement	*'Incidental things [to design low carbon buildings] are the more demanding, getting the low carbon solutions could be very straight forward but what we find difficult to achieve*

low carbon strategies	*is the on-site renewables both in terms of space, cost and maintenance in the future… the delivery of the solution is more complicated than its technicality...'*
Low carbon performance as a building requirement	*'If you want to design low energy buildings, you have to make them commercially interesting'* *'It's about getting the client to do it and there is a fair number [of clients] that don't understand what low carbon design entails. And it's going to get more and more complex, as regulations start to get more and more onerous'* *'[Moving towards low carbon design] implies changing the current mindset to understand the value of carbon'* *'It comes down to capital costs, what the client can afford tends to drive everything. You hope that the clients take on board the aspirations but they may have a different agenda. It is about affordability.'* *'I guess is part of the philosophy of the firm to push a bit and be ahead of the game but we can't always do it. Some clients, we have to give them the minimum because we could draw it but they won't have the money to build it.'*
Procurement method and low carbon buildings	*'The procurement method is absolutely critical. Normally, in design and build procurement, it would not necessarily be the same design architect carrying through. Somebody else may come on board and he doesn't have the embedded knowledge in the job, he does not understand the design strategies.'* *'Splitting up the process between two separate people with different agendas. The design is likely to deteriorate and also its performance'* *'I don't see a problem on actually getting to zero carbon buildings but it requires the clients to buy it, it requires the contractors to actually build it properly… that's the issue.'* *'There is a degree of interpretation on that design and build procurement offers. There are opportunities for changes which could get abused so you lose the rigor of the design intent and of what gets finally implemented in a building.'* *'It's the designer's role to make sure that design meets the standards and the builder's work shouldn't be more complicated than it was before.'* *'It's about getting the contractor and the delivery team to be more 21st century rather than stuck in their ways. If you can show that it has commercial benefit on the overall picture, that's a start… you can show that sustainability has its commercial merits…'*

Chart summarising what the RIBA Plan of work 2007 and the recommendations of the Green Overlay for designing sustainable buildings (Gething 2011), compared to the observation in the case studies (right column):

	RIBA	Sustainability considerations	Checkpoints	Observed in the cases
Conceptual design	A B	Identification of sustainability aspirations, requirements and constraints	Review clients' needs, targets, consultations	The identification of aspirations and statutory requirements is done in performance-driven processes by cards, databases for benchmarking, consultations (BREEAM)
	C	Development of environmental strategies, systems, cost and energy plans	Pre- sustainability assessment, deviation from the aspirations reported, initial Part L assessments	Identification of strategies, conversations for performance understanding, changes in the targets are not reported, the assessment is done by a rough simulation model and in-house tools
	D	Development environmental strategies	Interim Part L	Designers were doing BREEAM assessments for planning application and using SBEM or proprietary software for BREEAM energy credits evidence. BREEAM is the inscription of the target.
Detailed design	E	Specifications, technical design, statutory and sustainable assessment	Sustainable assessment substantially complete, details audited airtightness, insulation continuity, subcontractors' package coordination	The design is being developed. The spefications are defined. The dialogue helps to develop the details. The reference to performance requirements and remedial work may be incomplete in the tenders
	F	Tenders statutory approval	Part L submission, sustainable assessment information, sustainable criteria demonstrated, monitoring techniques	Design is unlikely to be finilised, sustainable assessemtn could vary. Value engineering may produce changes. Part L is submitted
	G	Collating documentation	Sustainable standard specified	Regulatory standards are stated and Part L compliance guide the delivery documentation.
	H	Evidence from contractors	Appraisal of tenders	Construction sustainability credentials of contractor are assessed. The value engineering exercises may produce changes to reduce cost and time onsite.
	J	Building contracts and hand-over to contractor	Design stage sustainability assessment ready, construction sustainability procedures developed with the contractor	The energy performance is unlikely to be monitored during construction. The changes on site do not tend to be recorded. There could be an incomplete update of documentation
	K	Review of information, commissioning, training and monitoring	Interim testing and monitoring of construction, comparison of changes of specifications against the agreed ones	The energy assessment is done for the Part L updated model. The changes are evaluated in the light of designer's experience. The targets are movable until meeting the minimum regulatory requirement.
	L	Assisting the user during initial occupation, revision of project performance in use	Assisting in fine tuning the building, declaration of energy use	Building users' manuals are produced. Workshops may be held. There is no real monitoring of in-use performance. Designers are unlikely to assist the users beyond the provision of manuals.

Circumstances specific to the case studies analysed in conceptual design

	Context of the project	Specific investigations
1	Regeneration project, part of a larger scale development to revitalise a deprived area in Wales.	Embodied carbon was a criterion in the master plan as well as the reduction of energy use by renewable sources Life cycle cost including payback cost with carbon offset effectiveness, embodied carbon calculator, climate change and overheat considerations
2	Construction of a school in 12 months to replace the existing one. Time and cost were the drivers of this project. Key to deliver targets and milestones in time.	Client required a minimum of 20 per cent of energy supplied by renewable sources. The county also required the achievement of BREEAM Very Good. Due to the urgent need of spaces in the existing school, this project had to be delivered for the use of the new school term in September 2011. Embodied carbon was outlined in relation to build up materials however they were not implemented.
3A	Construction of a school to replace the old one. Client had experience in the commissioning of other schools where they gained awareness of energy efficiency.	Running cost was an important criterion for the client who had a portfolio of educational schools. Energy driven strategies were supported as a means to use the budget allocated for the operation of the school for educational material. Changes were made to the design to make it more energy efficient and save on operational costs.
4A	The school site was located in an area that caused conflicts with the neighbourhood next to the site due to new volume of traffic as result of the school construction and operation. The team and the client were eager to counterbalance the neighbourhood opposition by creating a high sustainable standard school that did not perturb the natural area of the site which was claimed to be of public use as a park	The life cycle cost was a 'life document' entangled with the simulation results so to assess the suitability of energy strategies.

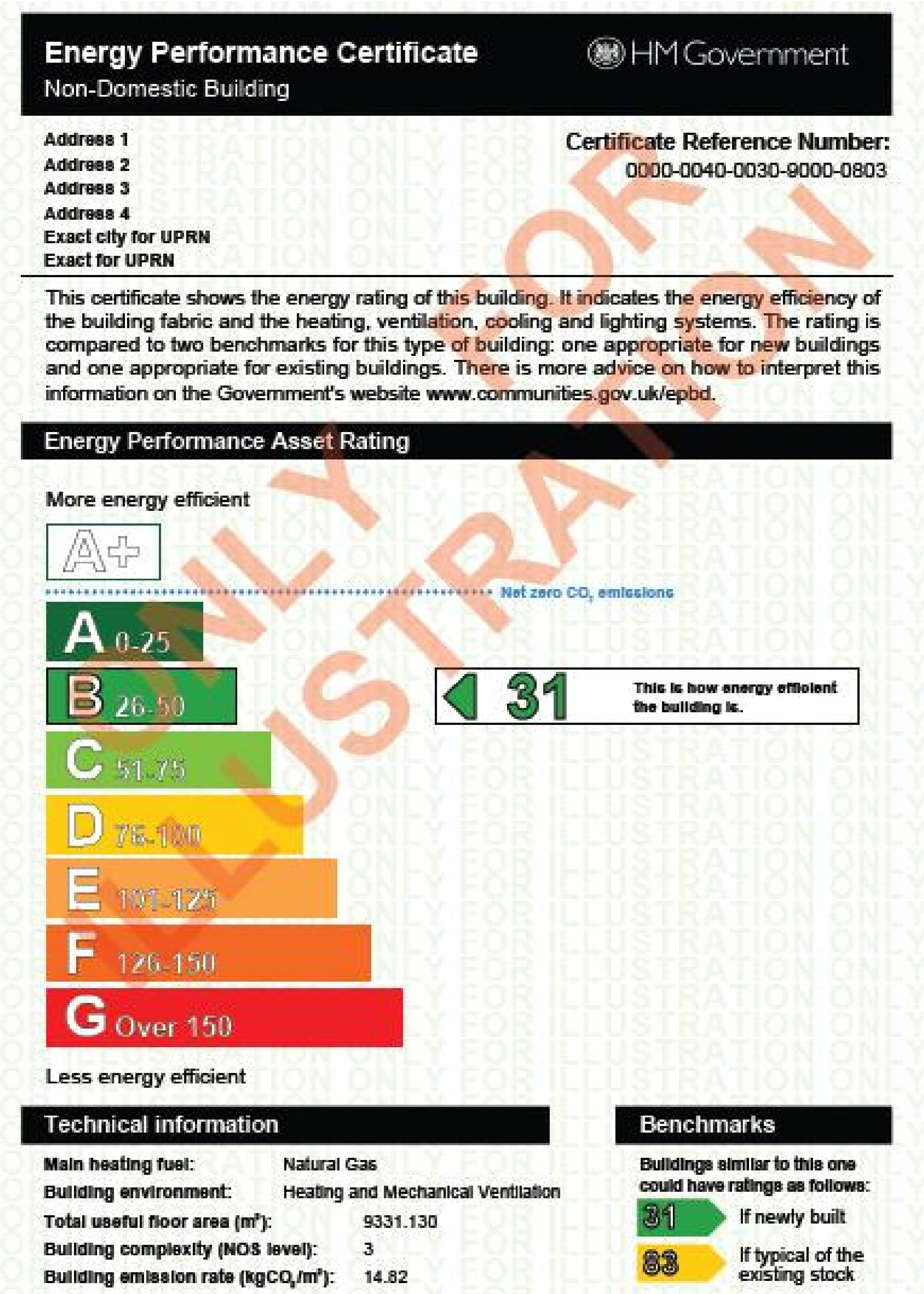
Building aspects and standards (extracted from case study 1 documentation)

ASPECT	INDICATOR	STANDARD/GUIDELINE
Energy performance	EPC Building emission rate kgCO2/m2 (EPC report) HVAC systems performance Heating & cool ingdemand (MJ/m2), heating and cooling consumption (kWh/m2), auxiliary consumption (kWh/m2), heat System seasonal efficiency SSEFF, cooling SSEER (seasonal eff ratio)	BREEAM Part L evidence
Low and zero carbon technologies	Energy/cost synergies: energy generated per year kWh/y, carbon offset (Kg CO2/y), % carbon offset per year, payback (in year), Land use, local planning criteria, noise, feasibility for exporting heat/electricity, cost per unit of carbon savings (£/kgCO2)-capital costs, costs of installation, available grants % of energy supplied by low and zero carbon technologies FIT rate (p/kWh); RHI tariff p/kWh and duration (years) Generation capacity of renewable energy <no benchmark, discretionary, individual perceptions??>	BREEAM Renewable energy options (market incentives) Trade literature

Overheating	Maximum 120 hours over 28C, external temperature difference not exceeding 5C, internal air temperature not exceeding 32C	BB 101, DCSF Low carbon calculator, ClasSBEMt calculator tool for compliance with airflow performance standards, ClassCool tool by DCSF
	Temperature: winter design week and day per classroom and per hour: dry bulb and resultant; mid season; summer;summer design day (temperature (T) load (kW) <?> per hours- dry bulb, ambient temperature, solar gains, internal gains	
	Range of incidence (temperature): Annual Number of Hours of Dry Bulb Temperatures (ºC) During Occupied Hours, % frequencies and dry resultant temperatures (using Design summer day and test reference year	
	Winter heating temperatures; 28C not exceeded for 80 hours during occupancy period	BB 87: Environmental design for schools
	25C not exceeding more than 5% working hours	British Council for Offices guide
Thermal performance	Air temperature, mean radiant temperature, humidity PMV, others	Adaptive comfort approach Thermal comfort Fanger CS1 (check case 2)
Solar gain	Solar gain against ambient air temperature Temperature What's the indicator of solar gain? Ks	CIBSE AM 11 Building energy and enviromental modelling, Health and Safety (Miscellaneous Amendments) Regulations 2002, BB 87, BB 101 and Part L
Ventilation	Fresh air ventilation rate (ACH?) Summer maximum temperatures Internal CO2 levels based on space occupancies	BB 101, Part F and the Workplace Regulations, CIBSE codes for mechanical ventilation of kitchens and workshops
Air infiltration	m3/h/m2 of façade area @ 50Pa	Part L
Building fabric and materials	U-values	BB87, BB93 acoustic properties and performance , Building regulations (Part L, E)
Glazing materials performance	Wall: thermal properties u-v <unified wording>, testing, workmanship, onsite accuracy (tolerances, verticality, thickness, level), G value, solar control outer G-value	Centre for Window and Cladding Technology (CWCT) standard Part 5 thermal, moisture and acoustic performance
	Air permeability (m3/h/m2) for fixed and (m3/h/lin.m2) for opening lights <is this the same thatn the air infiltration 3 lines up?>	BS EN 12152: A4 peak pressure 600Pa
Climate change adaptation	Thermal performance indexes <which ones? Read cibse AM11!>	UK Climate Impacts Programme, CIBSE Test reference Year CIBSE AM 11 Building energy and environmental modelling
Lighting	Use of efficient luminaries with a minimum light output ratio LOR of 80%; control gear for any fluorescent lamp either type A or B as defined <?>	SSLD Guideline Note 4: Lighting systems in schools, CELMA 11 energy class
	Efficacy of luminaire lumens per circuit Watt. Electric lighting uniformity ratio; automatic daylight dimming when under % daylight factor	BB90, CIBSE code for lighting, Part L2A
Building controls	Inclusion of automatic meter reading, optimisation, weather compensation, scheduling, time extension, frost protection and holiday setting with a user interface	Part L and CIBSE TM 39

	Inclusion of control and monitor space temperature per room, individual and automatic temperature monitoring for occupied spaces, optimum start, stop control of plant operation and weather compensation, permit time and holidays schedules and scheduled out-of-hours operation programming, alarm and hard copy record of any plant failure resulting in low or high temperature, log domestic hot water flow and return temperatures, monitor incoming gas power and water consumption, software based maintenance system to assist planned maintenance; lighting controls, monitor water tank storage temperature BMS power consumed by individual meters, areas/zones of the building, current, kWh, power factor, maximum kWA demand	Prescription /checklist of minimum characteristic i.e.
Hot Water	Final discharge temperature, storage availability, pressure, emergency provision, metered by a device with the capability to be read electronically; minimum system efficiency in relation to fuel input, standing losses for electrically heated hot water services i.e. hand washing W/basin	Prescription
Hot Water storage	Water supply, time, volume per people. Temperature for water storage and circulation	CIBSE guidelines
Glare	Prediction techniques for solar gain, glare index	Design guidance from Society of Light and Lighting: Lighting guide 5, BB90, EN 12464 CIBSE, CIE
Daylight	Daylight factors which ones?, uniformity of daylighting	BREEAM, EN 15193 Energy performance of buildings- energy requirements for lighting
Acoustics	Internal noise levels from equipment external noise sources Performance of construction elements dB noise tolerance, reverberation, maximum weighted standardised impact sound pressure level, sound absorption coefficient (octave band centre frequency Hz)	BB 93: Acoustic Design of Schools, Part E BREEAM
Emergency lighting	Efficacy lumens per circuit watt Time controls and daylight level photocell controls Light pollution minimisation Prescription	BB90, 100, BS EN 60598-2-22:1999, BS EN 50172, LG12, CIBSE and the Building Regulations Approved document B, Fire Safety, Light pollution BS 5489
Mains distribution	Panel boards (MCCB) with submetering and minimum spare capacity Prescription	BS7671 section 607 earthing arrangements
Flexibility	ICT/data, flexibility requirements (not energy or performance related but affecting the passive design strategy)	BB95: Schools for the Future- design for learning communities
Equipment	Energy certification, band ratings	EPBD

This section includes some examples of the data obtained in the field. In order to protect the anonymity and confidentiality of the research participants, some information has been removed.



Energy Performance Certificate
Non-Domestic Building

HM Government

Address 1
Address 2
Address 3
Address 4
Exact city for UPRN
Exact for UPRN

Certificate Reference Number:
0000-0040-0030-9000-0803

This certificate shows the energy rating of this building. It indicates the energy efficiency of the building fabric and the heating, ventilation, cooling and lighting systems. The rating is compared to two benchmarks for this type of building: one appropriate for new buildings and one appropriate for existing buildings. There is more advice on how to interpret this information on the Government's website www.communities.gov.uk/epbd.

Energy Performance Asset Rating

More energy efficient

A+

Net zero CO_2 emissions

A 0-25
B 26-50
C 51-75
D 76-100
E 101-125
F 126-150
G Over 150

31 This is how energy efficient the building is.

Less energy efficient

ONLY FOR ILLUSTRATION

Technical information

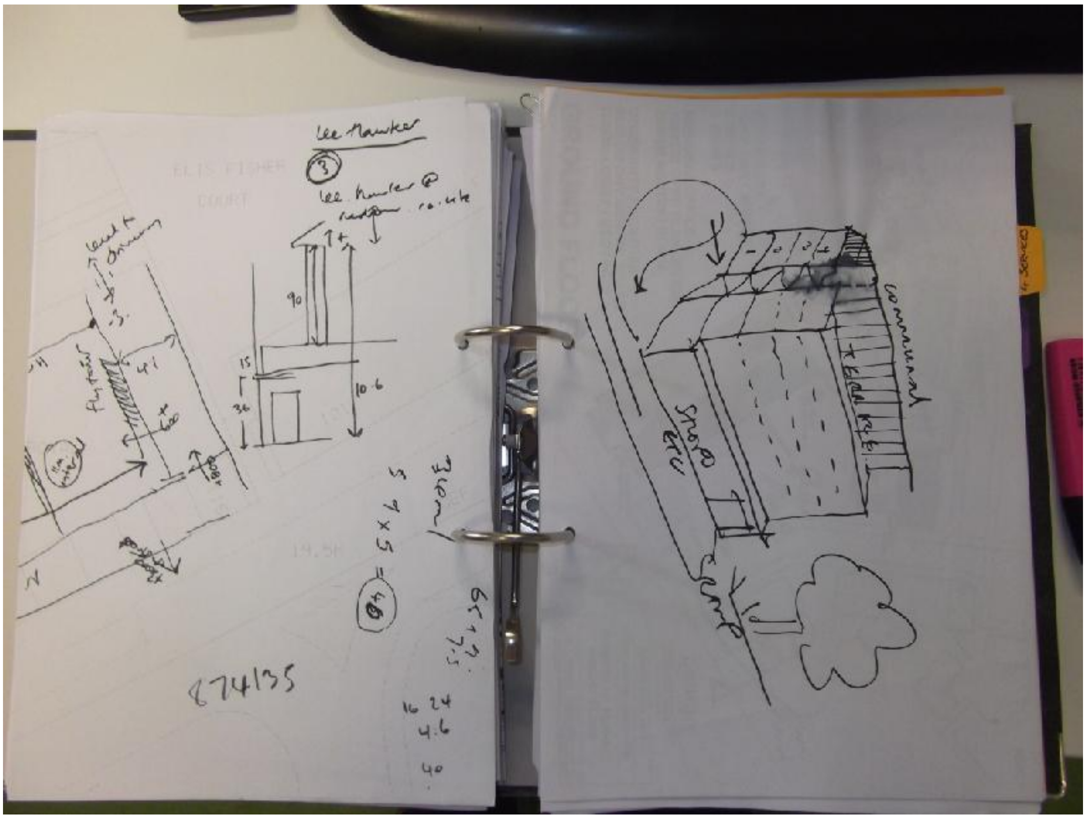
Main heating fuel:	Natural Gas
Building environment:	Heating and Mechanical Ventilation
Total useful floor area (m^2):	9331.130
Building complexity (NOS level):	3
Building emission rate ($kgCO_2/m^2$):	14.82

Benchmarks

Buildings similar to this one could have ratings as follows:

31 If newly built

83 If typical of the existing stock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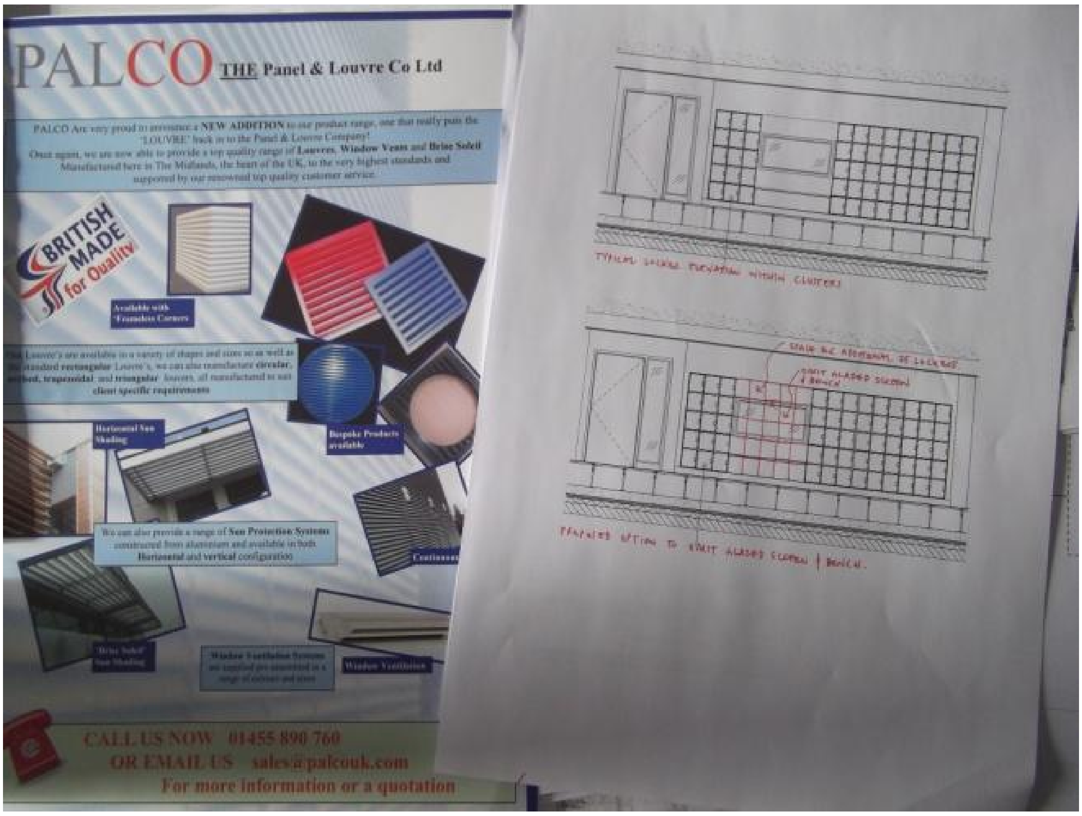
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Building Regulations:

Specific parameters can be relaxed or tightened during the briefing process. However, whilst the Building Bulletin documents are for guidance only, the Building Regulations are mandatory and the following documents are particularly relevant to the building services engineering design:

- Part L2A 2010: Conservation of Fuel and Power
  Sets specific carbon emissions targets per m² of building per annum. It applies to new buildings and was revised in 2006 to align with the EU's Energy Performance of Buildings Directive. Further revision is due to come into affect in October 2010 which will apply to the School, and demands 25% less carbon emission per m² than the 2006 edition.

- Part F: Ventilation
  Sets fresh air ventilation rates per person with a view to providing acceptable carbon dioxide levels inside buildings. Revised in 2006 & 2010 and will overlap with BB 101.

Building Regulations
L2A. Conservation of Fuel & Power
Part F: Ventilation

4.2 Low Carbon Approach

Energy use and the resulting carbon dioxide emissions are key sustainability topics for the school. In order to meet minimum energy requirements a three-stage hierarchy will be used, as illustrated in the diagram below.

The diagram shows the relative carbon savings against cost for the different aspects of the design to be targeted and hence outlines the design priorities or hierarchy.

The hierarchy will be applied to Ebbw Vale 11 16 school by; first implementing a passive design approach providing the largest carbon savings for the smallest additional cost.

The requirement for conditioning of spaces is passively reduced as far as possible and then the building systems will ' trim' the comfort conditions. The building systems are being designed to minimise energy in construction, use, maintenance and demolition.

Lastly we are committed to a site wide energy strategy incorporating renewable district heating source and looking to incorporate renewables on the building as well.

These 3 themes are developed further in the following pages.

Low Carbon Approach, demonstrating cost against environmental benefit

4.2.1 Energy reduction – Passive Design Approach

The building will be designed with a passive approach in mind for all disciplines. Passive design principles provide the largest energy savings at lowest cost. The key aspects of which are highlighted below:

Building orientation

• Orientation predominantly east-west with clear north and south facing facades, makes use of passive solar gain in the winter, whilst more effectively controlling unwanted gain in summer.
• A robust exterior façades will protect against the driving wind and rain, leaving sheltered and calm interior Concourse.

Natural daylight

• Maximise natural daylight within the building in order to maximise energy savings and occupant well-being
• Daylight modelling in ensuring lively day-lit spaces achieving sufficient Lux levels whilst not experiencing overheating
• Daylight linked lighting to reduce power for lighting and internal gains

Solar gain & Control

• Brise soleil controls solar gain in summer, and should be horizontal on south façades (where the sun is high in the sky) and vertical on the west facade (where the sun is low)
• Utilising passive solar gain provides heating energy savings and pleasant winter spaces.

Exposed thermal mass

• Thermal mass refers to building elements with high specific heat capacity which passively attenuate external heat fluctuations
• In summer it provides a cool surface to absorb heat during the day which can purged from the space at night with secure night-time ventilation.
• In winter it will buffer against external temperature fluctuations and reducing heat losses and associated energy for heating.

Natural & Mixed mode ventilation

• Intelligent natural ventilation design, to incorporate acoustic, air quality and thermal comfort requirements
• Mixed mode ventilation for energy savings in densely loaded spaces

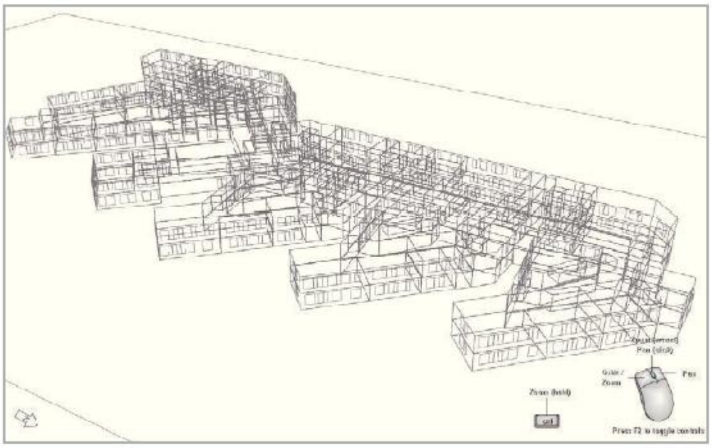
Building Fabric

• Space planning to allow for thick wall construction, within which high performing insulation will achieve exceptional U-values.
• Risk of cold bridging minimised with robust detailing and thermally broken louvres and dampers.
• A well sealed building to provide significant carbon emission savings. Through dedication from the architect in detailing, the contractor in construction and the occupants in use.

Passive Design utilising exposed concrete soffits and good daylight design at the Roland Levinsky Building, Plymouth

This report has been produced with the following aims in mind:

- To confirm the brief with the Client and raise briefing questions
- To provide information to allow the Quantity Surveyor to estimate costs for the M&E engineering services.
- As a basis for the development of the next design stage

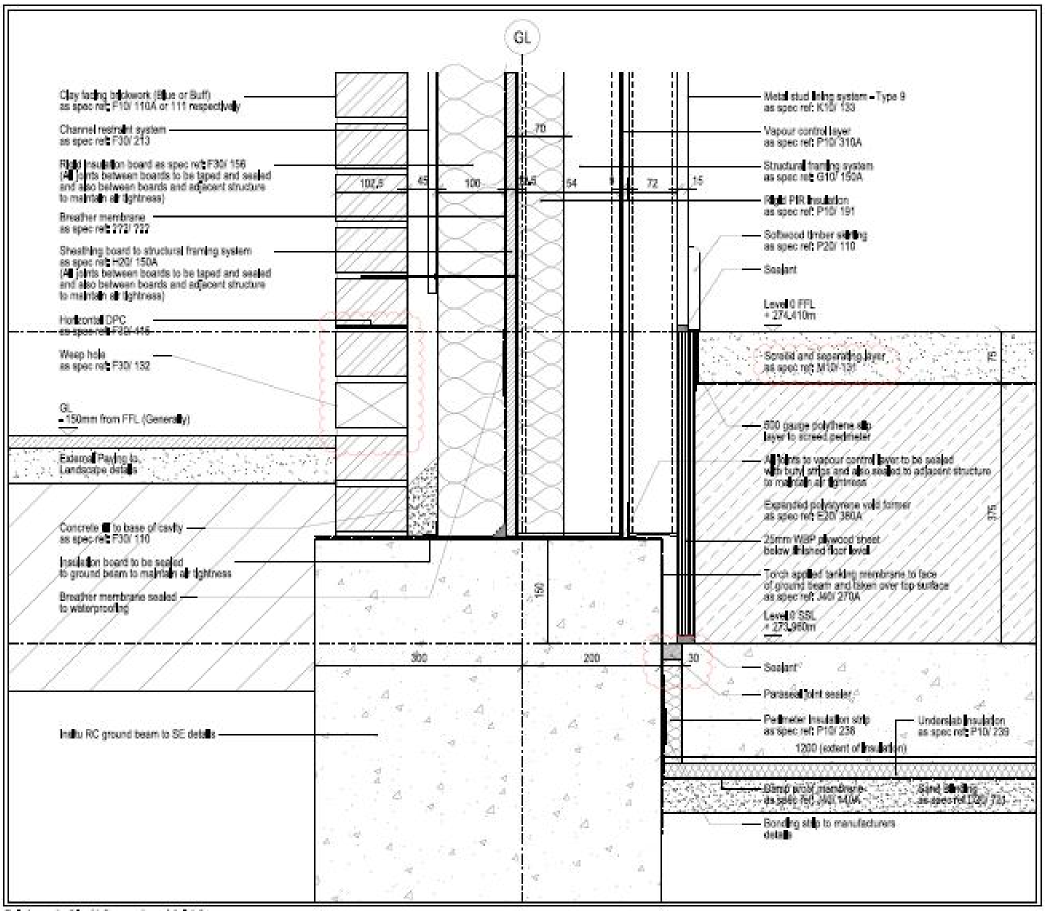


Ref	Title	Responsible for credit	Information required within Stage D Report
Hea 6	Lighting Zones & Controls	Lighting	1. Confirmation within Stage D report that lighting will be zoned to allow separate occupant control of the following areas: a. Teaching space/demonstration area b. Whiteboard/display screen c. In office areas, zones of no more than four workplaces. d. Workstations adjacent to windows/atria and other building areas separately zoned and controlled. 2. Confirmation within Stage D report that manual lighting controls will be easily accessible for the teacher whilst teaching and on entering/leaving the teaching space.
Hea 9	Volatile Organic Compounds	Architect	1. Specification clauses for relevant materials outlining the requirements needed to meet the criteria set out within the table in the BREEAM guidance.
Hea 10	Thermal Comfort	M&E	1. Confirmation that dynamic thermal modelling been carried out in accordance with CIBSE AM11 Building Energy and Environmental Modelling. 2. A copy of the results from the modelling demonstrating summer temperatures significantly better than the recommendations of Building Bulletin 101 e.g. there are fewer than 60 hours a year where temperatures rise above 28°C.
Hea 11	Thermal Zoning	M&E	1. Description within Stage D report and/or marked-up M&E drawings confirming: · Scope of the heating/cooling system · The type of user controls for the above systems · The zoning allows separate occupant control of each perimeter area (i.e. within 7m of each external wall) and, where applicable, the central zone (i.e. over 7m from the external walls).
Hea 12	Microbial Contamination	M&E	1. Statement within Stage D report confirming that: All water systems in the building are to be designed in compliance with the measures outlined in the Health and Safety Executive's "Legionnaires' disease - The control of legionella bacteria in water systems". Approved Code of Practice and guidance, 2000.
Hea 13	Acoustic Performance	Acoustician	1. A copy of the acousticians report and calculations confirming: · The specific performances standards achieved/prescribed for each relevant room/area - Classrooms/music accommodation/roof noise · The standards comply, and where relevant exceed the levels required by BB93. 2. Specification clause stating: Pre-completion acoustic testing is carried out by a suitably qualified acoustician to ensure that all relevant spaces (as built) achieve the required performance standards. Any remedial works required in spaces that do not meet the standards are completed prior to handover and occupation.
Hea 16	Drinking Water	Architect/M&E	1. Marked-up drawings showing: · Location, number (minimum 2no.) and type of compliant water coolers 2. Description within Stage D report to confirm that water coolers will be: · Mains fed and chilled, attached to both the wall and the floor to prevent vandalism, and contain security covers to protect all water and electrical connections.
Hea 17	Specification of Laboratory Fume Cupboards	M&E	1. Statement within Stage D Report confirming that fume cupboards will be manufactured and installed in accordance with the following: a. General purpose fume cupboards: BS EN 14175-2 b. Recirculatory filtration fume cupboards: BS 7989 c. Building Bulletin 88 2. The discharged velocity from the extract fan stack from a ducted fume cupboard will be ≥10m/s as recommended by BS EN 14175-2.:
ENERGY			
Ene 1	Reduction of CO2 Emissions	M&E	1. A copy of the EPC output from the approved software for the assessed building at the design stage. 2. The accredited energy assessor's name and accreditation number (this information will be on the EPC).
Ene 2	Sub-metering of substantial energy uses	M&E	1. Description within Stage D report or technical drawings confirming that: · Separate accessible energy sub-meters, labelled with the end energy consuming use, are provided for the following systems: a. Space Heating b. Domestic Hot Water c. Humidification d. Cooling e. Fans (major) f. Lighting g. Small Power (lighting and small power can be on the same sub-meter where supplies are taken at each floor/department). h. Other major energy-consuming items where appropriate
Ene 3	Sub-metering of high energy load and Tenancy areas	M&E	1. Marked-up drawings and site plan detailing: · Location of meters. 2. Description within Stage D report or technical drawings confirming: · Metering arrangements for each department/function and/or tenancy area

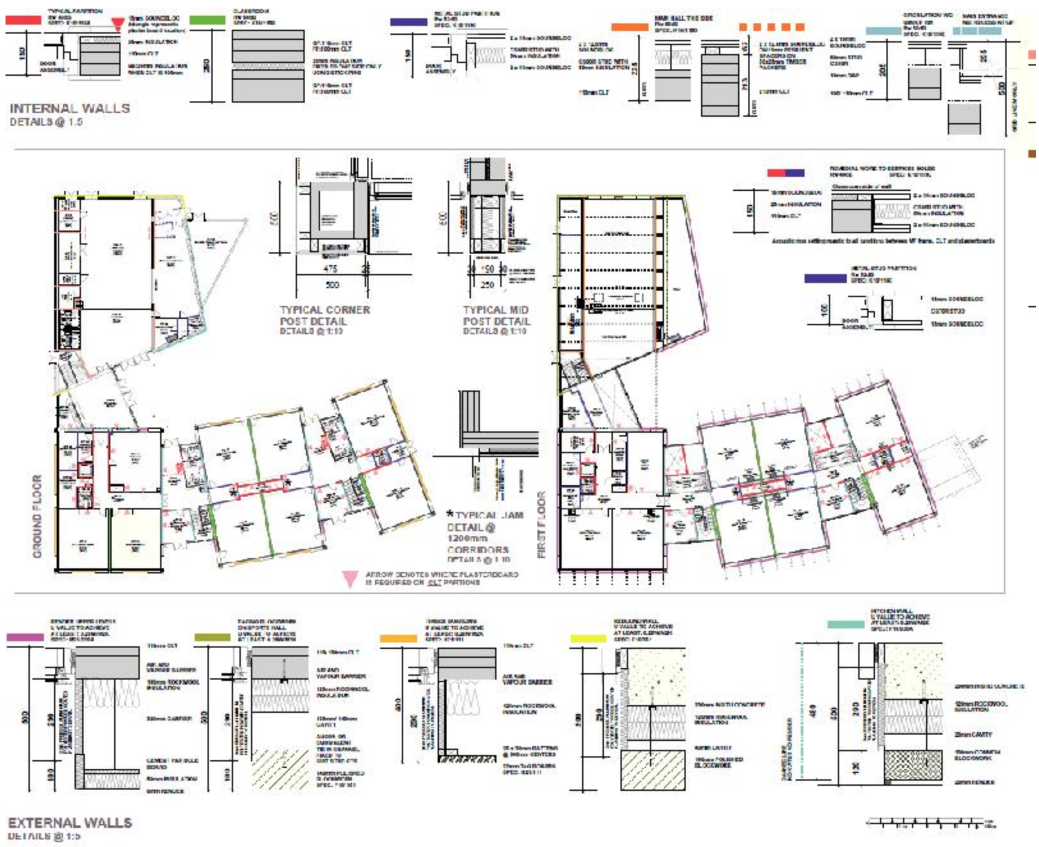
A design stage BREEAM report will be undertaken prior to construction starting on site, at that point a design stage rating will be issued. Prior to the design stage assessment a pre assessment exercise is used to determine the anticipated BREEAM rating. The pre assessment for this project is shown below which indicates a BREEAM score of 73.99%. This equates to a BREEAM rating of excellent.

Hea 13	Acoustic Performance	2	2	Amber [illegible]
Hea 16	Drinking Water	1	1	Green M&E
Ene 1	Reduction of CO_2 Emissions	15	11	Amber [illegible]
Ene 2	Sub-metering of Substantial Energy Uses	1	1	Green M&E
Ene 4	External Lighting	1	1	Green M&E
Ene 5	Low Zero Carbon Technologies	1	2	Green M&E
Ene 10	Free Cooling	1	1	Green M&E
Tra 1	Provision of Public Transport	2	0	Amber [illegible]
Tra 2	Proximity to Amenities	1	0	Red
Tra 3	Cyclist Facilities	2	2	Green CIA
Tra 4	Pedestrian and Cycle Safety	1	1	Green LA
Tra 5	Travel Plan	1	1	Green [illegible]
Tra 6	Deliveries and Manoeuvring	1	1	Green LA
Wat 1	Water Consumption	3	2	Amber M&E
Wat 2	Water Meter	1	1	Green M&E
Wat 3	Major leak Detection	1	1	Green M&E
Wat 4	Sanitary Supply Shut Off	1	1	Green M&E
Wat 5	Water Recycling	1	1	Green [illegible]
Wat 6	Irrigation Systems	1	1	Green [illegible]
Mat 1	Materials Specification (major building elements)	6	4	Amber A
Mat 2	Hard Landscaping and Boundary Protection	1	1	Green LA
Mat 3	Re-use of Building Facade	1	1	Red
Mat 4	Re-use of Structure	1	1	Red
Mat 5	Responsible Sourcing of Materials	3	3	Amber A
Mat 6	Insulation	2	2	Green A/M&E
Mat 7	Designing For Robustness	1	1	Green A/LA
Wst 1	Construction Site Waste Management	4	2	Amber [illegible]
Wst 2	Recycled Aggregates	1	1	Amber S
Wst 3	Recyclable Waste Storage	2	1	Amber LA
LE1	Re-use of Land	1	1	Red
LE 2	Contaminated Land	1	1	Red
LE 3	Ecological Value of Site AND Protection of Ecological Features	1	1	Red
LE 4	Mitigating Ecological Impact	2	1	Amber E
LE 5	Enhancing Site Ecology	3	3	Amber E
LE 6	Long Term Impact on Biodiversity	2	1	Amber E
LE 7	Consultation with Students and Staff	1	1	Green E/C
LE 8	Local Wildlife Partnership	1	1	Amber [illegible]
Pol 1	Refrigerant GWP – Building Services	1	1	Amber M&E
Pol 3	Preventing Refrigerant Leaks	1	1	Amber M&E
Pol 4	NO_x Emissions from Heating Source	3	3	Green M&E
Pol 5	Flood Risk	3	3	Green [illegible]
Pol 6	Minimising Watercourse Pollution	1	1	Green [illegible]
Pol 7	Reduction of Night Time Light Pollution	1	1	Green M&E
Pol 8	Noise Attenuation	1	1	Green [illegible]
Inn 1	Innovation Considerate Constructors	1	0	Amber [illegible]
	Innovation – Daylighting	1	1	Green M&E/A
	Innovation – Reduction in CO_2	2	0	Amber M&E
	Innovation – Low or Zero Carbon Technologies	1	0	Amber M&E
	Innovation – Water Meter	1	1	Green [illegible]
	Innovation – Materials Specification	1	0	Amber A
	Innovation – Responsible Sourcing of Materials	1	0	Red
	Innovation – Construction Site Waste Management	1	0	Amber [illegible]
	Innovation – BREEAM Accredited Professional	2	2	Green [illegible]
Percentage Score			73.98%	

Need to include full pre assessment table from the stage C



Brickwork Clad/ Screed on Void former



1 Introduction

This feasibility study has been prepared in order to establish the most appropriate local low or zero carbon (LZC) energy sources for the proposed new Gateway to the Valleys (G2V) school at Tondu.

The report has been prepared in accordance with the Ministerial Interim Planning Policy Statement (MIPPS) 01/2009 and Draft Technical Advice Note (TAN 22) on Planning for Sustainable Buildings. It is also intended to satisfy the requirements of the BREEAM assessment for a feasibility study at RIBA Stage B.

The following LCZ technologies are discussed in detail:

- Solar Hot Water
- Biomass
- Combined Heat and Power (CHP)
- Ground Source Heat Pumps
- Photovoltaics (PV)
- Wind Power

In addition, an appraisal of ICT heat recovery, rainwater harvesting and greywater use is also presented.

1.1 Feasibility Overview

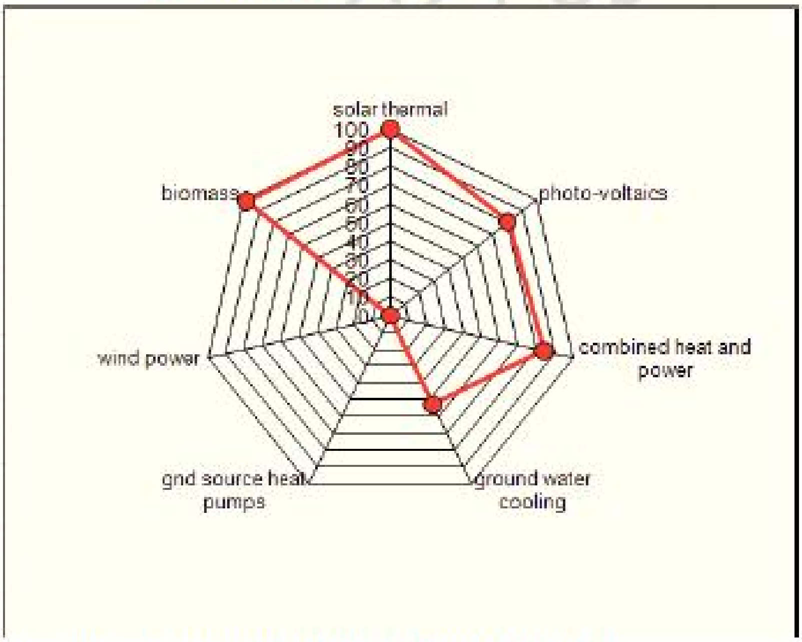


Figure 1: Summary of feasibility – CIBSE TM38 Tool

The CIBSE TM38 Tool is a quick guide to the feasibility of a number of LZC technologies for a particular project. By responding to a number of fundamental questions on each technology, as well as prioritizing key criteria, the tool produces a graphic to give an early indication of the potential use of each LZC

1.2 Building Loads

The proposed G2V development will consist of:

- New secondary school/community building at Tondu to accommodate pupils.
- The total floor area for the building is estimated at 14,331m^2.

The building loads used in this report are based on:

- Energy Consumption Guide 73 – Schools
- BSRIA Rule of Thumb
- Our design experience from previous school design projects

Building loads for the new G2V facilities have been estimated as:

Heating annual consumption:	100kWh/m^2/year
Peak heating load	70W/m^2
Peak domestic hot water demand:	190kW
Electricity annual consumption:	20kWh/m^2/year
Electrical peak demand:	100VA/m^2

Calculation	Energy Calculation - Temperatures	Made by	SC	Date	31/

Core Hours 8-6

Temp	Hrs Below Jan 1 - Apr 31	Hrs in range Jan 1 - Apr 31	Hrs Below Oct 1 - Dec 31	Hrs in range Oct 1 - Dec 31
-1	1	1	0	0
0	11	10	3	3
1	21	10	21	18
2	34	13	39	18
3	92	50	59	20
4	159	67	81	22
5	222	63	111	30
6	319	97	149	38
7	443	124	219	70
8	603	160	335	116
9	793	190	457	122
10	984	191	592	135
11	1160	176	711	119
12	1258	98	830	119
13	1332	74	935	105
14	1391	59	1028	93
15	1424	33	1084	56
16	1439	15	1102	18
17	1440	1	1104	2
18	1440	0	1104	0
19				
20				

Out of hours 06-Oct

Temp	Hrs Below Jan 1 - Apr 31	Hrs in range Jan 1 - Apr 31	Hrs Below Oct 1 - Dec 31	Hrs in range Oct 1 - Dec 31
-1	6	6	0	0
0	13	7	0	0
1	27	14	4	4
2	42	15	10	6
3	72	30	32	22
4	107	35	56	24
5	147	40	77	21
6	205	58	103	26
7	290	85	122	19
8	364	74	175	53
9	455	91	224	49
10	512	57	287	63
11	549	37	313	26
12	575	26	358	45
13	594	19	402	44
14	599	5	443	41
15	600	1	456	13
16			459	3
17			460	1
18				
19				
20				

Below is our revised annual energy consumption figures for Chilton Trinity. This calculation is based c
assumptions on tab 2 of this document and includes for the additional ANC items: the staff-base teaki
and the LED clocks.

GAS	Total kWh/year/m² Core Hours Only
HOT WATER & LTHW REQUIREMENT	73.9
KITCHEN REQUIREMENT	7.5
SCIENCE & TECH	3.9
TOTAL BIOMASS kWh:	55.9
TOTAL GAS kWh:	29.5

ELECTRICITY	Total kWh/year/m² Core Hours Only
AIR HANDLING UNITS*	6.5
SPECIALIST EXTRACT*	0.1
PUMPS/BIOMASS AUGER/ACTUATORS*	1.1
CONTROLS	0.4
SMALL POWER (INC. KITCHEN)	8.0
INTERNAL LIGHTING	11.1
EXTERNAL LIGHTING	0.3
COOLING*	4.6
IT	7.9
SUB-TOTAL ELECTRICITY kWh:	40.0
ANC ADDITIONS	0.4
TOTAL ELECTRICITY kWh:	40.4

Note - * denotes a power factor of 0.95 applied

CARBON	$kgCO_2$/year/m² Core Hours Only
GAS (@ 0.194 $kgCO_2$/kWh)	5.7
BIOMASS (@ 0.025 $kgCO_2$/kWh)	1.4
ELECTRICITY (@ 0.52 $kgCO_2$/kWh)	20.8
ELEC. GENERATED FROM 150m² PV	-0.9
SUB-TOTAL CARBON $kgCO_2$	27.0
ANC ELECTRICITY (@ 0.52 $kgCO_2$/kWh)	0.2
ANC ELEC. GENERATED FROM 37m² PV	-0.2
TOTAL CARBON $kgCO_2$	27.0

	Total kWh/year (core hours)	Total kWh/year (out of core hours)	Total kWh/year (Wet Leisure Enabling Use Only)	Total kWh/year (Sum of all)
GAS				
HOT WATER & LTHW REQUIREMENT	739,790	264,296	63,489	1,067,576
KITCHEN REQUIREMENT	75,236	26,879	6,457	108,571
SCIENCE & TECH	38,940	13,912	3,342	56,193
TOTAL BIOMASS kWh:	558,987	199,703	47,972	806,662
TOTAL GAS kWh:	294,979	105,384	25,315	425,678
ELECTRICITY				
AIR HANDLING UNITS*	64,987	31,054	5,577	101,619
SPECIALIST EXTRACT*	975	466	84	1,524
PUMPS/BIOMASS AUGER/ACTUATORS*	10,911	5,214	936	17,062
CONTROLS	4,002	1,913	343	6,258
SMALL POWER (INC. KITCHEN)	80,283	38,363	6,890	125,536
INTERNAL LIGHTING	111,405	53,235	9,561	174,200
EXTERNAL LIGHTING	2,818	1,347	242	4,406
COOLING*	46,147	22,052	3,960	72,159
IT	79,047	37,773	6,784	123,604
SUB-TOTAL ELECTRICITY kWh:	400,577	191,416	34,377	626,370
ANC ADDITIONS	4,114	1,966	353	6,433
TOTAL ELECTRICITY kWh:	404,690	193,382	34,731	632,803

Note - * denotes a power factor of 0.95 applied

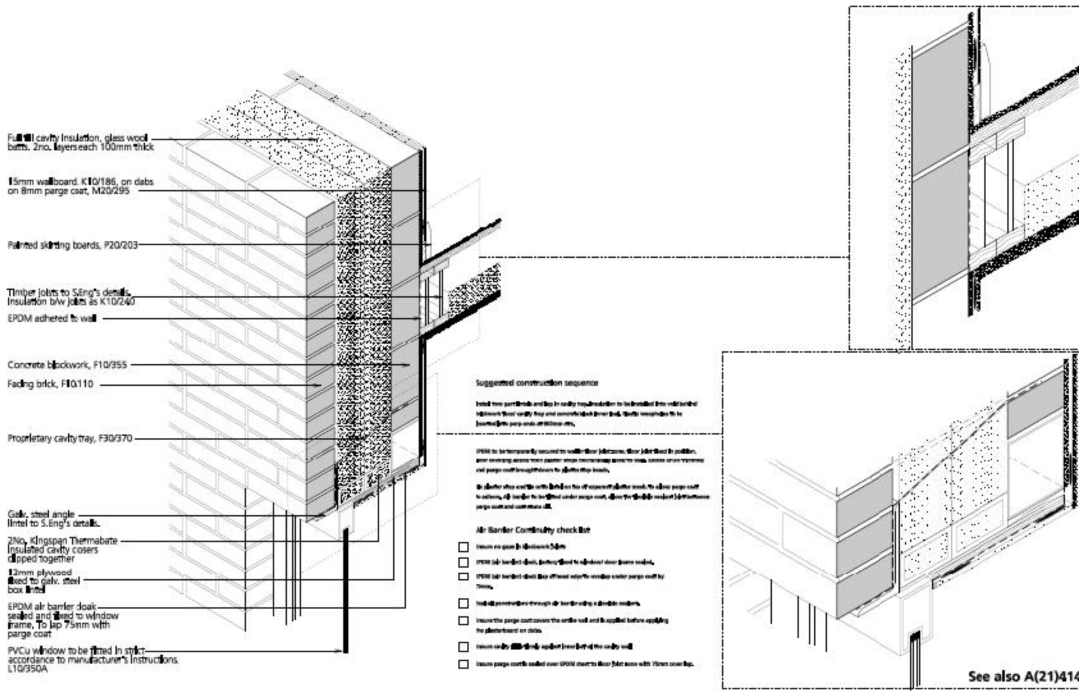
CARBON	$kgCO_2/year$ Core Hrs Only	$kgCO_2/year$ Total	$kgCO_2/year/m^2$ Total
GAS (@ 0.194 $kgCO_2/kWh$)	57,226	82,582	8.3
BIOMASS (@ 0.025 $kgCO_2/kWh$)	13,975	20,167	2.0
ELECTRICITY (@ 0.52 $kgCO_2/kWh$)	208,300	329,057	32.9
ELEC. GENERATED FROM $150m^2$ PV	-9,406	-9,406	-0.9
SUB-TOTAL CARBON $kgCO_2$	270,095	422,400	42.2
ANC ELECTRICITY (@ 0.52 $kgCO_2/kWh$)	2,139	3,345	0.3
ANC ELEC. GENERATED FROM $42m^2$ PV	-2,165	-2,165	-0.2
TOTAL CARBON $kgCO_2$	270,070	423,580	42.3

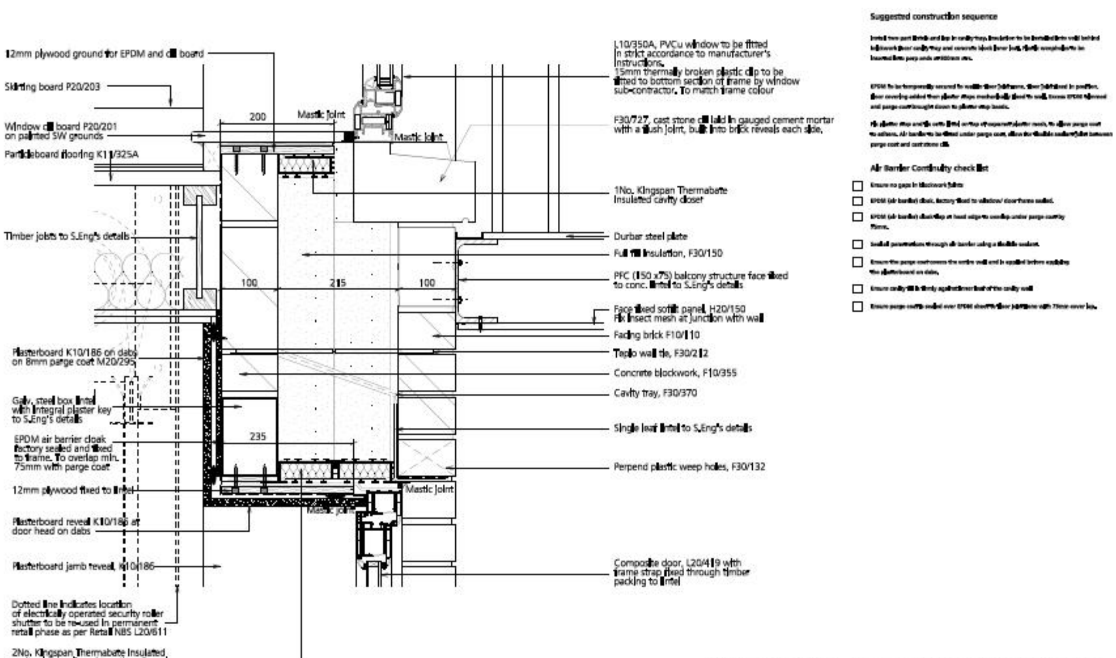
Annual Utilities Targets can be found within the Robert Blake & Elmwood calculation

Construction stages in progress	
Plot 1	Foundation blockwork below cavity tray under construction
Plot 2	Foundation blockwork below cavity tray under construction
Plot 3	Foundation blockwork below cavity tray under construction
Plot 4	Foundation blockwork below cavity tray under construction
Plot 5	Foundation blockwork below cavity tray under construction
Plot 6	Foundation blockwork below cavity tray under construction
Plot 7	Foundation blockwork below cavity tray under construction
Plot 8	Foundation blockwork below cavity tray under construction
Plot 9	Infill to slab
Plot 10	Infill to slab
Plot 11	Infill to slab
Plot 12	Infill to slab
Plot 13	
Plot specific observations	
Plot 1	
Plot 2	Missing vertical DPM rear corner poor lap joints on front corner.
Plot 3	Insulation party wall
Plot 4	Poor lap joint on vertical DPM & Insulation party wall
Plot 5	
Plot 6	Missing vertical DPM at party wall & Insulation party wall
Plot 7	Missing vertical DPM at party wall & Insulation party wall
Plot 8	Missing vertical DPM at party wall & Insulation party wall
Plot 9	
Plot 10	
Plot 11	
Plot 12	
Plot 13	
Design	
At the design stage it was thought that the vertical DPM in the cavity would act as a secondary air barrier at the wall slab junction. Whilst the material is well suited to achieve a damp proof course achieving an air tight barrier in the foundations with a relatively stiff material is more difficult. The problems encountered fixing the first layer of bituthene may be addressed by the application of the second bituthene strip.	
Materials	
Brick delivery still awaited.	
Buildability	
The vertical DPM was to be formed using a wide self adhesive bituthene strip linking the gas membrane to the cavity tray. This was to be formed by a continuous sheet of bituthene: however, due to difficulties handling the material the decision was taken to apply the bituthene DPM in two stages. The first stage involved affixing the bituthene DPM to the gas barrier membrane to achieve a 150mm lap with the underside of the slab at the slab	

perimeter. No problems were experienced fixing the smaller bituthene strip prior to the slab being cast. Once the slab was cast and the formwork removed the bituthene proved susceptible to damage whilst the blockwork was brought up. There were a few instances where the bituthene DPM was damaged, primarily at the party walls where short jointing sections of bituthene had been used. There were also a few instances where forming good lap joints proved difficult due to adhesion problems where the DPM surface had become wet or picked up debris prior to fixing. Again these should be addressed when the second bituthene layer is applied.
Construction sequencing/programme
If the vertical DPM detail is used in the future as the DPM material is prone to damage and loss of adhesion consideration needs to be given to the construction sequencing for installing the vertical DPM and whether it can be protected from damage from follow on trades.
Trade issues
Problems were encountered with dimensional variation in the party walls due to difficulties experienced securely locating the temporary formwork. Remedial works were carried out to the slab to correct the alignment of the party wall cavities before the insulation was installed. In most instances a good fit was achieved between the perimeter of the slab and the party wall insulation. Where there were still gaps a cement paste was used as infill. There were two instances where the insulation was cut slightly short in the party wall and one where it was cut low. Due to level variance in the slabs the bricklayers had to use relatively thick beds of mortar for the first two courses of superbricks off the slab. The quality of brickwork at this junction is important from an air tightness perspective and the workmanship was very good with full beds and perps.
Feedback from site team
Problems were still being experienced with the supply of bricks as a result the bricklayers commenced work on the foundation blockwork 12 working days behind programme.
Photographs

Photograph 5 – Example plot 2 difficulty forming external corner





Townhouse Detail 24 - For detail location refer to L(00)400 series


earthwool
Acoustic Roll

Project: Ethnographic Research

Code: ---

Date: ---

Interviewer: **Gabriela Zapata**

Length of interview: **45 minutes**

… standards, and I think the key thing, I can't remember whether ?? we spoke about this last time, it's who pays for the building, who pays for the actual building to start with and who then pays for the running of it. And if you've got two different organisations you get a conflict of interest that the people who are doing the initial outlay for building the building, they're going to say I want to do it as cheaply as possible irrespective of the fact that actually it might mean greater maintenance costs for the twenty five year period for example that PFI type projects, you know typically run for. So again it's looking for that joined up thinking between the two, you know, and if you were to turn around and say well you know the basic product, the cost of maintaining it is (interruption – mumbling in background) you know, how can you make it more viable for the initial supplier if somebody turns round and says well actually we've budgeted for X £s per month and for that aspect of it, whereas you know now it's going to be less than X, do you sort of share the differences and sort of say ?? a contribution to that. But then again what do you compare it to? Is to sort of saying well you know that's where you start to subsidise the initial kind of build cost, it's always going to be a challenge you know in terms of those two aspects of it. You know if you were doing your own private house you know well, you know what I'm going to spend more money on better insulation, this, that and the next, because you know the benefits and …

Yeah, in the long term yeah.

(02.00) … and you reap the benefits. So I think there's that aspect which is probably very, you know an interesting point to question a quantity surveyor on, you know, they've got a task to do, they've got to get it for as little money as possible. And again it's, it's how much interpretation there is in terms of what's being provided and as much as you can write specifications there is still a degree of interpretation on that sort of design and build offers, you know flat(?) opportunity for change which I think gets, not abused but I think that's where you lose the rigour of what the design intent is to get it finally implemented in a building. So, it's like sourcing, you may for example say source a product which is you know from a company which has got a very good environmental record, and that's why you want to choose them, you know, you've perhaps got standards about what, where we source products from, you know, we want to see companies with their certification and things like that, and timber for example sourced from renewable and replenished forestry stocks and so on and so forth. And in the same way a lot of the contractors have signed up to those sorts of things but you know if you really wanted to go, you know, if you're going to go and give them a shopping list and sort of say you know I want free range sausages, they're not going to go and buy free range sausages you know! It's, and that's, that to me is I think the lack of control, you know, that we don't maintain through the project because of D & B. Now it used to be you know D & B was all about, you know, it's the sort of project where you know cost and time were the most important, you know we talked about this, we spoke about the three aspects last time, and it's design which is you know likely to deteriorate or not to be as crisp as you know the intention is, and that could be in terms of obviously appearance, but also in terms of building performance. So you know it's trying to get that buy in from everybody down the line. So I think there's a very interesting set of questions that you could ask to the quantity surveyor in terms of you know how do they view sustainability. And I think you know the contractor, and again I think there are two aspects to it, there's the sort of company policy and then there's the actual implementation you know, you know, and it's, I think it would be interesting to see it, I mean you know we're all under commercial pressures, as I say, even more so in these sorts of times, and at what point do you, you know it's not about selling out, but it's, you know, it's about maintaining your, you know your, the, you know the ethics and belief in the product.

Yeah, but I think also it's a matter of being real and what is achievable because it seems to me that sometimes policies and regulations just aim for aspirations and things that from the very beginning are pretty much impossible to get, given the context and the financial situation.

(06.09) Mm, yes.

So it's sort of, for me I think it's important to find the proper balance in what sustainability is within the, you know, that is possible you know.

I, yeah.

Because we could all say OK let's just go green and let's get crazy about being sustainable, but that's not going to be real and maybe it's not financially viable, it's not commercially real, you know, and …

Absolutely, I think you know and if you were to talk to John and like David, obviously G2V(?) they wanted to go for BREEAM(?) outstanding. Now some of the aspects of that are about sourcing materials locally and you know the local workforce. Now you put that into the mix, you know, is the local workforce the cheapest? And I think you, there's a question there in terms of you know we have the likes of (?) system, you know for large public sector projects, over what £250,000, so, are you familiar with the (?) process?

Yeah, mm mm.

(07.20) Yeah, you know and that whole thing is it's about, it goes out to the general marketplace you know and on the premise that it should be a fair and reasonable competition to win work, you know based on its value rather than proximity to where the project is. So there's an interesting sort of trade off between the two there, that actually if you've got a company that says, yeah we can do that, but you know they're outside of the requirements to get that BREEAM point, you know, you know you've got the, the conflict between you know traditional market forces of best value based on cost, versus the best intentions for the you know sustainability aspects of it. So again that's a very interesting query and quandary you know, how do you have these two things, and at what point, you know is there an optimum? If you look at the larger companies, they're sourcing materials from all over the world to get consistency of product, you only have to look at the likes of McDonalds, their product is consistent, you can go into any McDonalds restaurant anywhere across Europe and it's going to be the same pretty much. But how do they do that? Is it about sourcing locally? No it's not. Whereas if you go down to say Devon, you get local food ending up in the local supermarkets, the big supermarkets like Sainsburys and Morrison. So there's obviously a value that's attributed to locally sourced materials for something like that, farmers' markets, they have it, but that doesn't equate to building products, nobody's going to necessarily be sort of saying oh all our stud, internal stud partitions are sourced locally, it doesn't mean anything because there's a bigger picture. So you know that's an interesting question I think that's worth raising, that if you look down all those criteria of you know to get BREEAM outstanding, when you look at the question what's the most immediate way that you might interpret that question, the next proposal, or the next response is how can you meet the criteria to gain that point, whatever that may take. Now is that trying to bend the rules or you know do it, and again, it's trying to achieve these things, not by fair means or foul, but it's about, there's a degree of interpretation. I came across this, I went to a talk a couple of years ago, it was like a debate, you know, in 2025 we'll be able to design carbon neutral university campuses, and there were some people who spoke for it, some people spoke against it, and the people who were speaking for it were referring to ? legislation and guidelines are going to be changing. So what we call a carbon footprint now is going to get redefined. So that's not actually us adapting and being, you know trying to meet new criteria, it's moving the goalposts. So I think again it's worth looking at those sorts of things, you know, why are these goalposts being moved? Is it because the original targets aren't actually achievable? And to be absolutely honest about it, where does your carbon footprint start for example? Biomass boilers, absolute joke I think, it's, you have biomass boilers being put into inner city schools, you've got to have a delivery every two weeks of wood chip, what's the carbon footprint, you've got to use a lorry. So again, it's about being appropriate to the site, if you're in a fairly rural area and you've got wood chips, it makes absolute perfect sense to use it. So again it's, how many of those things are you actually doing to get the tick in the box? The tick in the box, it's what's informing the design? Is the BREEAM criteria for example informing the design, or are you adapting the design just so you get the BREEAM ticks you know? It's got to be because it's of benefit to it.

Yeah, I mean at the end BREEAM is not an ends in itself, it's just, it could be a way to get things but it's not the ultimate formula, but sometimes it taken that way.

(12.39) Well yeah, but I think there's a lot of focus on BREEAM. I mean you look at how many BREEAM assessors there are, and the role of the BREEAM consultant on projects like this, I think that in its own right is a limitation of how much gravity it has, but is it, is it starting to just sort of misguide people, that the ?? things would be. It's there because it's an actual benefit to the design and you're not just putting in a biomass boiler just because you get an extra BREEAM tick in the box for it. And that I think is a key thing that's worth looking at, otherwise you could end up with a standard product building, right here's a school, we know it meets BREEAM X(?) but you just go and plonk it on site and find it doesn't fit or it doesn't work because it's just, it just isn't appropriate, in which case it's a waste. And fundamentally, that what a lot of these things, sustainable aspects are about, that it's not, it's about being efficient, and if you're just putting something there that you're not going to use, that's about as inefficient as it gets. And I think that would be an interesting reality check I think, because I think there is a lot of smoke and mirrors, do you know the phrase smoke and mirrors?

Mm mm!

(14.14) Yeah you know that people put up these sorts of fronts, yeah we do all these things, when actually it means very, very little. And John will certainly be able to tell you, because BREEAM's obviously of even greater significance on his project at the moment, going for the outstanding levels on the project. So yeah.

Yeah, well I suppose, as anything, as any tool, as any mechanism, I mean BREEAM has it's good points and I mean weakness and strengths, but it's, I think this ? people could work differently. And I, I mean to be honest I'm not sure how deceive(?) we are, because some, at some level it's actually bringing up discussions that might not be there, if BREEAM is not in force, or if BREEAM couldn't be there. But it's also again this thing of are you customising the project to meet BREEAM or are using the project to inform somehow decisions but working with what the potential of the project is. So it's/instead(?) of finding a balance there, that I think it's important.

Yeah, have you looked at any other equivalent standards for sustainability in the Middle East or America?

Yeah, like the LEED or CEPAS?

Yeah, yeah.

Yeah, yeah.

(15.51) And how, have you looked at how they compare to BREEAM in terms of how they operate and how do they influence the design process and the procurement of the building finally? And you know does one tend to have a greater rigour and is more successful than another?

Do you have experience working with other …?

I don't, no, no.

Yeah, I mean I am familiar to the systems, I know overall how they work, but I mean I haven't seen them in use, being used.

Yeah.

It could be interesting to see that too.

Yeah, I mean it's, you know, remarkably the Middle East has got some quite high sustainability aspirations, it's, on the surface you'd probably have thought that they didn't have much, when you look at their approach to air conditioning and highly serviced buildings and so on and so forth, but they do have …

There are some interesting things going on there.

Absolutely.

And I think they find that they don't come with as many resources and things are, I mean in the medium, long term it will be depleted, I think that is giving them some kind of motivation to actually trying to be like more carbon neutral, or to use energy in a more efficient way.

(17.29) Yeah.

But I mean that's also part of their own limitations, being located where they are and you know …

Limitations you could also turn into opportunities …

Oh potential, yeah exactly.

LAUGHS You've got miles and miles of open sand, and a lot of sunshine! What more do you want?!

Yeah exactly.

So it's just the fact that it's a lot easier to pump oil out of the ground rather than put in solar sustainable systems. So again that's an interesting situation, you know, compare it to what we have here, you know where we try and put solar panels out in weather like this, and you think (laughs) … And again that's the mindset, it's like well what's the point, when you look at it for what it is, but you can still achieve quite a bit with solar panels, I think everyone's trying to I think convince people. And I think the other thing about it is the visible and the tangible aspects of it, that actually things like solar panels and the wind turbines, you know if someone said what are the sustainable aspects of a building? Those are the first things that they say, because that's what they've seen. Whereas you know the orientation of the building, the amount of exposed glazing on the south side …

Yeah, the fabric and …

(18.53) Exac … Yeah, well yeah the fabric but even more fundamental, the bits that you get for free ?? you know whereas if you line your building up that way compared to lining it up that way, you know with south access, you can actually get better quality of light, the more consistent morning light and evening light, well factories always used to be, have all the north lights so you didn't get the glare. And again it's trying to get people to understand those aspects, that those are the bits that are for free. You or I might do that, when you look at a building, go right it's sitting north/south, how many other people are actually going to go round and understand their environment, and that's, you know, if you look at for example, people live throughout the world in some extraordinarily harsh environments, we consider them harsh, they understand how you can use them. So with Eskimoes, who on earth is going to live in somewhere where it's minus 20 for eight months of the year? Well hang on a sec, they managed to survive, you know, and not just survive, but they've survived for many, many years, and they, it's, they feel strongly about it for their cultural aspects, you can live there. You know you look at Bedouins who live in the Desert, you know the complete opposite, again survive in very warm environments, but they can make cooling effects, because they understand about if you can get some breeze into your tent or into the houses, you know, a lot of the houses in the Middle East they're very tall, so you don't get the daylight penetrating into it, you know if you have a little bit of water, like a fountain, again you create that sort of stack effect and you've got air coming in. They've understood science, so all those things that happen for free, it doesn't cost carbon wise, you know, to have a fan coming in here and extracting out there, it's all about understanding the basics of you know simple scientific principles, and understanding where it's appropriate to use, it's getting people to recognise those and those are the bits that you get for free. So for example, if your building is based on solar(?) glass(?) and then you have someone, like well we can do a frame in steel because it's cheaper. Hang on a sec, no, no, it's not just, the frame isn't just there to support the building, the frame actually has other parts to play in the whole environmental model of what the building is, and that's what I think you get exactly the same with those, the ceiling tiles I was describing earlier, it's understanding that right there's a reason why it's like that, you know. And I think trying to get, it's about educating people, these days it's very easy to find a solution by the press of a button, you know, that you go and buy a gadget that solves something, you want to be warmer, you find a gadget, you press the warm button, you want to be cooler, you find a gadget and press the cold button. Well, we don't want to be reliant on that, so you design your building so it's you know, it's not certain that it's always going to be hot or it's always going to be cold, so the building's ?? intelligent, but it's that degree of forward thinking. And I think there's a big education hurdle to get over to get … And again if you go and talk to people, on both sides of the job, but you know I will be talking bi …, I say this biasly, I feel that these people don't understand what we've been doing, to the depths that we've taken it. Yeah, and I think that's shown when we get the questions going, can we use this as an alternative? And you go well it doesn't work for this reason, that reason and that reason, I can see why you want to use it because it looks the same, but that's where the similarity ends. So it's about educating them to really understand what …

Mm, yeah why ???

(23.40) So I mean how do you get sustainability to be, to get people to buy into it? I think that's … showing … If you can show that it has commercial benefit on the overall picture, that's a start, it's when it gets broken up into the responsibilities of procurement of running procurement, running the building you know, and splitting it up between two separate people, you've got two different agendas, that's when it starts to make things a bit more complicated. But if you can, if you can show sustainability has commercial merits, that's when I think you'll start ???

You're right, yeah, no, yeah.

… being more attentive to things like that.

I'm just wondering because you are sort of working more on the design consultant side of the spectrum …

(24.40) Yeah.

When you are doing your work, how do you account for these things here? Because maybe their perception or their main criteria is you know cost, time …

It is, yeah.

… probably risk of implementing things that haven't been tried before.

Yes, mm mm.

I mean is there any way that these sort of, I mean I'm just curious …

LAUGHS

… to see how to build a bridge in communication here because it seems to be like a different focus. It's not really … And it's also passing this ownership of this, and making this ? when they take this, they follow it as much as possible you know.

I think there's something else which is interesting as well. So up until here you've got the design phase, and then from here on, that's the construction (drawing diagram?). (Interruption) So you've got these two bits here, now when we're trying to win work, like this project, the contractor, they have input into this as well. Now the contractor has two teams, they've got the winning, sorry, the bid team, then they've got the delivery team (slow and hesitant as if continuing to draw diagram?). Now those guys there are part of the bid team, so you know these guys are talking to them and saying you know we've got to get all the points and the points they've got to, this point here, and they've won the bid, all the things that were being put into it suddenly get being taken out. And I've seen this on several projects. How do you then ensure that it happens? Well that's, that is, that's the, *the* question. And I think the problem is that, because all of these guys here are employed by the contractor, they have, they're in a very, very influential position over final decisions that are made, so you know having gone through all of this, and we've ticked all our little boxes, it's looking great, these guys come along and they rub them out and you just have a row of little empty boxes, because it's cheaper. But again, it's not on everything don't get me, you know don't get me wrong, but again it's on those things where, you know, it's delivery team don't understand everything that's in this final package. And I think it's very interesting if you spoke to the delivery team and sort of said, right, what are your key criteria? That's the number one thing. And QS's are always under pressure to get the best price, and it's, I think it's about ensuring the information in this is as rigorous as possible so that when you start choosing, for example the products that you're putting in the specifications, you know, and you're showing it on your drawings and that's going to the contractor, if these specifications here are as bullet proof and as watertight as possible then they don't have the chance to change it. But there are a couple of things that need, you know, if you're writing performance specs, that should fundamentally be watertight you know, it's got to be plasterboard that's, you know, it's white, it's robust, it does this in terms of fire, it does this in terms of acoustics and it's sourced from these people because they've got excellent green credentials, for example. If they come back and they say, well we can get it from somewhere else and it does the first three but actually it doesn't do that one there, you know, that is as important factor, albeit it's not one of the sort of traditional aspects of the building specification, but it is these days you know. So I think it's about getting the contractor and the delivery team to be more 21st century, rather than why are they stuck in their ways? Well there is this aversion to risk which is totally understandable, but I think it's about getting them to understand that you know they're new products, they're not, it's not the risk aspect of it, sometimes some of these things put in excuses to find something which is you know more economic, that's always I think going to be a problem. And it's a challenge, it's a real challenge.

Yeah. And what about the fact that usually, or maybe that's what I think, maybe I'm wrong, you have sort of like a, let's say a budget where different things are allocated there and these sort of start from the beginning, it's not like you have like a blank budget to work on.

(31.43) No, OK.

And how, you know, all these things are located? Because there is this perception that you know greener design or more sustainable buildings are more expensive.

Mm mm.

And how, this is somehow included in this sort of bubble of what the cost will be.

Yeah, I think there is a lot of myth that for example green buildings are more expensive. But I think so many things change in this industry, you know, if you speak to the Concrete Marketing Board they will tell you that concrete is more sustainable than steel. If you went to speak to the Steel Marketing Board, and it's the use and ? statistics. So I think it's about trying to cut through some of those aspects of it. In terms of where we're understanding costs, under D & B that's not really a main criteria as such, you know, we know that Jordan(?) partition systems, you may know that's probably one of three or four systems that you may well specify, we will, we always ask our contractors if they have lists of preferred suppliers, if they've got procurement chains and agreements and things like that, so that we're not specifying product 'Y' when in fact they've got a purchasing agreement with product 'X' which gives them a good price. And if we looked and thought that product 'X' wasn't appropriate because of say the green criteria, we would tell them. And again it's about where the responsibility, if BREEAM excellent for example is a key criteria of the brief, and your contractor comes along and says well we've got purchasing agreements for these products here sort of thing, you know, these won't contribute to the safeguard(?) of BREEAM points or things like that, you know, informing the contractor as soon as possible and saying we will not meet the brief if we go this way, we may for example advise and say well no, rather than, you know, if it was gypsum, you know we would go Lafarge(?), you know different, you know because they may have something which is more appropriate and has aspects of its product which then makes it work. So if you can understand that early on, because there's nothing worse than you've designed everything, the detailing and things like this, and say well can we swap out, you know, the internal walling supplier from one to the other, oh yeah it's possible, but you know you've got all these things in chain, everything that it interfaces with has to change, not just in terms of detail but in terms of the criteria. So we for example would, we've been asked if we'd change the height of the roofs because the contractor said oh they're OK(?), we can lower those by a metre can't we? Well yeah, what's the implication? It might be that we've got less wall area, we've got less windows, we've got to fit it(?) with natural ventilation at a higher level. So it's understanding the impact so you end up creating more scenarios which you need to resolve, work out and clarify, and close out, which takes time and it costs. And again if you only had the design review process once, so you've understood everything that you're putting in has got a good sustainability aspect and criteria, that's got to be a key benefit for things to progress, and if things progress smoothly it's cheaper for the contractor, you're not going over, doing things twice, there's more chance of it hitting site and being implemented.

And just, I have another question, I'm just starting to understand how D & B works. Usually there is this design team which works before planning and submits this project to planning and starts developing an overall detail, in order to be able to have tenders and so on.

(36.45) Yes.

And then they, after the tenders are out, there is some kind of bidding and then contractor probably gets involved. Do contractors also have some kind of designers in their team to further develop this work, or basically the same people, or it varies?

(37.10) It, on the schools, the two schools are quite different in terms of the procurement of winning the job was led by the contractor, whereas with *(removed for confidentiality and anonymity purposes)* we've designed the school with all the consultants, speaking to the local authority as a client, you've got a design and now a contractor has won the job. So then we'll be innovated(?) across. So it's different, but in some respects, like I was saying here, the contractor had a bid team that's informing the design and then the delivery team had a different set of people. In terms of the delivery team, do they have designers? (blows raspberry)

Yeah, no, not really.

Not really, I mean they have the design manager, but do they really instigate, I think they're more, they understand that there's a design that needs to be provided, but again it's still you know, they're still familiar with that, you know, that's, the £ signs are certainly bigger than the green agenda, I personally think. And it's (sighs) it's, that's the key thing you know, will people pay more for a green building? I don't know. I don't think so. But should a green building cost more? I don't think so, it may take a bit more time in terms of the sort of design/development because if you were to build a building and just said, right I want X hundred square metres and it's got to meet these new values, you could design something within a few weeks and get it built. When you look at now all the criteria and agendas that we have to take into account, such as the sustainability aspects to meet all those statutory requirements, buildings have got a lot more complex in terms of all the agendas that they've got to meet, so there's a lot more design work and design resolution that is required on our behalf, not just our behalf but all the consultants, you know, we didn't have sustainability advisors twenty five years ago, there wasn't, that word didn't even exist in terms of construction, obviously it does now, but again have for example clients really developed and now understand it or are they still sort of thinking, well you know I don't see why I should be paying more than you know 3, 4, 5% of the construction costs on my consultants' fees when you could look at it and say well actually there's a far greater degree of design resolution that needs to be involved these days. So the role of the architect, I think you could start to argue is far, far greater, we still have to design the building but to design a building these days, there's a lot more questions to ask, and I think that's something which I don't think is quite understood. You get joint formed(?40.44) clients/developers, but those who aren't, you know, they sort of well in four weeks' time we'll see your first designs and another four weeks after that we can have a, seen(?) ready to submit to planning. And there's a lot to do these days, a lot, and particularly when you look at what needs to be submitted these days to planning in terms of things like construction detailing and those aspects which start to inform the final build product, there's a lot more to do I think. And again, people don't recognise, or they're still fairly traditional in their outlook, as to what needs to be submitted if you want to get a building built, you get planning permission, and then you get building permission and then you go and build it, and then it's all done isn't it? Well planning ask for a lot more these days, and if you look at any like medium to large scheme, ?? environmental impact assessments, lists of carbon impacts and so on and so forth, it's a lot more than just you know a set of drawings in a completed form and a check/cheque(?). So I think that is an interesting thing that's worth understanding. And again it's like getting the client to do it, a lot of clients do you know, there's a fair number that I don't think really understand what it entails. And it's going to get more and more complex, as regulations start to get more and more onerous.

OK, well … Well thanks a lot, I won't take more of your time.

(42.33) OK, no problem.

Yeah, thank you.